Electricity generation in Microbial fuel cell (MFC) by using mixed microbial culture with synthetic medium


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ABSTRACT

In the present investigation, power generation in MFC containing salt bridge as a proton exchange material using mixed microbial culture from the dairy waste treatment plant (anaerobic digester) was studied. Power output by the MFC with mixed culture was 2.8 mW/m². The synthetic medium decomposes with fermentative process by mixed microbial culture producing hydrogen as the fuel for fuel cell. The electricity produced with microbial fuel cell was studied with different parameters like open circuit voltage, the current flowing through the external circuit and the variation of power output with the load resistance. The exploitation of mesophilic, chemotrophic bacteria allows a flexible access to different substrates including complex carbohydrates. The performance of microbial fuel cell over the period of fermentative utilization of the synthetic media was investigated and the role of microbes in the electricity generation of microbial fuel cells is reported in the paper.

KeyWords

Microbial fuel cell, Salt bridge, electricity, mixed culture.
Introduction

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 ionic conducting membrane. The MFC uses hydrogen fuel and oxygen extracted from the air to produce electricity. As long as these substances are fed into the fuel cells, it will continue to generate electric power. The progress in fuel cells for their commercialization is restricted mainly because of the production and supply of hydrogen from the external sources. In recent years, the in situ production and continuous supply of hydrogen in fuel cells is made possible due to fermentative microorganisms. MFC's make use of the catabolic activity of microorganisms for converting chemical energy into electricity. Microbial fuel cells (MFCs) make use of the catabolic activity of living cells for converting chemical energy into electricity (14,15). Bacteria at anode compartment oxidize organic matter and transfer electrons to a cathode through an external circuit producing current. Protons produced at the anode migrate through the solution across a salt bridge to the cathode where they combine with oxygen & electrons to form water. The direct oxidation of microbial hydrogen shows a number of potential advantages. It does not require the separation and purification of the gas for its subsequent conversion in conventional fuel cells. The separation of the hydrogen gas from microbial cultures is considered to be an important issue as a large fraction of the gas remains dissolved in the microbial medium promoting the growth of hydrogen-consuming microorganisms and thus further lowering the hydrogen yield. Additionally, high hydrogen partial pressures are known to limit the microbial hydrogen. When microorganisms consume a substrate such as sugar in aerobic conditions they produce CO2 and water. However when oxygen is not present they produce CO2, H+ & e-. It has been known for several years that microorganisms or enzymes can be used to produce electricity in microbial fuel cells (MFCs) (13). Only re-
cently, however, it has been shown that MFC’s can be used as a fixed film bioreactor to convert dissolved organic matter to electricity without addition of exogenous mediators (10,5).

The configuration of MFCs opens up possibilities for other applications, such as small scale power plants, batteries and sensors. However, for an extended period, MFCs have remained a scientific curiosity because of their limited efficiency. Several problems still exist in this technology, each needing further attention. The growing success of catalytic fuel cells has given rise to a wide variety of technological solutions for most electrochemical problems. Recently, efforts have been made to use different wastes as a fuel for MFCs due to environmental concerns. Electricity generation from various carbohydrates and carboxylic acids has been tried out with microorganisms (11,7,9). The use of domestic and industrial waste water in MFCs is of interest in recent years (6,8,9) Pure cultures have been tried by researchers for the electricity generation in MFCs(1,2,3,4) MFCs that make use of mixed bacterial cultures have some important advantages over MFCs driven by pure culture(12).

The aim of the present study was to investigate the possibility of electricity generation at mesophilic conditions with synthetic medium by using mixed microbial culture from the dairy waste treatment plant. The salt bridge was used as proton exchanging material. The electricity produced with microbial fuel cell was studied with different parameters like open circuit voltage, the current flowing through the external circuit and the variation of power output with the load resistance. The exploitation of mesophilic, chemotrophic bacteria allows a flexible access to different substrates including complex carbohydrates. The performance of microbial fuel cell over the period of fermentative utilization of the synthetic media was investigated.
Materials and Methods

Microbial inoculum and medium:

Various chemicals required were of analytical grade and purchased locally. The activated sludge from dairy waste treatment plant was collected from Warana Dairy wastewater treatment plant (Warananagar, India) and used as inoculum during the start up of a mixed culture MFC. The synthetic medium containing glucose and mineral solution was used to fill up anode chamber in MFC. The concentrations of various chemicals used were as follows for 1.0 L of distilled water: glucose 10.0 g, Na acetate 1.4 g, FeCl₃ 12.0 g, NH₄Cl 0.30 g, NaH₂PO₄·H₂O 0.66 g, KCl 0.120 g, NaHCO₃ 2.0 g. The activated sludge was directly added as inoculum (10 %) into the anode chamber containing sterile synthetic medium. The initial pH of medium was adjusted to 7.0 using 1.0 N HCL and 1.0 N NaOH. The MFC was operated at mesophilic temperature of 25 to 30 °C.

