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BACTERIA EATING POLLUTION AND GENERATING ELECTRICITY

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ABSTRACT

The continuous use of fuels like petroleum is recognized as unsustainable because of their natural exhaustion and contribution to the pollution in the environment. Not only for the environmental perspective but also for the economic sustainability, we necessarily need to develop alternative, renewable and pollution free fuels. Harvesting energy from the sun (solar energy), earth (geothermal energy), water (hydropower), or wind are few of the alternative and renewable energy sources. It has been well appreciated that fuels, such as ethanol, butanol, methane and hydrogen can be produced by microorganisms. But by using bacteria in a microbial fuel cell (MFC), electricity can be extracted from wastewater, converting organic material in the waste water to electricity using bacteria, leaving behind clean drinking water in the process (bacteria are appreciated as electricigens). Harvesting electricity with microbial fuel cells can proficiently convert organic wastes, renewable biomass and even mud into electricity and harmless by-products. This capability offers the potential for using bacteria (or their components) to generate electricity at low cost while transforming industrial, domestic, and farm toxic pollution. This is an exciting aspect for human kind around the world who lacks adequate sanitation and resources to clean up toxic waste. Though the MFC technology is not yet well developed to produce substantial quantities of energy in a cost effective way, the area reviewed in the present communication requires more research and is highly prospective.

KEYWORDS: **Bacteria, Microbial Fuel Cells, Electricity, Pure water**

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INTRODUCTION

It has been known for years for bacteria for their potential to generate electricity by metabolising vast variety of substrates[1]. But only in the past few years this capability has become more than a laboratory invention. A new form of renewable energy technology, the microbial fuel cell (MFC) can generate electricity from what would otherwise be considered as a waste material. The capability of organisms to carry out this process is the basis of Microbial Fuel Cells (MFCs) which work in a similar way to a battery and are usually composed by a cathode and anode separated by a cation exchange membrane. In certain settings the ability of the MFC microbial population to degrade a wide range of environmental wastes may be more important than production of electricity itself, especially when the MFC technology can be used for environmental cleanup *in situ*. The idea of using microbial cells in an attempt to produce electricity was first conceived by M.C. Potter who was first to perform work on the subject in 1911[1]. Potter managed to generate electricity from *E. coli*. In 1931, Barnet Cohen created a number of microbial half fuel cells that were capable of producing over 35 volts (when connected in series), with a production of current of 2 milliamps[2]. The current design concept of an MFC came into existence by important contribution made by Suzuki[3]. At present, there is much work done with regard to MFCs, with multiple combinations of electrodes and microorganisms[4,5,6,7,8,9,10,11].

MICROBIAL FUEL CELLS

An MFC could be described as a fuel cell that contains microorganisms which, as a part of their metabolic process, oxidize organic material or wastes releasing electrons and protons. In this way MFCs couples the metabolism of a microorganism to an electrical circuit (Fig. 1). MFC consists of anodic and cathodic chambers partitioned by a proton exchange membrane (PEM)[12]. The anode compartment is usually maintained under anoxic conditions, whereas the cathode can be suspended in aerobic solutions or exposed to air. Electrons flow from the anode to the cathode through an external electrical connection that generally includes a resistor, a battery to be charged. The electrons are absorbed by the anode and are transported to the cathode through an external circuit whereas after crossing a PEM or a salt bridge, the protons enter the cathodic chamber where they combine with oxygen to form water. Microbes in the anodic chamber extract electrons and protons in the dissimilative process by oxidizing organic (for example glucose) waste substrates[4] a typical electrode reaction of which is shown below using glucose as an example substrate.

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

The overall reaction is the breakdown of the substrate to carbon dioxide with a concomitant production of electricity as a by-product.

POTENTIAL OF BACTERIA TO GENERATE ELECTRICITY

Bacteria extract energy by transferring electrons from a reduced substrate at a low reduction oxidation (redox) potential, such as glucose to an electron acceptor with a high redox potential such as oxygen. The energy gained can be calculated as $\Delta G = -nxFx\Delta E$ (with n the number of electrons exchanged, F Faraday's constant (96485 Coulomb/mol) and ΔE the potential difference between electron donor and acceptor). If bacteria derive reducing equivalents from glucose in the form of NADH, and subsequently shuttle electrons from NADH (redox potential -320mV) to oxygen (redox potential +840mV), the potential difference is~1.2 V [ΔE= (0.840V)-(-0.320V)], and the energy gain would be ΔG=-$2x10^2$ kJ/mol (2 electrons per molecule of NADH). If the electron acceptor is sulphate (redox potential -220mV), the potential difference decreases to ~100 mV, yielding a

ΔG of ~$2x10^1$ kJ/mol. The amount of energy available for the bacteria to grow is very low in that case as compared to the glucose. To study more on bacterial energy conservation please follow ref. 13.

