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WASTE MANAGEMENT AND ENERGY GENERATION WITH THE HELP OF MICROBIAL FUEL CELL

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Abstract: This paper depicts the tasks and biotechnology implicated in the microbial fuel cell (MFC), which transform biochemical metabolic energy into electrical energy and decomposes organic waste. Microbes in MFC can be fed organic waste such as domestic wastewater, lignocellulose biomass, brewery wastewater, starch processing wastewater, landfill leachates, and so on to generate electricity. MFC can also be used for waste water treatment (especially if it contains a high level of organic waste), as biosensors, and in the production of secondary fuels such as hydrogen. MFCs show up in a number of different forms, and they have a wide spectrum of uses.

***Index Terms* – Microbial fuel cell, biochemical, microbes, lignocellulose.**

I. INTRODUCTION

A fuel cell is a device that converts chemical energy from a fuel into electricity via a chemical reaction involving positively charged hydrogen ions and oxygen or the other oxidizing agent. Fuel cells differ from batteries including that those who require a continual supply of fuel and also oxygen or air to sustain the chemical reaction, whereas in a battery, the chemicals in the battery react with one another to generate an electromotive force (emf). As long as these inputs are accessible, fuel cells can produce electricity endlessly. Fuel cells come in a variety of sizes, but they all have an anode, a cathode, and an electrolyte that allows positively charged hydrogen ions (protons) to move between the two sides of the fuel cell.

Catalysts in the anode and the cathode cause the fuel to undergo oxidation reactions that also produce positively charged hydrogen ions and electrons. Following the reaction, the hydrogen ions are drawn through the electrolyte. All at the same, electrons are drawn from the anode to the cathode via an external circuit, actually results in direct current electricity. Water is formed when hydrogen ions, electrons, and oxygen react at the cathode.

II. TYPES OF FUEL CELLS

1. Proton Exchange Membrane Fuel Cell.
2. Direct Methanol Fuel Cell.
3. Phosphoric Acid Fuel Cell.
4. Alkaline Fuel Cell.
5. Molten Carbonate Fuel Cell.
6. Solid Oxide Fuel Cell.
7. Microbial fuel Cell

III. MICROBIAL FUELL CELL

A microbial fuel cell (MFC) is a bioreactor that converts chemical energy in the chemical bonds of organic composites to electrical energy. MFC employ microbes which generate electricity from biochemical energy produced during metabolism of organic substrates. MFC consists of anode and cathode connected by an external circuit and separated by proton exchange membrane (PEM) it is mostly a salt bridge. In anode chamber, decomposition of organic substrates by microbes generates electrons (e-) and protons (H+) that are transferred to cathode through circuit and membrane respectively. Organic substrates are utilized by microbes as their energy sources, outcome of this process is in release of high-energy electrons that are transferred to electron acceptors (molecular oxygen) but in absence of such electron acceptor in a MFC, microorganisms shuttle electron onto anode surface that results in generation of electricity. Bacteria are most preferred microbes that can be used in MFCs to generate electricity while biodegradation of organic matters or wastes. Biodegradable organic rich waters (municipal solid waste, industrial and agriculture wastewaters) are ideal sources of sustainable energy sources for electricity production. MFCs can also be used as

Biosensors and in secondary fuel production.

IV. TYPES OF MFC

4.1 Double Compartment MFC System

In general, this type of MFCs has an anodic and a catholic chamber connected by a PEM that mediates proton transfer from anode to cathode while blocking diffusion of oxygen into anode. This type of system is generally used for waste treatment with Simultaneous power generation. Scaling up of two compartment MFCs to industrial size is quite

