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Microbial Fuel Cells

Jagadeesh, U.[1], Ganesh, H. S.[2] and Srikanth, G. S.[3]

[1]Teaching Associate, Department of Microbiology, ANGRAU, Agriculture College, Bapatla

[2]PhD Scholar, Department of Plant Pathology, UASR, College of Agriculture, Raichur

[3]PhD Scholar, Department of Agricultural Microbiology, UASB, GKVK, Bangalore

SUMMARY

Microbial fuel cells (MFCs) are devices that can use bacterial metabolism to produce an electrical current from a wide range organic substrate. Due to the promise of sustainable energy production from organic wastes, research has intensified in this field in the last few years. MFCs function on different carbohydrates and complex substrates. As yet there is limited information available about the energy metabolism and nature of the bacteria using the anode as electron acceptor; few electron transfer mechanisms have been established unequivocally. Depending on the operational parameters of the MFC, different metabolic pathways are used by the bacteria. This determines the selection and performance of specific microorganisms. Hence, further development of MFC applications, a greater focus on understanding the microbial processes in MFC systems is required, which is discussed below.

INTRODUCTION

Energy saving programs are being implemented as the global demand for energy is rapidly increasing. Energy demand has been projected to grow more than 50% by 2025. Biomass is increasingly recognized source of energy and waste streams are being regarded as the most optimum substrates for bioenergy production. The advances in the conversion processes will improve the sustainability of biofuels, while higher efficiencies will reduce the environmental impacts. The use of fossil fuels, especially oil and gas, for all human needs in recent years has accelerated and this triggers the global energy crisis. Renewable bioenergy is viewed as one of the ways to decrease the current global warming crisis. It is well known that fuels, such as ethanol, butanol, methane and hydrogen can produce by microorganisms. But the electricity production using microbes, which is known as microbial fuel cells (MFCs), is recent development in energy biology and highly attracting area.

Microbial Fuel Cells

Microbial fuel cell (MFCs) is a device that converts chemical energy from fuel into electricity through chemical reaction with oxygen or another oxidizing agent. MFCs are a new bioelectrochemical process that aims to produce electricity by using the electrons derived from biochemical reactions catalyzed by bacteria. The energy generated by MFCs is expected to supply enough energy to partially cover the energy demand in urban WWTPs. MFC technology represents a novel approach of using bacteria for generation of bioelectricity by oxidation of organic waste and renewable biomass (Boas *et al*., 2023).

In MFCs, the electrons released by bacteria from the substrate oxidation in the anode compartment (the negative terminal) are transferred to the cathode compartment (the positive terminal) through a conductive material. In the cathode, the electrons are combined with oxygen and the protons diffused through a proton exchange membrane. MFCs require sustained electron release in the anode and electron consumption in the cathode. The attainable metabolic energy gain for bacteria is directly related to the difference between the anode potential and the substrate redox potential. The optimal design for MFC is still under investigation, and different materials for the electrodes as well as more selective membranes for proton exchange are being currently developed to enhance their performance. It seems that small cells connected in series offer higher potentials than bigger reactor volumes. Nowadays, the main drawback for the full-scale application of MFC is the cost of materials and the low buffering capacity of domestic wastewater. For this reason, there is no industrial application of MFC to date.

Anodic reaction: $CH_3COO^- + 2H_2O \longrightarrow 2CO_2 + 7H^+ + 8e^-$

Cathodic reaction: $O_2 + 4e^- + 4H^+ 2H_2O \longrightarrow 12H_20$

The overall reaction is the breakdown of the substrate to carbon dioxide and water with a concomitant production of electricity as a by-product. Based on the electrode reaction pair above, an MFC bioreactor can generate electricity from the electron flow from the anode to cathode in the external circuit. A typical MFC consists of an anodic chamber and a cathodic chamber separated by a PEM (Ma *et al.*, 2023). One compartment MFC eliminates the need for the cathodic chamber by exposing the cathode directly to the air (Fig. 1).

