HANS SHODH SUDHA , Vol. 1, Issue. 1, (2020) pp. 51-56

Microbial fuel cell: a potential technology for treatment of waste water and generation of bioelectricity

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ABSTRACT

Rapid urbanisation and industrialization has led to increase in the quantum of waste water generation in the country. Waste water can be generated from domestic, industrial and commercial sources. The municipal waste water contains majorly organic material and coliform bacteria. The waste water needs to be treated in Sewage Treatment Plants (STPs) before it is being released in a receiving water body or land. The principle for waste-water treatment is oxidation of organic matter resulting in reducing organic load,removing solid impurities and diseasecausing bacteria. Under conventional waste water treatment technologies digestion of waste water sludge is being used to generate biogas. A different approach is the use of microbial fuel cell technology for anaerobic digestion of organic matter and production of bio-electricity. This approach directly couples waste water treatment with electricity generation and has high energy efficiency as compared to conventional treatment technologies. Microbial Fuel Cell technology has been actively worked upon to realize its maximum potential. The continuous development of the technology is allowing greater power output. This paper outlines Microbial fuel Cell technology specifically with respect to waste water treatment covering the use, advantages, limitations and future prospects for development of the technology

KEYWORDS: microbial electrochemical technologies, waste conversion, bioenergy, hybrid technologies

1. INTRODUCTION

Release of large volume of untreated or partially treated waste water (sewage)is a major source of pollution of surface water bodies including rivers in the country. The increase in generation of waste water is linked to urbanization and industrial growth. The proportion of population residing in urban areas has increased from 27.8% in 2001 to 31.2 % in 2011. The number of towns has increased from 5,161 in 2001 to 7,935 in 2011 (Central Public Health & Environmental Engineering Organisation, 2013).The uncontrolled growth in urban areas has left many Indian cities deficient in infrastructure services such as water supply, sewerage, storm water drainage and solid waste management(Central Public Health & Environmental Engineering Organisation, 2013). The main source of waste water is from municipal, industrial and commercial sources. There is a gap in the generation and treatment of waste water in India. The total amount of sewage generation is 61754 million litre per day (MLD) of which only 22963 MLD gets treated where as 38791 MLD remains untreated (National status of waste water generation & treatment, 2019). There is also an increase in the generation of industrial wastewater and non-point dischargesdue agricultural activities.

The treatment of waste water is a priority area for reducing water pollution. Accordingly sewage treatment plants (STPs) are being built. These STPs work on the principle of removal of solid impurities and reduction of organic load through microbial digestion. Wastewater treatment consists of a combination of physical, chemical, and biological processes (Henry and Heinke, 2004). The microbial digestion of organic load in waste water is treated through technologies such as Activated Sludge

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Process, Trickling Filters, Rotating Biological Contactors, anaerobic processes, Up-flow Anaerobic Sludge Blanket (UASB) Process. These technologies in association with physical methods for separation and aeration form mainstay of sewage treatments (Kamyotra and Bhardwaj 2011). Tertiary treatment technologies are applied where there are refractory pollutants which need to be removed from waste water and the end use of the treated water.

The conventional technologies are energy intensive and generate large volume of sewage sludge. Sewage treatment is at the interface of civil and chemical process engineering and microbiology. Continued work is being carried out on the waste water technologies for (i) efficient removal of organic load, (ii) removing recalcitrant pollutants, (iii) making technologies energy efficient, (iv) reducing sludge volumes, and (v) generating maximum energy locked in the organic load of waste water. Many new wastewater treatment technologies including hybrid technologies are being developed and tested (Tee et al. 2016). Constructed wetlands using a consortium of plants and microbes for treatment of waste water is also gaining prominence and acceptance. Another technology being actively researched is that of Microbial Fuel cell technology.

The use of microbial fuel cells in waste treatment is developing with increase in current density and waste removal efficiency (Park and Zeikus, 2003; Rabaey et al. 2005a, 2005b). Nevertheless, several bottlenecks still exist, each requiring an appropriate development (Pham et al. 2006). Microbial Fuel Cell has been regarded as a promising technology for waste water treatment despite issues of scalability, low power density and high costs (Pham et al. 2006; Li and Sheng 2012; Li et al. 2017).

