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Microbial Fuel Cell for Electricity Generation and Waste Water Treatment

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Abstract: Energy problem is a global issue that has a serious effect on many countries in the world. The demand for energy is currently growing far greater than the supply of the nationally generated energy. In order to overcome energy crisis and the output pollution of the generation, it is suggested to use the Microbial Fuel Cell (M.F.C). M.F.Cs are devices that use bacteria as a catalyst to oxidize organic and inorganic matters and generate electric current. With the modifications that are suggested by this study, there will be clean, available and suitable energy source. Besides having the property of being efficient, eco-friendly and cheaper than the other resources, it can utilize the sewage to generate electricity and produce clean water, which mean cleaner environment with a great supply of energy and clean drinkable water. Facing challenges that affect the development of the M.F.Cs is an important aspect to be studied, so our study suggests solutions nearly for all the challenges facing them like the types of the electrodes, output pollutants, the catalyst in the cathode chamber and the real application.

Keywords: Microbial Fuel Cell, Anode, Bacteria, Cathode, Agar, Biofilm, Catalyst

1. Introduction

Renewable energy field is the majority of the current age because of its importance in developing the humanity. The demand for energy nowadays is going far greater than the generated energy. There are many renewable and nonrenewable energy sources like the fossil fuels and wind energy. There is no effective way to keep us working with fossil fuels and reduce greenhouse emissions. The efficiency is an essential component of any plan to get us back on the track of balanced growth. So, new energy sources and technologies must be developed to achieve the required efficiency.

Also, their output pollution should be taken in mind as it may affect the environment. As a result, these new solutions should produce carbon dioxide at a lower rate. If we see the example that in man's life-essential activities, wastes are produced, a technology that can use these wastes and turn them into useful energy, is probably the most close-to-Nature form of energy production.

In order to decrease the pollution and find an eco-friendly energy source, it is suggested to use the microbial fuel cells (MFC). MFCs are devices that benefit from the natural metabolism of microbes to produce electrical power. There are many challenges facing the MFCs such as the output pollutants and how to reduce them, best electrodes to get the highest performance, suitable substrate to provide food for the bacteria (microbes), facing limiting factors of the MFCs, the cost of the catalyst and its performance, the exchange field, and the best design for all the project.

Unlike costly and difficult to be obtained energy alternatives, this device provides inexpensive energy source for any person at any time. As a result from these challenges, this research is proposed to be figured out to help solving them, that's why there can be found new, efficient and clean energy sources. Also, it is said to help finding clean environment with more energy sources and clean water from the technique of wastewater treatment by the M.F.C projects.

2. Related Works

Harnessing the metabolic activity of bacteria can provide energy for a variety of applications, once technical and cost obstacles are overcome. [10]. Microbial fuel cells (MFCs) can provide an answer to several of the problems which traditional wastewater treatment faces [14]. Butyrate is used as a substrate for the bacterial field. [11]. Power generated with acetate found to be higher when compared with other substrate [2, 11]. The waste water was used as a substrate to provide food for the bacteria and produce the highest output voltage [12]. (MFC) is one such renewable and sustainable technology that is considered to be one of the most efficient energy sources [15]. Ferricyanide (K3 (Fe (CN) 6) is frequently used as an electron acceptor in the MFCs due to its good performance and low over potential [8]. The main challenge in implementing MFC on a large scale is in maintaining low costs, minimizing hazards while maximizing power generation [16]. For cathodes, platinum (Pt), activated carbon (AC), graphite based cathodes and bio cathodes are used [3, 4]. For anode, carbon felt, graphite felt, carbon mesh and graphite fiber brush are frequently used due to their stability, high electric conductivity and large surface area [9, 8]. "Recently, some students from Harvard University experimented MFC device and they produced enough electricity to power a LED bulb for up to a year" [7]. The composition, concentration and type of the substrate affect the microbial community and power production [1, 13]. In most of the MFCs, acetate is commonly used as a substrate due to its inertness towards alternative microbial conversions (fermentations and methanogenesis) that lead to high efficiency and power output [13]. One of the limiting factors is cost of the electrode and membrane materials [9]. Temperature is an important limiting factor in the MFCs. [6].

If the challenges facing the MFCs could be solved, then a new efficient and clean energy source will be found to help in developing the humanity and getting new and magnificent world. Also, our group predicted the efficiency of the project to be 73:80% greater than the other attempts in the M.F.Cs field, which mean huge electrical production, with having the quality of being clean and green to the environment.

3. Methodology

3.1. Participants

We are a group of 4 stem students from STEM Egypt High school for boys in the 6^{th} of October city. We are 4 males (100% males), M: 16 years old and we are completely Egyptian Students.

