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Microbial Fuel Cells as an Alternate Strategy for Sustainable Energy Generation

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Globally there is steady increase in energy demands. The lack of sustainability of current fossil-centered energy strategies and safety issues relating to nuclear energy has resulted in a shift in energy policies around the world. The need for alternative non-fossil, non-nuclear technology has been stressed by experts and research on this line has produced promising results. The discovery of electro-active or electrogenic bacteria capable of producing electricity has been a potent area of research with an objective to develop microbial fuel cells. The microbial fuel cell (MFC) is a promising technology for sustainable energy generation, remediation, and sensoring. The MFC concept is based on microbial exocellular electron transfer, or the capacity of microbes to transfer electrons produced from the metabolic oxidation of organic substrates to insoluble, extracellular electron-accepting compounds. This paper presents a review of the latest developments in fuel cell technology and its future prospects.

Key words: Microorganism, Fuel cells, Recombinant DNA

Microorganisms from environmental samples exposed to significant environmental and its have been exceptionally rich sources of primary and secondary metabolites, including important nutrients, antibiotics, immune suppressants etc (Chellaram *et al* 2009; Chellaram 2011; Chellaram *et al*, 2013; Anbuselvi *et al*, 2011) The need for sustainable energy resources as an alternative to fossil fuels is imperative. Fossil fuels are associated with global climate change because combustion of fossil fuels releases vast quantities of CO_2 in the atmosphere. The other main concern is the bitter fact that they are not an inexhaustible resource. Governments all around the world realize the need for efficient alternatives to fossil fuels, which are not only pollution free but sustainable in long run. Microbial Fuel Cells (MFCs) are considered to be one among the recent advances that show great promise for development as a sustainable energy resource. (Aelterman *et al*., 2006; Logan *et al*., 2006).

Even though current generation by microbes has been reported by Potter, as early as 1910 (Potter, 1911), the real appreciation for this discovery came very late, when it was discovered that microorganisms could transport the electrons gained from cellular metabolism to insoluble minerals (e.g. manganese) in a process termed extracellular electron transfer (Lovley DR, 1993). When current and power generation was found to enhance by addition of electron acceptor, this was considered as a major breakthrough. 1990s saw a surge in MFCs research and various researchers developed various MFC reactors using domestic or industrial wastewater as substrate, which greatly

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accelerated the progress of technology (Aelterman *et al*., 2006; Liu *et al*., 2004; Logan *et al*., 2006; Rabaey and Verstraete, 2005)

MFC has potential advantage when compared with hydrogen fuel cells, especially the need for a pure source of highly explosive gas in hydrogen fuel cells, which is difficult to manipulate. The MFC concept is based on microbial exocellular electron transfer, or the capacity of microbes to transfer electrons produced from the metabolic oxidation of organic substrates to insoluble, extracellular electron-accepting compounds. Microbial electron transfer to electrodes can be achieved directly by transferring the electrons produced via bacterial cell membrane cytochromes and protein complexes (Zhou *et al*., 2012).

Various microbes from different natural environments such as marine sediments, drainage water and soils can form biofilms on graphite anodes, oxidize the dissolved organic matter contained in the environment and use the electrode as the final electron acceptor. MFC opens doors and possibilities to harvest electricity from organic waste and renewable biomass. The potential of this field has resulted in the dramatic increase in publications ranging form fuel cell designs to reports of electrogenic microbes from various environments. This review will provide an overview of the recent advances in this MFC research and also will try to discuss about the future prospects.

Applications of MFC

Meteorological buoys were the first devices powered by MFC technology. The advantage of benthic MFCs is that they do not require the addition of exogenous microorganisms. Electrons are produced from the metabolism of naturally occurring microorganism in the marine sediments. Benthic MFCs generate power through the microbial oxidation of organic substrates in anoxic marine sediments coupled to reduction of oxygen in the overlying water column. The meteorological buoys acquired their complete power from the benthic MFC letting them to run uninterruptedly and independently. Benthic MFCs have worked for numerous years with any reduction in power output. Limitations of MFCs are the high cost of materials such as the nafion membrane commonly used in laboratories as a proton permeable membrane (Ashley and Kelly, 2010) Efforts to develop low cost MFCs are underway, and a novel earthen pot MFC was developed to use in India with a production cost of US $1/piece (Behera *et al*., 2009).

The possibility for wide range of applications has been envisaged due to use of an anode as a final electron acceptor. Production of power from wastewater is one of the active areas of research. Various Studies have demonstrated that any compound degradable by bacteria can be converted into electricity (Pant *et al*., 2009). The range of compounds include, but by no means limited to, acetate (Bond and Lovely, 2003), glucose (Liu and Logan, 2004), starch (You *et al*., 2006), cellulose (Feng *et al*., 2008), wheat straw (Galvez *et al*., 2009), pyridine (Patil *et al*., 2009) and complex solutions such as domestic waste water. Irrespective of the potential, scale-up of MFCs for large-scale treatment of wastewater will be a problem.

