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Effectiveness of microbial fuel cell in sustainable energy production during wastewater treatment: A mini review

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Abstract
In recent years microbial fuel cells (MFCs) got much attention by developed countries as an alternate source of energy. Microbial Fuel Cells (MFCs) are alternate source of clean energy which combines wastewater treatment without emission of Greenhouse gases. Microbial activity is utilized by MFC for generation of low magnitude current, microbes consumes hydrocarbons present in wastewater as carbon source. This paper deals with basic idea about the mechanism of wastewater treatment, energy production and key components of MFCs application.

Keywords: Wastewater, Microbial Fuel Cell (MFC), Power generation

Introduction

In the present scenario with the growing population, demand for energy is also growing day by day. Energy production is done from three types of fuels as fossil fuels, unconventional energy sources and nuclear fuels. Fossil fuel has problem of greenhouse gas emission as (SO_x, NO_x, CO_2 and CO) in addition for power production and polluting atmosphere severely and leading to the adverse effects on human health [4].

On the other hand developed nations have started paying attention towards new ways of energy generation as sustainable energy solution with lesser or no emissions as wind energy, solar energy, wave and tidal energy. Later on these technologies were joined by the fuel cell which uses microbial action for electron transfer which gives the flow of current through the external circuit connected with the fuel cells [2] with greatest benefits as no release of greenhouse gases, higher efficacy and static mechanism of the system [5]. On the other hand these fuel cells (FCs) have major drawback of greater biomass creation and high initial cost [4, 5]. Utilization of MFCs have extended as researchers have done more study on application, this led to a system which combines biological activity and hence leads to redox reaction for power generation. Adding microbes to MFCs work likes a biocatalyst for the electrochemical reactions which are taking place into anode and cathode chambers. MFCs retain the difference with traditional fuel cell by running on relatively higher temperature range of 15–45 ºC with neutral pH [1].

Among types of FCs microbial fuel cell (MFC) changes chemical energy into electrical energy by microbial action under absence of oxygen. Possibly electrical current was brought into light by Potter in 1911. On later stages till now it got several advances over passage of time [4]. Substrate plays a very crucial role in MFCs as it works as a carbon source for bacteria to sustain, concentration and chemical composition of the compound present will decide the extent up to which bacteria will consume the substrate. Substrate is the reason for biological film creation on the anode and power roduction capacity of MFCs. Other than the organic substrates usage sulphides, nitrates, and sulphates removal is also being done these days [3].

MFCs as shown in the fig are made up of two cavities comprising one electrode each which are parted by a proton exchange membrane. Every MFC has two electrodes, as cathode and anode. Reaction taking place on any electrode help to recognition anode and cathode, as oxidation takes place on anode and reduction reaction takes place on cathode. Microorganisms in the anode oxidize the organic substrate which produces electron and proton in return. Proton moves toward cathode by penetrating PEM in the MFC while electron travels toward anode through the external connected circuit. Electrons and protons react with each other in cathode chamber with instantaneous conversion of oxygen into water [4]. At cathode, reduction of oxygen into water remains the major issue due to its low reaction kinetics and high potential which are to be overcome. Lesser energy generation is another concern in MFCs as compared to the chemical fuel cell. Researchers have developed hybrid system to deal with this problem usage of MFCs as super capacitors [1].

Microorganism plays important role in detaching the organics and produces proton and electron in the anode slot [4]. The reactions are as follows through which MFCs run.

