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Bioelectrochemical Treatment of Sugarcane Wastewater Using Microbial Fuel Cells and Methane Production

K. M.Gopalakrishnan, V. Sampathkumar, G. Nithya Prakash and G. Boobalakrishnan

Erode Sengunthar Engineering College, Department of Civil Engineering, Thudupathi-638 057

Energy need has been increasing worldwide exponentially at present global energy requirements are mostly dependent on the fossil fuels, which eventually lead to foreseeable depletion of limited fossil energy sources. Concerns about climate change, increased global demand for the finite oil and natural gas reserves and security are intensifying the search for alternatives to fossil fuels. Generation of electricity using microbial fuel cells (MFC) is seemingly gaining importance in the research fraternity. These 2 approaches of alternative fuel generation have numerous advantages clean, efficient, renewable and does not generate any toxic byproduct. A study on power generation from sugarcane wastewater using membrane less microbial fuel cell in a batch mode and the effect of DO and inoculums. MFCs can also be modified to produce hydrogen gas by maintaining the cathode in an oxygen-free condition and adding in an external small voltage. Microbial fuel cell is fabricated as a 2 chamber system loaded with sugarcane wastewater sludge ratio of 1:5. To increase the efficiency of MFC, the cells operate in 2 conditions of aerobic and anaerobic. Aerated MFC was further studied by varying sludge volume. The maximum power production was found in the feed of sludge ratio 1:5. Utilizing chemical wastewater for the production of renewable energy (bioelectricity) from anaerobic treatment is considered as a feasible, economical and sustainable process.

KEYWORD

Sugarcane wastewater, Microbial fuel cell, Bioelectrochemical treatment, Power production.

INTRODUCTION

Microbial fuel cell

Microbial fuel cells (MFCs) convert the metabolic energy which bacteria obtain from their electron donor, directly into electricity. The electrons flow from the bacteria toward an anode and further through an external circuit. At the cathode, the electrons are used to convert oxygen into water, closing the cycle. Microbial fuel cell (MFC) technologies represent the newest approach for generating electricity- bioelectricity generation from biomass using bacteria. While the first observation of electrical current generated by bacteria is generally created to potter in 1911. In the early 1990s, fuel cells became of more interest and work on MFCs began to increase. Experiments that were conducted required the use of chemical mediators, or electron shuttles, which could carry electrons from inside the cell to exogenous electrodes. The breakthrough in MFCs occurred in 1991 when it was recognized that mediators did not to be added.

One of the main bottlenecks in MFCs is the electron transfer from the bacteria to the anode. Either oxidizing a compound at the anode surface or reducing a compound at the bacterial surface or in the bacterial interior surface can require certain energy to activate the oxidation reaction. In an MFC, microorganisms degrade (oxidise) organic matter, producing electron that travel through series of respiratory enzymes in the cell and make energy for the cell in the form of ATP. The electrons are then released to a terminal electron acceptor (TEA) which accepts the electrons and becomes reduced.

Some bacteria can transfer electrons exogeneously (that is outside the cell) to a TEA, such as a metal oxide, like iron oxide. It is these bacteria that can exogeneously transfer electrons, called exoelectrogens, which can be used to produce power in an M F C .

A microbial fuel cell is 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 oxidised by microorganisms, generating CO_2, electrons and protons. Electrons are transferred to the cathode compartment through an external 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. A microbial fuel cell (MFC) technology are a promising yet completely different approach wastewater treatment as the treatment process can become a method of capturing energy in the form of electricity of hydrogen gas, rather than a drain on electrical energy. However, the power production low and it was not clear whether the technology would have much impact on reducing wastewater strength. This changed and the link between electricity using MFCs and wastewater treatment was clearly gorged when it was demonstrated that domestic wastewater could be treated to practical levels while simultaneously generating electricity. Besides, electricity generation microbial fuel cell has a few more applications. These include production of water and sediments. All metal components present in the wastewater can be precipitated and can be obtained as compounds or sediments. This property of MFC can be used as a biosensor or COD measurement device. A slightly modified MFC can also be used for hydrogen production.

Bioelectricity generation

The following components are required to the electricity generation are : (i) A reducing chamber (anode, positive end), (ii) a oxidising chamber (cathode, negative end), (iii) a catholyte, (iv) anolyte, (v) mediator, (vi) proton transport channel and (vii) external electrical circuit.

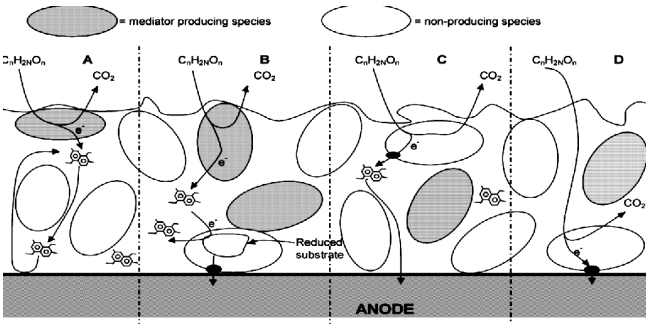

Figure 1. *Anode process*

Anode : The anode is the positively charged electrode and anode attracts electrons or anions. The anode and cathode are defined by the flow of current. In the general sense, current refers to any movement of electrical charge. The anode may be a source of positive charge or an electron acceptor. A charge can flow either from positive to negative or from negative to positive! Because of this, the anode could be positively charged or negatively charged, depending on the situation. The same is true for the cathode. This process passes through the external circuit and reaches cathode (Figure 1).

Cathode : The cathode is the negatively charged electrode. The cathode is the source of electrons or an electron donor. It may accept positive charge. Because the cathode may generate electrons, which typically are the electrical species doing the actual movement, it may be said that cathodes generate charge or that current moves from the cathode to the anode. It is also solid conductive material.

Reducing agent : Atoms, ions and molecules that have an unusually large affinity for electrons tend to be good oxidizing agents. Elemental fluorine, for example is the strongest common oxidizing agent. F_2 is such a good oxidizing agent that metals, quartz, asbestos and even water. Other good oxidizing agents include O_2, O_3, and Cl_2, which

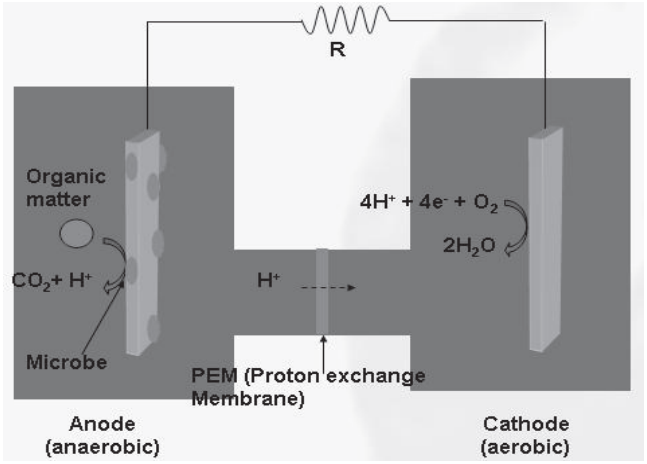

Figure 2. *Working of microbial fuel cell*

are the elemental forms of the second and third most electronegative elements. Good reducing agents include the active metals, such as sodium, magnesium, aluminium and zinc, which have relatively small ionization energies and low electro-negativities. Metal hydrides, such as NaH, CaH_2, which formally contain the H^- ion, are also good reducing agents.

Some compounds can act as either oxidizing agents or reducing agents. One example is hydrogen gas, which acts as an oxidizing agent when it combines with metals and as a reducing agent when it reacts with non-metals.

$$Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2\,Ag(s)$$

stronger reducing agent | stronger oxidizing agent | weaker oxidizing agent | weaker reducing agent

Working of a MFC in mediator : Bacteria get this energy in a two-step process. The first step requires the removal of electrons from some source of organic matter (oxidation) and the second step consists of giving those electrons to something that will accept them (reduction), such as oxygen or nitrate (Figure 2). If certain bacteria are grown under anaerobic conditions (without the presence of oxygen), they can transfer electrons to a carbon electrode (anode). The electrons then move across a wire under a load (resistor) to the cathode where they combine with protons and oxygen to form water. When these electrons flow from the anode to the cathode, they generate the current and voltage to make electricity.

