ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Biological Fuel Cells.

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ABSTRACT

Presently the majority of the electrical energy that we utilize is produced through thermal or combustion processes that are both inefficient and environmentally damaging. Since the quantity of electrical energy used has also been rising year after year, scientists have been researching alternative methods for producing electrical energy. An attractive alternative comes in the form of fuel cells, which are expected to have a higher fuel to electricity efficiency with minimal environmental interference as compared to currently used processes. Biological fuel cells provide new opportunities for the sustainable production of energy from biodegradable, reduced compounds. Microbial Fuel cells (MFCs) are one of the classification of Biological Fuel Cells. Microbial fuel cell is such a device which can directly convert chemical energy to electricity. It has draw world-wide attention in the new century, and a growing number of scientists are working on the topic. We describe a new chamber-based Benthic Microbial fuel cell (BMFC) that incorporates a suspended, high surface area and semi-enclosed anode to improve performance. In Aquinas Bay, two chambered BMFC prototypes generated current continuously for over 200 days. One BMFC was pumped intermittently, which produced power densities more than an order of magnitude greater than those achieved by previous BMFCs with single buried graphite-plate anodes.

Keywords: Microbial fuel cell, enzymatic fuel cell, anode and electricity energy

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ISSN: 0975-8585

INTRODUCTION

Biological Fuel Cells

One type of genuine fuel cell that does hold promise in the long-term is the biological fuel cell. Unlike conventional fuel cells, which employ hydrogen, ethanol and methanol as fuel, biological fuel cells use organic products produced by metabolic processes or use organic electron donors utilized in the growth processes as fuels for current generation. A distinctive feature of biological fuel cells is that the electrode reactions are controlled by biocatalysts, i.e. the biological redox reactions are enzymatically driven, while in chemical fuel cells catalysts such as platinum determine the electrode kinetics.

Unlike chemical fuel cells, biological fuel cells operate under mild reaction conditions, namely ambient operational temperature and pressure. They also employ neutral electrolyte. In biological fuel cells, the catalyst is either a microorganism as simple as Baker's yeast or an enzyme. Biological fuel cells convert the chemical energy of carbohydrates, such as sugars and alcohols, directly into electric energy. As most organic substrates undergo combustion with the evolution of energy, bio-catalyzed oxidation of organic substances by oxygen at the two electrode interfaces provides a means for the conversion of chemical energy into electrical energy. In normal microbial catabolism, a substrate such as carbohydrate is oxidized initially without participation of oxygen, while its electrons are taken up by an enzyme-active site, which acts as a reduced intermediate.

$$C_6H_{12}O_6 + 6H_2O \longrightarrow 6CO_2 + 24H^+ + 24e^-,\ E^0 = 0.014\ V \quad \cdots\cdots\cdots (1)$$

The electrons are diverted to the electrode by some means in the absence of oxygen and made to pass through the outer circuit, and ultimately combine with an electron sink, namely, molecular oxygen as follows.

$$6O_2 + 24H^+ + 24e^- \longrightarrow 12H_2O,\ E^0 = 1.23\ V \quad \cdots\cdots\cdots (2)$$

If a continuous fuel flow to the aforesaid microbial fuel cell is maintained, it acts as a biological fuel cell.

Types of Biological Fuel Cells

There are two types of biological fuel cells, namely

- Microbial fuel cells and
- Enzymatic fuel cells

Microbial Fuel Cells

The use of microorganisms in biological fuel cells eliminates the isolation of individual enzymes, thereby providing cheaper substrates for biological fuel cells. Microorganisms can be used in four ways for producing electrical energy:

(i) Microorganisms can produce electrochemically active substances through fermentation or metabolism. For the purpose of energy generation, fuels are produced in separate reactors and transported to the anode of a conventional fuel cell. Accordingly, in this configuration, the microbial bioreactor is kept separated from the fuel cell.

(ii)The second configuration, the microbiological fermentation process proceeds directly in the anodic compartment of the fuel cell.

(iii) In the third configuration, electron-transfer mediators shuttle electrons between the microbial biocatalytic system and the electrode. The mediator molecules accept electrons from the biological electron transport chain of the microorganisms and transport them to the anode of the biological fuel cell.

(iv)The fourth configuration is that the metal-reducing bacterium having cytochromes in its outer membrane and the ability to communicate electrically with the electrode surface directly result in a mediator-less biological fuel cell.

