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Microbial Fuel Cells and Their Applications in Electricity Generating and Wastewater Treatment

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***Abstract*—**This research is an experimental research which was done about microbial fuel cells in order to study them for electricity generating and wastewater treatment. These days, it is very important to find new, clean and sustainable ways for energy supplying. Because of this reason there are many researchers around the world who are studying about new and sustainable energies. There are different ways to produce these kind of energies like: solar cells, wind turbines, geothermal energy, fuel cells and many other ways. Fuel cells have different types one of these types is microbial fuel cell. In this research, an MFC was built in order to study how it can be used for electricity generating and wastewater treatment. The microbial fuel cell which was used in this research is a reactor that has two tanks with a catalyst solution. The chemical reaction in microbial fuel cells is a redox reaction. The microbial fuel cell in this research is a two chamber MFC. Anode chamber is an anaerobic one (ABR reactor) and the other chamber is a cathode chamber. Anode chamber consists of stabilized sludge which is the source of microorganisms that do redox reaction. The main microorganisms here are: Propionibacterium and Clostridium. The electrodes of anode chamber are graphite pages. Cathode chamber consists of graphite page electrodes and catalysts like: O_2, $KMnO_4$ and $C_6N_6FeK_4$. The membrane which separates the chambers is Nafion117. The reason of choosing this membrane is explained in the complete paper. The main goal of this research is to generate electricity and treating wastewater. It was found that when you use electron receptor compounds like: O_2, MnO_4, $C_6N_6FeK_4$ the velocity of electron receiving speeds up and in a less time more current will be achieved. It was found that the best compounds for this purpose are compounds which have iron in their chemical formula. It is also important to pay attention to the amount of nutrients which enters to bacteria chamber. By adding extra nutrients in some cases the result will be reverse. By using ABR the amount of chemical oxidation demand reduces per day till it arrives to a stable amount.

***Keywords*—**Anaerobic baffled reactor, bioenergy, electrode, energy efficient, microbial fuel cell, renewable chemicals, sustainable.

I. Introduction

THESE days, it is very important to produce clean energies in order to prevent environmental pollutions and global warming. The main negative environmental impacts and environmental pollutions is because of using fossil fuels. Because of these problems scientists and researchers are studying about different ways for generating energy and electricity. Fuel cells are one of the ways that we can get help from them for electricity generating without any special pollution and negative environmental impacts. There are different kinds of fuel cells like: methanol fuel cells, solid oxide fuel cells and this research is about microbial fuel cells that can simultaneously produce electricity and do wastewater treatment. There are also different kinds of microbial fuel cells like: air cathode microbial fuel cells, two tanks MFC with a catalyst solution, microbial fuel cell mass, etc. A microbial fuel cell that has two tanks with a catalyst solution was built and used in this research.

II. Experimental

In general, mineral materials like Hydrogen or methanol are used in bio cells [8]. Ensymes are used as the catalysts in fuel cells [2]. The temperature in which these cells work properly is in the range of 20 °C-40 °C [1]. This feature is one of the positive points about fuel cells because when it is hard to achieve high temperature this way can be used instead. When whole organisms are used in a microbial fuel cell a number of enzymes and nutrients will be used instead of just one. The result of this is that microorganisms which are in the system act like reactors which produce energy. Microorganisms produce electron and proton by oxidation reaction in anode chamber. The electrical current of electrons goes to cathode chamber by an external circuit. The result will be the difference of voltage between these two chambers because of different solutions.

A. Anode Type

The material which is used as a cathode must have these features:

1. High electrical conduction
2. Resistant against corrosion
3. Very high special area (area in volume unit)
4. High porosity
5. Resistant against obstruction/blockage
6. Cheap
7. Easy to build
8. The possibility of usage in large scale

The most important feature among those that mentioned is high electrical conduction [4]. A simple experiment by using a voltmeter is enough for initial assessment. We can do this experiment by putting the first electrode of voltmeter on the surface of anode and putting another electrode of voltmeter in the distance of one centimeter from another electrode and now we can read the resistance [4]. Any material has its own resistance. The following table shows the resistance of some materials:

The electrons that were produced in the anode chamber have to travel to where the wires are connected in the shortest amount of time, and in this process, the only thing that can reduce electrical power is the internal resistance of the system. For this

