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Review Article

Future of Energy Demand by Microbial Fuel Cell: Review on Green Energy

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ABSTRACT

The colossal energy utilization in conjunction with the incrementing growth of population, made the need to develop energy assets. Energy sources accessible have been categorized into fossil fuels, nuclear and renewable energy sources based on their mode of origin and reliability. Microbial Fuel Cell is progressive in the future of environment protection. The technology will be nearer to realistic applications with the introduction of profoundly efficient electrode materials and catalysts to diminish production costs making it more sustainable. The primary components of fuel cells are electrodes i.e. anode and cathode. The anode is an electrode that induces oxidation and loss of electrons. The cathode is where there is reduction and the production of electrons. Anode surface fuel oxidation produces electrons and oxidized by products. The electrons later pass through an external circuit to the cathode. Microbes absorb nutrients from their surrounding environment within the MFC and release in the form of bioelectricity.

Keywords: Biochemical, Current, Fuel Cell, Voltage, Waste

Introduction

The fossil fuel depletion and inevitable global warming have become worldwide problems, thus, significant efforts have been made to generate and utilize renewable energy to alleviate these crises.[1] Methods for obtaining energy compounds from biomass, such as ethanol, methane, and hydrogen, have been developed using environment friendly technology and some of these technologies have been put to practical use.[2] It is important to establish the technologies that are able to obtain energy in various forms according to the environments and circumstances of each region.[3] Apart from the above technologies, biofuel cells utilizing microorganisms and enzymes, which can generate renewable electrical energy from organic matters contained in biomass, begin to attract attention as a means to obtain sustainable energy.[4] It has not been put into practical use completely yet, but without the problem of by-products, electricity can be directly obtained from the devices.[5] Biological fuel cells convert the chemical energy of carbohydrates, such as sugars and alcohols, directly into electric energy. As most organic substrates undergo combustion with the evolution of energy, biocatalysed oxidation of organic substances by oxygen at the two electrode interfaces provides a means for the conversion of chemical energy into electrical energy.[6] In normal microbial catabolism, a substrate such as carbohydrate is oxidized initially without participation of oxygen, while its electrons are taken up by an enzyme-active site, which acts as a reduced intermediate.[7] Moreover, if biomass waste is used as the fuel, no food competition will occur. Therefore, using this method, energy can be obtained sustainably.[8-10]

There are various types of biomass, e.g., sustainably harvested wood, waste paper, food waste, sewage sludge, and various wastewaters. Taking wood based biomass as a fuel example, when everything is burnt using available technology for thermal power generation, there will be nothing left, we will lose some other useful compounds contained in it.[11] On the other hand, in biofuel cells, although electricity is generated from the sugar obtained from the biomass, other components in the wood, such as lignin, can be used for purposes other than power generation. Generally, the energy density of the biomass used as a fuel for MFCs is high. For example, glucose and xylose, found in various plant biomass, can produce up to 20 or 24 electrons per molecule, provided that they are completely oxidized to carbon dioxide. It is possible to generate 4430 Wh power per kg of glucose according to the calculation described later.[12-15] For reference, a typical lithium-ion battery has a weight energy density of about 200 Wh per kg. This comparison means that glucose and xylose are two biofuel sources of interest, especially as electron donors. Therefore, MFCs using glucose or xylose as their fuel have great potential as a means of obtaining high energy. In biofuel cells, biological reactions are used for the oxidation reaction of biomass, they are divided into two based on the type of catalyst used: (1) enzymes and (2) microorganisms. With the constant research of sustainable, renewable and alternative energy sources.[10]

Often the energy sources are used as solar cells or wind mills. Microbial Fuel Cells (MFCs) may also be part of the picture. A Microbial Fuel Cell (MFC) is a bio-electrochemical system that harnesses the natural metabolisms of microbes to produce electrical power. Within the MFC, microbes consume the nutrients in their surrounding environment and release a portion of the energy contained in the food in the form of electricity.[11] The idea of using MFCs for producing electricity dates back to 1911.[12] Research on this subject and the creations of MFCs occurred sporadically throughout the rest of the 20th century. Recently the need of renewable and clean forms of energy and the need of wastewater treatment have triggered wide research interest in developing the MFC technology to address both of these human needs. For example, Scientific American had a popular article introducing the MFC technology.[13] In real-world applications of MFCs are yet limited because of their low power density level of several thousand mW/m^2.[14] Efforts are being made to improve the performance and reduce the construction and operating costs of MFCs. Meanwhile, finding niche applications in which the technology can be used immediately in practice will certainly help technology advances and eventually achieve these long term goals.[15]