Enzymatic Fuel Cells

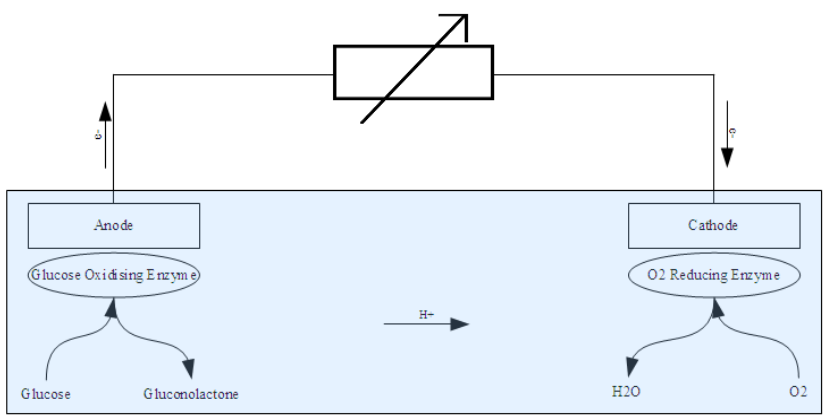

Figure 1: Mechanism of Enzymatic Fuel Cell

In contrast to microbial biological fuel cells, enzymatic biological fuel cells utilize the redox enzymes rather than the whole microorganism as a biocatalyst. The redox enzyme, which are separated and purified from an organism, participates in the electron transfer chain that occurs between the substrate and the anode by oxidizing the fuel.

The specificity of the enzyme reactions at the anode and cathode electrodes of an enzymatic fuel cell eliminates the need for other components required for conventional fuel cells, such as a case and membrane. To date, no commercial enzymatic biofuel cell exists, mainly due to poor stability & power output. Enzymatic fuel cell mechanism is shown in Fig.1

EXPERIMENTAL WORK

Yeast Microbial Fuel Cell

Materials required:

- Gelatin mix- 36 gram
- Dry yeast- 3 gram
- Glucose – 10 gram
- Laboratory thermometer
- Easy carbon electrodes- 2 numbers
- Silver wires (connecting wires)
- Multimeter
- Toray paper (carbon paper)
- Potassium ferricyanide 1.9 gram

Working principle:

The yeast consumes glucose in presence of Fe (III) to produce electrons

$$C_6H_{12}O_6 + 6H_2O + 24Fe\ (III) \longrightarrow 6CO2 + 24Fe\ (II) + 24H^+ + 24e^-$$

Construction procedure

Preparing the Microbial Media

Take a beaker of 500 ml and measure 120 ml of water and pour into the beaker. Then bring water to a strong boil. Make sure to get at least 100ml boiling water. Measure 100 ml of the boiled water and discard the rest from the beaker. Add the gelatin and glucose and stir for about two minutes. Make sure that all the contents are fully dissolved. When the thermometer shows that the temperature has cooled to around 37^0c, add yeast and Potassium ferricyanide and stir to dissolve. Stir for several minutes allowing the media to cool naturally. Then pour out the medium into a mold and cool it. Use the cold water to rinse out any yeast bits stuck to the side and pour into the mold. Mix well and place it in a cool place to set. Continue to maintain normal conditions for the yeast to mature for a day. Similarly prepare the gelatin cake with the addition of glucose and Potassium ferricyanide and without the addition of yeast in the same way.

Study of Voltage Characteristics of the MFC with Change of Medium

Concentration, Quantity of Yeast and Mediator

While changing one parameter all the remaining parameters are kept constant. Effect of change of medium concentration over MFC is studied and tabulated in Table.1

Table 1: Effect of change of medium concentration over MFC

Glucose added in grams	Voltage obtained in volts (V)
1	0.8
2	0.89
3	0.95
4	0.99
5	1.13
6	1.45
7	1.79
8	2.13
9	2.56
10	3.053
11	3.053
12	3.053
13	3.053
14	3.053
15	3.053

This table shows that while glucose is added considerable change in voltage is observed. After getting steady state voltage, there is no change in voltage by adding glucose. Shown in Fig.2

