MICROBIAL FUEL CELL

A PROMISING GREEN ENERGY PRODUCTION TECHNOLOGY FROM WASTEWATER

DEBABRATA DAS, Professor and Former Head, Department of Biotechnology, IIT Kharagpur, Distt.-Sangrur (Punjab)—148 106

The quest for novel and sustainable energy resources has always been there, but never like in the present times. Concerns regarding depleting fossil fuels, global climatic changes, waste management, and even non-edible feedstock have pushed the focus on alternate solutions that cater to such multiple problems at one go.

India is world's sixth largest energy consumer, accounting for 3.4% of global energy consumption. Due to India's economic growth, the demand for energy has risen at an average of 3.6% per annum over the past 30 years. More than 50% of the country's commercial energy demand is met through its vast coal reserves. About 76% of the electricity consumed in India is generated by thermal power plants, 21% by hydroelectric power plants, and 4% by nuclear power plants. The country has also invested heavily in recent years on renewable sources of energy.

Industry sources estimate that the total Indian water treatment market is worth more than Rs 50 billion, with approximately one-third for water provisioning, one-third for municipal water treatment, and one-third for industrial water treatment. The overall water market is growing at 15%–20% per annum.

20 L experiment set up

Use of fuels cells is one such alternate energy technology that is being studied for full-scale implementation. These can be classified into three subgroups: catalytic, enzymatic, and microbial. Since the turn of the century, the research on MFCs (microbial fuel cells) has experienced rapid increase. MFCs are unique in their ability to utilize microorganisms, rather than an enzyme or inorganic molecule, as catalysts for converting the chemical energy of feedstock directly into electricity.

MFCs are bio-electrochemical reactors/ devices in which microbes oxidize fuel (substrates for microbial growth such as glucose, acetate, or wastewater) and produce electrons. Electrons produced by the microbes from these substrates are transferred to the anode and flown to the cathode linked by a conductive material containing a resistor, or operated under a load (producing electricity that runs a device). In most MFCs, the electrons that reach the cathode combine with the protons, which diffuse from the anode through a separator, and

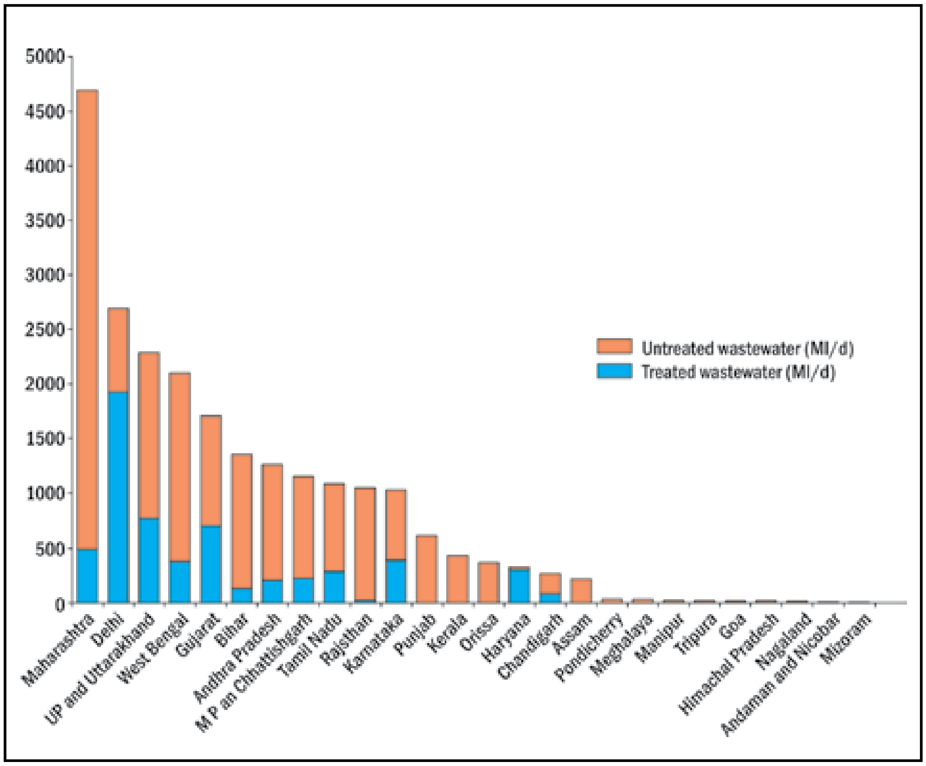

Figure 1 State-wise domestic waste generation and treatment (2001) [Source: Central Pollution Control Board, Ministry of Environment and Forests, Government of India]