2. MICROBIAL FUEL CELL (MFC)

2A. Principle and Construction

Microbial fuel cells were first conceived in the 1900s by Michael Cressé Potter and the progressive development of the technology makes it relevant even today (Santoro et al. 2017). Microbial fuel cell (MFC) technology uses microorganisms to transform chemical energy of organic compounds including those found in waste water into bioelectricity (Angenent et al. 2004; Aelterman et al. 2008; Lovley 2008; Logan 2009).

A typical MFC consists of an anaerobic anode compartment and aerobic cathode compartment, which are separated by a selectively permeable cationic membrane. Microbes form a biofilm over the anode. The oxidation of organic substrate by the microbes present on the anode under anaerobic conditions results in generation of electrons and protons. The electrons move to the anode surfacefrom the biofilm by various means (Cao et al. 2019), Fromthe anode, the electrons move to cathode through the electrical circuit, while the protons migrate through the electrolyte across the selectively permeable cationic membrane to the cathode compartment (Logan and Regan 2006). Electrons and protons are consumed in the cathode by reduction of electron acceptor. The electrical power is harnessed by placing a load between the two electrode compartments.

The microbes are at the core of a MFC. The biofilm covering the anode is generally composed of bacterial species such as *Geobacter* sp., *Shewanella* sp., *Pseudomonas*sp.etc (Gorby et al. 2006; Pham et al. 2006; Nevin et al. 2008; Wang et al. 2013). These bacteria have two important qualities *viz.* (i) ability to digest and degrade organic substrate from variety of sources, and (ii) ability to transfer the electrons produced by the digestion of waste to the anode (Cao et al. 2019).

The bacterial biofilms secrete external intermediary compounds such as humic acids, methylene blue which are called as electron shuttles and transfer electrons generated to the anode surface (Rabaey et al. 2004). These bacterial also develop appendages or pili on the surface known as nanowires (Bond and Lovley 2003). These nanowires assist in carrying electrons to anode surface (Reguera et al. 2006). Sometimes consortium of bacteria isolated from the sewage sludge or waste water are also employed in MFC (Behera and Ghangerkar, 2009; Lu et al. 2009; Cao et al. 2019).

A range of organic substrates can be used for anaerobic digestion by the microbes in bioelectricity production. These range from simple molecules such as glucose, acetate, propionate and butyrate (Ahn and Logan 2010) to complex substrates like waste sludge, fruit and vegetable wastes(Ge et al. 2013; Choi &Ahn 2015). Domestic wastewater can also be used for continuous electricity production (Choi &Ahn 2013).

The microbial fuel cell can be single chamber, double chamber or stacked cells (Aelterman et al. 2006, Chaturvedi and Verma 2016). The architecture of the anode and cathode also influence the current density (Zhuwei et al. 2007). Current density is the bioelectricity generated per unit area of the electrode. The cationic membrane is an important component of the MFC separating of the anode and cathode chambers. This membrane is called semi permeable because it allows only H^+ ions or the protons to pass through and does not allow any other substance including electrons to pass through it. Several different types of materials such as nylon fibers, glass fibres etc. have been employedin construction of the membrane (Chae et al. 2007).

The level of biofilm formation on anode and the surface area determine the level of electricity generated. The anode material determines effectiveness of bacterial adhesion and efficiency ofelectron transfer to the cathode (Zhuwei et al. 2007). The **c**athode in the MFC reduces oxygen to produce water. Therefore, the cathode material need to have catalytic properties for oxygen reduction. Platinised carbon electrodes are commonly employed as oxygen-reducing cathodes in MFCs. The practical use of Pt-based cathodes in field situations is limited due to their high cost and degradation of the Pt catalytic surface of cathode in field situations. The mechanism of oxidation and reduction in the MFC is not clearly worked out. An example using glucose as the substrate is as follows (Pham et al. 2006):

Anode: $C_6H_{12}O_6 + 6\ H_2O \rightarrow 6\ CO_2 + 24H^+ + 24e^-$

Cathode: $24\ H^+ + 24\ e^- + 6\ O_2 \rightarrow 12\ H_2O$

The total reaction is as follows:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Electrical energy

2B. Advantages and limitations

Microbial Fuel Cell enables recovery of energy directly on breakdown of organic waste in wastewater, while limiting both the energy input and the excess sludge production (Rabaey and Verstraete 2005). A major limiting factor in microbial fuel cells is the current density, which is affected by the organic substrate used in the microbial fuel, the micro-organisms present, architecture of the anode and cathode, shape of fuel cell. Another important limitation of the technology is scaling-up to commercial level (Chaturvedi and Verma 2016). Research has been undertaken to improve the current density of the microbial fuel and make them scalable to real-life practical applications. Improvements have taken place with respect to increase in current densityand scale.