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reason, it is necessary to choose a material for the anode that has high electrical conduction. The usage of Carbon paper, Carbon piece and RVC is very common as the anode in microbial fuel cells [14]. Electrical conduction of these materials is high and they are also suitable for bacterial growth. As an example, we can mention flexibility and resistance as the features of Carbon papers. In order to prevent corrosion in the side that Carbon paper is connected to the copper wire it is necessary to make an epoxy. The main problem of using copper wires is that in a short space of time they corrode and release copper into the water, which is a toxic material for bacteria, or simply the connection between the wires and Carbon papers will fail. (In the structure of the microbial fuel cell which was built in this research carbon papers are connected to copper wires). The function of anti-oxidation wires or titanium wires is better in microbial fuel cells. Usually Carbon papers have two types: 1- simple Carbon papers 2- waterproof Carbon papers. It is common to use simple Carbon papers as anode. Carbon pieces are more flexible and porous in comparison with Carbon papers.

TABLE I
RESISTANCE LIST OF SOME MATERIALS

Resistance	Type of material
0.1 Ω/cm	Copper
0.8 Ω/cm	Carbon paper
130 Ω/cm	Polymer paper
1.6 Ω/cm	Graphite ribbon
2.2Ω/cm	Carbon piece

B. Membranes, Separators and Transferring Chemical Materials

In the structure of hydrogen fuel cell membrane is one of the main system parts that separate the two gas phases, which are Hydrogen and Oxygen, and make a way for conducting proton between the two gas phases [16]. These membranes are called proton exchange membranes. In microbial fuel cells protons are conducted by the help of water, and thus, there is no need of membrane as a main system part. Some researches conducted in 2004, showed that a microbial fuel cell without a membrane produce more electrical energy in comparison with a microbial fuel cell with a membrane [4]. According to this, it can be concluded that a membrane in microbial fuel cells can have a reverse result on producing electricity. One the main reasons of membrane usage in microbial fuel cells, is for separating the solutions and materials, which are in cathode and anode chambers. Membranes must be permeable that protons which are produced in anode chamber can enter to the cathode chamber [3]. The main problem which exists for using membranes in microbial fuel cells is that they can reduce the good system performance and they are expensive.

C. Cationic Exchange Membranes

Nafion117 membrane is the most used membrane in bio cells [4]. This membrane has a lot of applications in a Hydrogen fuel cell. The reason of using this membrane is to make a conductor and stable place in order to have a high proton density and it becomes possible to control the materials which are in water. Nafion117 can be used as a proton exchange membrane but in microbial fuel cell ions like: Na^+, K^+, NH_4^+, Ca^+ and Mg^{2+} are in the first priority. When a nutriment decomposes, the protons that were produced in the anode chamber will be used in the cathode chamber.

Fig. 1 The image of Nafion117 membrane which is used in bio cells

D. Anion Exchange Membranes

If H^+ ions cannot enter effectively into a cation exchange membrane, the question arises of how the PH can be set in it.

Researches show that protons can transfer using chemical materials as a buffer among the membrane [15]. For this reason, a cation exchange membrane is used as a separator in microbial fuel cells that have two chambers.

E. Dipole Membranes

The structure of a dipole membrane consists of two cation and anion membranes that are classified and connected with each other. If the voltage arrives to the amount that is higher than the amount that lets protons to enter to another chamber, water will be decomposed and the result will be the transfer of OH^- anions and H^+ cations in order to stabilize the load. It is expected that the amount of energy which is needed for water decomposition is not high, because water is decomposed to H^+ and OH^- ions and it will not electrolyze to Hydrogen and Oxygen. The calculations which were done shows that a dipole membrane is needed in a microbial fuel cell when the voltage is 0.38 volt in order to have a 100% separation of anode and cathode chambers when 1 molar solution of acid and base is used [10].

$$\Delta V = \frac{-2.3RT\Delta PH}{F}$$

F. Other Membranes and Separators

To understand that cations and anions can help to save load in a microbial fuel cell a new way of using different membranes in microbial fuel cells was found. The main function of these membranes is to save solutions separately and load transfer by using little ions. For this purpose it is suitable to use ultrafiltration (UF) membranes specially those which are used in wastewater treatment in microbial fuel cells [11]. These membranes have very tiny holes. In the case that a high electrical current wanted to be produced and UF membranes are used, high pressure is needed; thus, if the hydraulic pressure is not high enough, the produced electrical current will be low.

