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INVESTIGATING THE ABILITY OF MICROBIAL SOLAR CELL IN ELECTRICAL ENERGY PRODUCTION

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Abstract: The present study aims to Fabricate a promising Microbial Solar Cell (MSC) for electricity generation using (sludge, wastewater and mixed *algae*), two single chamber MSCs were applied, firstly the sludge and *algae* cell (SMSC) was used and factors such as pH, types of light source, temperature, configuration of electrode and mixing ratio have being studied. The best pH, light source, temperature, configuration of electrode, and mixing ratio of the sludge and *algae* experiment are found to be 7, sun light, 30 ºC, square electrode, and 1:1 respectively would be used in the wastewater and *algae* cell (WWMSC) for finding the most effective substrates for electrical energy generation. By comparing the Voltage resulted from sludge Microbial Solar cell (SMSC) and wastewater Microbial Solar cell (WWMSC). It was found that (SMSC) produce higher electrical energy than (WWMSC) with a voltage equal to 180 mV.

Keywords: *Microbial Solar Cell, electricity, Sludge, wastewater, Algae.*

1. Introduction

Environmental pollution and energy supply are two of the most significant issues facing the livings globally. In addition, environmental problems are linked to energy sources, notably the CO_2 increase in atmosphere is due to combustion processes. Hence, the critical issue is the development of alternative energy sources that have a minimal effect on the environment [1]. One of the ways in which both environmental objectives and energy can be achievable, is Photovoltaic panels [2]. However, their pollution caused during its production and their cost must be reduced. Nowadays, using microbial fuel cells (MFCs) look like a promising option to obtain energy in sustainable manner [1]. MFCs hold a great promise to address energy and environmental problems simultaneously by electricity production from the microbial conversion of biodegradable organic matter or even waste [3-5].

MFCs are a very interesting option for environmentally friendly energy production, when the organic substrates are available. However, the necessity of substrates transformed in the anode and oxygen in the cathode becomes a problem when self-sustaining systems was developed. In various studies, the oxygen requirements of MFCs have been addressed using photosynthetic systems [6, 7]. These systems are based on *algae*, which release oxygen during the light phase while capturing CO_2 from the atmosphere. This characteristic is very important because CO_2

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Concentration globally have drastically increased during last year's [8]. Due to the coupling of CO_2 capture and oxygen generation, in recent years the implementation of solar energy technologies using MFCs has received significant attention. Microbial Solar Cell (MSCs), or Photo microbial fuel cells (PMFCs): are systems converting light into bioelectricity by using the cost-free solar radiation to generate energy, biodegradable substrate and *algae* or photosynthetic bacteria [6].

Recently Different shapes of MSCs have been tested. Some of them are based on the separation of photosynthetic energy conservation, and dark electricity (heterotrophic) generation temporally or spatially without using artificial mediators [9]. These systems solve the oxygen requirements, in the cathodic chamber of the MFC; but do not solve the biodegradable organic substrates and fuel requirements, of the anodic chamber.

In this context, the main aim of this research was to develop a self-sustaining MSC in which the solar energy and CO_2 was used instead of fuel. To do that, the oxygen was provided by using a photosynthetic system at the cathode, which was coupled to a microbial anodic system, fed with the substrates excreted by the *algae* in a one-compartment electrochemical cell. In this manner, the *algae* culture growth was promoted by incoming solar energy, providing in situ supply for both the substrates required for the oxidation reaction taking place in the anode, and the required oxygen for the electrochemical reduction reaction. The main advantages of the integration of microbial cell and solar Energy in (MSC) are first: aeration systems are not required any more, second: the anodic chamber does not need to be fed with any fuel and third: CO_2 is captured from the atmosphere.

2. Materials and Methods

2.1 The MSC fabrication

The MSC consists of a plastic container with 10L of total volume, 8L of working volume. Stainless steel grid used as cathode and graphite plate was used as anode, both electrodes were connected by copper wire which was connected to digital miltimeter (Model No.VC9205A), for measuring the generated voltage, The square electrodes area were 20.25 m^2 and 15.89 m^2 for the circular ones, respectively. Sludge and wastewater samples were collected from Al-Rustamiyah wastewater treatment plant in Baghdad, *algae* collection was from a water channel located in the Baghdad University, all to be used in the MSC. Figure (1) shows the fabricated MSC and figure (2) shows the Schematic diagram of the fabricated MSC.

