

BIOELECTRICAL PRODUCTION BY MICROBIAL NANOWIRES**Omar Adel Badawi Omar**

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Abstract: Bacterial nanowires, which are electrically conductive appendages or threads that facilitate the transfer of electrons outside the bacterial cell, produced by a number of bacteria, have shown the potential to be useful in many fields, especially bioenergy and bioremediation. Bacteria have developed a group of nanowires in different forms, including Pilli, which are fine structures protruding from the surface of bacteria and used for adhesion, movement, and the formation of biofilms in some species that participate in extracellular respiration and use their filaments to transfer electrons. The world is currently witnessing an energy crisis due to the continuous increase in energy requirements around the world, so the trend today is to use microbial fuel cell (MFC) technology, which is an encouraging technology for generating electricity and a source of clean and environmentally friendly energy that uses microorganisms to convert the chemical energy of organic compounds into electricity using bacterial nanowires. Most MFC studies are being done for electricity generation, which is the primary application of the technology at the moment, and it is a fascinating technology that can use a variety of substrates, MFC cell with bacteria to achieve bioenergy production despite the fact that the energy levels in all these systems were relatively low

Keywords: -



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Introduction

Bacterial Nanowires

Bacterial nanowires Microbial nanowires are electrically conductive appendages or filaments that facilitate the transfer of electrons outside the bacterial cell. They are produced by a number of bacteria, most notably the genus *Shewanella*. Bacterial nanowires are diverse from both a physiological and functional perspective. The exact role that microbial nanowires play in their biological systems is not fully understood, but there are several proposed functions that occur naturally outside the environment.

Bacterial nanowires have shown potential to be useful in many areas, especially bioenergy and bioremediation. Bacteria have evolved a variety of nanowires, including pili, which are tiny structures protruding from the surface of bacteria and used for adhesion, motility, and biofilm formation in some species that participate in extracellular respiration and use their pili for electron transfer. The limited number of studies on microbial nanowires to date have shown that long-range electron conduction via microbial filaments is possible and that this type of extracellular electron transfer is important in many anaerobic bioenergy processes. Studies of *Geobacter* nanowires have already suggested that different species produce nanowires such as Type IV pili (T4P) with different mechanisms of conduction. Many microbial communities exchange electrons via nanowires not only for anaerobic respiration, but also as an electrical signal between cells.

The potential of gut microorganisms to electrically interact with their eukaryotic host via nanowires is intriguing, so recent studies have focused on understanding these biological phenomena of nanowires. *Geobacter sulfurreducens* nanowires, called electrobacteria, are composed of pili that have metal-like conductivity attributed to the overlapping orbitals of aromatic amino acids. *Geobacter* species nanowires have been implicated in direct interspecies electron transfer, which may be an important pathway in converting organic waste to methane. Nanowire networks confer conductivity to *Geobacter* biofilms that convert organic compounds to electricity in microbial fuel cells Lovley, D. and MFCs.

Microbial fuel cells

Bioelectrochemical devices that use microorganisms as biocatalysts to convert the chemical energy contained in organic or inorganic compounds into electrical current. The idea of using multifunctional cells to produce electricity dates back to 1911. More recently, the need for renewable and clean forms of energy and the need to treat wastewater have led to a broad research interest in developing MFC technology to meet both of these human needs.

The main problem with using microbial cells is that the energy generated by the cell may not be sufficient, for example, to operate sensors continuously. This problem can be solved by increasing the surface area of the electrodes. Another limitation is that they cannot work at very low temperatures due to the fact that microbial reactions are slow at low temperatures.

Characteristics of Microbial Fuel Cells (MFC)

There are some unique properties of MFCs that make this technology more useful than other technologies:

1. MFCs provide relatively higher efficiency in using the chemical energy of electrical current.
2. MFCs can produce good results in varying temperature conditions (from 20 to 40) degrees Celsius (which makes this technology unique to other current bioenergy practices).
3. During MFC operation, they do not require external electricity for ventilation to provide oxygen (as an electron acceptor) as the cathode can be passively ventilated.

Components of Microbial Fuel Cells

1- Anode Chamber The material used to make the anode is a conductive material and the material should also be environmentally friendly and chemically inert. Carbon materials are

widely used in MFCS for example, graphite plates and graphite rods, graphite electrodes, graphite granules, carbon cloth, carbon brush and stainless steel.

