Microbial Fuel Cell

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***Abstract*— Recently, microbial fuel cells (MFCs) have received much attention due to their mild operating conditions and various biodegradable substrates as fuel. A traditional MFC consists of an anode and a cathode compartment, but single-chamber MFCs exist. Microorganisms actively catabolize the substrate, and bioelectricity is generated. MFCs could be used as a power generator in small devices such as biosensors. In addition to the advantages of this technology, it still faces practical obstacles such as low power and current density. In this paper, various parts of MFC, such as anode, cathode, and membrane, have been reviewed, and some practical options have been proposed to overcome the practical problems in this area. This research review also demonstrates the improvement of MFCs with a summary of their advantages and possible applications in future applications. Various vital factors affecting bioelectricity generation on MFCs have also been investigated, and these critical parameters are thoroughly discussed.**

I. INTRODUCTION

In recent decades, energy consumption has been on a prosperous trend. Energy sources are divided into three groups: fossil fuels, renewable sources, and nuclear sources; in which non-renewable energy sources, which comprise a considerable part of energy consumption, can be divided into two main classifications: nuclear and fossil energy. Fossil fuels negatively affect nature due to carbon dioxide emissions. From what has been said, it follows logically that the consumption of fossil fuels has seriously threatened human life with drastic consequences such as global warming and atmospheric pollution.

However, various countries around the world have made remarkable efforts to find a piece of a compelling solution to the energy crisis by turning their sights to renewable energy sources such as solar, wind, and water-generated energy. As a result of these efforts, one of the latest proposed alternative energy sources is the fuel cell (FC), which generates energy using high-value metal catalysts (in the traditional version). FC has many advantages over other types of power generators, e.g., no emissions of polluting gases (such as SOx, NOx, CO2, and CO), higher efficiency, and the absence of moving parts. As a result, lack of noise, and so on. On the other hand, the only disadvantages of these new energy sources are the high price and high production weight.

One type of FC is the microbial fuel cell (MFC), which uses an active microorganism as a biocatalyst in an anaerobic anode chamber to produce bioelectricity. Although, in 1911, Potter observed an electric current produced by bacteria, for the next 50 years, limited functional results were obtained in this area. However, in the early 1990s, FCs became much more attractive devices; subsequently, MFCs were considered a promising technology. In addition, the field of MFC research expanded considerably in 1999 when it was discovered that the mediator is not an obligatory part of MFC.

Almost all MFCs consists of anode and cathode chambers that are physically separated by a proton exchange membrane (PEM). An active biocatalyst in the anode oxidizes organic substrates and produces electrons and protons. Protons are guided into the cathode chamber through the PEM, and electrons are transferred through the external circuit. Protons and electrons react in the cathode chamber and parallel oxygen reduction to water. It is worth noting that the active biocatalyst in the anode compartment oxidizes carbon sources or substrates and generates electrons and protons. Oxygen in the anode chamber will inhibit electricity production; therefore, a pragmatic system must be designed to keep bacteria separated from Oxygen (anaerobic chamber for anodic reaction).

II. WORKING ON MICROBIAL FUEL CELL

The operation of microbial fuel cell (MFC) technology is based on the principle of redox reactions. Bacteria oxidize organic matter to produce carbon dioxide (CO_2), electrons, and protons. The natural metabolism of microbes is used to generate electricity. The substrates are converted into electrons by the bacteria. A two-chamber MFC is shown below to illustrate how MFC technology works. It consists of an anode, a cathode, an exchange membrane, or a salt bridge. Where the anode chamber is anaerobic, and the cathode chamber is aerobic. The exchange membrane is either a cation exchange membrane or a proton exchange membrane, connecting the two chambers, and only protons can diffuse.

III. MICROBIAL FUEL CELL DIAGRAM

As seen in the above diagram, the MFC comprises an anode and a cathode chamber divided by a proton exchange membrane (PEM). Protons, electrons, and CO_2 are created at the anode when bacteria or microorganisms oxidize the fuel or substrate. At the same time, the exchange membrane allows the protons to enter the cathode chamber.