3.2. Research Design

Variables in our study vary according to the experiment that we want to do. All the variables are illustrated in every experiment below.

3.3. Measures

The multimeter was used to measure the output voltage, internal resistance, watts and the current. Meter to measure the length of the components of the prototype. Balance to know the mass of each material.

Materials

Table 1. *Shows the materials used in building the prototype.*

Material	Amount/ Size
Two glass-boxes	18*20*15cm
Short section of plastic pipe (polyethylene or PVC) for salt bridge	25cm
Agar	250 g
Salts (NaCl, KCl, KNO, NaOH, etc.).	125 g (For each one)
Graphite- Stainless steel-Carbon paper-copper- Aluminum)	2*10*15 cm
Mud (Bacteria)	-------
Bacterial substrate (Glucose- Sucrose- Acetate-Butyrate)	125 g (for each substrate)
Copper wire (plastic coated).	50 cm
Salt Water	2 liters
Wires with alligator clips	2 wires

3.4. Building the Prototype

Step1: Preparing the salt bridge from Agar: To make the salt bridge, agar was (whose percentage is 5 - 7%) with the potassium chloride (whose percentage is 93 - 95%) and water until they boiled, and let them get dry inside the pipe. This step is said to take about 45 minutes.

Step 2: (This step is said to take about 40 minutes). Conduct each component with the other to figure out the prototype as shown in figure 1 and figure 2:

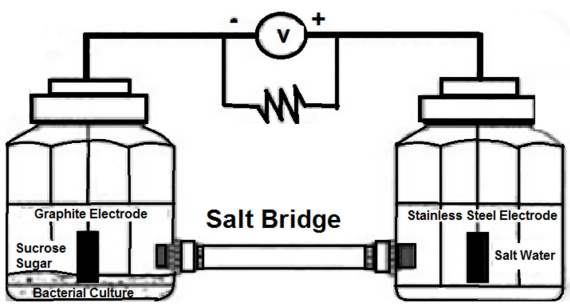

Figure 1. *Shows the components of the prototype.*

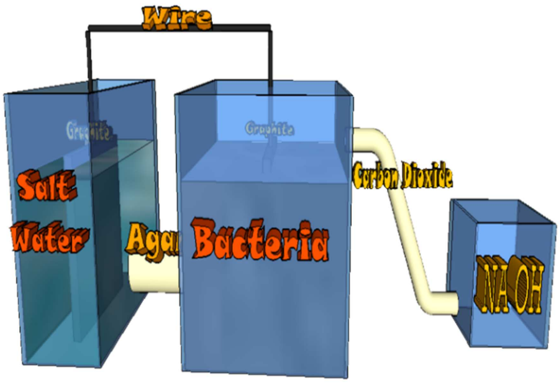

Figure 2. *Shows the final shape of the prototype.*

Experiment 1: The purpose from this experiment is to examine different anode types like (Graphite- Carbon paper) (Independent). It had been completed using mud as a source for the bacteria (controlled) and artificial wastewater as a source for the bacterial food (controlled). Also, a plat of Stainless steel will be used as a cathode electrode (controlled). After testing each electrode and collecting our data (in 40 minutes) the results were observed as shown in table 2:

Table 2. *Shows the output voltage by different anode electrodes.*

Electrode Type	Maximum power density (W/m^2) (Error ± 0.015)
Graphite	2.6
Carbon paper	0.8

From these results, it was observed that graphite plates can help producing the highest power density (Dependent), so it is recommended to use it as anode electrode to ensure the highest output voltage.

Experiment 2:

This experiment had been done to examine different substrates (Glucose – Sucrose – Acetate - Butyrate) (Independent) and find the difference in power density as shown in table 3. It had been done using Graphite as anode electrode and stainless steel as a cathode electrode (controlled). By collecting the data, it was found that sucrose can provide the highest power density, so it is advisable to use it as a substrate in the MFCs.