Microbes are ubiquitous throughout virtually all soils, sediments and streams on the planet. This makes MFCs very attractive for this sensor application that only requires low power but where replacing batteries may be time consuming and expensive.[16] Specifically, sensors can be used to collect data on the natural environment for understanding and modeling ecosystem responses.[17] However, the sensors require power for the operations of measurement and communications. MFCs can possibly be used to power sensors particularly in the river and deep water environments where it is difficult to replace batteries. Powered by MFCs, the sensors can be left alone in remote areas for many years without maintenance.[18] To facilitate the use of MFCs in this niche application, examining the performance characteristics of MFCs, in particular the performance with sample types commonly found in those environments, the thermal limits that dictate the temperature range in which MFCs can function, the electricity production variation over time.[19-20] On the basis of the performance characteristics, determine the conditions under which MFCs work most efficiently to generate electricity. The result of this can be used to create more efficient MFCs on a large scale as a new sustainable energy source.[21]

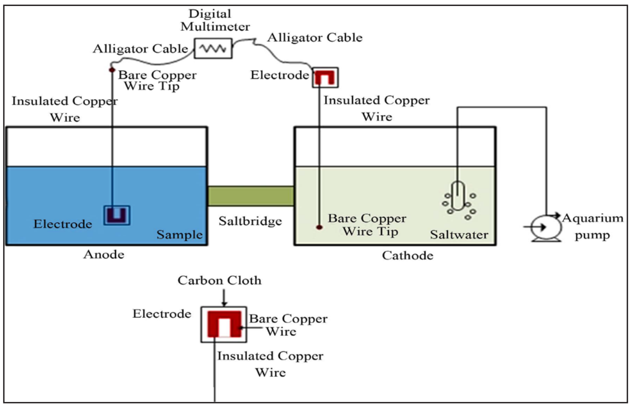

Figure 1.Diagram of Microbial Fuel Cell System Setup[18]

This Figure 1, shows the diagram of the MFC experimental system setup. The MFC is made of the following four parts: 1) anode chamber, which holds the bacteria and organic matter in an anaerobic environment, 2) cathode chamber, which holds a conductive saltwater solution, 3) salt bridge, also known as proton-exchange membrane, which separates the anode and cathode and allows protons to move between the two chambers. Bacteria in the anode chamber create protons and electrons during oxidation as part of their digestive process. The electrons are pulled out of the solution in the anode.[23-25] The electrons released in MFCs after microbial oxidation of a substrate are transferred to the anode. The electron then leaves the anode and flows through an external electrical circuit before reaching the cathode, thereby producing electricity.[26] Finally, in the case of an oxygen reduction reaction, these electrons react with protons and oxygen at the cathode, producing water as the final and clean product. As long as the current flows over a potential difference, power will be directly generated via bacterial catalytic.[27]

