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Review Article

ECONOMIC ELECTRICITY GENERATION FROM MEDIATOR-LESS MICROBIAL FUEL CELL WITH CONSORTIA OF SALT BRIDGE AND CARBON RODS

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ABSTRACT
Microbial fuel cell is an applied aspect of microbes, i.e., using bacteria to generate electricity. It uses carbon source like sugars or any other organic waste. Bacteria like *E. coli*, *Pseudomonas methanica, Pseudomonas fluorescence, Pseudomonas putida, Proteus vulgaris, Bacillus subtilis* and many more that lives at anode are able to consume sugars under anaerobic conditions. They then release protons while depositing electrons externally on anode. Electrons and protons combine with an oxidant at cathode. In this process electricity is generated with carbon dioxide and other useful by products. This electrical current is shown on multimeter keeping the visual indication that microbes are healthy and happy. We have used the technology with *E. coli* bacteria and received an output of 0.40 V and with *Pseudomonas fluorescence* the voltage output noted was 0.32V and by combining both the bacterial culture an output of 0.54 V was obtained. Recent research on microbial fuel cell is based upon the increasing efficacy of microbes to produce electricity and simultaneously enhancing its production at commercial scale. Since it is a rechargeable approach it can be recharged by changing its culture media. New researches are being carried on to using other materials instead of organic waste like nuclear waste which on one hand generate electricity with microbes as bio-catalyst and on the other hand gets degraded. Since it does not have any moving mechanical part, it can be used in remote areas as power supplement with no noise pollution as such.

INTRODUCTION
Some of the reduced fermentation products or microbially reduced artificial mediators can abiotically react with electrodes to yield a small electrical current. This type of metabolism does not typically result in an efficient conversion of organic compounds to electricity because only some metabolic end products will react with electrodes, and the microorganisms only incompletely oxidize their organic fuels. A new form of microbial respiration has recently been discovered in which microorganisms conserve energy to support growth by oxidizing organic compounds to carbon dioxide with direct quantitative electron transfer to electrodes. These organisms, termed electricigens, offer the possibility of efficiently converting organic compounds into electricity in self-sustaining systems with long-term stability (Lowry 2006).
The idea of using microbial cells in an attempt to produce electricity was first conceived at the turn of the nineteenth century. M.C. Potter (1911) was the first to perform work on the subject in 1911. Potter managed to generate electricity from *E. coli*, but the work was not to receive any major coverage. In 1931, however, Barnet Cohen drew more attention to the area when he created a number of microbial half fuel cells that, when connected in series, were capable of producing over 35 volts, though only with a current of 2 milliamps. Haacke (1892) and Klein (1898) have shown that electrical currents in plants are essentially a manifestation of vital phenomena, and that differences in electric potential are connected both with respiration and carbon assimilation. Waller's investigations have also shown that the excitation of living vegetable protoplasm gives electrical response no less than that of animal protoplasm. He has demonstrated that leaves in a condition of active metabolism give an instant electrical response to the influence of sunlight, which was modified under conditions affecting protoplasmic activity. Apparently almost immediately upon the perception of the stimulus of light, electrical energy begins to be absorbed in the process of photosynthesis (Potter, 1911).

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MATERIALS AND METHODS

A microbial fuel cell (MFC) is a device that converts chemical energy with the aid of the catalytic reaction of microorganism. An MFC consists of anode and cathode separated by a cation-specific membrane or a salt bridge. In the anode compartment of an MFC microorganisms oxidize fuel (substrate) generating electrons and protons. The proton and electrons are transferred to the cathode compartment, the protons through the membrane or the salt bridge and the electrons through the external circuit. They are consumed reducing oxidant at the cathode, usually oxygen supplied by aeration;

$4H^+ + 4e^- + O_2 \longrightarrow 2H_2O$ or
$4H^+ + 4e^- + 2O_2 \longrightarrow 2H_2O_2$

In a typical MFC, an anodic electrode potential is developed when the electrons from the oxidation of fuel by microorganisms are available to the electrode. Electrons cannot be transferred from the normal microbial electron transport systems to the electrode due to the non-conductive nature of the cell surface structure. Electrochemical mediators were employed to render electrode. The mediators are usually toxic phenolic compounds. Therefore, the long-term operation of mediated MFCs cannot be achieved with limited commercial applications although MFCs can be used for various purposes including biosensors and electricity generation.

