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Use of soil microorganisms for production of electricity through Microbial fuel cells

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Abstract

The world's energy demands are continuing to rise, resulting in a worldwide energy crisis and environmental pollution for finite, environment-related damages, dependence on fossil fuels can not be sustainable for that reason experts are focusing on alternative, renewable, and carbon-free energy sources. Energy sources that are both environmentally and economically sustainable are required. Microbial fuel cells (MFCs) have recently received a lot of attention due to their low operating temperatures and ability to use a variety of biodegradable substrates as fuel. MFC technology is a highly advantageous notion that can be utilized in numerous sectors of industrial, municipal, and agricultural waste management due to the application of microbes toward bioremediation while also resulting in the generation of energy. There are single-chamber MFCs as well as traditional MFCs with anode and cathode compartments. Bioelectricity is produced when microorganisms actively catabolize substrate. Understanding of its components, microbiological processes, limiting variables, and construction designs in MFC systems must be simplified, and large-scale systems must be developed for them to be cost-effective as well as increase electricity production.

Key words : Bioelectricity, Exo-electrogenic bacteria, Microbial fuel cell, Microbial consortium, Soil microorganism.

Abbreviations :
MFC – Microbial fuel cells
OC - Organic carbon
PEM – Proton Exchange Membrane
SMFC – Soil-Based Microbial Fuel Cell

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Bioelectricity production is the generation of electricity by organisms as a result of electron production during metabolism. These produced electrons can be captured to maintain a stable or continuous source of energy production. When given a suitable substrate, bacterial cells can metabolize the components, producing electrons that can be harvested and used by connecting them via a circuit [16]These components can be combined to form a 'microbial fuel cell' (MFC), which can provide energy. The anaerobic digestion of substrate by microorganisms is required for the production of electrons as a result of their metabolism above reactions represent the metabolic reactions performed by microbes in the absence of oxygen[1] and then in the presence of oxygen[2,5] Natural bacteria or secreted enzymes are used to break down the fuel in soil-based Microbial Fuel Cells, which are primarily used to generate electricity from the soil. Bacteria and enzymes operate as biocatalysts in MFCs to generate electricity[24].

Microbial fuel cells are bio-electrochemical systems that take advantage of exoelectrogenic microorganisms ability to respire by transferring electrons beyond the cell[6]. The primary advantages of biological fuel cells over conventional fuel cells are the gentle operating conditions, such as ambient temperature and near-neutral pH. It can enable virtually endless uses of potential fuel. However, appropriate electrocatalysts for oxidation are in short supply. The basis of MFCs is based on the fact that one of the primary properties of microbes is the creation of electricity, as they transport electrons from an oxidized electron donor to an electron acceptor at a higher electrochemical potential. Microbial fuel cells (MFCs) have been shown in recent years to be a promising but difficult technology that serves the dual objective of pollution removal and energy recovery. MFCs have now been widely utilized to treat a variety of commercial and domestic effluent, including molasses, yogurt, oil refineries, beer brewers, the chocolate industry, the paper industry, and so on.

Microbial fuel cells :

It should be noted that an MFC is a part of a hybrid system that is different from traditional aerobic or anaerobic systems[8]. The microbial fuel cell are expanded or grown anaerobically, putting a name to the ultimate objective of transporting power[9]. The strategy should be geared toward limiting oxygen spillage, particularly across the cathode and proton exchanger membrane/salt bridge, to minimize the occurrence of aerobic action[23]. If oxygen leaks into the anode chamber, it is quickly consumed by the microscopic organisms, resulting in low redox potential[11].

An MFC is typically made up of several components that are divided into two chambers: anodic and cathodic chambers, which contain the anode and cathode, respectively. A proton exchange membrane (PEM) separates these chambers[3]. It's a bioreactor device that converts chemical energy directly into electrical energy via electrochemical and biochemical enzymatic reactions[12]. An MFC, in other words, is a bio-electrochemical transducer that converts organic matter to electricity. Potter pioneered the use of MFCs to generate electricity in the early twentieth century[13]. To catalyze the degradation of organic and inorganic waste materials, various microbes (bacteria, microalgae, and fungi) are involved[14,15].