Figure 1. Fabricated MSC

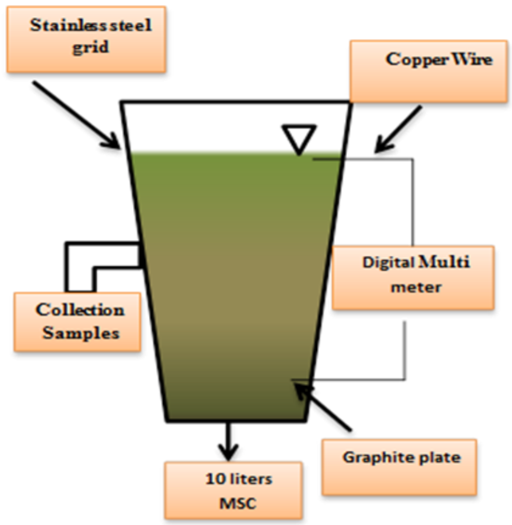

Figure 2. Schematic diagram of the fabricated MSC [10]

2.2 Algae Collection

The collection of algae samples was from a water channel at Baghdad University.

2.3 Algae preparation

The collected *algae* were washed with 10% HCl concentration, and then rinsed with distilled water.

2.4 Algae identification

For non-diatoms *algae*, prepare a permanent slide of the sample and test it with 40X zoom power by using an electric microscope [11]. Diatoms *algae* can be identified by taking a drop of sample put in the center of glass slide and dried on a hot plate at 70°C, a drop of nitric acid are added to clear diatoms structure, after drying , a glass cover contain Canada balsam are placed over, and left to the next day for testing [12].

2.5 Algae purification

Purification of *algae* aims to get an axenic culture empty of bacteria, fungi, and viruses. In order to purify *algae* the steps in [12] must be followed.

2.6 Algae growth rate counting

Algae growth rate during sludge and wastewater experiment was measured as follow: 100 ml of the sample filtered with filter paper of 0.45µm with vacuum pump, and then dried at temperature of 105 °C. The dry weight was determined daily according to the following equation:

$$\text{Dry weight (mg/ml)} = \frac{(A-B)*1000}{Volume}$$

Where: A: the filter paper weight after filtration.
B: filter paper weight before filtration.

2.7 Sludge and Wastewater Samples

The samples of sludge and wastewater were collected from Al-Rustamiyah plant, for wastewater treatment and used as source of bacteria for the electricity generation process. The location of Al-Rustamiyah wastewater treatment plant - the old project is in Baghdad (33°16'30.8" N, 44°31'57.4" E), the activated sludge samples are autoclaved for 20 min, 121 °C and 1.5 bar to exclude the effect of other microorganisms.

2.8 The Studied Parameters

To obtain the maximum production of voltage, five parameters were studied: light source, pH, temperature, electrode's configuration and mixing ratio.

- **Light Source**

The light can affect the performance of the MSC, and for investigating it's effect, three different light sources were used: sun light, led light with and fluorescent lamp, both with 36 watt.

- **pH**

The pH can affect the electricity production and for investigating it's effect, the follow values were tested 6.5, 7, 7.5 and 8. The pH values was measured by using pH meter with type of (WTW- 3110/Germany).

- **Temperature**

The effect of temperature on the electricity production was studied, by testing four different temperature degrees (28, 30, 32, and 40) ^{o}C, the used temperatures were maintained by using a heater.

- **Configuration Of Electrodes**

To study the effect of electrode configuration on the electricity production, two configuration for both cathode and anode were used: square and circular.

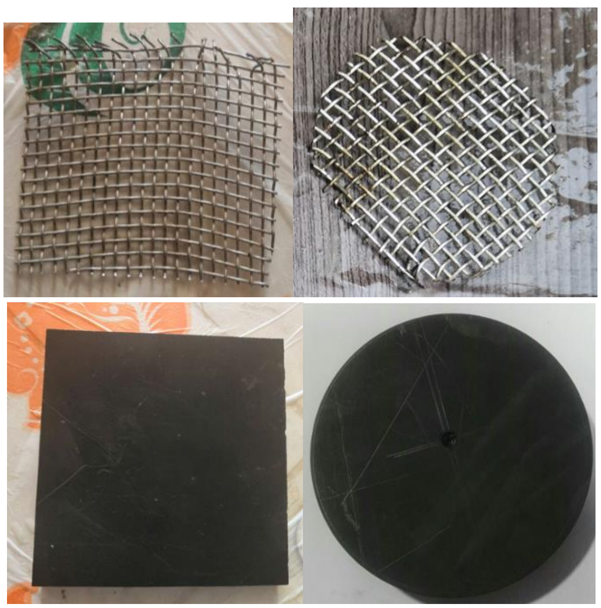

Figure 3. The Used Electrodes Configurations

- **Mixing Ratio**

To study the effect of mixing ratios of (*algae*/sludge) on the electricity production, four ratios were used 1:1, 1:2, 1:4 and 1:5.