At Anode:

$$Hydrocarbons + H_2O \rightarrow CO_2 + H^+ + e^-$$

At Cathode:

$$O_2 + H^+ + e^- \rightarrow CO_2 + H^+ + e^-$$

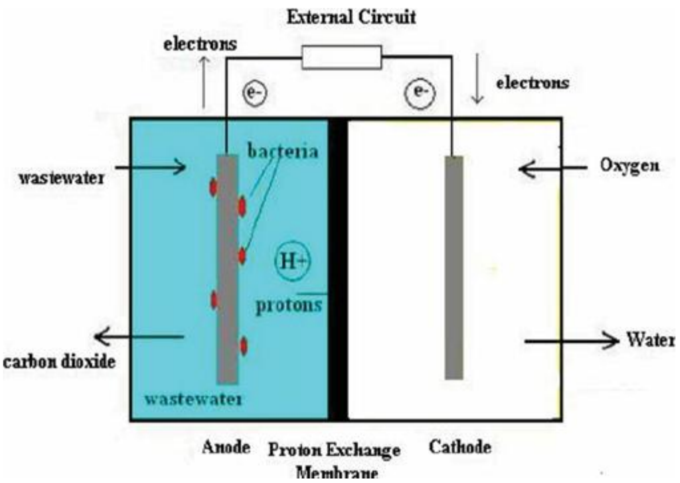

Fig 1: Schematic Diagram of a typical MFC

Study on different types of organic compounds are being received through municipal and industrial wastewater have been carried out for wastewater contaminants degradation followed by power generation through MFCs evidencing a new source of non-renewable energy source with pollutant decomposition [4].Due to microbial action oxygen is formed in the anode slot and this oxygen hampers the activity of microbes giving a decline to the electricity production. Microbes could be divided from oxygen produced, by laying a membrane between two distinct cavities which also let the charges pass through it from anode slot where microbes raise to the cathode cavity where electrons react with oxygen to give H_2O. Based on the transfer of charges especially proton MFCs could be categorizes as i) MFCs with mediator and ii) MFCs without mediator [2, 4]

MFCs classification could be done on the basis of various factors as power cell voltage, density biological parameters and substrate loading rate. MFCs efficacy depends on the factors which are as follows:

- Supply and consumption of oxygen in cathode slot
- Substrate oxidation in anode slot
- PEM porousness
- Electron displacement from anode cavity to anode surface [1]

MFCs got various advances over the passage of time but the major challenges in full-scale application of MFCs are i) Concentration of the substrate if increased more than a particular value for a particular cell then the power production will be stalled and ii) power yield is lesser from it because of high inner resistance. Due to which most of the power is spent in driving the charges within the cell through PEM. Higher inner resistance is found because of PEM which parts the anode and cathode compartment within MFCs. If PEM is absent then inner resistance will drop down and power production could be elevated but it's just a proposed theory [1].

Another set of problem starts at full scale application when it has to deal with real time problems, cases and theoretical proposed solutions are discussed. Starting discussion from anode chamber, studies over time on MFCs have made some advancement in dealing with MFCs applications problems. Microbial activity kinetics and bacteria interaction with electrode is not being understood entirely. Understanding for electron transfer mechanism between bacteria and electrode is not very well explained. Bacteria attraction towards the electrodes, colony formation on anode surface, interaction and interspecies cooperation and development of biofilm on anode surface is much complex issues because of involvement of bio-electrochemistry [1].

MFC Technology Contribution in Wastewater Treatment

Wastewater handling is basic necessity of present scenario for meeting water demand of growing population. Wastewater is full of nutrients and organics and its treatment consumes energy and hence it becomes expensive for operation and maintenance purposes. MFCs prove to be quite distinctive technology which ensures wastewater handling with simultaneous energy production. It uses organics present in wastewater being treated through active bacteria, present anaerobically, generating power with good quality effluents, which could be used through redox reaction in MFCs. It has edge over conventional energy without greenhouse gases discharge leading towards greener energy generation by relatively lesser consumption of resources. It has advantages with relatively bigger disadvantages of high initial cost and greater implementation problem in real time problems. Over years researches have done lots of work for improvement and still there are several issues which are still needed to be improved.