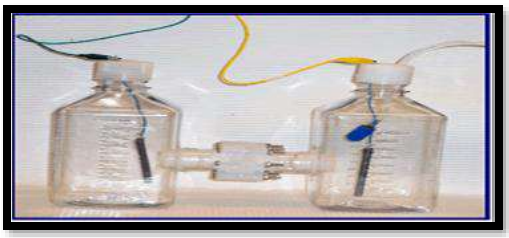

Figure 1 Double Compartment MFC system

4.2 Single Compartment MFC System

In a single compartment MFC, an anodic chamber is linked to a porous air exposed cathode separated by a gas diffusion layer or a PEM. Electrons are transferred to porous cathode to complete circuit. Limited requirement of periodic recharging with an oxidative media and aeration makes single compartment microbial fuel cell system more versatile. Among different advantages, single compartment MFC includes its reduced setup costs (due to absence of expensive membranes and catholic chambers) that make flexible application in wastewater treatment and power generation.

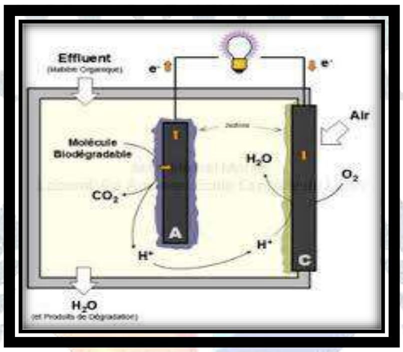

Figure 2 Single Compartment MFC System

4.3 Plate type microbial fuel cell

In a P-MFC solar energy is converted to electricity in a natural way. Plant uses sunlight to photosynthesize, thus producing organic compounds. Part of these compounds is used by the plant to grow on and part is passively released or actively excreted via the roots into the soil. In the soil microorganisms break down the organic matter to CO2. In a P-MFC the electrons are taken up by a conductive material which functions as an electrode (anode). In a second compartment – which is separated from the first one by a membrane –a counter electrode (cathode) is placed where the electrons are used to reduce oxygen. The flow of electrons through a wire enables us to harvest this energy as electricity.

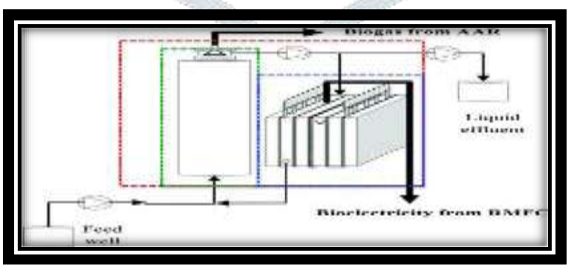

Figure 3 Plate type microbial fuel cell

V. MFC DESIGN

There are many different configurations are possible for MFCs. A widely used and inexpensive design is a two- chamber MFC built in a traditional "H" shape, consisting usually of two bottles connected by a tube containing a separator which is usually a cation exchange membrane (CEM)such as Nafion or Ultrex,or a plain salt bridge. The key to this design is to choose a membrane that allows protons to pass between the chambers (the CEM is also called a proton exchange membrane, PEM), but optimally not the substrate or electron acceptor in the cathode chamber (typically oxygen). In the H-configuration, the membrane is clamped in the middle of the tubes connecting the bottle. However, the tube itself is not needed. As long as the two chambers are kept separated, they can be pressed up onto either side of the membrane and clamped together to form a large surface. An inexpensive way to join the bottles is to use a tube that is filled with agar and salt such as KCl (to serve the same function as a cation exchange Membrane), and inserted through the lid of each bottle. H-shape systems are acceptable for basic parameter research, such as examining power production using new materials, or types of microbial communities that arise during the degradation of specific compounds, but they typically produce low power densities. The amount of power that is generated in these systems is affected by the surface area of the cathode relative to that of the anode and the surface of the membrane.