G. Chemical Flask in Membrane (Oxygen and Nutrients)

Cation exchange membranes are not only permeable to transfer protons but also are permeable to transfer gases and other chemical materials. These features of these membranes were studied for Oxygen transfer but for other materials it must be studied and examined. Chemical flask can be calculated like [13]: $J_m = K_{cm}(C_{An} - C_{Cat})$, J_m is chemical flask, K_{cm} is mass transfer coefficient, C is density of nutrients in anode and cathode.

H. Type of Cathode

The hardest part of building a microbial fuel cell is making the anode part. The chemical reaction which happens in cathode chamber is complicated in the way that it is necessary to have electrons, protons and Oxygen in the same catalyst phase [5] and also to have them in a reaction that consists of three phases (solid catalyst, air and water). Two sides of the catalyst must be in contact with water and air, and it also must be on the conductor surface. By using a system, as previously mentioned, protons and electrons can arrive at the same points in different phases. The materials that were suggested for the anode can also be used for the cathode.

I. Carbon Cathodes with Platine Catalysts

The material which is used mostly for cathode is Carbon paper that Platine catalyst is on the surface of it. If these materials are used in building microbial fuel cells, the surface which is and the surface that is without line must be in contact with air.

J. Watery Catalysts

If Oxygen is not used in cathode, there is no need to another catalyst and it is possible to use simple Carbon cathodes. The most famous catalyst is Ferry cyanide that we have the following process:

$$Fe(CN)^{3-}_{6} \longrightarrow Fe(CN)^{4-}_{6}$$

It is also possible to use solutions that consist of Permanganate and iron ions as catalysts.

K. Microbial Fuel Cell Building and Designing Principles

There are different materials that can be used for building a microbial fuel cell. System performance, stability and the period for when a microbial fuel cell is suitable for use depends on the method of connection, layout and shape of the units. Classifying microbial fuel cells is based on the catalyst, internal materials and input energy. The method of connection, relates to the way in which the cathode and anode chambers are connected with each other and the general structure of the microbial fuel cell. Layout and shape of units means the general shape of the units that depends on the type of microbial fuel cell.

L. Different Types of Reactors

1- Microbial fuel cells with air cathode
2- Watery cathodes by using Oxygen solution
3- Tube reactors
4- Series microbial fuel cells
5- Metallic catalysts
6- Bio Hydrogen microbial fuel cells

- How the microbial fuel cell in this research was built?

The microbial fuel cell used in this research is type 2, as previously mentioned. This microbial fuel cell has two chambers, one of the cathode chamber and the anode chamber. These two chambers are connected with each other, but are separated by a Nafion117 membrane. Thus, they are still connected according to the methods previously discussed for membranes and separators. The other parts of this microbial fuel cell are the copper wires, which are the connectors and electrodes. The electrodes are used in the cathode, while Carbon pages are used in the anode chamber.

M.Anode Chamber Structure

The whole structure of this microbial fuel cell is made up of Plexiglas including cathode and anode chambers. This chamber has three main parts which are these: electrodes which are carbon pages, anaerobic baffled reactor, wastewater solution that has a stable sledge as the base; this solution consists of nutrients and a group of anaerobic bacteria that decompose organic materials and nutrients. This chamber has also another part which is a gas discharge valve and the other valve for discharging extra sledge.

N. Cathode Chamber Structure

Cathode chamber consists of carbon page electrodes, dissolved Oxygen, dissolved catalysts like ferry cyanide and iron ions. Membrane structure in this microbial fuel cell: The membrane which is used as a separator is Nafion117. Nutrients which was used for microorganisms in anode chamber: The source of nutrients which was used was an intravenous sugar solution [12].