Power Generation Capacity

Domestic wastewater has purely hydrocarbons which are easier for bacteria to decompose as compared to the other kinds of wastewater such as industrial wastewater which have complex structure hydrocarbons to decompose as compared to the domestic wastewater hydrocarbons. As compared to the household effluents brewery and food processing industries produces effluent of same structured organics with higher concentrations which becomes much easier for alternate energy generation using MFCs. Theoretically it is viable process through which wastewater treatment is done and simultaneously energy production is found but with some losses, making it practically applicable. MFCs energy balance analysis could be done through electricity generation and consumption through the external circuit connected to it [5, 6].

The benefit of MFCs over other existing technologies is due to the efficacy of it generating electricity from organic matters present in wastewater. This energy generation is cleaner unlikely to the anaerobic digestion (AD) process which produces CH_4 or H_2 and incineration of these gases gives energy leading to the gaseous discharges. MFCs work at ambient temperature for continuous extraction of energy consuming lesser amount of energy as compared to the anaerobic digesters. MFCs generate normalized energy recovery (NER) of 0.026 kWh/m^3 of wastewater or 0.080 kWh/kg of chemical oxygen demand (COD) from municipal wastewater. It also reduces the cost of running by lesser amount of sludge production and aeration required as well. Energy consumption for MFCs is reported to be 0.024kW or 0.076 kWh/kg of COD in average, required for reactor feeding and mixing purposes leading towards a positive energy balance in domestic wastewater theoretically [5].

Maximum outputs derived from MFCs are much lesser than the mark of 1 kW/m^3 out of 10 kg/m^3d of COD for a real time energy efficient application. Variety of wastewater received from several sources adds up into hurdle due to efficiency for full scale application with lesser power density reached because of efficiency depletion due to variation in characteristics of wastewater received. Hydraulics and configuration improvement can improve energy extraction with decentralized treatment scheme [5].

Effluents with Positive Environmental Impact

Any wastewater treatment technology would be said sustainable if it produces effluent at standards of wastewater so that it could be reuse or reclaimed. Wastewater contamination level should be brought down to meet acceptable environmental standards, from liquid to solid and atmosphere as well [5].

MFCs show better removal through microbial decom-position of many hydrocarbons including those even which are hard to decompose biologically. This better performance is due to the anaerobic and partially aerobic condition existing together. Researchers have found MFCs removal efficiency to be good for hydrocarbons, nutrients, sulphur compounds and metals too with concentration limitation of COD< 20mg/l. As compared to the fossil fuel based power production it produces lesser CO_2 due to controlling reaction on cathode. Comparison of MFCs and activated sludge process, amount of sludge produced it is found to be 0.4–0.8 g-VSS/ g COD and 0.1 g VSS/ g COD respectively, leading to the curbed solids handling costs in MFCs. Hence secondary pollution chances gets reduced which are associated with sludge treatment and disposal. In MFCs biocatalyst, electrodes and PEM is being used which is again fossil fuel based products which might have negative environmental impacts so for envisaging environmental impacts of MFCs in wastewater treatment much stiff evaluation is needed [5].

Efficient Operation

Full scale application of MFCs for the treatment process should have virtues such as sustainable, vigorous and serviceable with steady operation curbing resources for operation and maintenance. A biofilm is developed on electrodes by bacteria in MFCs which provides resistance towards toxic contaminants and fluctuations such as pH, temperature and organics concentration. MFCs have advantage that real time accountable monitoring and control through electrochemical reactions making it a vigorous technology. Many MFCs have been found to be treating wastewater on both pilot and bench scale as well [5].

Several studies show that MFCs performance declines with the passage of time if run for the longer time operation. Maintaining the controlling bacteria in MFCs in wastewater with changing environmental conditions such as various ions production, different ions interaction etc. becomes big task. Electrodes also degrade with the continuous operation of MFCs hurting the performance on longer time run. Electrode degradation takes place often resulting into fouling, corrosion, clogging of electrode material and catalyst deactivation. Over the time period fouling takes place and keeps increasing. All these key factors` problem have been addressed but still these solution are far away from proving to be effective for full scale application [5].