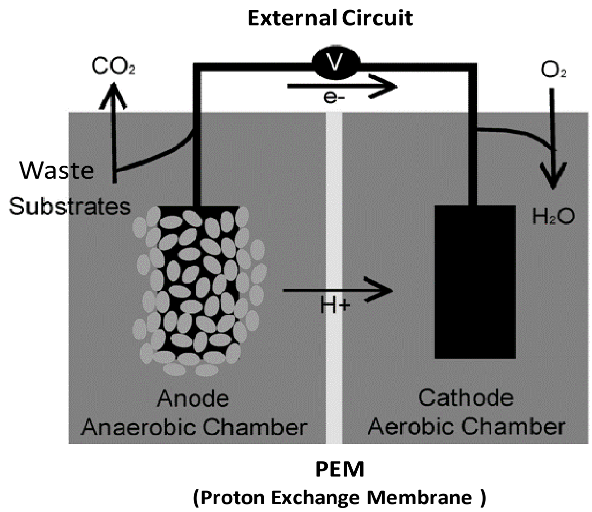

Figure 1 A
Typical Schematics of a Microbial Fuel Cell (MFC)

TYPES OF MFCS

More broadly, there are two types of microbial fuel cells i.e., mediator and mediator-less microbial fuel cells. In mediator microbial fuel cell most of the microbial cells are electrochemically inactive. Mediators found naturally could be used to enhance electron transfer in MFCs which act as shuttle between anode and electron carriers inside the cell. Mn^{4+}, thionine, methyl viologen, neutral red, methylene blue, humic acid and Fe (III)-EDTA are such typical mediators[14,15]. However mediator-free microbial fuel cells 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). In a microbial fuel cell operation, the anode is the terminal electron acceptor recognized by bacteria in the anodic chamber. Therefore, the microbial activity is strongly dependent on the redox potential of the anode as described above. Some bacteria, which have pili on their external membrane, are able to transfer their electron production via pili. Many microbial fuel-cell studies are mainly dependent on fermentation process by fermentative microorganisms which is a well-known mechanism for anaerobic metabolism of organic matter[16].

MICROORGANISMS AND THEIR FUNCTIONAL ROLES IN MFCS

There are three categories of microbes that can be used in MFCs. First, those who can directly transfer electrons to anode using anode as terminal electron acceptors, second those who cannot directly but use mediators to transfer electrons to anode, third those who can accepts electron from cathode. There are two subcategories in the second which are of those who can use natural mediators and those who cannot. There are lots of reports on microorganism that can directly transfer electrons to anode. Marine sediments and waste water sediments are the main sources of these microorganisms. Since all of the microorganisms are metal reducing in nature, some of them could be the high source of electrons. *Geobacters, Shwenella* and *Rhodoferax* behave similar to their natural condition as anode which acts and behaves as metal oxides[17,18,19]. However *Clostridium butyricum* is only mediator-less microorganism which does not reduce metals[20]. *S. putrefaciens*, *G. sulferreducens*, *G. metallireducens* and *R. ferrireducens* transfer electrons to the solid electrode (anode) using this system[19,21]. In general mixed cultures are preferred as they have potential to use a wide range of substrates. Mixture of electrophiles and anodophiles together use array of substrates and could be used efficiently for generation of electricity from waste water. Sulphate/sulphides mediated systems have a major role in power generation[22] and most of the times sludge is rich in these compounds which may be due to the metabolic activity of sulphur bacteria. Table 1 represents performance of MFCs based on both axenic (single bacterial species) and mixed culture systems.

Table 1
Performance of MFCs based on both axenic and mixed culture systems

Microorganism	Substrate	Current (mA)	Power (mW/m^2)	References
Shewanella putrefaciens	Lactate	0.031	0.19	23
Proteus vulgaris	Glucose	0.80	4.50	24
Geobacter sulfurreducens	Acetate	0.40	13.0	18
Rhodoferax ferrireducens	Glucose	0.20	08.0	19
Pseudomonas aeruginosa	Glucose	0.10	88.0	15
Escherichia coli	Lactate	2.60	91.0	15
Mixed seawater culture	Acetate	0.23	10.0	25
Mixed active sludge culture	Glucose	30	3600	26