Microbes remove the electrons from organic matter and transfer them to the anode in the anaerobic chamber. The electrons move across the resistor to the cathode where they combine with protons and oxygen to form water. Almost any biodegradable organic matter can be used. Examples include human, animal and industrial wastewater, alongwith sugars, starch and cellulose. Light is even a potential source of 'matter' in photo biological fuel cell systems that utilize photosynthetic bacteria, amino acids and proteins.

Electron acceptors : In a microbial fuel cell (MFC), exoelectrogens, which transfer electrons to the electrode, have been regarded as a key factor for electricity generation. MFC methods we can use exoelectrogens from the anode of an MFC. Disparate microorganisms were identified depending on isolation methods, despite the use of an identical source. Denaturing gel gradient electrophoresis (DGGE) analysis showed that certain microorganisms became dominant in the U-tube MFC. The predominant bacterium similar to Ochrobactrum sp. and Alphaproteobacteria and to be able to function as an exoelectrogen in Bacillus sp. and Paenibacillus sp., using the plating method, which belonged to the gram-positive bacteria, the formicates. U-tube MFCs with mixed culture although the isolates produced low currents, various bacterial groups were found to be involved in current production.

Electron transfer mechanism : MFCs as a research tool have expanded our knowledge of bacterial electron transfer mechanisms. Unlike natural external electron acceptors, such as Fe (III) or Mn (IV), anodes in MFCs do not participate in mineral dissolution reactions and electron transfer rates can be quantified. Anodes also provide a stable source of electron acceptor and do not generate reduced products that can interfere with downstream genomic or proteomic ap-

plications. Additionally, colonized anodes can be adapted to detect the presence, redox potential and reversibility of electro active components in biofilms.The power of MFCs to elucidate mechanisms of solid-phase electron transfer. Applying cyclic voltammeter techniques to anode biofilms. Which function in anode electron transfer and metal chelating and may aid in adhesion to anode surfaces Shewanella use outer membrane cytochromes and putatively.

Nanowires : Transfer electrons through conductive nanowires, this work shows that extracellular electron transfer mechanisms are not mutually exclusive within a single species. This may account for observed discrepancies in research findings by different laboratories. Understanding how bacteria attach to anodes could allow the design of more efficient electron transfer systems. Genetic and metabolic engineering of electrode active bacteria, including the over expression of essential cytochromes or shuttling compounds.

Mediators : Mediators are using 2 types in MFC the following are : (i) Mediator and (ii) mediator less. The production of high concentrations of mediators by mixed cultures primarily containing P.aeruginosa, coupled with a very low internal resistance MFC achieved by using ferricyanide as a catholyte. Pyocyanin and related compounds produced by Pseudomonas, can shuttle electrons to an electrode to produce electricity in MFC. Mediator-free microbial fuel cell do not require a mediator but uses 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.*

Proton exchange membrane : Proton exchange membranes (PEMs) are one of the most important components in microbial fuel cells (MFCs), since PEMs physically separate the anode and cathode compartments while allowing protons to transport to the cathode in order to sustain an electrical current. Regarded as having excellent proton conductivity, though many problems for its application in MFCs remain. We investigated problems associated with Nafion including: Oxygen leakage from cathode to anode, substrate loss, cation transport and accumulation rather than protons and biofouling. The oxygen flux from cathode to anode through the Nafion membrane was evaluated using uninoculated MFC reactors with different catholytes (anolyte NMB; catholyte phosphate buff or distilled water) by measuring DO accumulation in the substrate-free NMB solution of the anode chamber over time. DO probes were placed in both the anode and cathode chambers.

MFC in traditional method : MFC design factors and operational parameters for continuous electricity reduction using artificial wastewater. Renewable energy generation and waste disposal for the sustainability of future societies. Microbial fuel cells (MFCs) have been considered as a promising solution by linking both tasks at the same time. MFCs are devices that convert chemical energy contained in the bonds of organic or inorganic compounds to electrical energy with the aid of bacteria as biocatalysts. MFCs can also be modified to produce hydrogen gas by maintaining the cathode in an oxygen condition and adding in an external small voltage. The electrons and protons travel to the cathode, the former via an external circuit and the latter diffusing through electrolyte and a proton exchange membranes (PEM).

The protons and electrons subsequently combine at the cathode by a catalyst, such as platinum, to form water. The set of microbial community electrons to attach growth to set of mechanism of nanowires. MFC attached growth in the process of parameters. The benthic microbial fuel cell represents a new approach for generating power for long-term, persistent operation of ocean environment monitoring and wastewater. In addition to persistence, these fuel cells do not utilize any reactive catalysts or produce hydrogen. This presenting increased safety as well as being environmentally

friendly. They provide sustainable energy as they utilize carbon compounds naturally available in the environment as fuel.

Classification of MFC

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 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. More broadly, there are 2 types of microbial fuel cell mediator and mediatorless microbial fuel cells. Microbial fuel cells the following classifications are : (i) Electrolytic microbial fuel cell, (ii) soil microbial fuel cell, (iii) plant microbial fuel cell and (iv) mediator-free microbial fuel cell.

Electrolytic microbial fuel cell : A variation of the mediator-less MFC is the microbial electrolysis cells (MEC). While MFC's produce electric current by the bacterial decomposition of organic compounds in water. MEC's 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 electro synthesis, in which carbon dioxide is reduced by bacteria using an external electric current to form multi-carbon organic compounds.

Mediator microbial fuel cell : Most of the microbial cells are electrochemically inactive. The electron transfer from microbial cells to the electrode is facilitated by mediators, such as thiamine, methyl viologen, methyl blue, humic acid, neutral red and so on (Scott and Murano, 2007a, 2007b). Most of the mediators available are expensive and toxic (Figure 3).

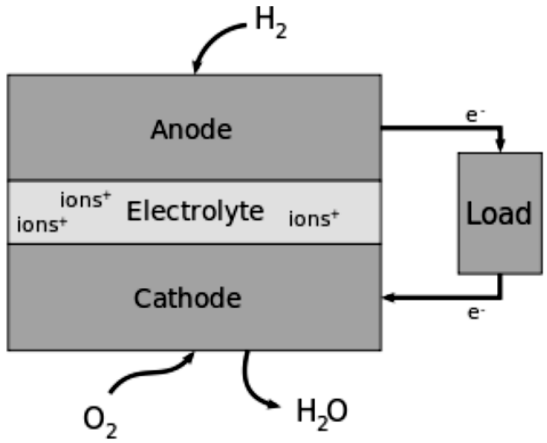

Figure 3. *Ion exchange process*

Soil based microbial fuel cell : Soil-based microbial fuel cells adhere to the same basic MFC principles as described above, whereby 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 and are full of complex sugars and other nutrients that have accumulated over millions of years of plant and animal material decay. 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. Soil-based MFCs are becoming popular educational tools for science classrooms.

Phototriphic biofilm microbial fuel cell : Phototrophic biofilm MFCs (PBMFCs) are the one which make use of anode with a phototrophic biofilm containing photosynthetic microorganism, like chlorophyta, cyanophyta. Since they could carry out photosynthesis and thus they act as both producers of organic metabolites and also as

electron donors. A microbial fuel cell yield one of the highest power densities and, therefore, show promise in practical applications. Researchers face difficulties in increasing their power density and long-term performance so as to obtain a cost-effective MFC.

Mediator-free microbial fuel cell : 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 hydrophilic 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 and 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.

Plant microbial fuel cell : 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. Given that the power is thus derived from living plants (*in situ* energy production), this variant can provide additional ecological advantages.

Proton exchange membrane : In the archetypical hydrogen oxide proton exchange membrane fuel cell design, a proton-conducting polymer membrane (the electrolyte) separates the anode and cathode sides. (PEMFC) efficient frontier this called a 'solid polymer electrolyte fuel cell'. On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what are commonly referred to as multi-facilitated proton membranes.