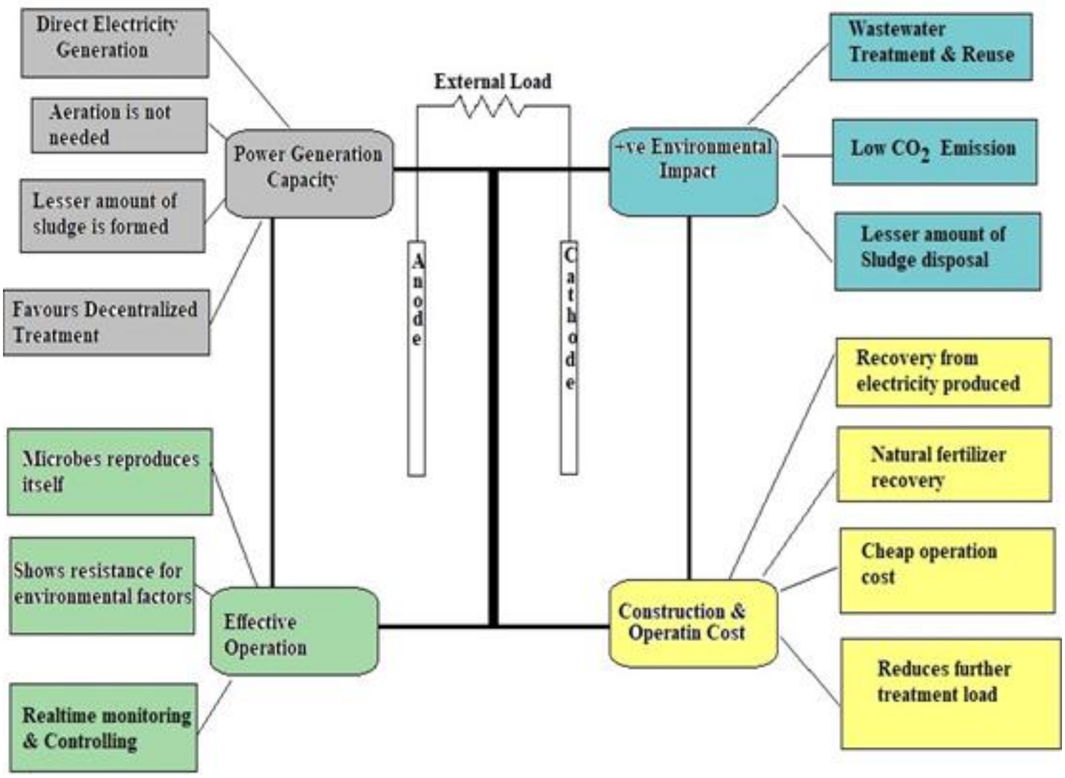

Fig 2: Benefits opportunity of a typical MFC

Construction and operational Cost

Initial cost for MFCs installation, operation and maintenance, chemicals and materials being higher becomes less applicable. Although these economic challenges involved could be overcome through public private partnership (PPP). Additional revenue generated through power generation and natural fertilizer formed in the form of sludge, could recover some of the cost involved earlier [1].

Theoretically MFCs gives NER approximately 0.004 kWh/kg COD and the sludge produced as aftermath of hydrocarbons decomposed works as a valuable natural fertilizer. If compared with ASP which consumes energy with the rate of 0.6 kWh/ kg COD giving rises to the operational cost of the treatment facility. Capital cost is higher in MFCs installation because of costly components such as PEM separator and electrodes encompassing carrier material, catalyst and current collector. Therefore capital cost is proving to be the biggest hurdle in MFC technology commercialization [5].

Conclusion

In this paper we suggest MFC usage because with the rising problem of wastewater generation and meeting rising demand of energy and potable water is necessary because this technology has positive environmental impact with lesser amount of solids production with good removal efficiency. This technology is a bit complex but still it will be promising if by further studies on this technology it could be made economical.

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