History of Microbial Fuel Cell

In 1791, the Italian physician and physicist, Luigi Galvani, who investigated the nature and effects of electricity in animal tissue was the first to observe a bioelectric phenomenon when he observed twitching of an isolated frog leg upon passing a brief electrical discharge through it. As a result, the term bioelectricity was coined after that observation.[28] In 1838, a Welsh physical scientist and lawyer, William Robert Grove, developed a wet-cell battery and called it the "Grove cell". This is a two-fluid electric cell consisting of amalgamated zinc in dilute sulfuric acid and a platinum cathode in concentrated nitric acid, separating the two by a porous ceramic pot to generate about 12 amps of current at about 1.8 volts.[29] In 1893, a founder of the field of physical chemistry, Friedrich Wilhelm Ostwald, experimentally determined the interconnections between the various components of the fuel cell: Electrodes, electrolytes, oxidizing and reducing agents, anions and cations by relating physical properties and chemical reactions. In 1910, Michael Cresse Potter, a professor of Botany at the University of Durham, UK, demonstrated that organisms could deliver current and produce voltage when he was researching how microorganisms degrade organic compounds.[30] Later in 1911, Potter discovered electrical energy from cell cultures of Saccharomyces and Escherichia coli using platinum electrodes. This discovery led him to construct a basic microbial fuel cell.[31] In 1931, Cohen at Cambridge, UK, revived Potter's idea when he described how a batch of biological fuel cells generated over 35 V.[32] In the 1960s, the idea of the fuel cell became popular when the Space Administration and National Aeronautics exhibited interest in converting organic waste into electricity on its long space flights. Bacteria and algae were among the first organisms used in biological fuel cells. During this period, the Rohrback group designed the first biological fuel cell in which Clostridium butyricum was used as biomaterial to produce hydrogen by glucose fermentation.[33] Quite quickly, the use of biological fuel cells as a power source became commercially available, but was unsuccessful, eventually disappearing from the market. In 1966, Williams showed that rice husk is a potential source of lignocellulose as it can produce upon fermentation many useful enzymes and biofuels resulting in 40 mA at 6 V using biological fuel cells.[34] The fuel cell revolution started when MJ Allen and H Peter Bennetto at Kings College, UK, demonstrated improved biological fuel cells using various microbes to increase both the reaction rate and the efficiency of electron-transfer using mediator systems.[35] They combined an understanding of the electron transport chain and significant advancements in technology. In 1999, certain electrochemically active bacterial species using no mediator molecules were first discovered by the Byung Hong Kim group (Korean Institute of Science and Technology, South Korea) to transport electrons to electrodes.[36] Using electrochemical tests, they found that the Shewanella sp. Is capable of electrochemical reactions, the finding demonstrated gave results that microorganism can recover up to 83% of electrons from glucose oxidation (without a mediator) in the presence of Fe^{3+}.

Working Mechanism of (Electrochemical) Microbial Fuel Cells

A fuel cell is an electrochemical device that uses a hydrogen rich fuel and oxygen to create electricity by an electrochemical process. It consists of two electrodes and an electrolyte to allow the passage of H^+. A fuel cell works as follow:[37]

- A fuel rich of hydrogen or pure hydrogen enters the anodic site where a catalyst is present to separate the hydrogen's electrons from its protons
- Simultaneously, oxygen is fed at the cathodic side where ½ O2 molecules combine with the electrons and protons to produce water
- At the anode side, electrons travel via a conducting medium or circuit to reach the positively charged cathode. That flow of electrons is what generates an electrical current
- The movement of protons from the anode side is facilitated through an electrolyte or a proton exchange membrane in some specific types of fuel cells
- The fuel cell continues to generate a current as long as the fuel is supplied

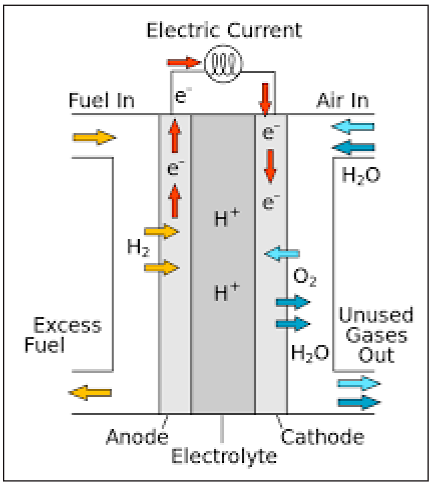

Figure 2.Basic Anatomy of a Fuel Cell[38]

The type of electrolyte used in a fuel cell plays a big role in determining the kind of chemical reaction happening inside the cell, the catalysts required and many other factors such as temperature.[39]

The difference between typical electrochemical systems and bio-electrochemical ones is that the latter use microbes as catalysts in addition to the use of organic matter specifically as a source of fuel and energy. These systems can be classified into three main categories: Electro genesis systems, Electrolysis Cells and Enzymatic Fuel Cells.[40]

Electro genesis systems (Microbial Fuel Cells): Electro genesis systems are often referred to as microbial fuel cells. They harness energy from organic waste using two electrodes, the cathode and the anode. The latter acts as an electron acceptor before transferring the electrons to the cathode, that flow of electrons produces a current the mechanism of an MFC will be discussed in details in the following sections.[41,42]