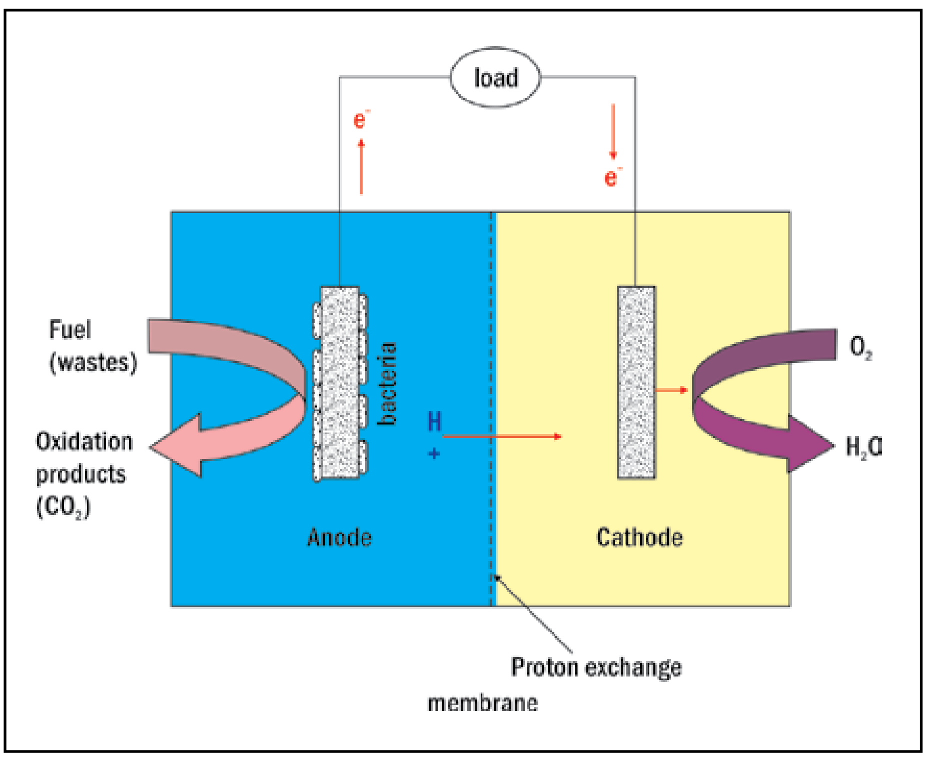

Figure 2 The design and working mechanism of an MFC. Glucose (the substrate) is metabolized by the bacteria, which then transfers the electron to the anode, from which it goes out to the external load and flows back into the cathode to combine with O_2 and the proton to form water.

oxygen provided from air; the resulting product is water.

Most microbial cells have cell walls and other surface structures which are electrically non-conductive. Chemical mediators, like neutral red, methylene blue, resorufin, and so on, can be used to facilitate the transfer of electrons from the microbial cells to the electrode, acting like an invisible 'wire' between the cell membrane and the electrode surface. But these can be toxic to the microbes in the long run. A few microbes have membrane-associated proteins that facilitate electron transfer, which is harvested by the anode, constituting a separate class of MFCs, termed 'mediator-less MFCs'. Shewanella and Geobacter sp. are well known in this genre, often speculated to use special tube-like protrusions from their cell membrane to the electrode surface, known as 'nanowires', to transfer electrons. These do not require any external chemical mediators. The microbes of this category usually form a thin film on the surface of the electrode, where they reside, metabolizing the fuel, and providing a steady flow of electron to the electrode.