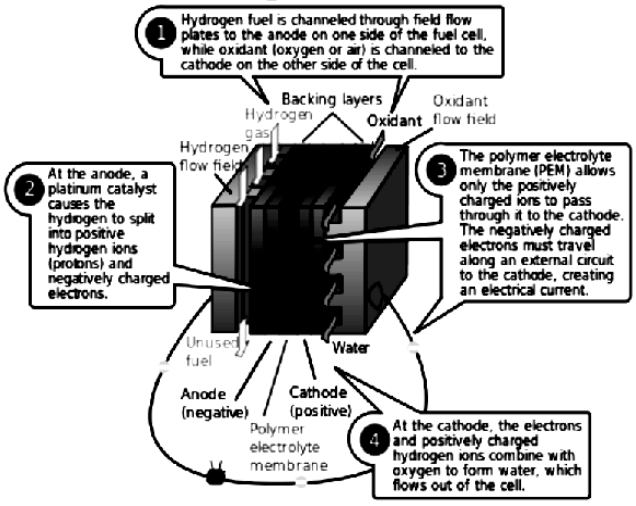

Figure 4. *Proton exchange membrane fuel cell*

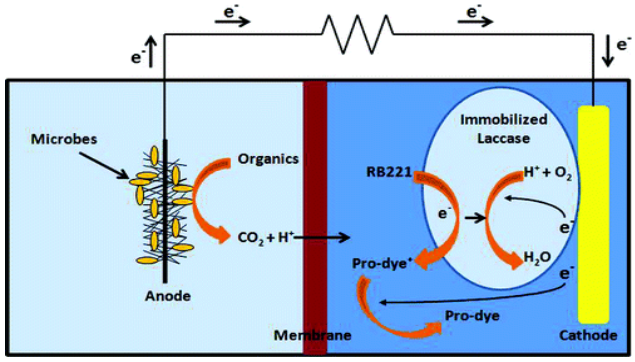

Figure 5. *Chamber fuel cell*

The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons and protons to form water (Figure 4). In addition to this pure hydrogen type, there are hydrocarbon fuels for fuel cells, including diesel, methanol and chemical hydrides. The waste products with these types of fuel are carbon dioxide and water.

Dual chambered fuel cell : A dual-chamber microbial fuel cell (MFC) effect of cathodic enzymatic decolourization of reactive blue 221 (RB221) on the performance in. Immobilized laccase on the surface of a modified graphite electrode. The cathode compartment in order to decolourize the dye and enhance the oxygen reduction reaction (Figure 5). First, methylene blue which is an

electro active polymer electro polymerized on the surface of a graphite bar to prepare the modified electrode. Utilization of the modified electrode with no enzyme in the MFC increased the power density upto 57% due to the reduction of internal resistance from 1000 to 750Ω.

Using the electro polymerized-enzymatic cathode resulted in 65% improvement of the power density and a decolourization efficiency of 74%. Laccase could act as a biocatalyst for oxygen reduction reaction alongwith catalyzing RB221 decolourization. Treatment of RB221 with immobilized lactase reduced its toxicity upto 5.2%. Degradation products of RB221 using GC–MS and the decomposition pathway. The mechanism of dye decolourization on the enhancement of the MFC performance.

Single chambered fuel cell : The oxygen reduction due to microaerophilic biofilms grown on graphite cathodes (bio cathodes) in single chamber microbial fuel cells. Pt-free cathode performances are compared with those of different platinum-loaded cathodes, before and after the biofilm growth. Membrane less SCMFCs operating in batch-mode, filled with wastewater. A substrate (fuel) of sodium acetate (0.03 M) periodically added and the experiment. A maximum of power densities, when biofilms developed on the electrodes and the cathodic potential decreased.

The power output almost constant with an acetate concentration of 0.01–0.05 M and it fell down when the pH of the media exceed 9.5, independently of the Pt-free/Pt-loading at the cathodes. Quasi-stationary polarization curves performed with a three-electrode configuration on cathodic and anodic electrodes showing that the anodic over potential, more than the cathodic one.It may limit the current density in the SCMFCs for a long-term operation.

Anaerobic cathode condition : The release of the electrons means that the mediator returns to its original oxidised state ready to repeat the process. It is important to note that this can only happen under anaerobic conditions; if oxygen is present, it will collect all the electrons as it has a greater electro negativity than mediators. The mediator and micro-organism, in this case yeast, are mixed together in a solution to which is added a suitable substrate, such as glucose. This mixture is placed in a sealed chamber to stop oxygen entering, thus forcing the micro-organism to use anaerobic respiration. An electrode is placed in the solution that will act as the anode as described previously.

Aerobic condition : When micro-organisms consume a substance, such as sugar in aerobic conditions they produce carbon dioxide and water. However, when oxygen is not present they produce carbon dioxide, protons and electrons.

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$$

Microbial fuel cells use inorganic mediators to tap into the electron transport chain of cells and channel electrons produced. The mediator crosses the outer cell lipid membranes and bacterial outer membrane; then, it begins to liberate electrons from the electron transport chain that normally would be taken up by oxygen or other intermediates. In the second chamber of the MFC is another solution and electrode. This electrode, called the cathode is positively charged and is the equivalent of the oxygen sink at the end of the electron transport chain, only now it is external to the biological cell. The solution is an oxidizing agent that picks up the electrons at the cathode. As with the electron chain in the yeast cell, this could be a number of molecules, such as oxygen. However, this is not particularly practical as it would require large volumes of circulating gas. A more convenient option is to use a solution of a solid oxidizing agent.

Factors affecting microbial fuel cell

Substrate : Substrate in biological processes used for wastewater treatment, refers to the organic matter or nutrients in wastewater, that are converted during biological treat-

ment or that may be limiting in biological treatment. This coefficient is used for designing a complete-mix activated-sludge system and has to do with the biomass growth process. In specific circumstances, there will be a certain rate with which the soluble substrate will be depleted by bacteria. At a high substrate concentration, the utilization rate will be high and will be practically even to the maximum rate of soluble substrate utilization. The maximum rate of soluble substrate utilization coefficient is referred to by the symbol k.

Consortium in MFC : In spite of the fact that aerobic biotreatment remains a preferred technology for the elimination of biodegradable pollutants from wastewaters, waste slurries, waste gas streams and seriously polluted environmental compartments, including soils, sediments, ground waters and surface waters, remarkably little research concerning the dynamics of multiple pollutant degradation by microbial consortia has been conducted. Biodegradation research has emphasized biochemical pathways, assumed kinetic relationships, disregarded mixed cultures, particularly quasi stable consortia and failed to relate physical and chemical changes in process conditions with either biodegradative potential or capacity.

This has resulted in distorted understanding of factors affecting process performance and hence, retardation of the development of a sensible basis for biotreatment process optimization. Microorganisms can be present in biotreatment processes as discretely dispersed cells, as flocs or as biofilms. The latter two are by far the most common and both flocs and films can be considered as matrices of naturally immobilized cells.

Electrode membrane assembly : The PEM is sandwiched between two electrodes which have the catalyst embedded in them. The electrodes are electrically insulated from each other by the PEM. These 2 electrodes make up the anode and cathode, respectively (Figure 6). The PEM is a fluoropolymer (PFSA) proton permeable but electrical insulator barrier. This barrier allows the transport of