Table 3. *Shows the output voltage by different substrates.*

Substrate Type	I (current, mA) (Error ± 0.21)	P (mW/m^2) (Error ± 1.5)
Wastewater	4.85	26
Glucose	0.9	494
Sucrose	6.2	506
Acetate	1.27	23
Butyrate	0.46	305

Note: the reaction that takes place in the anode chamber can be explained by this formula:

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$$

Experiment 3:

The purpose of this experiment is to test different cathode electrodes to determine the best type. The electrodes that had been tested are the Aluminum, copper and stainless steel (They were considered as independent variables). The prototype will contain sucrose as a substrate and graphite plate as anode electrode (Controlled). Then, the output voltage had been measured with each electrode (Dependent). Note: Cathodic reaction:

$$12O_2 + 48H^+ + 48e^- \rightarrow 24H_2O$$

It was found that although the cathode does not take place in that reaction, but it has an effect on the output voltage. The data was collected as shown in table 4:

Table 4. *Shows the output voltage by different cathode types.*

Stainless steel	Copper	Aluminum
1.9 volt ±0.02	1.4 volt ±0.02	1.5 volt ±0.02

It had been observed that stainless steel can help producing the highest output voltage, so it is recommended to use it as a cathode plate in the MFCs.

Experiment 4:

By knowing the limiting factors of the MFCs, it was found that the temperature is an important factor in the project, so the suitable temperature for the project should be known to ensure the highest power density. In the prototype, graphite plate was used as an anode electrode, stainless steel as a cathode electrode and sucrose as a bacterial substrate (controlled). Then, the temperature of the prototype was changed inside the laboratory (Independent). It was observed that, the power density (dependent) was changed by changing the temperature according to table 5.

Table 5. *Shows the output voltage and the power density at different temperatures.*

T ± 1 (°C)	OCV (mV) (Error ± 1.5)	Pmax (mW/m^2) (Error ± 0.15)
20	111	0.73
25	112	0.75
30	117	0.82
35	119	0.88
40	133	1.01
45	125	0.90

From these results, it is recommended to apply the project at temperature of 40ºC.

Experiment 5:

In order to test how clean the prototype is, the prototype should obtain graphite plate as an anode electrode, stainless steel as a cathode electrode and sucrose as a bacterial substrate (controlled). Then, the temperature of the prototype was changed inside the laboratory to be 40ºC. After that, the Sodium Hydroxide (NaOH) was exposed to the omitted Carbon Dioxide (CO_2) and it was observed that, they reacted with each other and produced Sodium Carbonate ($NaCO_3$) according to the following formula:

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

In such a way, the project had been definitely an eco-friendly project as it has nearly negligible output CO_2. Also, it produces Sodium Carbonate that can be used in different ways like the manufacture of glass, help in processing wood pulp to make paper, water softening, refining aluminum, laundry soaps and other household cleaning products, taxidermy. So, it will help in many industries.

Experiment 6: This experiment was done to measure how efficient is the prototype. It was completed by testing the output voltage of the prototype many times and testing an ordinary M.F.C at the same time and measure how the efficiency increased. As shown in Table 6, the prototype has a high efficiency. There was some negative results like test 4, but the other tests had positive values. We calculated the efficiency of our project and we found that the average equals 73%.

The anode chamber must be kept isolated from the outside environment. For long-term operation, electrodes should be constructed in a way that limits corrosion of copper wire due to contact with liquids. Power can be significantly increased by using a catalyst such as Nitrogen-Enriched Core-Shell instead of platinum for hydrogen adsorption that has lower cost than platinum.

Table 6. *Shows the output voltage of the M.F.C.*

	Ordinary M.F.C (V)	**New Design (V)**
Test 1	0.9	1.7
Test 2	1.08	1.87
Test 3	1	1.9
Test 4	1.65	1.15

4. Design

As the mentioned before, the design of the real project is a huge limiting factor facing the development of the M.F.Cs. But the mind said "No" and it was decided that there will be a magnificent design for the real application of the M.F.Cs. As shown in figure 3-b, the design consists of number of cells put beside each other and all of them are connected with three main pipes in the upper side. One to collect the output Carbon Dioxide and lead them to scrubbing chamber in which it will react with the Sodium Hydroxide to produce the Sodium Carbonate then, it will be taken to the factories to perform their work and produce useful materials. The other pipe is to collect semi-salty water to the treatment plants. The third one is to add salt water to the cathode chamber to perform its work. All the cells are connected to collect all their output energy. There is another one is to add organic matters or liquefied mud to the anode chamber to perform their work as a source for bacteria. In the down side, there is another pipe to collect the used organic matters or the liquefied mud, as shown in figure 3-c, to get them in their fields after using their huge energy, after that they will complete their round in the nature.

Any project have conditions to be applied and our project have some special conditions:

1- High temperature.

2- Availability of salt water and the organic matters or mud.

In order to provide the first condition and the suitable temperature all the day to make it 24-hours working system, the walls of the plant is said to be made from a material that can store heat energy all the day and release it at night.

This material is called "Thermstone". It is made from cement bricks, sand and silica. This brick characterizes by many of the benefits of thermal insulation which provides high compared with conventional concrete and clay bricks.