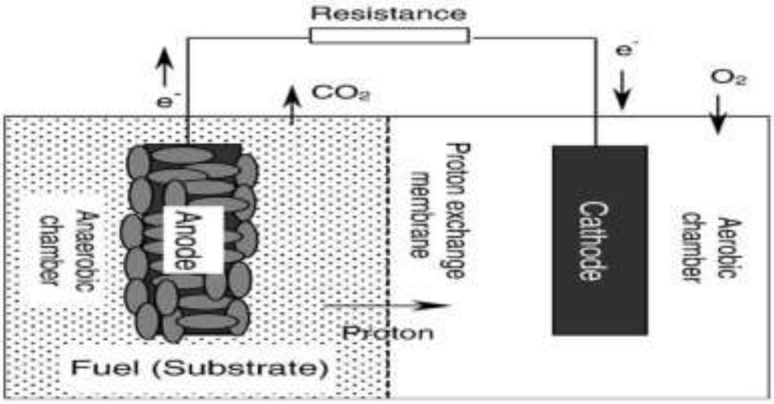

Fig.1: Schematic diagram of typical two-chamber microbial fuel cell.

Microbes used in Microbial Fuel Cells

Many microorganisms possess the ability to transfer the electrons derived from the metabolism of organic matters to the anode. A list of them is shown in Table (1) together with their substrates. Marine sediment, soil, wastewater, fresh water sediment and activated sludge are all rich sources for these microorganisms.

The bacterial communities present in these systems show great diversity ranging from primarily α-Proteobacteria that predominate in sediment MFCs to communities composed of β, ϒ, δ –Proteobacteria, firmicutes and uncharacterized clones in other type of MFCs. The bacteria capable of exocellular electron transfer collectively defined as exoelectrogens (Ida and Mandal, 2023).

Table 1: Microbes used in microbial fuel cells (MFCs)

Microbes	Substrate	Applications
Actinobacillus succinogenes	Glucose	Neutral red or thioninas electron mediator
Aeromonas hydrophila	Acetate	Mediator-less MFC
Alcaligenes faecalis, Enterococcus	Glucose	Self-mediate consortia isolated from MFC with a maximallevel of 4.31 W m-2.
gallinarum, Pseudomonas aeruginosa	Starch, glucose,	Fermentative bacterium
Clostridium beijerinckii	Starch, lactate,	Fermentative bacterium
Clostridium butyricum	Starch, molasses	Sulphate/sulphide as mediator
Desulfovibrio desulfuricans	Sucrose	Ferric chelate complex as mediators
Erwinia dissolven	Glucose	Ferric chelate complex as mediators
Escherichia coli	Glucose sucrose	Mediators such as methylene blue needed.
Geobacter metallireducens	Acetate	Mediator-less MFC
Klebsiella pneumoniae	Glucose	HNQ as mediator biomineralized
Lactobacillus plantarum	Glucose	Ferric chelate complex as mediators

The mechanism of electron transfer

Microbial fuel cells can harvest electricity from electrode-reducing organisms that donate electrons to the anode. While the microorganism oxidizes organic compounds or substrates into carbon dioxide, the electrons are transferred to the anode. The mechanism of electron transfer can occur by three different pathways (Fig. 2). First, electrons can be transferred to the anode through a soluble mediator in the solution bathing the electrode. Second, electrons can be transferred directly to the anode through proteins found on the outer membrane of the bacteria. In anaerobic environments, nitrate or sulfate can be reduced to nitrite, nitrogen, or sulfur ions. Another potential reduction for these bacteria is the conversion of carbon dioxide to methane or acetate. The process uses acetyl-CoA as an intermediate to build even longer chain fatty acids and alcohols. Interestingly, the substrates that these organisms need for the redox reactions can be readily obtained from wastewater or contaminated water, which would both provide energy and clean up the environment (Varshney *et al*., 2023).