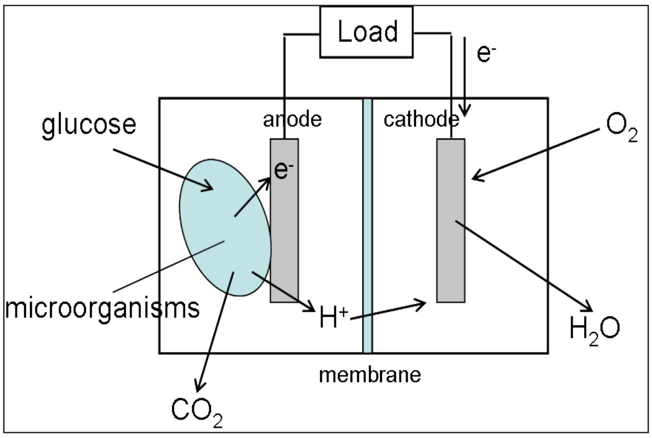

Figure 3.General Schematic of a Microbial Fuel Cell[43]

Electrolysis Cells (Microbial Electrolysis Cells): Similar to the microbial fuel cells, microbial electrolysis cells harness the energy existing in the organic matter. However, MECs perform the electrolysis of water and therefore needs an external power source to be able to generate hydrogen.[44] Unlike MFCs, MECs require anaerobic conditions at the cathode to prevent oxygen from interrupting the electrolysis.[45] The external power source can be provided by an MFC to reach the required potential that is usually 1.23 V.[46, 47]

Enzymatic Fuel Cells: EFCs use a specific enzyme to catalyze the oxidation reaction happening at the anodic chamber. Enzymatic fuel cells were created to substitute the use of precious metals that end up oxidizing in a typical fuel cell.[48] Enzymes are used both at the anodic and cathode chambers.[49] The main application of these cells is biosensors which still under research.[50, 51]

Types of Microbial Fuel Cell: A Microbial Fuel Cell is a device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms. A typical Microbial Fuel Cell consists of anode and cathode compartments separated by a cation (positively charged ion) specific membrane. In the anode compartment, fuel is oxidized by microorganisms, generating CO^2, electrons and protons. Electrons are transferred to the cathode compartment through an external electric circuit, while protons are transferred to the cathode compartment through the membrane. Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water. Broadly, there are two types of microbial fuel cell: mediator and mediator-less microbial fuel cells.[52]

Mediator Microbial Fuel Cell: Mediator-Based Electron Transfer Mechanism has low-molecular-weight redox species which may assist the shuttling of electrons between the intracellular bacterial species and an electrode. However, there are many important requirements that such a mediator should satisfy in order to provide an efficient electron transport from the bacterial metabolites to the anode: (a) The oxidized state of the mediator should easily penetrate the bacterial membrane to reach the reductive species inside the bacterium.[53] (b) The redox potential of the mediator should fit the potential of the reductive metabolite (the mediator potential should be positive enough to provide fast electron transfer from the metabolite, but it should not be so positive as to prevent significant loss of potential). (c) Oxidation state of the mediator should interfere with other metabolic processes (should not inhibit them or be decomposed by them). (d) The reduced state of the mediator should easily escape from the cell through the bacterial membrane. (e) Both oxidation states of the mediator should be chemically stable in the electrolyte solution, they should be well soluble and not get adsorbed on the bacterial cells or electrode surface.[54] The mediators can be coupled to the microorganisms in three different ways: (i) A diffusional mediator shuttling between the microbial suspension and the anode surface (ii) A diffusional mediator shuttling between the anode and microbial cells covalently linked to the electrode (iii) Mediator adsorbed on the microbial cells providing electron transport from the cells to the anode The microbial cells can be covalently linked to the electrode surface having eCOOH groups and amino groups of the microbial membrane resulting in the formation of amide bond.[55]

Most of the microbial cells are electrochemically inactive. The electron transfer from microbial cells to the electrode is facilitated by mediators such as thionine, methyl viologen, methyl blue, humic acid, neutral red and so on. Most of the mediators available are expensive and toxic.[56]