The roof of the plant is said to be made from a special type of glass to let sun rays enter the system as shown in figure 3-a. This glass is called "Laminated Glass" and it is hard to be broken because it's made of layers of safety glass bound together with a transparent adhesive.

To provide the system with a sufficient amount of heat energy, the system will be with a tracking system to make the roof movable according to the angle of the rays of the sun. Also, to get the highest possible benefit from this tracking system, there will be a number of solar cells working with the same tracking system to provide M.F.C system with the needed energy to lift the water and the liquefied mud to the cells. Furthermore, the solar cells system will provide additional energy out of the system.

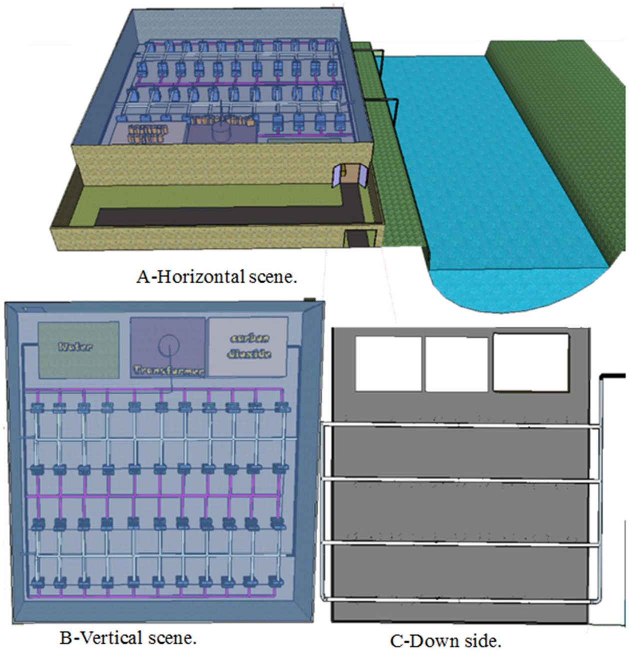

Figure 3. *Shows the design of the plant.*

5. Conclusion

With these modifications, our project will be a magnificent project for real application and green environment.

M.E.T is considered one of the best projects that helps in generating electricity because it depends on organic and agricultural wastes, such as Geobacter bacteria that is found in the mud, in generating electricity. The objective of the project is to achieve goals shown in figure 4.

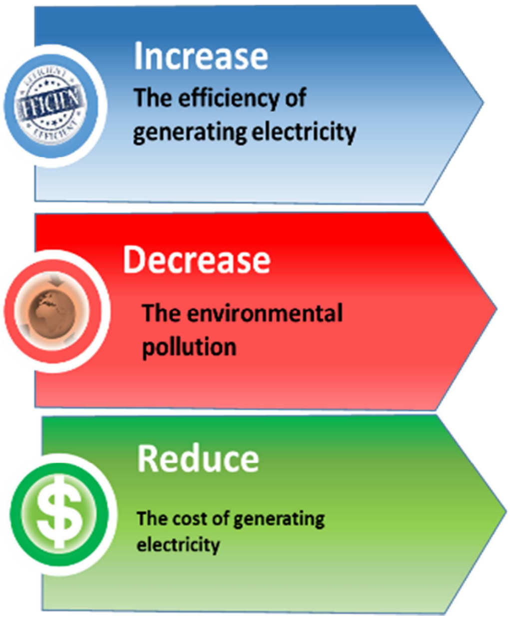

Figure 4. *Shows the goals of the project.*

There are many challenges that face our project. Platinum is one of the most difficult challenges facing MFC project because of its high cost as it may affect the whole project and impede its development. So, it is recommended to use alternative materials to be used as a catalyst to provide the project and make it more applicable in the real life. There was a suggested materials such as the Nitrogen-Enriched Core-Shell (N-Fe/Fe3C@C) and other materials as shown in table 7.

Table 7. *Shows different catalysts and their performance.*

	CR (%)
CC	26.9±1.1
CNT	24.1±3.0
Pt/C	39.8±2.6
N-Fe/Fe3C@C	43.6±0.8

That is why, we recommended using Nitrogen-Enriched Core-Shell as catalyst because of its low cost but there still be a problem which is the suitable laboratory to prepare it. If this project could be applied in the real life with these features, it is expected to help in producing clean energy with lower cost as shown in table 8.

Table 8. *Shows a comparison between the cost of the N-Fe/Fe3C@C and Platinum.*

Catalyst	Price (USD/g)
Platinum	$32.54
Nitrogen-Enriched Core-Shell	$20

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