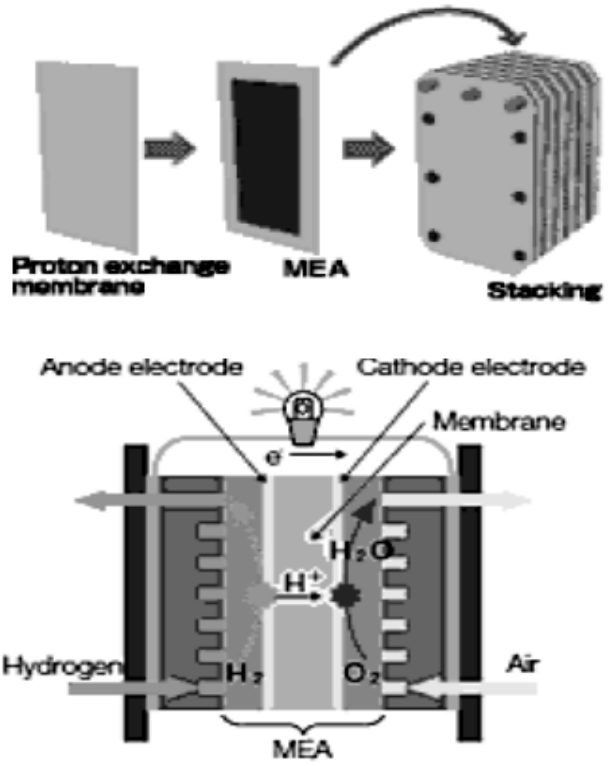

Figure 6. *Mechanism in a fuel cell*

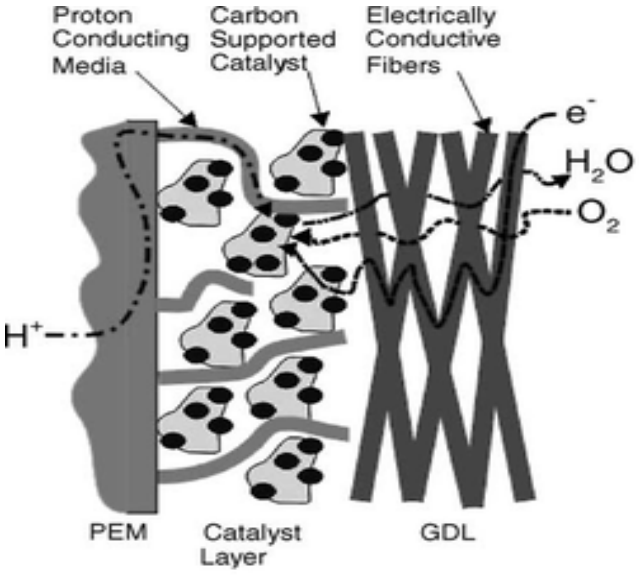

Figure 7. *Process of fiber reaction*

the protons from the anode to the cathode through the membrane but forces the electrons to travel around a conductive path to the cathode. The most commonly used Nafion PEMs are Nafion XL, 112,115,117, and 1110 (Figure 7). The electrodes are heat pressed onto the PEM. Commonly used materials for these electrodes are carbon

cloth or carbon fibre papers. Nuvant produces a carbon cloth called ELAT which maximizes gas transport to the PEM as well as moves water vapour away from the PEM.

Final electron acceptor : The performance of the cathodic electron acceptors (CEA) in the two-chambered microbial fuel cell (MFC) the following order: Potassium permanganate (1.11V; 116.2 mW/m(2))>potassium per sulphate (1.10 V; 101.7 mW/m(2))> potassium dichromate, K(2)Cr(2)O(7) (0.76 V; 45.9 mW/m(2))> potassium ferricyanide (0.78 V; 40.6 mW/m(2)). Different operational parameters considered to find out the performance of the MFC, like initial pH in aqueous solutions, concentrations of the electron acceptors, phosphate buffer and aeration. Potassium per sulphate found to be more suitable out of the 4 electron acceptors which had a higher open circuit potential (OCP) but sustained the voltage for a much longer period than permanganate. Chemical oxygen demand (COD) reduction of 59% using 10 mM per sulphate in a batch process. RALEX™ AEM-PES, an anion exchange membrane (AEM), performed better in terms of power density and OCP in comparison to Nafion® 117 cation exchange membrane (CEM).

Membrane and surface ara : The effect of distance between the electrodes and total surface area of anode on electricity production evaluate under variable external resistance. Electrode surface area acts as the media support for the microbes. Maximum power density at lower spacing between the electrodes and for the lesser surface area of the anode, respectively. It is done by the size of the pores and polymer pattern.

Application of microbial fuel cell

Power generation : Microbial fuel cells have a number of potential uses. The most readily apparent is harvesting electricity produced for use as a power source. The use of MFC's is attractive for applications that only require low power but where replacing batteries may be time consuming and expensive, such as wireless sensor networks. Virtually any organic material could be used to feed the fuel cell, including coupling cells to wastewater treatment plants. Microbial fuel cells (MFCs) have been progressing at an amazing speed in the past few years, with higher power density but lower cost being continuously achieved. However, most of the studies to date have been conducted at laboratory scale and many technological and economic barriers remain to be overcome prior to large-scale application of the MFC technique.

Bacteria would consume waste material from the water and produce supplementary power for the plant. The gains to be made from doing this are that MFCs are a very clean and efficient method of energy production. Chemical processing wastewater and designed synthetic wastewater have been used to produce bioelectricity in dual and single chambered mediator less MFCs (non-coated graphite electrodes) apart from wastewater treatment. Higher power production was observed with biofilm covered anode (graphite). A fuel cell's emissions are well below regulations. MFCs also use energy much more efficiently than standard combustion engines which are limited by the Carnot cycle. In theory an MFC is capable of energy efficiency far beyond 50%. According to new research conducted by René Rozendal, using the new microbial fuel cells, conversion of the energy to hydrogen is 8x as high as conventional hydrogen production technologies. However, MFCs do not have to be used on a large scale, as the electrodes in some cases need only be 7 μm thick by 2 cm long. The advantages to using an MFC in this situation as opposed to a normal battery is that it uses a renewable form of energy and would not need to be recharged, like a standard battery would.

In addition to this they could operate well in mild conditions, 20 °C to 40 °C and also at pH of around 7. Although more powerful than metal catalysts, they are currently too unstable for long term medical applications, such as in pacemakers. Besides wastewater power plants, as mentioned before, en-

ergy can also be derived directly from crops. This allows the set-up of power stations based on algae platforms or other plants incorporating a large field of aquatic plants. In recent years an increasingly important role in this field and has contributed considerably to moving MFCs forward toward large-scale implementations for both power generation and extended applications. Nevertheless, the development of MFCs is still in its infancy, the power density needs to be further improved, the cost reduced and a better understanding gained on the underlying mechanisms of electron generation and flow.

All these warrant further investigations at both laboratory and pilot levels and more cooperation of scientists and engineers from different disciplines and countries. Microbial fuel cells (MFCs) are devices that use bacteria to generate electricity from organic matter. Most of the current research performed on MFCs is concerned with increasing the power density of the system with respect to the peripheral anode surface area. Separators are needed to prevent electrodes from touching and short circuiting. Ion selective membranes, such as cation or anion exchange membranes and micro porous filtration membranes, have been used in MFCs to reduce oxygen transfer into the anode chamber. However, the use of membranes and some separators can decrease power generation and produce pH gradients between the anode and cathode and many of these membranes are expensive.

While treating sewage, particularly in small capacity treatment plant recovery of methane may not be attractive, because most of the methane produced in the reactor is lost through effluent of the reactor. The methane concentration of about 16 mg/L (equivalent COD 64 mg/L) is expected in the effluent of the reactor due to high partial pressure of methane gas inside the reactor. Hence, while treating low strength wastewater major fraction of the methane gas may be lost through effluents, reducing the energy recovery. In addition, due to global environmental concerns and energy insecurity, there is emergent interest to find out sustainable and clean energy source with minimal or zero use of hydrocarbons. Electricity can be produced in different types of power plant systems, batteries or fuel cells. Bacteria can be used to catalyze the conversion of organic matter into electricity. Fuel cells that use bacteria are classified as 2 different types: Biofuel cells that generate electricity from the addition of artificial electron shuttles (mediators) and microbial fuel cells (MFCs) that do not require the addition of mediator.

Biosensor : A microbial fuel cell is directly proportional to the energy content of wastewater used as the fuel, an MFC can be used to measure the solute concentration of wastewater. A single chamber microbial fuel cell can be used as a biosensor. The strength of wastewater is commonly evaluated as biochemical oxygen demand (BOD) values. BOD values are determined incubating samples for 5 day with proper source of microbes; usually activate sludge collected from sewage works. When BOD values are used as a real time control parameter, 5 day incubation is too long.

An MFC-type BOD sensor can be used to measure real time BOD values. Oxygen and nitrate are preferred electron acceptors over the electrode reducing current generation from an MFC. MFC-type BOD sensors underestimate BOD values in the presence of these electron acceptors. This can be avoided by inhibiting aerobic and nitrate respirations in the MFC using terminal oxidise inhibitors, such as cyanide and azide. This type of BOD sensor is commercially available.