5.1 Mediators

MFCs can be either mediated or mediator-less (see Fig). In mediated fuel cells,bacteria are suspended in the anode solution together with the nutrient, andbecause of some sort of electron carrier that is added to the liquid in the anode chamber, the electrons can be transported from the bacteria through the liquid tothe electrode. Almost any type of bacteria can be used in this type of MFC, but a lot of electrons and energy is however lost in the process, which limits the total efficiency of the fuel cell drastically. Mediator-less fuel cells however, are fuel cells that does not require any additional electron carrier in the solution in order to transport electrons from the bacteria to the electrode. This process gives better control over the fuel cell and allows for a higher efficiency potential. However, they do require very special bacteria. The MFC that is being modeled in this master thesis research is a mediator less fuel cell, and it uses the bacteria Shewanellaoneidensis (MR-1). The MR-1 can break down a broad range of different biological material, and if it is harnessed in the correct way, and prevented from breathing oxygen, it will emit H+ ions and electrons while doing it. If used in a fuel cell, the H+ ions pass through the membrane (PEM) into the cathode chamber, whilst the electrons are forced to go through the electrical circuit in order to get to the cathode electrode. At the cathode electrode the species react together with oxygen and creates water (H2O), much like a Carbonate fuel cell (CFC). The MFC has many possible advantages over CFC, which is one of the reasons an increasing amount of research is being conducted on it. First of all, the catalyst for the MFC is essentially free, since the bacteria can be grown almost anywhere. Whilst in a CFC, the catalyst is responsible for a substantial part of the total cost. The bacteria are also versatile, so that the same MFC can be used with many different types of fuel. In addition, the bacteria has been tested and found to be very robust, which means it can survive under extreme conditions of pH, temperature and salinity. And since the catalyst is produced by live cells, it can even have the ability to repair and heal itself if it is allowed. There are around 50 types of Shewanella species known, and all that are tested have shown to produce current if used in a MFC. It is believed that a lot of improvement can be done not only by changing the design of the fuel cell, but also by using microbiology to construct the best possible bacteria. However, the present MFC tests also show some disadvantages. The most obvious disadvantage is the low current density that has been achieved. Whilst CFC can obtain current densities in the order of 1 A/cm2, the current MFC experiments has only showed around 1 mA/cm2. It is believed that this can be increased by further redeveloping the design of both the fuel cell and the bacteria itself. However, even if it may have trouble reaching up to the same high power density as CFCs, its other advantages may still allow it a place in the market. Other problems that have occurred in the MFC shows that it has been difficult to keep the fuel cell running without the requirement of maintenance, and that it has been more sensitive to breakdown and decay than what would be preferable if it is to be used.