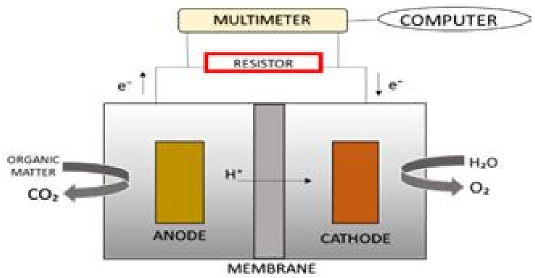

Fig 1. Schematic diagram of dual-chambered MFC

Components influencing MFCs :

Anode: The MFC's anaerobic anode compartment, where the breakdown of the organic substrate takes place, is crucial[16]. Carbon is one of the materials that can be used as the anode in MFC most frequently. Materials used as anodes have some unique properties that enhanced interactions between biofilm and material surfaces[18]. These included low cost, high mechanical strength, forming a surface, electrical conductivity, corrosion resistance, and many more. Commercially accessible sheets of stainless steel, nickel, and silver are suitable for use as metal anodes[19,20].

Cathode : Reduction reactions take place in a cathode chamber. Electrons are transported from the anode chamber to the aerobic cathode chamber via an external electrical circuit, and electrons and protons are recombined on the cathode electrode's surface. One of the primary impediments to real-world MFC applications is the cost and design of the cathodic electrode. Air cathodes are frequently used because they allow direct contact of the solution and conductor with air (three-phase interface: gas-liquid-solid), eliminating the need for forced systems to increase oxygen availability at the catalyst layer. To allow oxygen to diffuse through the electrode, air cathodes must be porous[21].

Proton exchange membrane (PEM):

Membrane materials play a most important role in MFC technology. The cost, achievable performance, configuration, and design of MFCs all influence membrane material selection[3]. Due to the transport of protons across the membrane in microbial fuel cells technology, electro-neutrality between the two chambers is a requirement for the PEM's proper operation[27].

Substrate : In production bioelectricity, a variety of organic substrates are used for anaerobic breakdown by microbes[23]. During studies, it was found that MFCs were used to generate power using simple substrates including glucose, acetate, propionate, and butyrate[24]. It has been claimed that using food waste leachate from bio-hydrogen fermentation as a viable substrate might increase power output.

pH : In addition to playing a role in the MFC's power generation, pH has a significant role in controlling the metabolic activities of microbial cells. Bacterial cells metabolic rate is shown to be at its peak between pH values of 6.3 and 7.8, which is near neutral. At pH 5.5, acidogenic bacteria are active, which encourages substrate breakdown and hydrogen generation (pollutants).

The rate of deterioration is slowed down by a pH range of neutral to alkaline. As a result, the effect of the slowing rate of electron release results in a reduction in power generation at a low rate of deterioration[25].

Temperature : Temperature is significantly more crucial in the MFC than it is in a basic fuel cell since the majority of the electrogenic population is active in the 20–35°C temperature range. This temperature range significantly accelerates the rate at which microorganisms grow at their optimum, promotes the formation of a biofilm, and controls the MFC's ideal pH. Higher operating temperature causes a greater reduction in chemical oxygen demand[26].

Mediators : A mediator is needed to transport the microorganisms created electrons from the substrate's anaerobic degradation to the electrode. The following qualities should be present in an MFC mediator for it to be perfect should link to NADH and have a high negative E^0 value, should be stable in both oxidized and reduced states, should be soluble in aqueous environments, should form a reversible redox couple at the electrode[22].

Types of MFCs :

Mediator-Less MFC: The development of mediator-less MFCs has rendered the usage of mediator chemicals unnecessary. Thus, in mediator-less of MFC, the development of biofilm by electrochemically active microorganisms on the anode surface results in the use of the substrate to produce electricity[28,29].