Benefits of microbial fuel cell

This graphic shows the basic setup for a microbial fuel cell. An MFC consists of an anode, a cathode, a proton or cation exchange membrane and an electrical circuit. Anode respiring bacteria cling to the anode of the MFC. In the course of their meta-

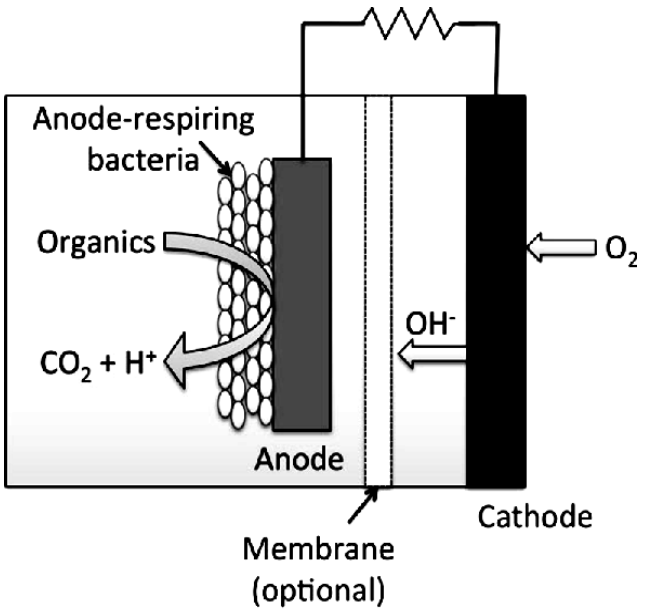

Figure 8. *Membrane process*

bolic activity, these bacteria strip electrons from organic waste. The electrons then flow through a circuit to the cathode, producing electricity in the process, in addition to CO_2 and water. In an effort to provide a sustainable system for waste treatment and energy production, microbial fuel cells or MFCs, which target electrons from waste streams and convert them into useful energy. Some of the planet's tiniest inhabitants may help address two of society's biggest environmental challenges: How to deal with the vast quantities of organic waste produced and where to find clean, renewable energy.

Resource recovery : Resource recovery is the selective extraction of disposed materials for a specific next use, such as recycling, composting or energy generation. The aim of the resource recovery is to extract the maximum practical benefits from products, delay the consumption of virgin natural resources and to generate the minimum amount of waste. Resource recovery differs from the management of waste by using life cycle analysis (LCA) to offer alternatives to landfill disposal of discarded materials. A number of studies on municipal solid waste (MSW) have indicated that administration, source separation and collection followed by reuse and recycling of the non-organic fraction and energy and compost/fertilizer production of the organic waste fraction via anaerobic digestion to be the favoured alternatives to landfill disposal.

Processes in sugarcane industry

Although India is the largest producer of sugarcane and sugar, the sugar factories in India are facing problems due to the mismatch between sugarcane price and sugar price. Sugar factories are not viable if they produce sugar alone. It is necessary to develop the factory into an integrated complex and use the valuable byproducts more beneficially. Molasses is one of the important byproduct of the sugar industry. The profits earned by the conversion of molasses to alcohol will be higher than that of the value realized by sale of molasses. There is a good demand for alcohol in the country, as production and consumption of alcohol are not quite balanced. The target of alcohol demand as projected in the perspective plan for chemical industry, prepared by the Govt. of India, Ministry of Industry, Department of Chemical and Petrochemicals is around 2400 million litre per annum. The distillery utilizes molasses captivity from the sugar factory as the main raw material. In order to add value to molasses, it is proposed to setup a green field distillery to convert all the available molasses to a mix of alcohol products.

In the sugar process, water requirements are the followings : Imbibitions, process water use, lime make up water, flocculants make-up water, filter wash, pan house requirements and service water requirements. The use of external supplies should be kept to a minimum, because they inflate the quantity to be disposed of ultimately. It is possible for a mill to exist without an external supply, providing water circuits in the mill carefully managed. In sugar process production water leaving the mill does so in the following ways :

1. Together with the products of the mill: In molasses and in filter cake.

2. In the form of vapour in: Boiler gases,

which may or may not be saturated, depending on whether a wet scrubber is used; vapour evaporated in cooling towers or spay pond; flash vapour from the heated juice flash tank; evaporation from diffuser or mills.

3. In liquid form as: Surplus condensate; overflow from the cooling water circuit; boiler blow down; drift loss from the cooling towers or spray pond; effluent (wash down or spillage) from drains

Sugarcane wastewater

Substantial increases in yields have occurred over the past 100 year due to improved cultivation and breeding of higher-yielding varieties typically, sugarcane juice undergoes 3 cycles of boiling and crystallization to extract as much sugar as possible. With each successive cycle, the left over molasses contains less sugar. The vast majority of cane sugar commercially produced today is known as 'centrifugal'. With this process, the pH is raised with lime and the mixture is heated to around 100^{0}C for several hours. During the sugar making process, juice extracted from sugarcane or sugar beets is boiled down until the sugars crystallize and precipitate out. The syrup left over after crystallization is referred to as molasses. Typically, sugarcane juice undergoes 3 cycles of boiling and crystallization to extract as much sugar as possible. With each successive cycle, the left over molasses contains less sugar.

Because molasses is the left over components of sugarcane juice after sugar is extracted, it contains a concentrated level of the vitamins and minerals that were present in the sugarcane itself. Molasses is particularly prized for its iron content, although it also contains other important minerals, such as calcium, magnesium and potassium. The amount of these nutrients depends on the variety of molasses and the process used to make it. Blackstrap molasses tends to have the highest nutrient content because it is the most concentrated and has had the most sugar removed. Every brand and variety of molasses is made differently so always check the nutrition label for the exact nutrient content (Figure 9). After filtering any remaining solids, the clarified syrup is decolourized by filtration through carbon. Bone or coal-based activated carbon is traditionally used in this role. Some remaining colour-forming impurities adsorb to the carbon. The production of ethanol from sugarcane is more energy efficient than from corn or sugar beets or palm/vegetable oils, particularly if cane biogas is used to produce heat and power for the process. A number of countries, in particular those devoid of any fossil fuel, have implemented energy conservation and efficiency measures to minimize energy utilized in cane processing and furthermore export any excess electricity to the grid. With a total world harvest of over 1 billion tonne of sugarcane per year, the global energy potentially the wastewater to using power production.

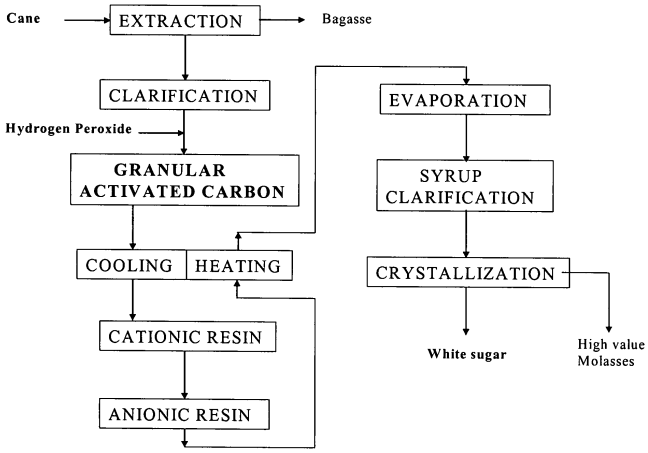

Figure 9. *Process in sugarcane industry*

Objective

The objectives which should be achieved are : (i) To design and fabricate the reactor, (ii) treatability of microbial fuel cell of sugarcane wastewater, (iii) to produce the electricity from sugarcane wastewater and (iv) methane production.

DESISN OF MEMBRANELESS-MFC

In the operation of mediator-less MFC several factors are considered as limiting steps

for electricity generation, such as fuel oxidation at the anode, presence of electrochemically. Active redox enzymes for efficient electrons transfer to the anode, external resistance of the circuit, proton transfer through the membrane to the cathode and oxygen reduction at the cathode. A membrane-less microbial fuel cell (ML-MFC) which converted organic contaminants.From artificial wastewater to electricity. Such membrane less microbial fuel cell can improve the economic feasibility and acceptability.

Anode chamber

The ML–MFC used in the study was made-up of acrylic cylinder having effective height of 60 cm and internal diameter of 15 cm. Anode compartment (depth 26 cm) was placed at bottom. The gas escape valve 10 mm Ø also given at the top of the anode chamber. The total anode area of size is 390 cm^2. It has 2 valves, one at the bottom of the tank for feeding. The one is used to electrode connection.