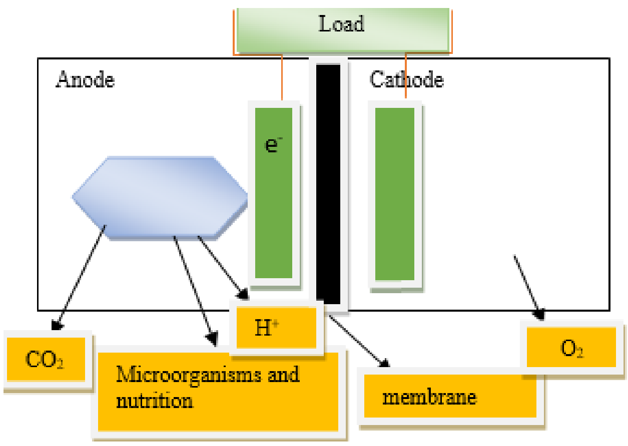

Fig. 2 General schematic of a microbial fuel cell

O. Voltage Production in Microbial Fuel Cells

The first thing which is important for an electrical source is the voltage that it can produce. Microbial fuel cells function in 0.7 volt generally. In order to increase the amount of produced voltage DC-DC convertors or DC conversion to AC conversion can be used. In microbial fuel cells the voltage which is produced is generally in the range of 0.3-0.7. Produced voltage can be calculated by using formula: E=I R_{ext}, E is the potential of pill, I is electrical current, R_{ext} is external resistant. By using the microbial fuel cell it is possible to decrease chemical oxidation demand of wastewater. The diagram of this is in results part.

III. Results and Discussion

By using compounds which receive electrons such as: O_2, MnO_4, and $C_6N_6FeK_4$, the speed in which the electrons are received will increase and in less time more electrical current will be obtained. The results show that the best compounds are those that have iron ions in their chemical formula, and therefore, are the best chemical material to be used for this purpose.

Fig. 3 The microbial fuel cell built for this research

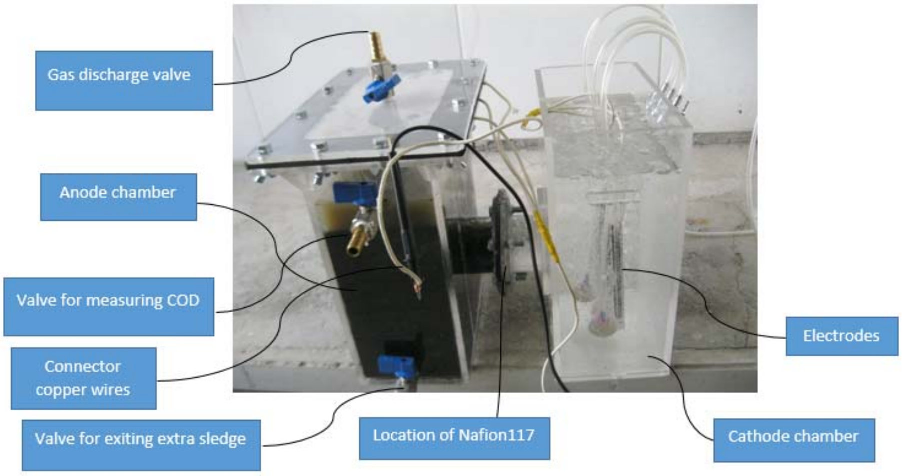

Fig. 4 Image of different parts of this microbial fuel cell

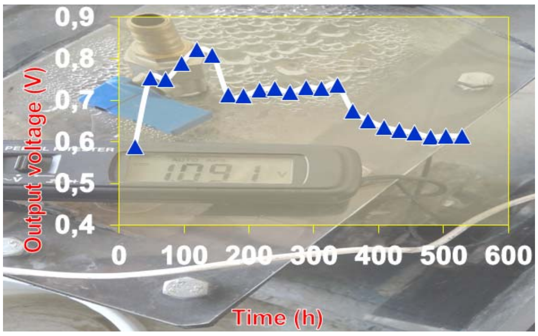

Fig. 5 Change in the output voltage

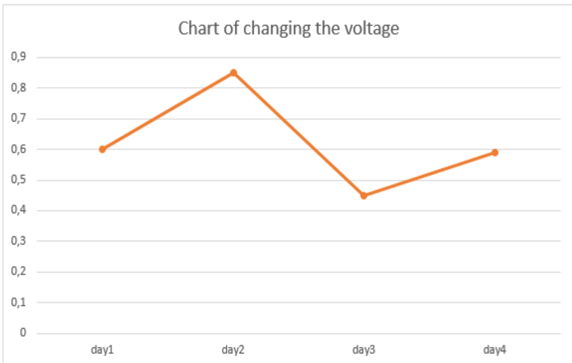

Fig. 6 Change voltage chart when nutrients is added

The level of nutrients entering the chamber that contains bacteria is also important [6], [7], [9]. It is not true that when you have more nutrients you will have more current, as sometimes it can have the reverse effect. After experiencing a reduction in the output voltage level, the extra nutrients were removed from the anode chamber and the system began to return to the desired status and the output voltage level returned to the range of 0.6-0.7 volts.

