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Fuelling the Microorganisms for Remediation

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Man-made chemical substances are the double-edged swords. They improve the human style of living. But at the same time, they can have adverse effect on human health and other living organisms in the environment. Certain human activities like mining, land development and management of aquifers release chemical substances rapidly, relative to the natural geochemical processes. These natural and man-made chemical substances can transcend several frontiers and their changed dynamics can have serious consequences on various ecosystems. For a long time, 'solution to pollution is dilution' has remained the major principle for dealing with the contaminants. Unfortunately, the Earth has a very limited capacity to dilute, assimilate and degrade many contaminants. Because of slower reaction rates, a few of these chemical substances tend to accumulate in various components of the environment. The energy demand for remediating these polluted environments is enormous in many cases. About 90 per cent of the world's energy needs is met from the fossil fuels. Because of the current rate of consumption, the reserves of fossil fuels are going to be depleted soon.

Finding new sources and technologies, and efficient utilization of energy are becoming more important in countries across the globe today. The sun is the ultimate source of energy on Earth and less than 3% of the radiation of the sun is fixed as the net primary production. Bioenergy contained in plant biomass has solar origin and may contribute considerably towards future sustainable renewable energy production. But, the production of bioenergy without competing with food production for arable land, fertilizers, and other energy inputs is very important now. Interestingly, the energy production is the chief metabolic activity of microorganisms. Most organic substances can serve as the source of energy to diverse group of microorganisms and hence they are transformed or degraded in the polluted environment. A selected group of electrochemically active microorganisms, also known as electricigens [1], have the ability to oxidize organic compounds to carbon dioxide while transferring electrons to the extracellular electron acceptors. The electrons are transferred via microbial membrane-associated components, soluble electron shuttles or nanowires. These electricigens are now employed for developing microbial fuel cells (MFC), which are the devices that generate electricity due to microbial catabolism of organic substances, without addition of any exogenous or production of electron mediators. In the search for the environment-friendly way of treating the polluted areas, MFCs represent an emerging green technology which not only transform biodegradable substrates but also generate electricity. The MFC systems have been applied to harvest electric power from marine and river beds, by utilizing the natural potential gradient between the soil layers and upper oxic water, and electrons released by the microbial oxidation of organic matter flow from the anode in the soil layers to the cathode in water through an external circuit [2]. The maintenance of potential difference between the oxic water and the anoxic bulk soil are due to various redox reactions, mediated by the activities of electricigens. MFCs can also be very useful for remediating the contaminated soil and wastewater treatment. The organic contaminants of soil or water can be transformed or degraded, with little or no residual treatment.

Electrodes inserted in the contaminated soil or wastewater can increase oxidant delivery, coupled with the electron transfer from *in situ* microbial degradation reactions. Sticking to the surface of an electrode, the microorganisms transfer electrons to the electrode, producing a current. The reaction kinetics, electrode configuration and various environmental factors such as the moisture content and redox conditions influence the performance of MFCs. In case of their application for enhanced *in situ* bioremediation of contaminants in soil and groundwater, the heterogeneity of soil or chemical contaminants in wastewater requires better understanding of the microbially-mediated processes. In the contaminated sites that have less organic matter, the reversing the process in which the electrodes donate electrons to the microorganisms can help the highly charged contaminant ions migrate toward the electrode and then stick to it [3]. By changing these charged contaminant ions to less mobile form, further spreading can be prevented. Use of electrodes as electron donors offer certain advantages such as positive selection of microbial strains with remediation potential and reduced competition among the native flora.

Electrochemically active microorganisms in the conventional MFCs act as biocatalysts using a part of the chemical energy of the substrate for their own metabolism and simultaneously delivering electrons to the anode of the fuel cell. By transferring electrons from an electron donor, such as glucose or acetate, to an electron acceptor, such as oxygen, the microorganisms gain energy. When the difference in potential between donor and acceptor is larger, the energetic gain for the microorganisms will be larger and the growth yield higher. Depending on the physiologies of microorganisms associated with the electrodes and the availability of electron donors and acceptors, electron transfer suffers from the competing reactions as fermentation, respiration or even methanogenesis. Percentage of electrons recovered from the substrate versus the theoretical maximum values for the coulombic efficiency is in the range of 20-60% [4]. More research efforts are required to improve otherwise low power output, ranging from 100 to 1000 W/m^3, of the existing MFCs.

MFCs are a clean technology for treating wastewater. The organic contaminants can be oxidized at the anode while the product at the cathode is water. Most organic compounds of wastewater can be removed by this anodic process. Since wastewater contains many constituents including nitrogen based compounds, the cathodic nitrate reduction in MFCs is also considered as a potential technology for nitrogen removal from wastewater [5]. Nitrate can be converted to nitrite, even N_2 gas from water, by receiving electrons from the cathode. The power output which is related to the fuel oxidation rate has been reported to be a function of fuel concentration expressing a Monod-

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type relationship [6]. The application of MFCs in wastewater treatment process has several advantages such as the recovery of energy in terms of electricity and generation of less sludge [7,8]. The current and power densities are now lower than what are theoretically possible and hence the performance of MFCs needs to be improved for energy generation. Nonetheless MFCs can substitute the activated sludge or trickling filters treatment systems of the centralized facilities for wastewater treatment. MFCs can also be used where the collection system for wastewater is uneconomical.

Since the current from MFCs is proportional to the concentration of assimilable organic contaminants, Kim et al. [9] suggested that these microbial devices could serve as the biochemical oxygen demand (BOD) sensor. MFCs as sensors can be used for the real-time analysis of BOD values by calculating the decline in BOD from the electricity produced. The major limitation of MFCs is low power density but the electricity may be sufficient to use certain direct current devices. The voltage output of MFCs is good enough to be used in many microelectrochemical systems, also referred as micromachines or Micro Systems Technology. Since MFC technologies can be adapted to local as well as field scale operations for waste remediation and specific pollutants removal, they are excellent options for protecting the environment. The carbon neutral nature of MFCs with no or less emissions is an added advantage. Advancements in the design of MFCs, new knowledge on the electrochemically active microorganisms, and biochemical pathway engineering for improved reaction rates will make MFC technologies performing better and becoming more popular.

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