Cathode chamber

Cathode chamber was also made of the same dimension. It has also 2 valves, the bottom valve due to the electrodes connection, the one is used for aeration control. Anode compartment (depth 26 cm) was placed at top.

Glass wool

Glass bead 4 cm depth were placed at the upper portion of the anode compartment, supported by perforated acrylic sheet.

Glass bead

Glass beads also 4 cm depth were placed at the upper portion of the anode and glass bead placed on glass wool.

Graphite plates in electrode

Three graphite rods were placed in the anode and cathode chambers, to be used as electrodes. The distances between the respective anode and cathode electrodes were 20 cm. Total apparent surface area of identical anode electrodes was 410.64 cm^2. The fuel was supplied from the bottom of the anode chamber and the effluent was discharged through the cathode chamber at top. The electrodes were connected with copper wire.

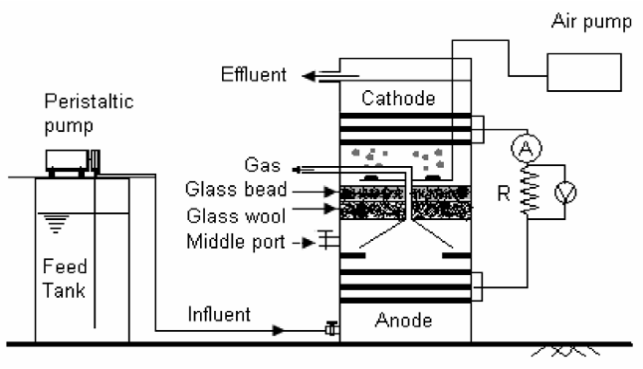

Figure 10. *Schematic diagram of ML-MFC*

Construction of reactor

For the construction of reactor, each part was assembled alone and then joined together. The following construction parts are : (i) Anode chamber construction, (ii) cathode chamber construction and (iii) assembling.

Anode chamber construction : Anode chamber has 2 parts, a feeding valve and electrode slot. The graphite plate was placed inside the chamber and it has been attached with copper wire to multimeter.

Cathode chamber construction : Cathode chamber has more complex construction process as compared cathode. A drain for collection of water was connected at the top. The aeration sparger has also connected through an aeration pipe.

Assembling : As the chambers are designed and assembled with maximum protection against leakage and effective processing of the reactor. The glass wool and bead placed over on the anode chamber. The reactor was also checked for leakage. Aerator has been connected to the aeration pipe and it was coupled with back up supply from compressor. This unit was also checked for leakage and aeration capacity (Figure 10).

Wastewater collection

Sugarcane wastewater collected from D.D.C Sugar Mills, Palacode, India will use as substrate. The wastewater can be considered as complex in nature due to the presence of proteins, carbohydrates and lipids content. After collection, the wastewater was transferred immediately to the laboratory and stored at 4^0C and the wastewater was not corrected for trace elements deficiency.

EXPERIMENTAL SETUP

Seeding

The external circuit is necessary for measuring the rate of electricity production.The electrodes were connected through the copper wire to multimeter had been connected parallel to the resistance.

Operation of the reactor

The next part was startup of reactor. Microbial inoculums would be required in this mediator-less microbial fuel cell. Sugarcane wastewater was applied at the rate of 5.011 L/d to the ML-MFC making total hydraulic retention time (HRT) of 49.8 hr. The cathode compartment was aerated at rate of 60 mL/min. The ML–MFC was inoculated with anaerobic sludge collected from Bhavani at Cauvery river. No microbial addition was carried out in the cathode compartment.

Experimental method

For the experimental setup a simple modification in the external circuit employed to measure electricity directly. A milli-ammeter is connected to the circuit in series. This circuit is made as current cannot be measured in parallel circuit. Also as the electricity produced was too low there has been no need of resistor in this setup (Figure 11).

Batch 1 unaerated with basic sludge feed of 1:5 : During the first of stage of seeding was done by mixing the sludge of the initial batch in 1:5 ratio. It was not aerated. This feed was given and the number of days taken for the initial output has been taken into account. The slurry of batch 1 was mixed in the ratio of 1:5 with wastewater and fed back to the MFC.

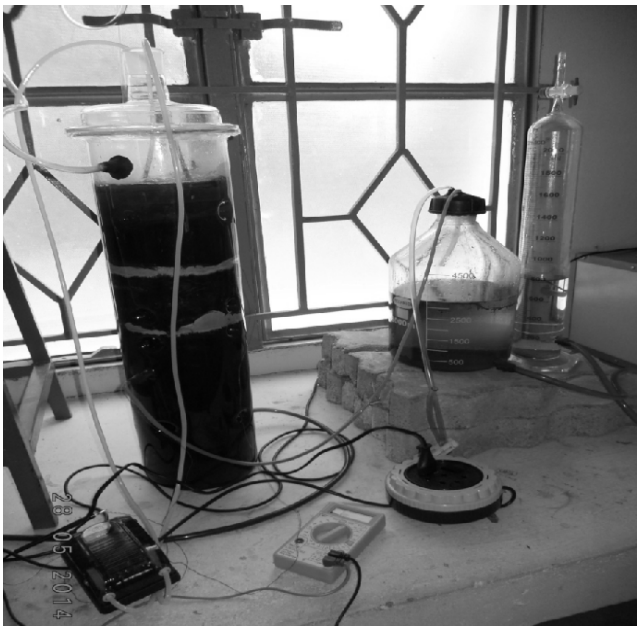

Figure 11. *Membrane less microbial fuel cell*

Batch 2 aerated with sludge 1:5 : This batch was aerated. The cathodic volume has been maintained at same level as of the previous batch. The slurry of batch 2 was mixed in the ratio of 1:5 with wastewater and fed back to the MFC.

Batch 3 aerated with sludge 1:6 : This batch also was aerated. The cathodic volume had been maintained at the highest level. The slurry of batch 2 was mixed in the ratio of 1:5 with wastewater and fed back to the MFC.

RESULT AND DISCUSSION

Characteristics of sugarcane wastewater

i. Sugarcane wastewater contains organic cellulose, hydrocarbons, glucose, sugar wastes and cleaning water.

ii. It is characterized by high concentrations of nutrients, organic and inorganic contents.

iii. Salting activities during sugar production may result in high levels.

iv. Wastewater may also contain acids, alkali with a number of active ingredients and disinfectants, as well as a significant mi-

Table 1. *Characteristics of wastewater from pickling unit, in mg/L*

Parameter	Value
pH	8.5
Alkalinity	1910
Chloride	20.49
Total solid	1320
Volatile solid	1120
Total dissolved solid	1130
COD	4000-8000
Suspended solid	190
Volatile fatty acid	600

Table 2. *Characteristics of wastewater from clarifier unit, in mg/L*

Parameter	Value
Ph	6.0
Alkalinity	191-200
Total solid	950-1020
Volatile solid	620-700
Total dissolved solid	700-850

Table 3. *Characteristics of wastewater from anaerobic outlet unit, in mg/L*

Parameter	Value
pH	6.5
Alkalinity	190-200
Chloride	25-35
Total solid	260-320
Volatile solid	120-170
Total dissolved solid	260-300
COD	6000
Suspended solid	19-30
Volatile fatty acid	60-80

crobiological load, pathogenic viruses and bacteria.

v. Other wastewater streams include cooling water from utilities, storm water and sanitary sewage.

Table 4. *Values of electricity production* (sugarcane wastewater feed at 6000 COD mg/L)

Hour	OCV, mV	P max, mW/m^2	P vol, mW/m^3
0	0	0	0
12	108	22.032	216
13	112	23.694	224
14	114	24.548	228
15	113	24.119	226
16	143	38.625	286
17	123	28.577	246

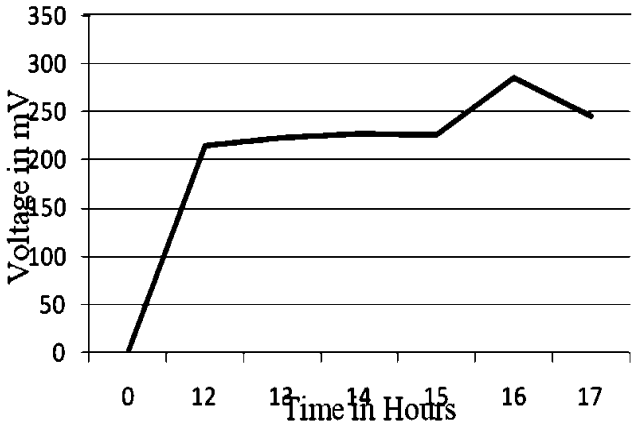

Figure 12. *Voltage production*

The process of wastewater characteristics considered to batch study for COD from anaerobic outlet digester. A microbial fuel cell analysis reduces to the COD and electricity production (Tables 1,2 and 3).