4. Comparison between using (WWMSC) and (SMSC) for electricity Generation Performance

After finishing the experiment in which the (SMSC) was used, and obtaining the best condition in which the maximum generation was recorded, then the (WWMSC) was used. A comparison was made by using two MSCs one was fed with sludge and algae (SMSC) and the other was fed with the wastewater and *algae* (WWMSC), while light source, pH, temperature, configuration of electrode and mixing ratio were fixed at the best values obtained from the experimental work using SMSC. The voltage generated by the two systems was measured daily, at the same time to evaluate the systems performance, and determine the most efficient one as a function of maximum electricity generation.

3. Results and Discussion

3.1 Effect of Light Source

Three different light sources were tested, the maximum voltage which obtained from the sun light was 176.12 mV, for the led light and Fluorescent lamp, the maximum voltage production was 126.43 mV and 149.977 mV respectively and This may be due to the *algae* preference for wavelength range (400-700 nm) for photosynthesis. It is known that the visible light spectrum from sunlight, the photosynthetic active radiation (PAR) is (400-700 nm) while led light contain wavelength of (360-950 nm) and for florescent lamp (300-580 nm [13, 14]. This demonstrates the preference for sunlight as a light source in this experiment. Figure (4) shows voltage production (mV) with time (days) at different light sources.

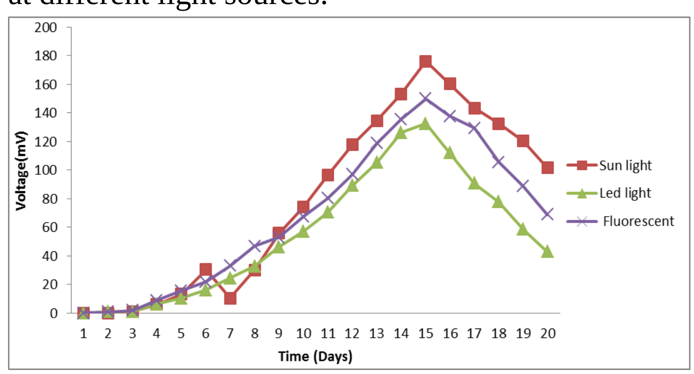

Figure 4. Voltage production (mV) with time (days) at different light source

3.2 Effect Of pH

Four values of pH were tested, the maximum voltage 153.001 mV was obtained at pH value of (7), and for pH values of 6.5, 7.5 and 8, and the maximum voltage production was 119.754 mV, 126.097 mV and 100.81mV. The decreased in voltage production which followed pH increase is due to decrease in algal cultures that is caused by decreasing the free carbon dioxide concentration in the medium, pH values above 8 eventually had no effect on algal photosynthesis. Therefore, it is recommended to keep the culture pH low enough so that free CO_2 concentrations in the culture will be above saturation (3.689 mg of carbon per liter). Also decreasing pH may have undesirable effects on algae cell proliferation. Figure (5) shows voltage production (mV) with time (days) at different pH.

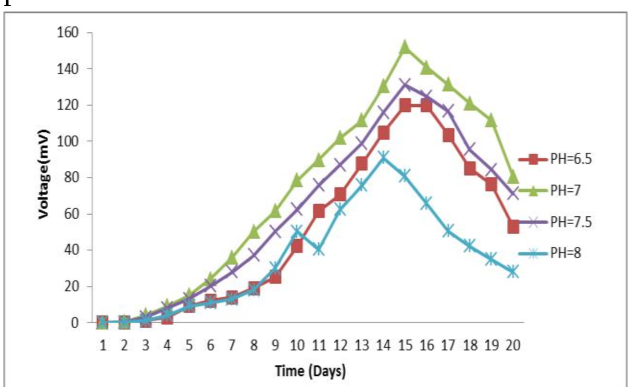

Figure 5. Voltage production (mV) with time (days) at different pH

3.3 Effect of Temperature

Four temperatures were tested; the maximum voltage production was obtained at temperature of 30 °C to be 178.21 mV. For temperatures value of 26 °C, 32 °C and 40 °C, the maximum voltage production was 155.54 mV, 144.701 mV and 78.712 mV respectively. For temperatures value of 26 °C, 32 °C and 40 °C, respectively It was found that, increasing in temperature improves the kinetics of oxygen reduction, and the reduction of the cell's internal resistance, the rate of the biochemical reaction can also increase and hence results of increasing the biomass growth rate and the microbial attachment on the electrode will be faster [15]. However the *algae* performance decreases by the high temperature. Figure (6) show voltage production (mV) with time (days) at different temperatures