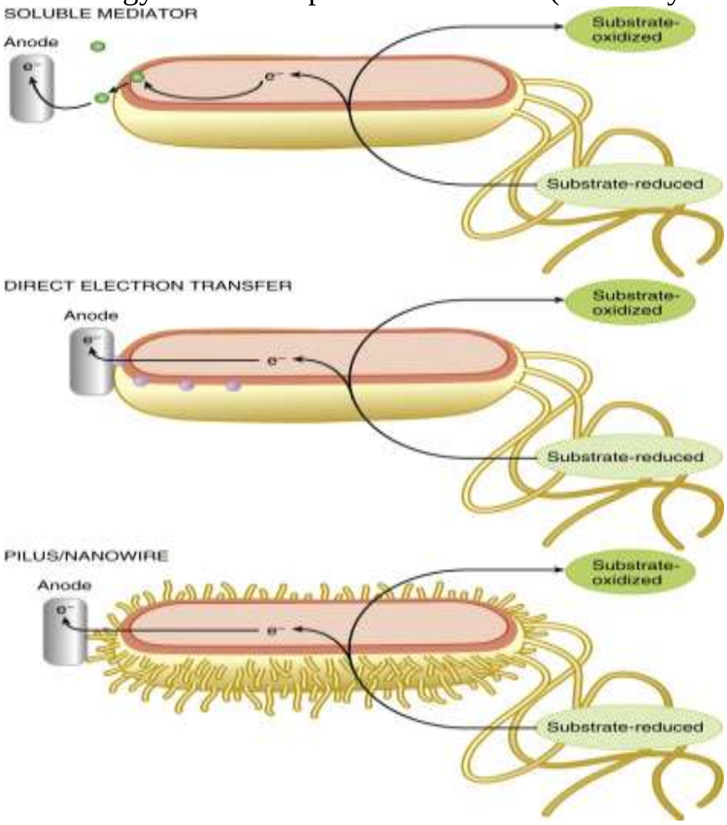

Figure 2: Transfer of Electrons to the Anode in a Microbial Fuel Cell

Application of MFC's

Although MFCs have been studied as an alternative energy source, their application is presently limited to certain niche areas such as power generation systems, bio-recovery, waste-water treatment etc. MFCs are attractive for power generation applications that require only low power, where replacing batteries may be impractical such as wireless sensor networks.

Wastewater treatment

Micro-organisms can perform the dual duty of degrading effluents and generating power. MFCs are presently under serious consideration as devices to produce electrical power in the course of treatment of industrial, agricultural, and municipal wastewater. When micro-organisms oxidize organic compounds present in waste water, electrons are released yielding a steady source of electrical current (Kamali *et al*., 2023).

Powering underwater monitoring devices

Data on the natural environment can be helpful in understanding and modeling ecosystem responses, but sensors distributed in the natural environment require power for operation. MFCs can possibly be used to power such devices, particularly in river and deep-water environments where it is difficult to routinely access the system to replace batteries. Sediment fuel cells are being developed to monitor environmental systems such as creeks, rivers, and oceans (Boas *et al*., 2022).

Power supply to remote sensor

Typically, batteries are used to power chemical sensors and telemetry systems, but in some applications replacing batteries on a regular basis can be costly, time-consuming, and impractical. A possible solution to this problem is to use self-renewable power supplies, such as MFCs, which can operate for a long time using local resources (Varshney *et al*., 2023).

BOD sensing

Another potential application of the MFC technology is to use it as a sensor for pollutant analysis and *in situ* process monitoring and control. Biological Oxygen Demand (BOD) is the amount of dissolved oxygen required to meet the metabolic needs of aerobic organisms in water rich in organic matter, such as sewage.

Hydrogen production

Hydrogen production by modified MFCs operating on organic waste may be an interesting alternative. In such devices, anaerobic conditions are maintained in the cathode chamber and additional voltage of around 0.25 V is applied to the cathode. Under such conditions, protons are reduced to hydrogen on the cathode. Such modified MFCs are termed bio-electrochemically assisted microbial reactors (BEAMR).

Factors affecting MFC's

Like other microbial systems, optimum temperature, pH, ionic strength and salinity enhance the bacterial growth which can improve the MFC performance. Despite the negative effect of salt on microbial growth, higher salinity and ionic strength can increase the conductivity of substrate and therefore enhance MFC performance. The energy efficiency of a fuel cell is generally between 40 and 60%; however, if waste heat is captured in a cogeneration scheme, efficiencies of up to 85% can be obtained.

The operational and functional advantages of MFCs are

- MFCs use organic waste matter as fuels and readily available microbes as catalysts.
- MFCs do not require highly regulated distribution systems like the ones needed for Hydrogen Fuel Cells.
- MFCs have high conversion efficiency as compared to Enzymatic Fuel Cells, in harvesting up to 90% of the electrons from the bacterial electron transport system.

Drawbacks of MFC

- Cost of materials is more
- Low buffering capacity of domestic wastewater

CONCLUSION

Provided the biological understanding increases, the electrochemical technology advances and the overall electrode prices decrease, this technology might qualify as a new core technology for conversion of carbohydrates to electricity in years to come. To improve the MFCs efficiency one should be focused on how to break the inherent metabolic limitation of the microbes for the MFC application.

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