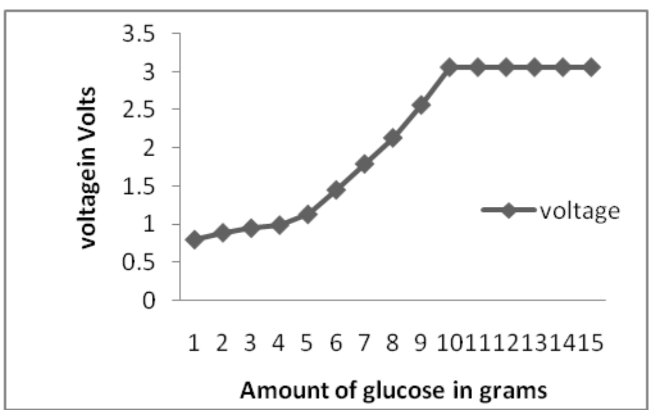

Figure 2: Effect of Change of Medium Concentration over MFC

Effect of quantity of yeast added to the cell on the voltage generation

The voltage is also changed with yeast added it is showed in table.2 and Fig.3.

Table 2: Effect of Quantity of Yeast added to the Cell on the Voltage Generation

Amount of dry yeast added to the gelatin cake in grams	Voltage generated In volts
1.0	2.56
2.0	2.79
3.0	3.02
4.0	3.022
5.0	3.022

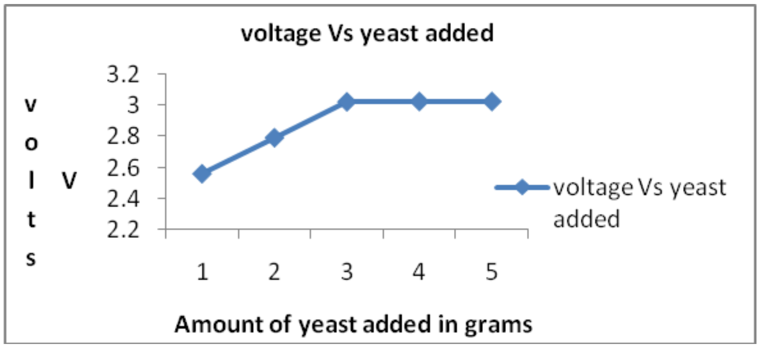

Figure 3: Effect of quantity of yeast added to the cell on the voltage generation

Effect of mediator on voltage generation

Mediator is also plays important role in voltage generation. Shown in table 3 and Fig. 4

Table 3: Effect of Mediator on Voltage Generation

Amount of potassium ferricyanide added in grams	Voltage in volts
1.0	2.41
1.1	2.54
1.2	2.60
1.3	2.75
1.4	2.80
1.5	2.84
1.6	2.91
1.7	2.93
1.8	2.96
1.9	3.02
2.0	2.96
2.1	2.945
2.2	2.92

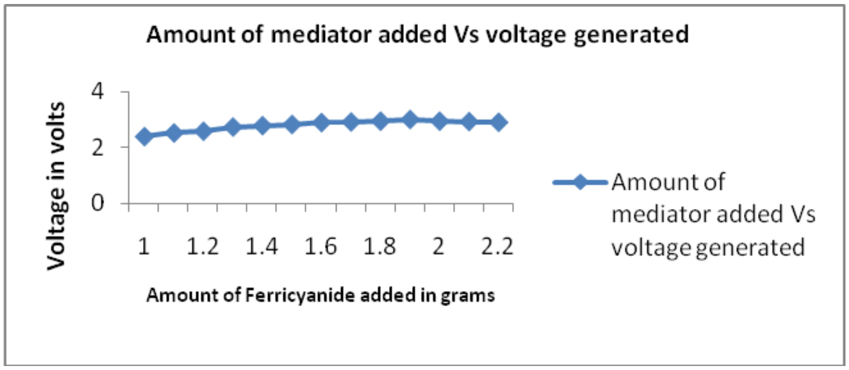

Fig.4: Effect of mediator on voltage generation

Geobactor Microbial Fuel Cell

Materials required

- Graphite electrodes (2 are required)
- Insulated electrical wire
- Electrically Conductive epoxy
- Non-electrically conductive epoxy
- Resistor (100 – 1000 Ohm)
- Voltmeter
- Wire cutters, wire strippers, plastic bucket, mud and water.

Description of some of the components:

Graphite electrodes

The graphite electrodes will serve as the anode and cathode of the sediment battery. One will be buried in the mud and the other suspended in the water above with 8.9 cm diameter x 1.3 cm thick disks.

Insulated wire

A separate piece insulate wire is affixed to each of the 2 electrodes so that current may pass from the electrode through the wire.

Electrically Conductive Epoxy

Conductive epoxy is used to ensure a low-resistance connection between the graphite electrodes and the wire.