2- Cathode Chamber: The cathode chamber contains the cathode material, which is a catalyst to increase the reduction of electrons and accept electrons. A catalyst such as platinum is used in the cathode electrode to increase the rate of oxygen reduction when oxygen is used as an electron acceptor. Oxygen is one of the best alternatives for electron acceptor because it is cheaper, abundantly available and has high oxidation and reduction capacity.

In general, a microbial fuel cell consists of the following parts: an anode chamber, which contains bacteria and organic matter in an anaerobic environment; a cathode chamber, which contains a conductive salt water solution; a proton exchange membrane, also known as a salt bridge, which separates the positive electrode and the cathode and allows protons to move between the two chambers; and an external circuit, which allows electrons to enter the cathode and acts as a path for electrons to move through when they are drawn from the solution at the anode.

As shown in Figure (1), bacteria in the anode chamber produce protons and electrons during oxidation as part of the digestion process. Electrons are drawn from the solution at the anode and placed on an electrode. The electrons are then delivered through the external circuit to the cathode chamber via the cathode electrode. The electrode is made of bare copper wires attached to nickel on a carbon cloth. Protons move from the solution at the positive electrode through the proton exchange membrane to meet the electrons at the negative electrode.

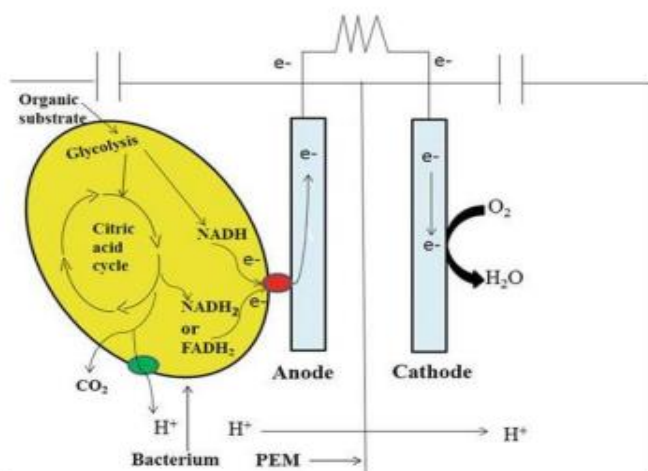


Figure (1) The general principle of operation of the microbial fuel cell

Types of Microbial Fuel Cells (MFC)

1- Dual Chamber:

It is the simplest design among all MFCs. In a typical design, one bottle (can be of different designs) is used as anode while the other is cathode, separated, physically separated by a proton exchange membrane (PEM). Usually, a specific medium or substrate is used in the anode and a specific solution is used to generate power.

2- Single Chamber:

This type is made of only one chamber which contains both anode and cathode. The anode electrode is either far away or near the cathode separated by a proton exchange membrane (PEM). This type of MFC is simple, economical and also produces a large amount of power in competition with the dual chamber.

Microorganisms used in microbial fuel cells

The main sources of organisms in microbial fuel cells are usually sediments, soils and sewage rich in bacteria. Various types of inoculums can be used at the anode. Many microorganisms have been found to have the ability to transfer electrons from their metabolic activity to the anode. Members of the Proteobacteria, Acidobacteria and yeasts are capable of

producing electricity. Marine sediments, soils, freshwater sediments and sewage have been found to be good sources of these electroactive microorganisms. Among these, some bacteria are particularly efficient at transferring electrons directly to the anode, via specialized groups of cytochromes and proteins including Pili. Other microorganisms require synthetic mediators for electron transfer. An example is *Pseudomonas*, a Gram-negative aerobic bacterium. This genus has a wide range of metabolic diversity, and *Pseudomonas aeruginosa* can produce chemical intermediates such as pyocyanins and compounds that can transfer electrons to an electrode and generate electricity in microbial fuel cells.

Among the many known bacteria capable of producing electricity and used in microbial fuel cells as pure cultures are the *Geobacter* species, which are Gram-negative, rod-shaped, obligately anaerobic bacteria that perform anaerobic respiration. This species is found in soil and aquatic sediments and has the ability to oxidize organic compounds and metals including iron and radioactive elements, making it important in bioremediation.