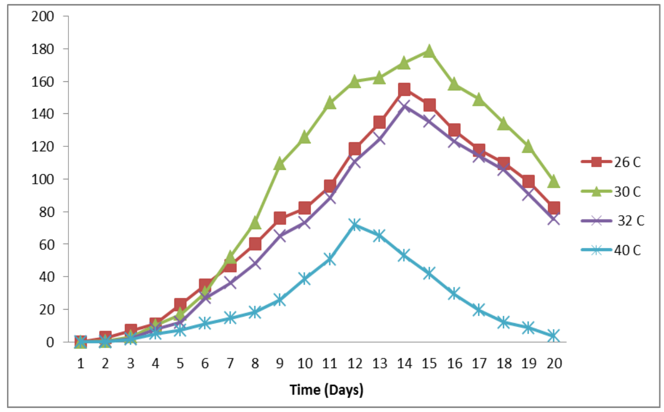

Figure 6. Voltage production (mV) with time (days) at different temperatures

3.4 Effect of Electrodes' configuration

The maximum voltage was obtained using square shaped electrodes was 177.598 mV. For both circular electrodes, square anode and circular cathode electrodes and finally circular cathode and square electrodes to be 97.06 mV, 128.567 mV and 145.856 mV respectively. This may be attributed to the attachment of bacteria, and algae on the square electrodes is higher than the circular electrodes, which reflects on its ability to decompose organics and this increase the electrons released [16]. Figure (7) shows the voltage of all the configurations used with time.

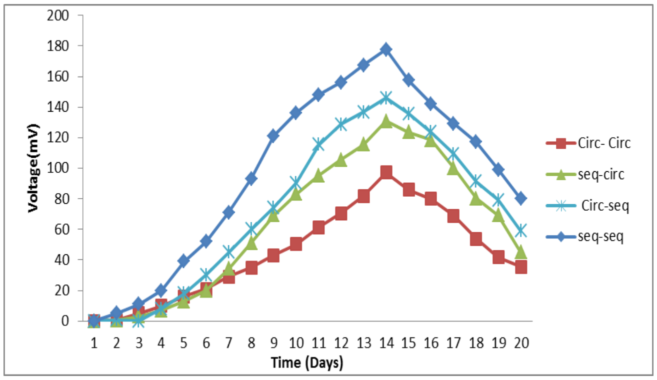

Figure 7. Voltage production (mV) with time (Days) at different electrode configuration

3.5 Effect of Mixing Ratio

Four mixing ratios (*algae*/sludge) were used (1:1), (1:2), (1:4) and (1:5) the maximum voltage was obtained at mixing ratio of (1:1) was180.421 mV, for mixing ratios of (1:2), (1:4) and (1:5), the voltage was 161.111 mV, 110.32 mV and 40.021 mV respectively, it was found that the equal quantities of *algae* and sludge in microbial solar cell give the maximum voltage, and this may refer to the C/N–ratio of the substrate mixture which is a major factor for obtaining a stable process. A C/N-ratio that is too low can result in high ammonia levels and have inhibitory effects on the digestion, as reported by [17]. Figure (8) show the voltage of all the mixing ratios used with time.