MFC construction and operation:

Salt bridge MFCs were constructed by joining two glass bottles (500 ml capacity each) with a U-shaped glass tube salt bridge (length = 26 cm, inner diameter = 0.6 cm). The bottles were made airtight by using rubber corks. The electrodes (length = 12.0 cm diameter = 1.2 cm) used were of graphite. The salt bridge was prepared using glass tubes with saturated KCl and agar powder and dipped in both chambers. Electrodes were soaked in distilled water for one day before use. Copper wire was inserted in electrodes to connect the circuit and all exposed metal surfaces were sealed with a non conductive epoxy material (M-seal).

The bottles were autoclaved at 121 °C for 15 min before use. The anode chamber was filled with 300 ml of synthetic medium and inoculum. The cathode chamber was filled with 1.0 N KOH as an electrolyte and supplied with air using air sparger. The anode chamber was continuously stirred with magnetic stirrer. The experiment was run at mesophilic temperature of 25 °C for 24 h.
Methodology:

The measurements of the system were made for 24 h at 20 min intervals using a Voltmeter connected to MFC. The open circuit voltage was measured at regular time intervals. The circuit was completed with a fixed load resistance of 1000 Ω and $V_{RL}$ was measured. After 10 h when the MFC shows the maximum performance, the MFC was tested with different load resistors Viz. 10 Ω, 100 Ω, 1 K, 10 K, 47 K, 100 K, 1 MΩ, 10 MΩ and $V_{RL}$ was measured. Current (I) was calculated at different resistance ($R_L$) from the voltage ($V_{RL}$). The power was calculated with different load resistors. The pH of the system was measured after the complete experiment run.

Results and Discussion

The electrical generation in MFC by using mixed microbial culture with synthetic medium has been studied by employing a fuel cell geometry designed and fabricated in our laboratory. The open circuit voltage of the MFC was measured for about 24 h. The variation of Voc with time is shown in fig.1. It is seen that the Voc increases with time, attends the maximum value of the order of 0.479 V at about 10 h and then there is slight decrease in Voc. This behavior of Voc with time ‘t’ is attributed to the rate of utilization of synthetic medium by microbes. The origin of voltage in MFC can be understood by considering the chemical reactions occurring at cathode and anode compartments given as follows.

At anode: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24 H^+ + 24 e^- + E_0 = 0.014 V$

At cathode: $6O_2 + 24 H^+ + 24 e^- \rightarrow 12H_2O + E_0 = 1.23 V$

Considering the above two reactions the maximum open circuit voltage expected theoretically for MFC is of the order of 1.216 V. However, in the present investigation the value of Voc observed is comparatively smaller than theoretical value. This lower value is attributed to the voltage drop (loss)
across the salt bridge.

In order to use the MFC as the source of electricity, we have studied the output current ‘I’ of the cell with time at 1000 Ω as load resistance. The variation of ‘I’ with time ‘t’ is shown in fig.2. It is seen that the maximum current observed from the MFC is of the order of 0.13 mA. The variation of magnitude of current with time ‘t’ depends on the number of electrons and H+ ions generated by the decomposition of organic matter by the microbes. From fig.2 it is seen that the current of the MFC at about 24 h becomes zero. This indicates that the synthetic medium has been completely utilized by the microbes in MFC.

It is well known that the power output of the electric generation source varies with the load resistance. One can draw the optimum power from the MFC only at a particular load resistance RL which depends on the internal resistance of the cell. The electrical characteristics of the MFC in terms of the current and voltage are studied with external load resistance RL. The variation of current and voltage with RL are shown in fig.3. The natures of the plots are similar to that of the standard behavior of an electric generation like photovoltaic cell.

By analyzing the data of fig.3 we have calculated the variation of power output with the load resistance RL. This is shown in fig.4. It is seen that for MFC studied in the present investigation gives the maximum power output of the order of 2.8 mW/ m² at the load resistance 100Ω. From the present experiment, it reveals that the synthetic matter can be used as a source of electricity by using the microbes as the catalyst.

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Fig. 1: Variation of Voc of MFC with time

Fig. 2: Variation of current of MFC with time
Fig. 3: Variation of $V_{RL}$ and $I_{RL}$ with load resistance RL

Fig.4: Variation of power output V/s load resistance