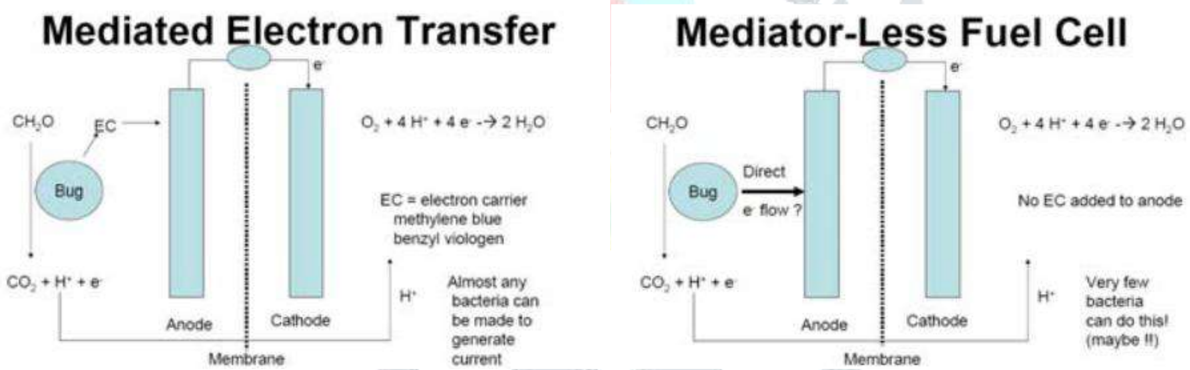

Figure 4 Mediated or Mediator-Less MFC

5.2 Charges Transfer

There are two types of charges that need to be transported in the MFC system, H+ ions and electrons. Both the ions and electrons are produced at the anode electrode, and need to be transported over to the cathode electrode. As previously mentioned, there are two transportation processes that promote charge transportation in the MFC, which are conduction and diffusion. In the initial MFC model, most of the electrical properties of the fuel cell will be estimated by external calculations, and the electrons will therefore not be taken into account as a species but rather assumed to have the same production and consumption rates as the H+ ions. Furthermore, the initial model will not include the electrical driving forces acting between H+ ions as a method of transportation, making the assumption that the transportation is achieved solely by diffusion. Because of this, the transportation of H+ ions is calculated in the same way as non-charged species. However, since it has a very low molecular weight it has a much higher diffusion coefficient, and therefore better transportation properties. Later versions of the model may include User Defined Functions that impose a special transfer of charged species depending on their charge and concentration, or possibly an additional increase in the diffusivity in order to account for the conductive transportation processes. Once the regular electrical system has been implemented it is also possible to model the effect of the electrical conducting Nano wires.

5.3 Electrodes

1. The choice of electrode material affects the performance of MFCs various materials have been investigated as electrodes to increase the performance and power output of the MFCs. For anode, carbon cloth, graphite felt, carbon mesh and graphite fibre brush are frequently used due to their stability, high electric conductivity and large surface area.
2. For cathodes, platinum (Pt), platinum black, activated carbon (AC), graphite based cathodes and bio cathodes are used. Though platinum coated electrodes are more efficient and superior in power production due to higher catalytic activity with oxygen than other electrodes, they are not cost effective.

3. Alternate catalysts for platinum include ferric iron, manganese oxides, iron and cobalt based compounds. Ferricyanide (K3(Fe(CN)6) is frequently used as an electron acceptor in the MFCs due to its good performance and low over potential. Bio cathodes increase the power by decreasing the over potential. Alternately, the cathode can contain oxygen and is preferred because it simplifies the operation of the cell and is the most commonly used electron acceptor in MFC.
4. The power output depends on proton transfer from anode to cathode. Transfer of protons to the cathode is a slow process that causes high internal resistance. Most of the MFCs require a salt bridge or PEM to separate the anode and cathode compartments. The PEM is commonly made from polymers like Nafion and Ultrex.
5. We have chosen a proton exchange membrane AGAR AGAR that is easily available and easy to make. It is very cheap as well.
6. Although membrane-less, single chamber MFCs are reported to produce higher power density, membrane absence would increase
7. Oxygen to the anode and thus lowers the coulombic efficiency and bio electro catalytic activity of the microbes.

5.4 Microorganisms

Commonly used Microbes in Microbial Fuel Cells (MFCs) Usually mixed culture of microbes is used for anaerobic digestion of substrate as complex mixed culture permits broad substrate utilization. But there are some regular MFCs designs which explore metabolic tendency of single microbial species to generate electricity. Organic component rich sources (marine sediment, soil, wastewater, fresh water sediment and activated sludge) are rich source of microbes that can be used in MFCs catalytic unit. Bacteria used in MFCs with mediator or without mediators have been extensively studied and reviewed (Table). Metal reducing and anodophilic microorganisms show better opportunities for mediator-less operation of a MFC.

Table 1 Commonly used Bacteria in MFC

Bacteria	Mode of operation
Actinobacillus succinogenes	Requires exogenous mediators
Erwinia dissolven	Mediator based MFC
Proteus mirabilis	Mediator based
Pseudomonas aeruginosa	With exogenous mediators
Shewanella oneidensis	With exogenous mediators
Streptococcus lactis	With mediators
Aeromonas hydrophila	Mediator-less MFC
Geobacter metallireducens	Mediator-less MFC
G. sulfurreducens	Mediator-less MFC