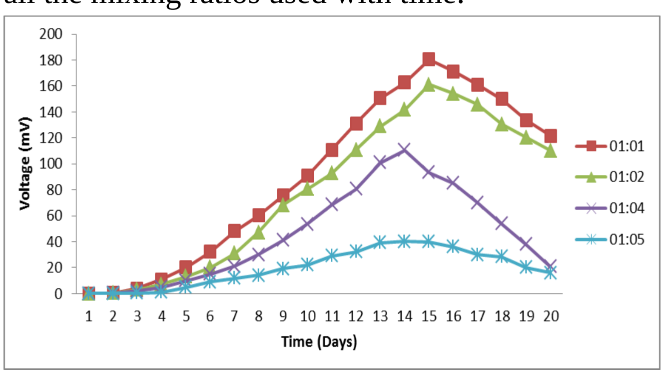

Figure 8. Voltage production (mV) with time (Days) at different mixing ratios

ANN was applied to predict the effect of pH, light wavelength, temperature and mixing ratio on voltage production (Y). When predicting MFC voltage, the network consisted of four input neurons corresponding to the state variables of the system with one hidden neurons and one output neuron, all neurons in each layer were fully linked with those of the adjacent layer. The ANN suggested a good result for the comparison of experimental and predicted results, showing a correlation coefficient (R^2) of 0.949. Fig (9) illustrates the importance of independent variables (inputs), a measure of how greatly the network's model could predict the changes in output voltage for different values of the independent variables. Mixing ratio plays the major role in voltage production (100%) followed by the temperature, wavelength and pH at importance of (71.9, 63.1 and 44.3 %), respectively.

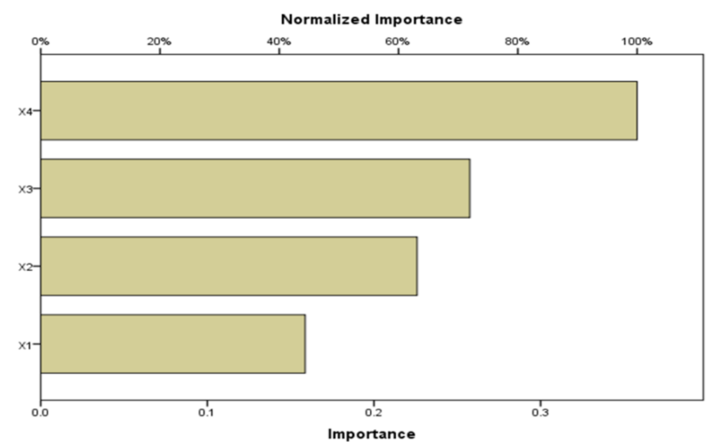

Figure 9. The independence variable importance of mixing ratio, pH, temperature and wavelength estimated by ANN

The multiple correlation methodology was employed to determine the relationship between the voltage production and pH, light sources, temperature and mixing ratio. Equation ($Y=aX_1^bX_2^cX_3^d\ X_4^e$) solves to determine these relationships by the application of the Excel program. Based on the experimental data, the independent variable coefficient can be calculated. The correlation coefficient (R^2) was found to be 0.983, which indicates better correlation between the experimental and predicted values.

3.6 Comparison between SMSC and WWMSC Performance for Electricity production

The maximum voltage obtained at optimum conditions from previous experiments was fixed in SMSC and WWMSC to make a comparison in voltage production. It was found that SMSC is better than WWMSC in voltage generation by producing 180 mV for SMSC and 163.765 mV for WWMSC respectively. Figure (10) show voltage production using the two substrates.

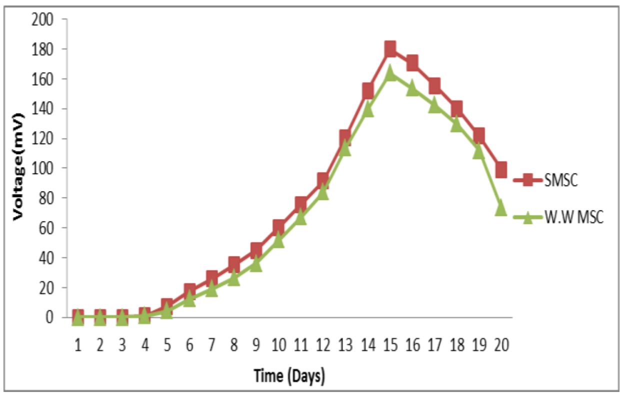

Figure 10. Voltage production (mV) with time (days) at SMSC and WWMSC

4. Conclusion and Recommendation

The present study employed MSC to produce electricity, expressed in voltage. In the first part of this study, five parameters have been examined for maximum voltage production, it has been found that the maximum voltage value, generated at optimum conditions, sun light as light source, pH of 7, temperature of 30 °C, electrodes 'configuration of square for both anode and cathode, with mixing ratio 1:1. In the second part of the experimental work a comparison in performance between SMSC and WWMSC for electricity production was made; it has been found that SMSC provide more electricity than WWMSC, and this may refer to that sludge contain more nutrient content which provide more suitable medium to the *algae* growth than wastewater in the stability of the other parameters.

5. Acknowledgement

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Conflict of interest

It must be mentioned that the publication of this article cause no conflict of interest.

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