Geobacter sulfurreducens is the most successful species to date in producing electricity. Its properties as microbial nanowires are important for long-range electron transfer across biofilms. Discovered by Dr. Derek R. Lovley and colleagues in 1987, this organism not only has the ability to bioremediate, but it can also produce electricity. Interestingly, *Geobacter sulfurreducens*, also called the electric generator, can form metabolically active biofilms that help convert acetate into electricity.

The table below shows the types of microorganisms that are considered fuel cells and the feedstocks they use.

Microorganism	Substrate
<i>Aeromonas hydrophila</i>	Acetate
<i>Clostridium beijerinckii</i>	Starch, glucose, lactate, molasses
<i>Candida melibiosica</i>	Glucose, fructose, sucrose
<i>Desulfovibrio desulfuricans</i>	Sucrose
<i>Erwinia dissolvens</i>	Glucose
<i>Methylobacterium anaerophilum</i>	Methanol
<i>Escherichia coli</i>	Glucose, sucrose
<i>Geobacter metallireducens</i>	Acetate
<i>Geobacter sulfurreducens</i>	Acetate
<i>Gluconobacter oxydans</i>	Glucose, ethanol

Applications of Microbial Fuel Cells (MFC)

Major applications developed in recent decades are electricity generation, wastewater treatment, biosensing and hydrogen production.

Bioelectricity generation

It is quite clear that most of the MFC studies are done for electricity generation, which is the primary application of the technology at the moment, and it is a fascinating technology that can use a variety of substrates, MFC cell with bacteria to achieve bioenergy production despite the fact that the energy levels in all these systems were relatively low in the anode chamber of the

MFC bacterial fuel cell the microorganisms oxidize the substrate into protons and electrons which are passed through the proton exchange membrane (PEM) and electrically conduct respectively to the cathode chamber the two MFC chambers can be electrically connected to a multimeter and an external resistance box, to measure the voltage and thus the power can be calculated using Ohm's law.

Using waste to generate electricity

The performance and efficiency of microbial fuel cells depends largely on the type of materials used in the metabolism by microbes. Simple and complex organic or inorganic sources present in wastewater from different sources are used as a base material for electricity production. Using wastewater as a base material has an important advantage: the electricity produced is cheap. Secondly, it leads to the treatment of wastewater. Extensive research has shown that these complex materials such as agricultural waste, which is the waste resulting from various agricultural processes such as agriculture, poultry processing industries, slaughter houses and agricultural industries, are oxidized by a different group of microorganisms and cause electricity generation. The advantages of using this method are:

- 1- Low-cost electricity production from waste materials
- 2- Year-round electricity production.
- 3- People will be able to produce electricity in their homes.
- 4- This technology will be useful for people living in poor countries such as Africa where there is no huge infrastructure required in power generation plants available.
- 5- Using microbial fuel cells cleans up waste and foreign biomaterials.

Many studies have shown that using cellulose to generate electricity using fuel cells, as cellulose is used to generate bioenergy using microorganisms from cattle rumen. Sedky and his group showed in their study that when using a dual-chamber MFC to generate electricity using bacteria and electrically active bacteria, when the farm was fed with cellulose at a concentration of 4 g / liter, a maximum power density of 4.9 mW / m² was obtained

In a different study, Katuri and his group used slaughterhouse wastewater to generate electricity. Slaughterhouse wastewater contains a large number of proteins, fats, and carbohydrates, which is an ideal source for generating electricity. A double-chamber microbial fuel cell was used, fed with slaughterhouse wastewater and anaerobic bacteria. The study showed that when the wastewater was fed at a concentration of 900 mg/L, a maximum power density of 578 mW/m² was obtained. The results of other studies have shown that chicken feathers can be successfully used as a cheap base material for generating electricity. In a 2014 study, Wang et al. used 400 mg/L of rice straw to obtain (137.6 ± 15.5 mW/m²)

Other applications

Microbial fuel cells can be used in wastewater treatment. Different types of wastewaters, such as sanitary waste and food processing wastewater, contain energy in the form of biodegradable organic matter that can be used in microbial fuel cell technology. Wastewater treatment has been used since 1991 to generate electricity or hydrogen gas as an effective treatment system due to its high operational sustainability and low material costs.

Other applications of MFC cells are their use to operate small vehicles or boats without the need to charge batteries and as power sources for portable electrical equipment as small power generators in areas without electricity or as additional generators in wastewater treatment plants in sugar and dairy factories. Currently, their applications are much broader, such as phosphorus recovery from wastewater, desalination of seawater and bioremediation in soil

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