In essence, MFCs are like any other bioreactors being run in batch, fed-batch, or continuous mode. Researches on the best combination of the microbe and anode chamber environment suggest best results with facultative anaerobes in an anaerobic environment, where the released electrons are not immediately taken up by the oxygen in the anode chamber itself. MFCs can be operated using pure cultures, but this restricts the range of fuels they can be operated on. For more complex fuels with a variety of carbon-sources, mixed cultures are more appropriate. They are generally obtained from

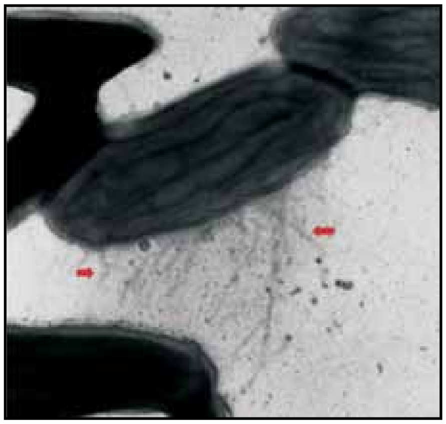

Figure 3 Microbial nanowires of Geobacter species

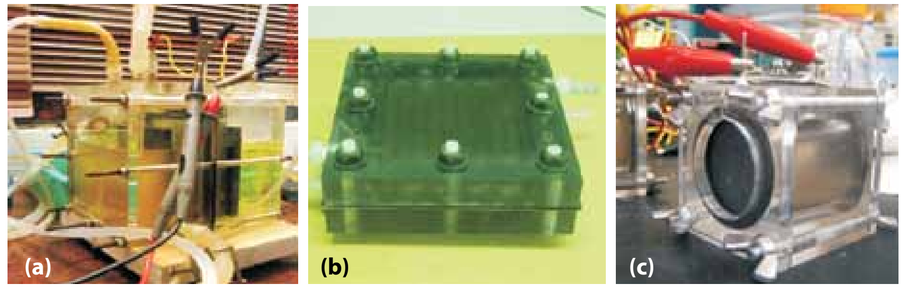

Figure 4. Different configurations of MFCs. (a) Semi-cubical two-chambered MFC (b) Flat-bed MFC (c) Air-cathode MFC

the microbial consortia local to that fuel environment.

MFCs are not new. The concept of microorganisms producing electricity was reported way back in 1911, but it did not create a stir in the scientific world back then. The interest resurfaced with the exploration of the use of microorganisms as catalysts in fuel cells from the 1970s. In the following years, there were reports of fuel cells with hydrogen-forming bacteria and microbial fuel cells treating domestic wastewater. However, it is only recently that MFCs with an enhanced power output have been developed which, for translation into an economically viable solution, is being optimized for minimal input cost. This research has been carried out to understand bacterial metabolism on electrodes, examine different substrates, select optimal electrode/catalyst materials, and optimize reactor configurations. Most of the research into optimizing power output from MFCs has focused on altering their designs in order to overcome electrochemical barriers to electron and proton flow, and to enhance the surface area and reactivity of the anode and cathode, and so on.

Based on the calorific content of glucose, a MFC can theoretically (at 100% efficiency during fermentation) deliver 3 kWh (kilowatt hour) for every kg of organic matter (dry weight) in one single fermentative step, as compared to that of 1 kWh of electricity and 2 kWh of heat per kg in hydrogen and biogas production by employing several process steps. This means that during fermentation in MFCs, hardly any energy is released under the form of external heat and all the biochemical energy in the waste can potentially be converted into electricity.

Though all of these sound good on paper, the dream of meeting the domestic electricity requirements using MFCs is still pretty far off from realization. Theoretical maximum potential for the biological metabolism process is in the range of 1.1–1.3V (volt). Although values of near 1V have been reported, the power density produced by the MFCs is still significantly lower than the theoretical limit, and nowhere close to those obtained with chemical fuel cells. Usage of expensive ion exchange membranes and catalysts (like Platinum) on electrodes escalate the cost of the MFC setup to exorbitant figures, and the cost-to-output ratio is, hence, far from acceptable for commercial usage.

But this has had no adverse impact on the quest to make this technology a viable source for the future. Research is on at a furious pace throughout the world, and cheaper and more readily available materials are being tested daily for their suitability side-by-side with materials with even more specificity for the microbes and fuel. Scaling up to pilot level is already on the way, and has even been implemented in a few locations on experimental basis.

Figure 5 Pilot scale MFC (Queensland, Australia)

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