Electrons are moved via an external electrical connection from the anode chamber to the cathode chamber to produce electrical energy. Protons and electrons are used up at the cathode, where they react with Oxygen (O_2) to make water. The anodic and cathodic reactions of the entire process are therefore stated as,

A. Anodic Reaction

$CH_3COO^- + H_2O + 2CO_2 + 2H^+ + 8e^-$

B. Cathodic Reaction

$O_2 + 4H^+ 4e^- \longrightarrow 2H_2O$ (where E° = 1.23 Volts)

From the above equation, we can observe that to maintain the potential for electricity generation; Oxygen must be consumed continuously. Using an air cathode or water bubbling, Oxygen is provided in the cathode chamber. The redox potential of Oxygen is higher than that of other electron acceptors. Therefore, it is considered a better receiver of cathode electrons.

Failure of electrode contact with Oxygen and slow reduction of Oxygen on the carbon electrode are shortcomings that lead to limited use of Oxygen in microbial fuel cell technology. However, the reaction of the cathode chamber can be improved by using electrodes coated with catalysts because catalysts are rare metals and expensive.

IV. TYPES OF MICROBIAL FUEL CELLS:

There are two types of MFC technology, which are mediator-free and mediator-type.

A. Mediator Free Microbial Fuel Cell (MFC)

The bio-electrochemical activation of bacteria is used in this form of MFC to transfer electrons to the electrode. Cytochromes, found on the outer membrane and aid in the transfer of electrons, is just one example of the electrochemically active redox enzymes they include.

A biofilm develops on the anode chamber's surface, ensuring that electrons are sent directly to the anode through conduction. Shewanella putrefaciens and Aeromonas hydrophila are two examples of bio-electrochemically active bacteria employed in this type.

B. Mediator Microbial Fuel Cell (MFC)

The MFC in question is not electrochemically active. This means that, without the assistance of a mediator like humic acid, the bacteria in the fuel cannot transmit electrons. This form of mediation uses unfavorable, harmful, and expensive mediators. The mediator lowers the oxidation state by snatching electrons and sending them to the anode for the reoxidation process. The majority of the time, laboratories employ this type.

The other types of microbial fuel cells are,

- Microbial Electrolysis Fuel Cell (MEFC)
- Soil-based MFC
- Phototrophic Biofilm MFC
- Nanoporous MFC
- Sediment MFC
- Membrane-less MFC

V. COMPONENTS OF A MICROBIAL FUEL CELL

A microbial fuel cell contains various components mainly divided into two chambers. They are the anode chamber and the cathode chamber. The anode chamber contains the anode, and the cathode chamber contains the cathode. Several components of a microbial fuel cell are discussed in this section.

- Anode chamber
- Cathode chamber
- Exchange Membrane
- Substrate
- Electrical circuit.
- Microbes or microorganisms
- Electrodes and copper wires for connecting electrodes.

A. Anode Chamber

It is a biocompatible, electrically conductive, and chemically stable component for the substrate. The bacteria in this chamber break down the substrate into energy, water, and carbon dioxide. These microorganisms are kept in an atmosphere with little Oxygen. It comprises graphite rods or plates embedded in a stainless steel mesh.

B. Cathode Chamber:

In this chamber, protons and electrons recombine. The oxygen (O2) level is reduced to water. It uses Pt as a catalyst.

C. Exchange Membrane

It acts either as a cation exchange membrane or a proton exchange membrane. The replaceable membrane in MFC technology uses Ultrex or Nafion. Protons can pass through this membrane. While on the other hand, electrons and protons are recombined.

D. Electrical Circuit

Electrons leave the anode chamber and travel through the electrical circuit to supply energy to the load.

E. Substrates

These are used to produce energy for the bacterial cell. The type of substrate used affects the power density, coulombic efficiency, performance, and economic viability of a microbial fuel cell. Organic substrates used in MFCs are proteins, volatile acids, carbohydrates, wastewater, and cellulose. The most commonly used substrate is acetate.

F. Microbes

Microorganisms or microbes used in MFC technology are based on a culture of bacteria.

1). Axenic bacteria

Metal that reduces bacteria

Geobacter sulfurreducens

Rhodoferax ferrireducens

Clostridium beijerinckii

Shewanella putrefaciens.

2). Mixed bacterial fuel

Alcaligenes faecalis

Pseudomonas aeruginosa

Enterococcus faecium

Proteobacteria

Desulfuromonas

Clostridium butricum

Bacteroides

Nitrogen-fixing bacteria like Azospirillum and Azoarcus

Aeromonas species

VI. CONSTRUCTION OF A MICROBIAL FUEL CELL

Utilizing microbial fuel cells, chemical energy is transformed into electrical energy by oxidizing organic waste and a variety of carbon sources. Anode and cathode chambers, microorganisms, exchangeable membranes, substrates, electrodes, and electrical circuits for producing electricity are some components used in building microbial fuel cell technology. Glass, plexiglass, and polycarbonate are used for the anode and cathode chambers. Carbon paper, carbon cloth, and graphite are used as anode electrodes. To preserve the aerobic nature of the electrode, an air cathode is used, which is made of black catalyst material or platinum material.