Membrane-Less MFC : PEM is used to transfer protons to the cathodic chamber that are created as a result of microbial degradation. The use of PEM, which results in a transmembrane potential difference and, in turn, resistance to the flow of ions in electrolytes, is eliminated by membrane-less MFC. In wastewater treatment applications, membrane-less MFCs are often chosen since membranes serve as electronic insulators and invariably cause fouling from suspended particles and soluble pollutants.

Catalyst-coated electrode MFC: To improve the effectiveness of the electrodes, certain chemicals are coated on their surface. Most of these compounds contain conductive polymers, such as polyaniline, which may help transmit electrons to the electrode[29].

Sediment-type MFC: This form of MFC works by inserting an electrode, or anode, into anaerobic silt that contains both organic substrates and a microbial population. built a sediment-type MFC that could power a wireless telecommunications device for a sizable period without any external control.

Microbial fuel cells from soil microorganisms :

Soil microorganisms are home to some of the most intriguing and tiniest species on the planet. The number of bacterial species per gram of soil has been estimated to range between 2,000 and 8.3 million. Plants can take up a variety of essential nutrients, and soil microorganisms can have a big impact on a plant's health. As a result, it was found that the soil with its tremendous diversity of microorganisms, would have the ability to generate energy.

Scientists have known for some years that microbes or enzymes may be used to generate power in microbial fuel cells (MFCs). However, it was only recently shown that MFC may be used as a fixed-film bioreactor to convert dissolved organic matter to electrical energy without the use of external mediators[26]. Bacteria like S*hewanella putrefaciens*[25], *Shewanella algae*, *Geobacter toluenoxydans, Geobacter metallireducens,* and *Rhodoferax ferrireducens*[28] may utilize an electrode as a final electron acceptor without using mediators. Methods by which these microorganisms transmit electrons to an electrode in an MFC are currently being studied.

Soil has been used to generate electricity in microbial fuel cells (MFCs) and has shown promise in a variety of applications[4]. Microbial fuel cells (MFCs), which transform chemical energy from soil organic molecules into electricity via catalysis by soil source exo-electrogenic bacteria, can use soil to generate electricity. Exo-electrogenic bacteria are commonly used in MFCs because they transmit electrons to the anode of the device either directly via highly conductive nanowires or membrane-associated proteins, or via soluble electron shuttles.To begin, the generated electrical signals of the MFCs, such as peak voltage, number of electrons, and start-up time, might be used to monitor pollutant toxicity and soil microbial activity[10]. Second, the utilization of MFCs would result in the eradication of pollutants such as phenol, petrol, and oil from the soil. Thirdly, the operation of MFCs eases methane emissions from paddy soil and sediment[7]. MFC with glucose as a substrate demonstrates soil's potential to generate bio-energy at a comparable level to wastes.

Principle of MFC :

An anaerobic anode chamber and an aerobic cathode chamber are physically separated by an ion-exchange membrane in an MFC bio-electrochemical system. In a conventional MFC, microorganisms are used to get crumbled with the substrate in the anode chamber, and the electron released by the microorganism is then transferred to the cathode via an external wire. The anode chamber is made up of a microbe (catalyst) and an electrode (anode), and it can be fed with growth media or wastewater (anolyte and redox mediator, respectively) (not required in case of mediator-less MFC). Water is formed on the cathode when the requisite protons and electrons are removed during bacterial substrate catabolism and combined with oxygen. Electrons usually flow to the cathode through a conductive substance with external resistance.

$$\text{Anode : } CH_3COO^- + 2H_2O \rightarrow CO_2 + 7H^+ + 8e^- \quad (E_o = -0.29\ V) \quad (1)$$

$$\text{Cathode : } O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (E_o = +0.84\ V) \quad (2)$$

Architecture of MFCs :

There are many types of reactors but they all share the same operating principles.