3. WASTE WATER TREATMENT AND BIOELECTRICITY GENERATION

In the microbial fuel cell, oxidation of organic and in some cases inorganic substrates present in urban sewage, agricultural, dairy, food and industrial wastewaters lead to direct generation of bioelectricity (Gude 2016). This treatment of waste water through microbial fuel cell reduces sludge production and is more energy efficient as compared to conventional waste water treatment systems (Logan 2008; Logan and Rabaey2012; Zhang et al. 2013). The management of sludge is a major concern in conventional waste water treatment while sludge production is less in waste treatment though MFC (Gude, 2016)

MFCs have been not only shown to treat municipal wastewaters which have low Biological Oxygen Demand (BOD) value of less than 300 mg/L but also waste waters with high BOD values of more 2000 mg/L (waste from food processing industry, dairy and distillery waste etc.). Many studies have been carried out on the bioelectricity generation using different types of waste waters. The different types of waste water included agricultural waste water, brewery and bakery waste, dairy waste water, distillery waste water, pulp and paper waste water and sewage sludge. The bioelectricity reported varied from 10 mA/m^2 to 125 mA/m^2 (Nimje et al., 2012;Samsudeen et al. 2015; Velasquez et al. 2011; Yuan et al. 2012), higher bioelectricity generation have also been reported (Cao et al. 2019).

In order to increase the bioelectricity generation output extensive research has been carried out on the electrode material and design. Development of air cathode has shown to improve efficiency of the MFC (Di Lorenzo et al. 2014). The air-cathodes are being developed as alternative to traditional Pt coated cathodes (Tharali et al.2016). Research is also being carried out on the bio-anode in the MFC to enhance the waste degradation and electricity generation. Genetic engineering is also being employed to have microbial strains which lead to enhanced bioelectricity generation at bioanode (Yong et al., 2014). The development of MFC needs to move towards reducing cost, stabilizing energy production and being able to adapt to different categories of wastes with reasonable waste degradation efficiency.

4. MICROBIAL FUEL CELL CENTRED HYBRID TECHNOLOGIES

Microbial Fuel Cell centred hybrid technologies are recently being developed for the treatment of waste water on sustainable basis (Wen Wei Li et al. 2017). Recently, efforts have been made to integrate MFC with other technologies to create hybrid systems. One such system is constructed wetland-microbial fuel cells (CW-MFC). Constructed wetland has been used for treatment of waste water. The constructed wetland utilizes consortium of plants and microbes for reducing organic load of waste water and has air water-interface and anaerobic zone whereas microbial fuel cell has aerobic and anaerobic chamber for waste water treatment and generation of bioelectricity. Studies have shown that this hybrid technology improves the removal of Chemical Oxygen Demand (Doherty et al 2015) and gives higher power density (Fang et al 2013). Scaling up of such hybrid system can be a way forward for more efficient waste water management.

Another hybrid system includes membrane bioreactor technology (MBR) with microbial fuel cell (MFC)(Wang Yong-Peng et al. 2012). This hybrid system allows higher bioelectricity generation by MFC as well asreduction in membrane fouling with significant increase in efficiency of denitrification in the bioreactor (Liu, W. et al 2018).

The inefficiency of nutrient removal by MFC technology can be overcome by integrating it with an algal system and the effluent from MFC can be treated with algae to remove the residual nutrients and improve water quality (Wen Wei Li et al. 2017). The hybrid system of MFC with algal system has been shown to remove carbon, nitrogen and phosphorus along with higher bioelectricity generation (Zhang et al. 2011).

5. CONCLUSION

Microbial Fuel Cell technology holds promise for sustainable waste water treatment. Research on MFC needs to focus on field level implementation with reduction of cost for development. The use of MFC based hybrid system needs to developed further. MFC is a potential technology for treating the rising quantum of waste water generation in future in a sustainable manner through use of interdisciplinary approaches of microbiology, biotechnology, electrochemistry and engineering.

6. Acknowledgements

Author acknowledges Principal, Hansraj College for constant support, guidance and motivation. The valuable suggestions provided by the anonymous reviewer for improvement of the manuscript is acknowledged.

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