Non-electrically Conductive Epoxy

Non-conductive epoxy is applied after the electrically conductive epoxy has dried and is used to protect the conductive epoxy and any exposed wire from contacting water or sediment.

Resistor

A resistor acts as a simulated load to the battery and allows the measurement of current by Ohm's Law V = I x R where: V = voltage (volts), I = current (amps), R = resistance-(Ohms).

Electrode Assembly

- Cut insulated wire to desired length and strip about 4 mm of insulation from the wire using wire strippers or a razor blade.
- Drill a small hole in each electrode. This hole may be in the top or side, depending on where the wire will be connected. This hole should not go through the graphite. It should be only deep enough to cover the exposed part of the newly exposed wire and a few millimeters of the insulation itself (~ 8 mm). The diameter of the hole should be large enough that the insulated wire may fit.
- Drip enough electrically conductive epoxy in the bottom of the hole to cover the exposed wire. Insert the wire so that the exposed wire is in the epoxy and allow it to dry. After the epoxy has dried, test the electrode to make sure that a good connection exists between the graphite and the free end of the wire. This can be done with a multi meter.
- After the conductive epoxy has dried, fill the remainder of the hole, generously with non-conductive epoxy. This will protect the electrical connection as well as give some mechanical stability to it.
- Allow epoxy to dry.
- Repeat the above steps to make the second electrode.

Sediment Battery Assembly

- Fill the bucket with a few centimeters of mud (10 cm).
- Place one of the graphite electrodes on the mud. This will be the "anode" of the sediment battery. Make sure to keep the free end of the wire dry and out of the mud.
- Add a few more centimeters of mud (5-7 cm) over the anode. The anode should be completely covered with at least a couple centimeters of mud.
- Carefully pour water (preferably water from the same body of water that the mud was collected) over the mud and anode. Be sure not to uncover the anode or disturb the mud very much. Add water to at least 10 cm deep over the mud. Allow the particles to settle over night.

- The next day, place or suspend the other electrode in the overlying water above the anode. This electrode is now called the cathode. As with the anode, keep the wires dry.
- Connect the anode and cathode wires together with the resistor in between.
- Using the volt meter, measure the voltage. Place the red wire from the multimeter on the cathode side of the resistor and the black wire on the anode side. Record the voltage. Measure the voltage daily or more frequently. See Fig.5

Precautions

The current (Amps) may be determined by using Ohms Law as described above. Make sure to add fresh water occasionally so that the cathode does not become dry (it does not need to be completely submerged.) Try not to disturb the sediment by moving the sediment battery.

RESULTS AND DISCUSSION

A Biological fuel cell is a bio-electrochemical system that drives current by bacterial interactions found in nature. Here tested four Microbial Fuel Cells in which they are employed with different types of bacteria, medium, mediator less and electrodes.

In the Yeast microbial fuel cell, the generation of electricity can be done with the help of expired gelatin which is not usable for commercial purpose and it also converts into solid form at the room temperature. By this we can get a voltage of 0.3V for a 3x3 piece of gelatin consistent for 48 hrs, if we make them in series the voltage will be increased. The voltage thus generated is 3.053 V, consistent for about 48 hours from the time of assembly.

In Geobacter microbial fuel cell the electricity is generated from the waste sludge. From this we can get 0.904V and ultimately we can get a useful byproduct Manure.

CONCLUSION

Microbial fuel cell technology shows considerable promise for future use. The convenience of maintaining a growing community of biocatalysts could mean a potentially unlimited source of energy. This would create long-lasting cells with numerous applications, but commercial and domestic. Waste management practices could benefit from MFC technology by becoming more sustainable and more efficient in treating both waste water and solids. An assortment of designs is currently being tested for efficiency and potential application to industry. Although power output and scalability are the largest current bottlenecks to marketability, there is research being done to overcome these obstacles. In a larger sense, green energy and sustainable practice are important research and development projects to pursue if we are to grow and prosper as a global community. While the concept of bioelectricity generation was first demonstrated nearly a century ago, MFCs as we now know them from recent work really need to be considered as a new technology. Biofuel cells conducted with yeast and bacteria that needed chemical mediators to be added to the reactor were very unlikely to have practical applications.

Thus, modem MFCs can be considered to have only emerged in 1999 with the finding electricity generation without the need for exogenous mediators. Since then, substantial progress has been made in the field despite the fact that only a relatively few research laboratories have been working in this area. We can expect that as more researchers engage in improving MFC technologies that advances will be made even more quickly.

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