Mediator-free Microbial Fuel Cell: Some mediators are inorganic in nature and pose a potential toxic nature toward the microbial flora employed in the MFC system. Therefore mediator free MFCs have been developed thereby eliminating the potential use of mediator compounds. Thus, in this type of MFCs biofilm formation on the anode surface by electrochemically active microbes leads to the utilization of the substrate producing electricity.[57] Mediator free microbial fuel cells do not require a mediator but use electrochemically 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 and others. Some bacteria, which have pili on their external membrane, are able to transfer their electron production via these pili. Mediator-less MFCs are a more recent area of research, due to this, factors that affect optimum efficiency, such as the strain of bacteria used in the system, type of ion-exchange membrane and system conditions (temperature, pH, etc.) are not particularly well understood. Mediator-less microbial fuel cells can, besides running on wastewater, also derive energy directly from certain plants. This configuration is known as a plant microbial fuel cell. Possible plants include reed sweet grass, cord grass, rice, tomatoes, lupines and algae.[58]

The mediator free microbial fuel cells are of designed in various types, like:

- Microbial electrolysis cell
- Soil-based Microbial Fuel Cell
- Phototrophic biofilm microbial fuel cell

Microbial Electrolysis Cell

A variation of the mediator-less MFC is the microbial electrolysis cells (MEC). Whilst MFC's produce electric current by the bacterial decomposition of organic compounds in water, MECs partially reverse the process to generate hydrogen or methane by applying a voltage to bacteria to supplement the voltage generated by the microbial decomposition of organics sufficiently lead to the electrolysis of water or the production of methane. A complete reversal of the MFC principle is found in microbial electrosynthesis, in which CO_2 is reduced by bacteria using an external electric current to form multi-carbon organic compounds.[59] MECs are analyzed and compared in terms of current production, hydrogen production rates, hydrogen recoveries and energy recoveries.[60] Current is typically normalized to either an electrode surface area (m^2) or the reactor volume (m^3), which allows for better comparison among different reactors than simply reporting the current (mA or A).

Current directly relates to the hydrogen production rate as the electrons that travel to the cathode are eventually converted into hydrogen gas. The use of high surface area anodes, close electrode spacing, different membrane materials, and improved reactor designs has rapidly increased both current densities and hydrogen recoveries in MECs.[61]

Soil-Based Microbial Fuel Cell

Soil-based microbial fuel cells adhere to the same basic MFC principles. Soil acts as the nutrient-rich anodic media, the inoculum and the Proton-Exchange Membrane (PEM). The anode is placed at a certain depth within the soil, while the cathode rests on top the soil and is exposed to the oxygen in the air above it. Soils are naturally teeming with a diverse consortium of microbes, including the electrogenic microbes needed for MFCs, are full of complex sugars and other nutrients that have accumulated over millions of years of plant and animal material decay. Moreover, the aerobic (oxygen consuming) microbes present in the soil act as an oxygen filter, much like the expensive PEM materials used in laboratory MFC systems, which cause the redox potential of the soil to decrease with greater depth.[62, 63] The concept of this type of MFC involves insertion of one of the electrode (anode) in anaerobic sediment which constitutes of both, the organic substrates and the microbial community. This electrode is connected to the cathode which is placed in aerobic water.

Phototrophic Biofilm Microbial Fuel Cell

Phototrophic Biofilm MFCs (PBMFCs) are the ones that make use of anode with a phototrophic biofilm containing photosynthetic microorganism like chlorophyta, cyanophyta etc., since they could carry out photosynthesis and thus they act as both producers of organic metabolites and also as electron donors. The sub-category of phototrophic microbial fuel cells that use purely oxygenic photosynthetic material at the anode are sometimes called biological photovoltaic systems. A study conducted reveals that PBMFCs yield one of the highest power densities, therefore, show promise in practical applications.[64] Researchers face difficulties in increasing their power density and long term performance so as to obtain a cost effective MFC. The sub- category of phototrophic microbial fuel cells that use purely oxygenic photosynthetic material at the anode are sometimes called biological photovoltaic systems.[65]