Characteristics of wastewater

The wastewater characteristics of various wastes are categorized. Based on the different parameters, like total solid, total hardness, COD anaerobic digester outlet is considered for batch study. It is selected because it has low amount of hardness.

Electricity produced in terms of OCV

Electricity produced in the microbial fuel cell was analysed by the multicenter and is given in table 4. The figure 12 shows production of voltage as a function against time. The

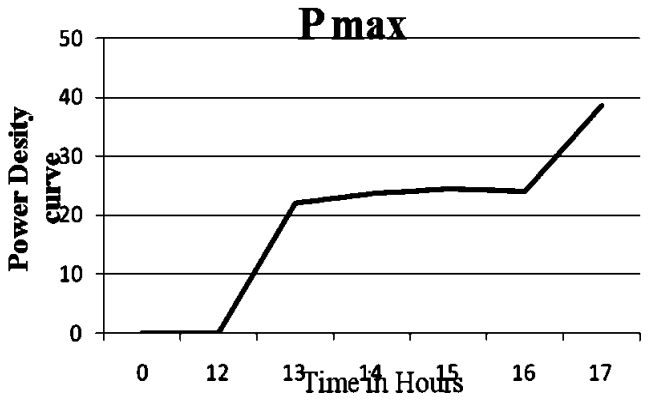

Figure 13. *Power density curve*

graph X-axis is time in hours and its Y-axis is voltage produced and it is measured in mV. Sugarcane wastewater produced voltage around 250 mV. This proves the ability of these wastewater to produce electricity. This is done in a quicker period adjuding use of sludge and enrichment positive. A power density is plotted as a unit of power against time (Figure 13). Pmax is the maximum power that can be produced in this cell for the sugarcane wastewater. The maximum power density is found to be in the range of 35-40 mW/m^2.

Unaerated batch with sludge vVolume 1:5

During this batch the kitchen waste sludge and also sugarcane wastewater is used. Chane in circuits is done to measure the electric current produced (Table 5).

Aerated batch with sludge ratio 1: 5

Thus unaerated batch was tested; the effect of aeration was studied in this experiment (Table 6). As results in the above experiments prove that, aerated condition makes the MFC to generate more electricity than the aerated condition. Further studies are proposed on aerated study (Figure 15).

Aerated study with sludge 1:6

This batch uses the full volume of the reactor. Aerated condition is maintained in the cathode compartment (Table 7). Three batches of study as shown in figures 14,15 and 16. Unaerated batch 1 with sludge ratio 1:5 produced the power very low as such cannot be shown in the graph. Aerated batch

Table 5. *Values of electricity production in unaerated batch*

Hour	Current, μA	P max, mW/m^2	P vol, mW/m^3
0	0	0	0
10	0	0	0
20	0	0	0
30	0	0	0
35	0	0	0
40	0	0	0
45	0	0	0
49	0.10	0.240	0.480
50	0.18	0.778	1.550
51	0.20	0.960	1.920
52	0.20	0.960	1.920
53	0.22	1.162	2.323
54	0.24	1.382	2.765
72	0.34	2.774	5.549
74	0.34	2.940	5.880
75	0.35	2.940	5.880
76	0.36	3.110	6.221
77	0.36	3.110	6.221
78	0.36	3.110	6.221
97	0.41	4.034	8.069
98	0.42	4.233	8.457
99	0.43	4.438	8.875
100	0.44	4.646	9.293
101	0.46	5.078	10.157
102	0.47	5.032	10.603
121	0.71	12.098	24.197
122	0.72	12.442	24.883
123	0.73	12.790	25.597
124	0.74	13.142	26.285
125	0.85	21.528	65.884
126	0.90	28.637	77.120
145	1.40	47.040	94.080
146	1.50	54.000	108.000
147	1.50	54.000	108.000
148	1.70	69.360	138.545
169	1.90	86.640	173.774
170	2.00	96.000	192.476
171	6.00	864.212	250.685

172	6.10	893.221	279.640
173	6.20	922.146	380.988
192	6.40	983.565	1786.080
193	6.50	1040.120	1845.120
194	6.70	1077.236	1966.808
195	12.60	3810.000	2028.000
196	12.70	3870.125	2154.720
211	12.70	3932.214	7741.920
212	12.80	3993.658	7864.320
213	12.80	4704.321	7987.680
214	12.90	4771.512	9408.000
215	14.00	4839.120	9542.008
233	14.10	7975.124	15951.980
234	14.20	8028.587	16057.160
235	14.30	8046.954	16092.290
236	18.23	8072.554	16145.070
237	18.29	8081.973	16162.680
251	18.31	12962.870	25924.680
252	18.34	12973.685	25947.000
253	18.35	13029.587	26058.720
254	18.65	13141.279	26282.880
255	23.24	13367.446	26734.080
256	23.25	13594.112	27189.120
268	23.30	14760.547	27878.120
269	23.40	14880.240	28110.235
270	23.60	14880.240	28110.235
271	23.80	14880.240	28110.235

Table 6. *Values of electricity production in aerated batch*

Hour	Current, μA	P max, mW/m^2	P vol, mW/m^3
0	0	0	0
1	12	3456.0	6912.000
2	18.50	8214.365	1642.800
3	23.40	13141.325	26282.900
4	26.40	16727.695	33454.100
5	26.40	16727.000	33454.100
6	26.40	16727.000	33454.100
25	26.40	16727.000	33454.100
26	26.40	16727.000	33454.100
27	26.30	16727.000	33201.100
28	26.30	16600.00	33201.100
29	26.30	16600.00	33201.100
30	26.30	16600.00	33201.100
49	26.30	16600.00	33201.100
50	26.30	16600.00	32698.100
51	26.10	16349.021	32698.100
52	26.10	16349.021	32698.100
53	26.10	16349.021	32698.100
54	26.10	16349.021	32698.100
73	26.10	16349.021	32698.100
74	26.10	16349.021	32698.100
75	26.40	16727.000	33454.100
76	26.40	16727.000	33454.100
77	26.40	16727.000	33454.100
78	26.40	16727.000	33454.100
97	26.40	16727.000	33454.100
98	26.30	16600.000	33201.100
99	26.30	16600.000	33201.100
100	26.30	16600.000	33201.100
101	26.30	16600.000	33201.100
102	26.30	16600.000	33201.100
121	26.30	16600.000	33201.100
122	26.30	16600.000	33201.100
123	27.90	18681.000	37363.700
124	27.90	18681.000	37363.700
125	27.90	18681.000	37363.700
126	27.90	18681.000	37363.700
145	27.90	18681.000	37363.700
146	27.90	18681.000	37363.700
147	27.90	18681.000	37363.700
148	27.90	19357.400	37363.700
149	28.40	19357.400	38714.900
150	28.40	19357.400	38714.900
169	28.40	19357.400	38714.900

170	28.40	19357.400	38714.900
171	28.40	19357.400	38714.900
172	28.40	19357.400	38714.900
173	28.40	19357.400	38714.900
174	28.40	19357.400	38714.900
193	28.40	19357.400	38714.900
194	28.40	19357.400	38714.900
195	28.40	19357.400	38714.900
196	28.40	19357.400	38714.900
197	28.40	19357.400	38714.900
198	28.40	19357.400	38714.900
217	28.40	19357.400	38714.900
218	28.40	19357.400	38714.900
219	28.40	19357.400	38714.900
220	28.40	19357.400	38714.900
221	28.40	19357.400	38714.900
222	28.40	19357.400	38714.900
241	28.40	19357.400	38714.900
242	28.40	19357.400	38714.900
243	28.40	19357.400	38714.900
244	28.40	19357.400	38714.900
245	28.40	19357.400	38714.900
246	28.40	19357.400	38714.900
265	28.40	19357.400	38714.900
266	28.40	19357.400	38714.900
267	28.40	19357.400	38714.900
268	28.40	19357.400	38714.900
269	28.40	19357.400	38714.900
270	28.40	19357.400	38714.900
289	28.40	19357.400	38714.900
290	28.40	19357.400	38714.900
291	28.40	19357.400	38714.900
292	28.40	19357.400	38714.900
293	28.40	19357.400	38714.900
294	28.40	19357.400	38714.900
313	27.00	17496.000	34992.000
314	26.00	16224.000	32448.000
315	25.80	15975.004	31950.700
316	25.00	15000.000	30000.000
317	24.40	14288.660	28577.300
318	24.00	13824.000	27648.000