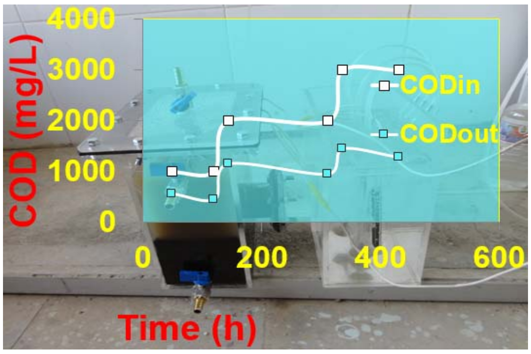

Fig. 7 Chemical Oxidation demand reduction chart

IV. Conclusion

This experimental study and research which is about microbial fuel cells and their applications in electricity generating and wastewater treatment had these conclusions:

There are different things that can affect the level of voltage produced by microbial fuel cells, and these features were explained in detail in previous sections. The microbial fuel cell is a new method and technology for electricity generation, which produces minimal pollution in the form of carbon dioxide as a result of the function of the microorganisms. Although this technology is in the initial stages of development, it has this potential to become one of the future methods for effective and efficient electricity generation.

Acknowledgment

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References

[1] Nipon P. Future Wasatewater Treatment Technology: Simultaneous Treatment of Wastewater and Electricity Generation, the Joint International Conference on Sustainable Energy and Environment, Hua Hin, Thailand, 2004.
[2] Habermann, W. and Pommer, E-H. (1991) Biological fuel cells with sulphide storage capacity. Appl. Microbiol. Biotechnol. 35, 128–133
[3] Microbial Fuel Cells for Wastewater Treatment, Yucatan Centre for Scientific Research (CICY), Mexico, Liliana Alzate-Gaviria, 2010,
[4] Ghangrekar M.M Shind V.B. Performance of membrane- less microbial fuel cell treating wastewater and effect of electrode distance and area on electricity production Bioresourse Technology Vol .98 pp:2879-2885 2007.
[5] Huang L. Zeng R.J. Irini A. Electricity production from xylose using a mediator less microbial fuel cell Bioresourse Technology article in press 2008.
[6] Environmental Health Perspectives Microbial power Rhodoferax ferrireducens Vol.113 pp: 755-759 2005.
[7] Liu Z.D Li H.R. Effects of bio-and bio-factors on electricity production in a mediator -less microbial fuel cell Biochemical Engineering vol.36 pp:209-214 2007.
[8] Zielke E.A. Application of Microbial Fuel Cell technology for a Waste Water Treatment Alternative February15 2006.
[9] Bitton G. Wastewater microbiology third edition published by John Wiley & Sons Inc. pp:307-321 2005
[10] Bennetto, H. P., 1990. Electricity Generation by microorganisms. Biotechnology Education, 1(4): 163-163.
[11] Choi, Y. et al. (2003) Dynamic behaviors of redox mediators within the hydrophobic layers as an important factor for effective microbial fuel cell operation. B. Kor. Chem. Soc. 24, 437–440
[12] Madigan, M.T. et al. (2000) Brock Biology of Microorganisms, Prentice Hall
[13] Tender, L.M. et al. (2002) Harnessing microbially generated power on the seafloor. Nat. Biotechnol. 20, 821–825
[14] Oh, S. et al. (2004) Cathode performance as a factor in electricity generation in microbial fuel cells. Environ. Sci. Technol. 38, 4900–4904
[15] Chen, Xi., Sun, Yaqin., Xiu, Zhilong, Li, Xiaohui., Zhang, Daijia., Stoichiometric analysis of biological hydrogen production by fermentative bacteria
[16] Tatsuya, Noike., Osamu, Mizuno., Takashi Miyahara., Method of producing hydrogen gas by using hydrogen bacteria, United State Patent March1, 2005