Factors Affecting The Mfcs Efficiency

Components of Microbial Fuel Cells

A typical MFC consists of an anodic chamber and a cathodic chamber separated by a Proton Exchange Membrane (PEM). A one compartment MFC eliminates the need for the cathodic chamber by exposing the cathode directly to the air. The dual chamber design is used for explaining the basic mechanisms of MFCs. The anodic and cathodic chambers comprised of glass, polycarbonate, Plexiglas, with a respective electrode of carbon paper, carbon-cloth, graphite, graphite felt, Pt, Pt black or reticulated vitreous carbon. These two chambers are separated by a proton exchange membrane (PEM, Nafion or Ultrex) .[66] The anodic chamber comprises organic matter, which is metabolized by micro-organisms, thus producing protons and electrons. A high potential electron acceptor to complete the process is found in the cathode chamber. An ideal electron accepter, without interference or harmful effects on the microbial population is required in order to improve power density. Because of its richness and non toxicity, oxygen is an ideal electron acceptor and prefers to be an oxidizing agent because it simplifies MFC operation.[67,68] Since microorganisms can generate electrochemically active substances that may be either the final products of anaerobic respiration or metabolic intermediaries, the MFC can be defined as a device using microbes to convert chemicals into electrical energy by a catalytic reaction.

Table 1.Materials Examples for Different Items[68]

Items	Materials
Anode	Graphite, graphite felt, carbon paper, carbon-cloth, Pt, Pt black, RVC
Cathode	Graphite, graphite felt, carbon paper, carbon-cloth, Pt, Pt black, RVC
Anodic chamber	Glass, polycarbonate, Plexiglas
Cathodic chamber	Glass, polycarbonate, Plexiglas
Proton exchange system	Proton exchange membrane: Nafion, Ultrex, polyethylene. poly, (styrene-codivinylbenzene), salt bridge, porcelain septum, solely electrolyte)
Electrode catalyst	Pt, Pt black, MnO2, Fe3+, polyaniline, electron mediator immobilized on anode

Catalyst (Carbon) used in Microbial Fuel Cell

Numerous research studies are being conducted to evaluate the influence of the electrode materials on the performance and cost of the MFCs. Carbon materials, which are noncorrosive, have been widely used because of their high electrical conductivity and chemical stability, e.g., carbon rod, carbon fiber, carbon felt and carbon cloth.[69] Biocompatibility, specific surface area, electrical conductivity and cost are important factors for its selection. Since its discovery in 2004, graphene has been attracting much attention for its use as an electrode because of its high specific surface area, electrical conductivity, biocompatibility. In fact, graphene has been already used in lithium-ion batteries, the development of graphene modified materials to increase the power density has progressed actively.[69, 70] One of the main challenges is the development of efficient and stable cathode catalysts for MFCs. Oxygen is an ideal electron acceptor for MFCs because of its high redox potential, availability and sustainability. However, the oxygen reduction reaction (ORR) is kinetically sluggish, resulting in a large proportion of potential loss.[71] Catalysts used in MFCs with a focus on their synthesis/ modification procedure, durability, performance, stability and economics. The criteria that ORR catalysts should meet for MFC applications and the evaluation methods based on MFC experiments are demonstrated. The cathode catalysts are categorized into carbon-based catalysts, metal-based catalysts.[72]

Figure 4.Carbon Materials Obtained in Different Formats: Grains, Powders, Pellets, Films and Coatings on Monolith and Foam Structures[73]

Carbon Black

Carbon Black (CB) is a product from incomplete combustion or thermal decomposition of hydrocarbons. Due to its high stability and large specific surface area, Carbon black is widely used as the support material for metal catalysts. However, simple chemical modification and the introduction of functional groups can create active sites that make Carbon black itself a metal-free ORR catalyst.[74, 75] In a study treating Carbon black with nitric acid, the MPD of the MFC equipped with the modified Carbon black was 3.3 times that with pristine Carbon black and was 78% of that with Pt/ C. A similar enhancement in MPD (71% of that with Pt/ C) was reported in another study by using nitric acid and ammonia gas as treatment reagents, which was likely attributed to the successful introduction of oxygen and nitrogen atoms on the Carbon black surface. Pyrolyzing Carbon Black and Poly Tetra Fluoro Ethylene (PTFE) under an ammonium atmosphere resulted in the co-doping of nitrogen and fluorine atoms.[76].