ENERGY RECOVERY USING BIOLOGICAL MASS AS FUEL

Biological mass has an energetic value, whether it is a food substrate or biological waste. On average 1 kg of sugar contains 4.41 kWh of energy or potentially $13x10^6$ Coulombs of charge. Out of 1 kg carbohydrates, one can currently produce 0.5 L of ethanol, 1.2 m^3 of H_2 gas, 0.36 m^3 of CH_4 gas or 0.5 m^3 of biogas. On average, these processes yield ~1 kWh of useful energy. Because the production of this 1 kg of sugar costs is high, using sugar to drive batteries is not a feasible process at a large scale. However, lots of substrates in terms of biological mass are available in the market at low prices. Although the intrinsic quality of this 'waste-biomass' is lower, the energy yield might still be sufficient to allow energy recovery utilizing MFC.

POTENTIAL APPLICATIONS OF MFCS

Microbial fuel cells have a number of potential uses and applications. Generating electricity out of biological waste or organic matter is undoubtedly the most 'green' (eco-friendly) aspect of microbial fuel cells. Thus generated energy from virtually any organic material can be used for downstream operations for example for waste treatment plant. Figure 2 is showing schematic of a direct way of producing supplementary power from bacteria consuming waste material in water. The major advantage of using an MFC at this situation is that it uses a renewable form of energy and need not to be recharged like a normal standard battery. In addition to that MFCs could function properly in even mild conditions at the temperature of 20°C to 40°C at a pH of around 7[5].

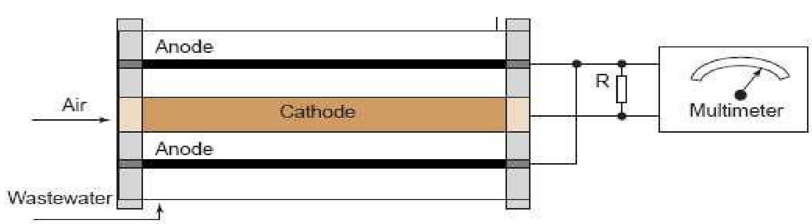

Figure 2 A
Direct way to generate electricity from waste water

Theoretically, 100% efficiency of fermentation could deliver ~1 kWh of electricity for every kg of organic matter (dry weight) in one single fermentative step. Substrates such as plain sugar and starch are easy to store, contain more energy than any other feed type per unit of volume and are easy to dose as described above. Furthermore, they have a more 'green' (eco-friendly) image. The current generated from a microbial fuel cell is directly proportional to the energy content of wastewater used as the fuel that is why an MFC can be used to measure the solute concentration of wastewater and could act as a biosensor system[17]. The strength of wastewater is commonly evaluated as biochemical oxygen demand (BOD) values. An MFC-type BOD sensor can be used to measure real time BOD values. An unusual application for MFC technology is to power implanted medical devices using glucose and oxygen from blood. An implanted MFC could provide power indefinitely and counteract the need for surgery to replace batteries. Abiotic fuel cell based on noble metal catalysts and activated carbon has been demonstrated to produce energy from blood glucose *in vitro* and *in vivo*[27]. In addition to that Interest has also been expressed in using human white blood cells as a source of electrons for an anode[28]. To commercialize Microbial Fuel Cells a vast number of companies have emerged. These companies have attempted to knot both the remediation and electricity generating aspects of the technologies. It is worth mentioning that many of these envisaged applications are not currently practicable and require significant improvements or enhancements if they are to be adopted as feasible technologies[29,30,31].

CONCLUSION

The universal fact that there is a lot of bio-waste that could actually be considered as stored energy from which bacteria (metabolically active) can generate electricity. Thus MFCs represents a promising technology for the production of energy. Currently limited applications are possible because of low MFC electricity production or stumpy power output. Of particular interest are some current applications of MFCs where wastewater treatment or bioremediation may be much more promising then the electrical production of the MFC itself. A better understanding of the microbiology involved in the electricity producing process is required for further enhancement in power output. Even if the generation of high levels of electricity from MFCs is a long way off, an understanding of the coupling of organic matter oxidation to electron transfer to electrodes could shed light into the diversity of microbial respiratory capabilities and might also lead to light up yet unknown applications of nano-electronics. Mutagenesis and rDNA technology can conceivably be used in the future to obtain some "super bugs" (microbes) for MFCs. Super bugs may be used as a pure culture or a mixed culture forming a synergistic microbial consortium in MFCs to offer better performance. Furthermore, there are many microorganisms yet to be discovered that might be considered beneficial for electricity production. This review is unable to give the entire field of MFC research in detail but hopes to highlight some important points regarding research in the field and recent important advances.

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