5.5 Substrates

Substrate used for Electricity Generation Substrate is a key factor for efficient production of electricity from a MFC. Substrate spectrum used for electricity generation ranges from simple to complex mixture of organic matter present in wastewater. Although substrate rich in complex organic content helps in growth of diverse active microbes but simple substrates considered to be good for immediate productive output. Acetate and glucose are most preferred substrate for basic MFC operations and electricity generation. Lignocellulosic biomass from agriculture residues as hydrolysis products (monosaccharides) are a good source for electricity production in MFCs. Another promising and most preferred unusual substrate used in MFCs operations for power generation is brewery wastewater as it is supplemented with growth promoting organic matter and devoid of inhibitory substances. Starch processing water can be used to develop microbial consortium in MFCs. Cellulose and chitin (from industrial and municipal wastewaters), synthetic or chemical wastewater, dye wastewater and landfill leachates are some unconventional substrates used for electricity production via MFCs.

Table 2 Substrates used for electricity generation

Microbes	Substrate	Applications
Actinobacillussuccinogenes	Glucose	Neutral red or thionin as electron
Clostridium beijerinckii	Starch,glucose,lactate,molasses	Fermentative bacterium
Aeromonashydrophila	Glucose	Self-mediate consortia isolated from MFC

VI WORKING PRINCIPLE

1. In its most basic form, a MFC is a device that uses microorganisms to generate an electrical current through the oxidation of organic material.
2. Microorganisms in the MFC metabolize organic substrates and extracellularly transfer electrons to an electrode surface.
3. The oxidation of the organic material liberates both electrons and protons from the oxidized substrate. Electrons are transferred to the anode and then to the cathode through an electrical network.
4. The protons migrate to the cathode and combine with the electron and a catholyte, a chemical such as oxygen, which is reduced at the cathode surface. As such, an electrical current is generated in a fashion similar to a chemical fuel cell, but with microbes acting as a catalyst on the anode surface .
5. Catalysts generally increase the rate of a reaction without being changed by or receiving energy from the reaction they catalyze.

6. As the Proton through membrane and electron through external circuit reaches cathode compartment new water molecules is formed. Thus waste water is treated along with electricity generation.