Carbon black as a cathode catalyst shows high economic viability. For example, polypyrrole/ carbon black (PPy/ C) yielded a MPD that is 70% of that with Pt/ C. When the MPD was normalized to the material cost, the composite was 15 times more efficient than Pt/C. Despite the excellent cost effectiveness, the durability of Carbon black catalysts in MFCs remains unknown.[77]

Figure 5.Carbon Black Sheet

Activated Carbon

Activated carbon (AC) refers to porous carbon materials (surface area > 1000 m^2 g^{-1}) that are produced by the thermal or chemical activation of a wide range of carbonaceous precursors.[56] The preparation of AC from silk fibroin was the first study showing that AC could catalyse ORR, which was attributed by the authors to the intrinsic nitrogen atoms. Later, peat-based AC was used as the MFC catalyst and achieved a MPD of 1220 mW m^{-2}, 1.2 times that with Pt/ C, indicating that AC might hold great promise for MFC applications. The results of the two studies also suggest that AC produced from different precursors will possess different chemical functional groups, BET specific surface areas and active sites, which may synergistically affect ORR catalysis.[78]

AC made from five precursors, including peat, coconut shell, hardwood carbon, phenolic resin and bituminous coal, were examined as the ORR catalysts in MFCs and yielded varied performance.[59] AC as an ORR catalyst exhibits excellent electrochemical. AC has attracted much attention due to its high cost effectiveness.[79]

Figure 6.Activated Carbon

Figure 7.Graphite Felt

Graphite

Graphite is multiple layers of carbon sheets bonded through weak van der Waals interaction. Due to its high electrical conductivity and high stability, graphite is commonly used as a fuel cell electrode. Exfoliation of graphite can form single-layer carbon nano sheets known as grapheme. The discovery of graphene was awarded the 2010 Nobel Prize for Physics and has drawn extensive attention in the past decade.[80] With high electrical conductivity and a high BET surface area, graphene-based cathode catalysts have been demonstrated to effectively catalyse the ORR in MFCs. Pristine graphite is not considered catalytic toward the ORR because of the lack of active sites. A more direct way to increase the BET surface area is to prepare crumpled graphene particles by capillary compression in rapidly evaporating aerosol droplets.[81]

Similar to other carbon catalysts, both graphite and graphene catalysts exhibit high stability.

The cost effectiveness of graphite and graphene is comparable to that of CNFs/ CNTs, but still less competitive to Activated Carbon. In the typical procedures, graphene oxide is first prepared, reduced to graphene and then subjected to modification. Therefore, a facile and efficient approach to creating graphene-based catalysts is highly desired and should be the focus of future studies.[82]

Electrodes: The efficiency of a MFC is dependent on a number of factors and one is the material of the electrodes. There have been many MFC designs and configuration that have been tested and developed in recent years to improve the performance and efficiency of MFCs. However, the challenge to find the balance between performance and material cost remains difficult. There are some advantages and drawbacks of some of the electrodes that are widely used in today's MFCs, in terms of their conductivity, surface properties, biocompatibility and cost. The electrodes have a certain resistance hence the most effective ones are the least resistive. "The anodic resistance contribute to the overall cell resistance in MFC operation." However, use of highly efficient electrode materials (i.e. platinum) is not economically feasible for large-scale applications thus investment on more cost-effective alternatives is priority in MFC research. The material characteristics which are critical for an effective electron transfer are high conductivity and mechanical strength. There is no requirement for bacteria adhesion. The scalability and cost-effectiveness are also taken into consideration.[83] The materials used in MFC experiments mostly include carbon material and other metals like platinum. It is widely recognized that type and concentration of bacteria on anode electrodes greatly affect the power/ current density in MFCs. In order to maximize bacteria adhesion, the surface area of the electrodes is increased are divided into a number of configurations: a plane structure, a packed structure and a brush structure.[84]

Application of Microbial Fuel Cell

There are numerous ways the Microbial Fuel Cell can improve the world. The MFC has current and potential uses in brewery and domestic wastewater treatment, desalination, hydrogen production, remote sensing, pollution remediation and as a remote power source. Many new applications are beginning to be tested and may come into widespread use in the near future. The organic carbon waste can be removed, electricity is produced. Industries that produce wastewaters high in easily degradable organic carbon are good candidates for this application. Examples are food industry, dairies, breweries, the bioproducts industry and the biofuels industry, such as biorefineries.[85]