Dual-chamber MFC: This is the most widely used design consisting of two chambers with the anode and cathode compartments separated by an ion-exchange membrane (Fig. 1). This design is generally used in basic research and literature suggests that the power output from these systems is generally low to their complex design high internal resistance and electrode-based losses.

Single chamber MFC : The anode and cathode are both kept in the same compartment. Anode is got separated from the cathode by PEM and is either positioned far from or close to it [18] Merging two chambers and moving the anode closer to the cathode can minimise internal ohmic resistance by eliminating the usage of catholyte, hence boosting power density.Compared to the two-chamber MFC, it offers a simple, cost-effective design and produces power in a more effective.

Up-flow MFC : This MFC build up in a cylindrical shape consists of an anode (bottom) and cathode (top) partitioned by glass wool and glass beads layers. The beads, which are located at the top and rise over the cathode, are supplied from the bottom of the anode. The gradient needed for the MFCs to function properly is provided by the diffusion barrier between the electrodes.

Stacked MFC : In connected this design, several single-cell MFC are connected in series or in parallel to achieve a high current due to a higher electrochemical reaction rate, a parallel connection can generate more energy than a series connection when operated at the same volumetric flow but is flown to higher short-circuiting compare to a series[14].

Applications :

Manufacturing of Bioelectricity: Utilizing organic carbohydrate substrates from biomass-derived from municipal, industrial, and agricultural wastes to produce bioelectricity is the key component of MFC. Another benefit of MFCs is the direct conversion of fuel molecules into electricity without the creation of heat.

Wastewater Treatment : The persistent problem of wastewater management has been solved perfectly by microbial fuel technology. Mostly, maximum power density, Coulombic efficiencies, and COD are the main three factors that determine the efficiency of MFC technology. Industrial, municipal, and other wastewater discharges serve as a major source of energy harvesting while also serving as an ideal substrate for bioremediation.

Bio-Hydrogen Production : When bacteria are used as catalysts in MFCs, they oxidize the substrates in the anodic chamber to produce protons and electrons, which are then delivered to the cathode via the PEM and the wire, respectively**.** The electrode that generates electricity or the bacteria that make reduced metabolites like methane or hydrogen gas can serve as the ultimate electron acceptor for the bacteria in the anodic compartment during substrate oxidation.

Bioremediation : Electrotrophs are any of a large variety of microorganisms that can take electrons from electrodes. These electrographic consortiums have excellent potential for heavy metal cleanup[24].

Advantages and Disadvantages :

At both the industrial and scientific levels, the generation of bioelectricity technology is employed for its numerous uses[25]. Comparing MFC technology to other energy generation methods that use fossil fuels, methanogenic anaerobic digestion, etc., which cause the release of carbon dioxide and contribute to global warming, is one of its most significant advantages[15].

The effectiveness of MFC technology is affected by several parameters, including technical ones like internal resistance, electrode potential, and oxygen supply that limit the technology's potential on a commercial and financial level[26]. The development of diverse microbial catalysts is required for the continuous power production by MFCs since it depends heavily on the building of biofilms by the microorganisms to assist the transport of electrons from the biofilm to the anode. Involvement of the pre-requisites for MFC technology is pricy and delicate, there is some doubt as to whether these materials can be used on a wide scale. Due to their lack of strength and durability, some materials, such as carbon fabric, paper, and rods, are not suitable for scaling up.

The production of abundant required energy from organic substrate can build MFC technology independent. The proton mass as well as the weak cathode created by the oxygen reduction reaction determine this resistance.MFCs have the following important benefits: Direct conversion of substrate energy to electricity, low activated sludge generation, robustness and insensitivity to environmental factors (*e.g.* temperature), lack of gas treatment, no energy input for aeration, and widespread application in areas without electrical infrastructures are all advantages.Because of its very effective uses in power production, pollution treatment, and sensing, the Soil Microbial Fuel Cell (SMFC) has lately been used as a sustainable technology in recent years.

Conflict of Interest :

The authors mention no potential conflict of interest.

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