Table 7. *Values of electricity production in aerated batch with sludge ratio 1:6*

Hour	Current, μA	P max, mW/m^2	P vol, mW/m^3
1	11.60	3229.440	4968.369
2	11.60	3229.440	4968.369
3	11.60	3229.440	4968.369
4	11.60	3229.440	4968.369
5	11.60	3229.440	4968.369
6	11.60	3229.440	4968.369
25	12.40	3690.240	5677.292
26	12.40	3690.240	5677.292
27	12.40	3690.240	5677.292
28	12.40	3690.240	5677.292
29	12.40	3690.240	5677.292
30	12.40	3690.240	5677.292
49	11.80	3341.760	5141.169
50	11.80	3341.760	5141.169
51	11.80	3341.760	5141.169
52	11.80	3341.760	5141.169
53	11.80	3341.760	5141.169
54	11.30	3064.560	4714.708
73	11.30	3064.560	4714.708
74	11.30	3064.560	4714.708
75	11.30	3064.560	4714.708
76	11.30	3064.560	4714.708
77	11.30	3064.560	4714.708
78	11.30	3064.560	4714.708

shows instant electricity production. The number of days in continues electricity output also differs. Sludge with 1:6 ratio is incapable of producing current. Log graph showing total current produced in all batches. Unaerated batch is the lowest current producer. It can be explained as it's the first reaction batch. Initial sludge used is mostly inactive. This is the difference between aerated and unaerated. As of batch 1:6 aerated sludge volume, it was getting low sludge input result in low current production.

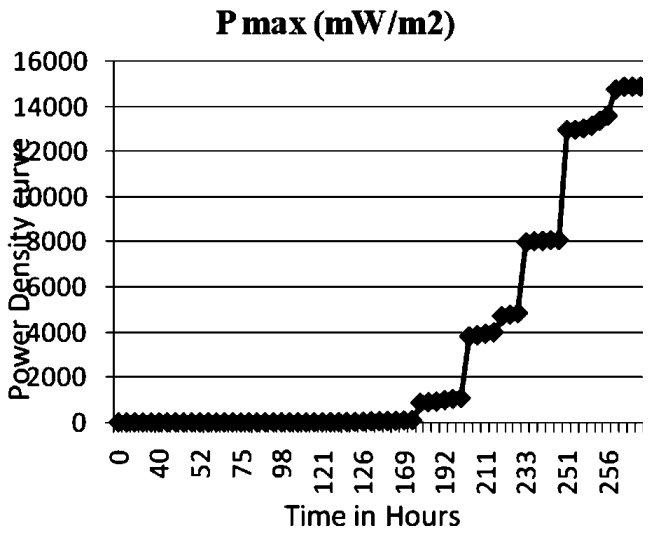

Figure 14. *Unaerated sludge 1:5*

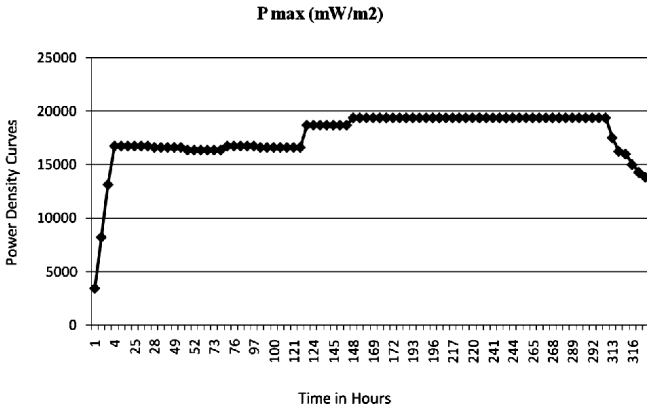

Figure 15. *Aerated sludge 1:5*

Performance of the ML-MFC for COD removal

The ML–MFC was operated at influent COD concentration in the range of 6000-8000 mg/L. After completion aerated and unaerated treatment of operation, when steady state condition for COD removal reached, the COD and BOD reductions were 88% and 87%, respectively. The observed COD removal efficiency was on the higher side of the maximum reported efficiency in the range of 80–90%. Further studies are required to explore maximum volumetric loading rate capacity for this ML–MFC. The COD removal percentage in anode chamber was 46.3% and remaining COD was getting removed in the cathode chamber. Lower COD removal efficiency observed in this case could be attributed to the mixed culture used as inoculums. Further investigation would be necessary to enhance the COD removal in anode compartment and hence, to increase current production. However, the overall efficiencies observed for COD and BOD removal demonstrated the ability of ML–MFC as an effective wastewater treatment process (Tables 8 and 9).

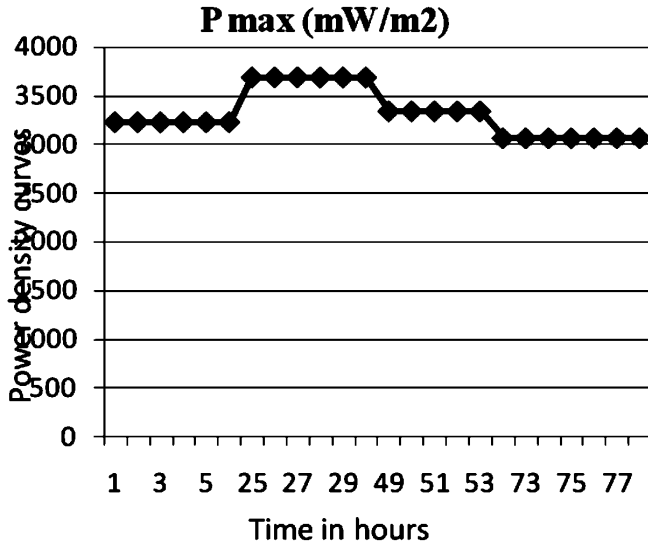

Figure 16. *Aerated sludge 1:6*

SUMMARY AND CONCLUSION

Summary

Microbial fuel cell was constructed based on design parameters. This cell was then verified for the production of electricity us-

Table 8. COD reduction

Wastewater treatment	COD reduction
Aerated with sludge 1:5	81.52%
Aerated with sludge 1:6	50.55%
Unaerated with sludge 1:5	74.86%

Table 9. *Columbic efficiency*

Total current produced	Columbic efficiency
Aerated with sludge 1:5	55%
Aerated with sludge 1:6	17%
Unaerated with sludge 1:5	50%

ing sugarcane wastewater as substrate. The same batch was used for testing the wastewater as the source of organic load and its ability to produce electricity. Two aerated and unaerated batches were used and their results were noted.

Conclusion

The membrane-less microbial fuel cell, inoculated with mixed anaerobic sludge demonstrated its effectiveness as a wastewater treatment process alongwith electricity production, without incorporating any costly component, such as mediator and membrane. The COD, BOD removal were achieved at varying levels. Granulation of biomass was observed in the anode compartment of the ML–MFC. Maximum power density was observed spacing between the electrodes. Further studies would be necessary to optimize the electricity production from this ML–MFC. With further improvements and optimization, it could be possible to increase power generation. Sludge which has been present in the same type of feed more than 4 week is very much active. It is shown in the unaerated mode. Also MFC as a continuous reactor can also be used. Going further toward the condition to be maintained in the reactor, aerated condition produces more electricity and it is instantaneous. In case of unaerated chamber, the current production is delayed by some time, due to inability of the reactor to complete the reaction in both chambers. 6-8 week of sludge is recommended for reaction. Thus, the combination of wastewater treatment alongwith electricity production might help in compensating the cost of wastewater treatment.

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