In MFC technology, most microbial population belongs to Shewanella and Geobacter species. Photosynthetic bacteria are efficiently used to produce electricity. Mixed bacterial cultures such as natural microbial communities, marine and lake sediments, domestic wastewater, and brewery wastewater are used in MFCs.

Substrates such as acetate, glucose, propionate, and butyrate are used in MFCs for energy production. In the production of bioelectric energy, various organic substrates are used, which participate in the anaerobic activity of microbes.

Household wastewater is effectively used to provide ongoing electricity. Pig wastewater is used for production with the highest power density; waste sludge is used for the manufacture of hydrogen and bioelectricity; and petroleum wastewater is used for producing bioelectric energy.

The design of the Microbial Fuel Cell technology determines how it is built. There are two types of MFC: single chamber and dual chamber, also known as the double chamber.

VII. ADVANTAGES, DISADVANTAGES, AND LIMITATIONS

A. Pros

MFCs are an inventive, quick, and easy technological solution. Despite the benefits of this technology, real-world challenges still exist, such as insufficient electricity production, unstable current, high internal resistance, and high cost of materials. The high price of platinum-based catalysts makes production expensive, and there isn't enough infrastructure to sustain hydrogen delivery. Many fuel cell technologies currently in use are still in the prototype stage and have not yet received scientific validation.

B. Cons

Sedimentary microbial fuel cells (SMFCs) benefit beyond power generation for low-energy applications. In addition to generating electricity, SMFCs can enhance the oxidation of reduced compounds at the anode, thereby removing excess or unwanted reducing equivalents from submerged soils. Additionally, SMFC could be used to control redox-dependent processes in sediment layers. Several cathodic reactions that may drive these sediment oxidation reactions have been investigated. Special attention is paid to two biologically mediated cathodic reactions using oxygen reduction and the manganese cycle. Both reactions imply low cost and high electrode potential and are interesting for MFC and SMFC-type reactors.

The cathode's reduction of molecular Oxygen is the fundamental drawback of the MFC system. The reduction of Oxygen at the cathode is now a significant limiting factor in MFCs, even though different metals have traditionally been utilized to catalyze the cathodic reaction.

VIII. THE FUTURE OF MICROBIAL FUEL CELLS

Although it has certain inherent constraints, like low production rates and the usage of secondary fuel cells, hydrogen power generation has shown promise in recent years. This motivated researchers to concentrate on microbial fuel cells. They created an anode chamber that held an anode with bacteria and wastewater (a biocatalyst). A biopotential is produced when bacteria prefer an acidic environment to grow and feed on sewage (voltage). A cathode was close to the anode chamber. A glass wool membrane was added that functions as a proton exchange membrane between the anode and cathode.

The cathode's exterior was open to the atmosphere. The MFC system had wastewater injected into it, and the researchers looked at how well it removed wastewater and its potential for producing bioelectric power. The output voltage grew throughout the first 37 hours, reaching a maximum of 212 millivolts (mV) and a 60% efficacy in removing wastewater. At pH 6 and 7, the voltage peaked at 308 and 291 mV, respectively.

According to lead researcher S. Venkata Mohan of the Bioengineering and Environmental Center of the Indian Institute of Chemical Technology, "The MFC system will have wider application potential in wastewater treatment plants (ETPs) shortly." According to him, the lack of pollutants and energy usage during wastewater treatment are the main benefits of energy from wastewater.

IX. CONCLUSION

MFC technology has proven to be effective for generating electricity and treating wastewater simultaneously. MFCs have recently attracted the interest of academics, and during the past two decades, their performance has significantly improved. Water treatment, sensor applications, heavy metal recovery, nitrification and denitrification, robotics, in situ power supply, and implantable power sources are just a few areas in which this technology is expanding. The most notable feature of MFCs is their capacity for wastewater treatment. MFCs have the potential for food-based wastewater treatment and sustainable power generation. Nearly every facet of the functioning of MFCs is the subject of research worldwide. Many businesses have started working on MFC reactor development and are doing well in the market.

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