Previous studies showed that an MFC could be operated without mediators using an electro-chemically active bacteria to transfer electrons to the electrode (electrons are carried directly from the bacterial respiratory enzyme to the electrode). Among the electrochemically active bacteria are, *Shewanella putrefaciens, Aeromonas hydrophila,* some bacteria, which have pili on their external membrane, are able to transfer their electron production via these pili. These bacteria are in demand as they are nowadays known as electric bacteria.

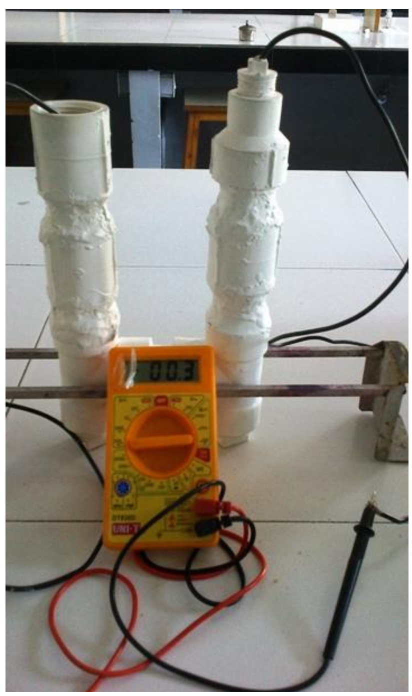

Figure 1. Microbial Fuel Cell

The bacterial cells in the anode of MFC consumed substrate as the transferred electrons directly to the electrode. In the subsequent studies it has been shown that electrochemically active microbes can be enriched using a fuel cell type electrochemical cell. Several steps have been identified as the limiting steps on a mediator-less MFC. They are fuel oxidation at anode, electron transfer from microbial cells to anode, resistance of the circuit, proton transfer through the membrane and oxygen reduction at the cathode.

In a mediator-less MFC, as in other MFCs, the membrane separates the anode from the cathode and the membrane functions as an electrolyte that plays the role of an electronic insulator and allows protons to move through. These functions of the membrane are believed to be indispensable in the operation of an MFC.

A fuel cell consisting of an anode embedded in marine sediment and a cathode in overlying seawater was used successfully to generate electricity. The anode embedded in the sediment was enriched with bacteria belonging to the family *Geobacteraceae*.

In this study attempts were made to develop a mediator-less MFC without using a membrane. Membranes are the major cost for the construction of an MFC.

Construction of Microbial fuel cell

Microbial fuel cell works on the capacity of micro organisms to convert carbohydrate substrate into microbe specific by-products and simultaneously producing electrons which help in electricity production.

MFC consists of two different chambers namely-

- Anodic chamber
- Cathodic chamber.

Both the chambers here are partitioned by a salt bridge consisting of Knox unflavored gelatin and kitchen salt.

From the anodic half consisting of bacteria and their substrates (in anaerobic conditions) electrons flow to cathodic chamber (aerobic conditions) consisting of the electrolytic solution through an external electrical connection maintained by the wires.

Microbes present in the anodic chamber oxidize the substrates present in the same to generate electrons through their metabolism consuming the carbohydrates. Carbon dioxide is produced as an oxidation product with the other by-products that are microbe specific, some of which are of real commercial or household value.

Electrons are first produced in anodic chamber and through anode placed in it, they are transported to the cathode in the cathodic half chamber via wires completing the external circuit.

Same is the case with protons that are produced in the anodic chamber by the activities of bacteria which are transported to the cathodic chamber through salt bridge for the completion of the circuit.