Electrogenic microbes involved in MFCs

Many different species of microorganisms have been reported from MFCs systems. Brevibacillus sp. PTH1, is one of the abundant strains often encountered in MFC systems. The other bacterial classes involved are Firmicutes, Acidobacteria and many species of Proteobacteria, as well as yeasts, mainly *Saccharomyces cerevisiae* [Walker and walker, 2006] and *Hansenula anomala* (Prasad *et al*., 2007). Various direct and indirect processes are involved in current production by these microbial strains. MFC efficiency can be determined by coulombic efficiency, and coulombic efficiency, is a measure of the number of coulombs recovered as electrical current compared to the theoretical maximum number of coulombs recoverable from the organic substrate added to the system. This efficiency is mainly determined by the type of microbes, the various metabolic pathways employed by the different strains determine this. When microorganisms in the MFC system are capable of completely oxidizing the organic substrate to CO_2 higher columbic efficiencies have been reported. The best examples of microbes with higher efficiency are *Geothrix fermentans* (94% columbic efficiency oxidizing acetate) (Bond and Lovely, 2005); Geobacter species (approaching 100 % columbic efficiency oxidizing acetate or 84% oxidizing benzoate); and *Rhodoferax ferrireducens* (83% columbic efficiency oxidizing glucose) (Ashley and Kelly, 2010) .

Types of MFCs

Two-compartment MFC systems

This system is used only in laboratories. A classic two- compartment MFC has an anodic chamber and a cathodic chamber separated by a proton exchange membreane (PEM) or in some cases connected with a salt bridge, to allow protons to move across to the cathode while blocking the diffusion of oxygen into the anode (Fig.1). Depending on the design, the compartments can take different practical shapes (Zhuwei Du, 2007).

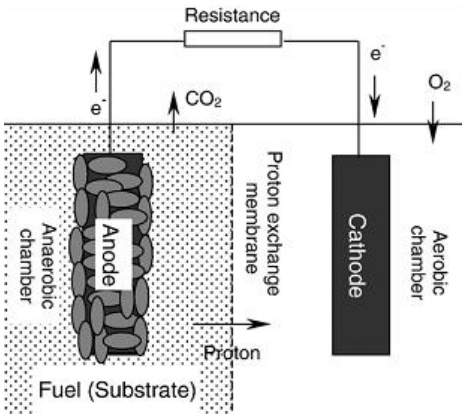

Fig. 1. Two compartment MFC systems (Zhuwei Du, 2007)

The complex design of two compartment MFCs makes them difficult for scaling up even though they can be operated in either batch or continuous mode. Comparatively the one-compartment MFCs offer simpler design with cost effectiveness. They usually possess only an anodic chamber without the requirement of aeration in a cathodic chamber (Zhuwei Du, 2007).

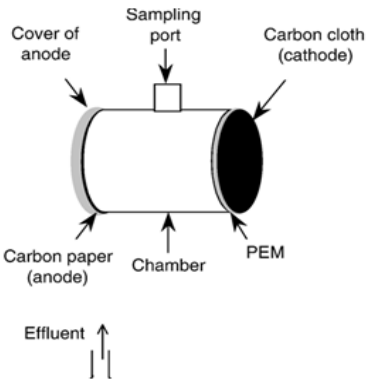

Fig. 2. Single compartment MFC system (Zhuwei Du, 2007)

The complex design of two compartment MFCs makes them difficult for scaling up even though they can be operated in either batch or continuous mode. Comparatively the one-compartment MFCs offer simpler design with cost effectiveness. They usually possess only an anodic chamber without the requirement of aeration in a cathodic chamber (Zhuwei Du, 2007).

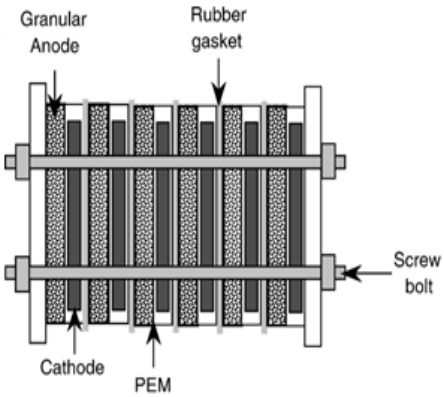

Fig. 3. Stacked MFC system (Zhuwei Du, 2007)

Future prospects

Improvement of power output depend on the potential of the microbes, the need to screen for new potent electrogenic microorganisms will be a great challenge in future. Mutagenesis and even recombinant DNA technology can be used in the future to acquire few "super bugs" that will enhance the efficiency of MFCs. Microbes may be used as a pure culture or a mixed culture forming a synergistic microbial consortium to offer better performance. One type of bacterium in a consortium may provide electron mediators that are used by another type of bacterium to transport electrons more efficiently to an anode. The next future challenge will be the development of cheap electrodes that resist fouling. Thought it is unrealistic to expect MFCs to rival conventional chemical fuel cells, the need to develop designs to scale-up the MFCs is urgent due to the sustainable nature of MFC technology.

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