Brewery Wastewater Treatment: Brewery and food manufacturing wastewater can be treated by microbial fuel cells because their wastewater is rich in organic compounds that can serve as food for the microorganisms. Breweries are ideal for the implementation of microbial fuel cells, as their wastewater composition is always the same, these constant conditions allow bacteria to adapt and become more efficient.[86] Currently, Fosters, an Australian beer company, has begun testing out an MFC to clean its wastewater while generating electricity and clean water.[68] Fosters has installed the first small-scale Microbial Fuel Cell for brewery wastewater treatment. Each long tube is one large Microbial Fuel Cell. Twelve MFCs are placed in parallel to clean the large volume of wastewater. Wastewater flows in at the top, is cleaned by bacteria and comes out the bottom as purified water. Partnered with the University of Queensland, Fosters' plans to improve the MFC's cleaning power and electrical output and eventually build a 660 gallon, 2 Kilowatt MFC that cleans all of the company's wastewater. The power generated from cleaning the brewery wastewater is expected to pay for the initial cost of the Microbial Fuel Cell in ten years.[87,88]

Sewage Treatment: Sewage wastewater can also be converted via microbial fuel cells to decompose the waste organic material contained within it. Research has shown that MFCs can reduce the amount of organic material present in sewage wastewater up to 80%. The process is very similar to brewery wastewater treatment, with the difference being that the water must first be pretreated to remove toxins and other non-biodegradable materials. This is a challenging step because sewage wastewater often varies in composition and may require extensive treatment before it can be cleaned by the MFC. However, this extensive treatment is justified by the electricity produced while cleaning the wastewater. The electricity production from MFCs will help to offset the high costs of processing wastewater. Wastewater treatment plants could end up dumping fewer pollutants into oceans and rivers if the money saved from the electricity bill is put to work further cleansing the wastewater.[89,90]

Generation of Energy out of Bio-waste/ Organic Matter: Electricity is being generated in a direct way from biowastes and organic matter. This energy can be used for operation of the waste treatment plant, sold to the energy market. Furthermore, the generated current can be used to produce hydrogen gas. Since waste flows are often variable, a temporary storage of the energy in the form of hydrogen, as a buffer, can be desirable.[91,92]

Remote Power Source MFCs can run low-power sensors that collect data from remote areas. For example, scientists have replaced a traditional wireless thermometer in the Palouse River in Washington with one powered by a MFC. This Microbial Fuel Cell is integrated into the riverbed, as shown in Figure 6. A simple Microbial Fuel Cell consisting of a cathode attached to an anode by a metal wire. By placing the anode in the anaerobic sediment of a river or ocean and placing the cathode in the aerobic water right above the sediment, a current is generated. Anaerobic bacteria that naturally grow in the sediment produce the small current that can be used to charge a capacitor to store energy for whenever the sensor needs it. One major advantage of using a Microbial Fuel Cell in remote sensing rather than a traditional battery is that the bacteria reproduce, giving the MFC a significantly longer lifetime than traditional batteries. The sensor can thus be left alone in a remote area for many years without maintenance.

The advancement of Microbial Fuel Cell technologies provides cheap, accessible power to remote regions of Africa, where 74% of the population lives without electricity. The electrical current produced by a simple homemade MFC is enough to recharge a cell phone battery, an important communication and lighting tool to rural African communities. The materials required to construct this simple MFC are soil, manure, copper wire, buckets and graphite cloth.[93-95]

Conclusion

Microbial fuel cells have become an interesting and promising area of research. There are many applications of MFCs will help to reduce the use of fossil fuels and allow for energy gain from wastes. MFC technology does not have the power to change the world single-handedly, microbial fuel cells will never be able to produce enough electricity to take the place of a coal-fired power plant. They will, however, help to bring the world to becoming a sustainable and more environmentally-friendly place. MFCs can be used as remote energy sources in a range of practical applications, including in braweries, domestic wastewater treatment, desalination plants, hydrogen manufacturing, remote sensing and pollution remediation. The waste materials can be used in these areas and stored in oil through the extensive use of MFCs

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