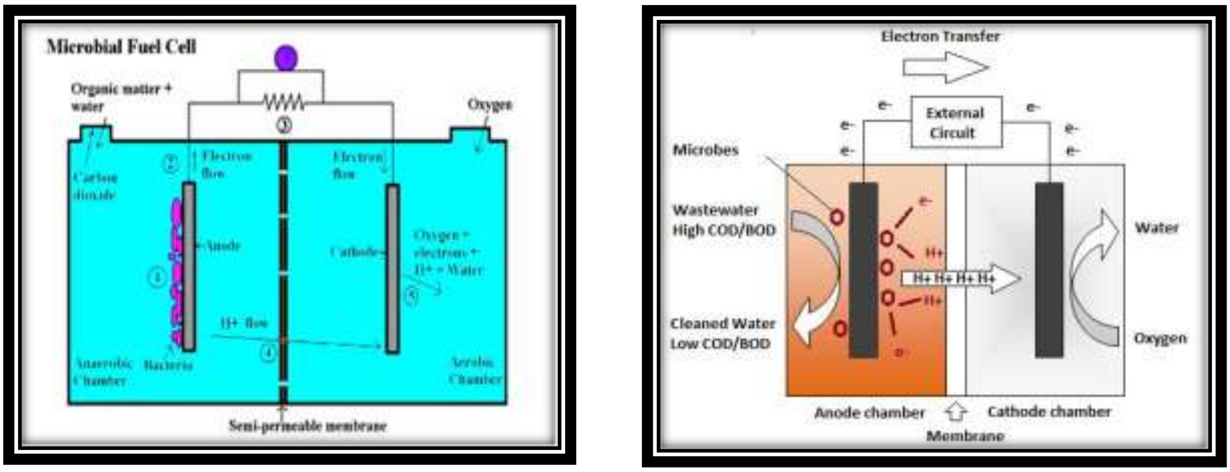

Figure 5 Working of MFC

VII APPLICATION OF MFC

7.1 Wastewater Treatment and Electricity Generation

Due to unique metabolic assets of microbes, variety of microorganisms are used in MFCs either single species or consortia. Some substrates (sanitary wastes, food processing wastewater, swine wastewater and corn stovers) are exceptionally loaded with organic matter that itself feed wide range of microbes used in MFCs. MFCs using certain microbes have a special ability to remove sulfides as required in wastewater treatment29. MFC substrates have huge content of growth promoters that can enhance growth of bio-electrochemically active microbes during wastewater treatment. This simultaneous operation not only reduces energy demand on treatment plant but also reduces amount of unfeasible sludge produce by existing anaerobic production. MFCs connected in series have high level of removal efficiency to treat leachate with supplementary benefit of generating electricity

7.2 Biosensors

MFCs with replaceable anaerobic consortium could be used as a biosensor for on-line monitoring of organic matter. Though diverse conventional methods are used to calculate organic content in term of biological oxygen demand (BOD) in wastewater, most of them are unsuitable for on-line monitoring and control of biological wastewater treatment processes. A linear correlation between Coulombic yield of MFC and strength of organic matter in wastewater makes MFC a possible BOD sensor. Coulombic yield of MFC provides an idea about BOD of liquid stream that proves to be an accurate method to measure BOD value at quite wide concentration range of organic matter in waste water.

7.3 Secondary Fuel Production

With minor modification, MFCs can be employed to produce secondary fuels like Hydrogen (H2) as an alternative of electricity. Under standard experimental conditions, proton and electron produced in anodic chamber get transferred to cathode, which then combines with oxygen to form water. H2 generation is thermodynamically not favored or it is a harsh process for a cell to convert proton and electron into H2. Increase in external potential applied at cathode can be competent to overcome thermodynamic barrier in reaction and used for H2 generation. As a result, proton and electron produced in anodic reaction chamber combine at cathode to form H2. MFCs can probably produce extra H2 as compared to quantity that pull off from classical glucose fermentation method. Wagner et al reported H2 and methane production by using microbial electrolytic cells that are modified MFC with increased external potential at cathode. Thus, MFCs provide a renewable H2 to contribute to overall H2 demand in a H2 economy.

7.4 Advancement in MFC Technology

Development of MFCs was triggered by USA space program in 1960s as a possible technology for a waste disposal system for space flights that would also generate power. MFC technology has been extensively reviewed focusing on recent improvement, practical implementation, anode performance, cathodic limitations, different substrates used in MFCs etc. MFCs have been explored as a new source of electricity generation during operational waste treatment. In addition, some of the recent modification in MFCs technology includes its use as microbial electrolysis cell (MEC), in which anoxic cathode is used with increased external potential at cathode. Phototrophic MFCs and solar powered MFC also represent an exceptional attempt in the progress of MFCs technology for electricity production.

IV. CONCLUSION

MFC is an ideal way of generating electricity since it not only as a renewable source but also it can be used to treat waste. It can also be used for production of secondary fuel as well as in bioremediation of toxic compounds. However, this technology is only in research stage and more research is required before domestic MFCs can be made available for commercialization. In our experiment we observe that it makes treats the waste water in 4-6 days, if this was to be naturally degraded it would take weeks. Our experiment is just a prototype for batch type scenarios which could be used in hotels or supermarkets, where they can dump their organic waste and somehow used for treatment of organic effluent from chemical, brewery, pharmaceutical etc. Manufacturing plants. Microbial fuel cell is a good step towards waste management and renewable source of energy useful to meet some demands of energy in future. Though it has some limitations it will be improved in forthcoming years and by use of MFC's along with other Renewable sources like Solar, Tidal, Hydro etc. we can make our energy sources cleaner and greener and treat waste water at low cost. The other wide application are MFC are also in the research stage like biosensors. Using MFC is not only environment free but also economical. In coming year MFC technology will be used for sustainable future.

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