With the movement of electrons and protons from anode to cathode, electricity is generated which is further detected by the multimeter connected at the external circuit.

In the present investigation microbial fuel cell is constructed using PVC pipes, carbon rods that serves as electrode, foam for positioning of electrodes and even distribution of charged particles. One chamber served as anodic chamber filled with 72 hrs old cell suspension culture growing in nutrient medium, another chamber served ad cathodic chamber containing supersaturated solution of electrolyte. Both the chambers are connected via 2 % agar salt bridge instead of any proton exchange membrane, carbon rods instead of any specific electrode and no mediator (Fig. 1).

RESULTS

Present study carried out using bacterial cell suspension culture growing in nutrient medium containing substrate, supersaturated solution of electrolyte in cathodic chamber and intersected by agarose salt bridge (Fig. 1). But when salt bridge instead of any proton exchange membrane, carbon rods instead of any specific electrode and no mediator as well we got the output as *E. coli* bacteria we received an output of

0.40 V and with *Pseudomonas fluorescence* the voltage output noted was 0.32V and by combining both the bacterial culture an output of 0.54 V was obtained (Table 1). Whereas, direct electron transfer from different *Shewanella putrefaciens* strains to an electrode was examined using cyclic voltammetry and a fuel cell type electrochemical cell. Both methods determine the electrochemical activity of the bacterium without any electrochemical mediators. In the cyclic voltammetric studies, anaerobically grown cells of *Shewanella putrefaciens* MR-1, IR-1, and SR-21 showed electrochemical activities, but no activities were observed neither in aerobically grown *Shewanella putrefaciens* cells nor in aerobically and anaerobically grown *E. coli* cell suspensions. The electrochemical activities measured by the cyclic voltammetric method were closely related to the electric potential and current generation capacities in the microbial fuel cell system. The concentration of the electron donor in the anode compartment determined the current generation capacity and potential development in the microbial fuel cell. When the high concentration of the bacteria (0.47 *g* dry cell weight/liter) and an electrode that has large surface area (apparent area: 50 cm^2) were used, relatively high Coulombic yield (over 3 C for 12 h) was obtained from the bacteria Kim *et al.* 2002.

Table 1: Microbes showing voltage output using various mediators, substrate with specific electrodes

Microbes	**Substrate**	**Mediator**	**Anode**	**Voltage**
E. coli	Dextrose	-	Carbon rod	0.40 V
Pseudomonas fluorescence	Dextrose	-	Carbon rod	0.32V
E. coli + P. fluorescence	Dextrose	-	Carbon rod	0.54 V

Microbial fuel cells (MFCs) are typically designed as a two-chamber system with the bacteria in the anode chamber separated from the cathode chamber by a polymeric proton exchange membrane (PEM). Most MFCs use aqueous cathodes where water is bubbled with air to provide dissolved oxygen to electrode. To increase energy output and reduce the cost of MFCs, we examined power generation in an air-cathode MFC containing carbon electrodes in the presence and absence of a polymeric proton exchange membrane (PEM). Bacteria present in domestic wastewater were used as the biocatalyst, and glucose and wastewater were tested as substrates. Power density was found to be much greater than typically reported for aqueous-cathode MFCs, reaching a maximum of 262 ± 10 mW/m2 (6.6 ± 0.3 mW/L; liquid volume) using glucose Liu et al. 2004.

They demonstrated to produce electricity in a MFC from domestic wastewater, while at the same time accomplishing biological wastewater treatment (removal of chemical oxygen demand; COD). Tests were conducted using a single chamber microbial fuel cell (SCMFC) containing eight graphite electrodes (anodes) and a single air cathode. The system was operated under continuous flow conditions with primary clarifier effluent obtained from a local wastewater treatment plant Liu et al. 2004.

So, this is kind of a novel approach to generate rechargeable electricity through live cell preparation that serves as a new dimension for the future as an alternate of energy. We have to identify the specific group of microbial cell lines that may offer optimal quantum of energy that can be further employed.

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