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Methods To Enhance The Efficiency Of The Microbial Fuel Cells (MFCs) - Production Of Electricity Via Wastewater Treatment

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Abstract: The exponential increase in the population has led to a waste management crisis. All over the world experts are working hard to develop a system that can efficiently eradicate this adversity. One such efficient method for the treatment of wastewater is via (Microbial fuel cell) MFC. MFC is a low-power generating renewable energy source. It aids in generating clean electricity by treating wastewater. But this technology is not entirely exclusive, it has its drawbacks such as the generation of low voltage current, high production cost, lower power output, and low energy conversion efficiency. This increases the need to improve the MFC to enhance electricity generation and wastewater treatment. Modification of various parts in the MFC system can aid to generate a positive result. The paper illustrates the probable methods to increase the efficiency of MFC for the generation of electricity.

Index Terms **- MFC, wastewater treatment, electricity generation, enhancement, development.**

I. Introduction

Wastewater is comprised of contaminated with human waste, food scraps, chemicals, etc. As per United Nations (UN), over 80% of the world's wastewater flows back into the environment without being treated or reused. Improper wastewater management is a leading cause of many diseases due to the release of bad odour, improper treatment of water, the annihilation of farmlands etc. Hence, there is an increasing need for the appropriate treatment of wastewater. Another crucial need of the hour is an alternative resource for the generation of electricity. The alarming depletion in the level of fossil fuels is a global crisis. Nearly 60 to 70 per cent of our electricity comes from fossil fuels. With the ever-increasing demand for these fossil fuels, these resources will soon be exhausted. Electricity produced via wastewater treatment can be a plausible solution. This can be done with the help of MFC.

MFC are bioelectrochemical devices that convert chemical energy in organic or inorganic compounds into the electric current with the help of microorganisms. Various types of MFCs are currently available, which include double-chamber MFC, single-chamber MFC, stacked MFC, up-flow MFC, etc. Apart from wastewater treatment and electricity generation, MFC also works as a hydrogen producer and biosensing. (Singh & Kalia, 2017) Though MFC aids in generating clean electricity and wastewater treatment, it has a lot of drawbacks like it generates low voltage (It can generate a maximum of 1.1 V) current owing to several losses, high production cost, lower power output, and low energy conversion efficiency. (Clauwaert, Peter et al. 2008) This increases the need to improve the MFC to enhance electricity generation and wastewater treatment. Modification of various parts of MFC can aid in increasing electricity generation. (Jung et al., 2018)

II. Working principle of MFCs

MFC aids in the generation of direct electricity from different sources of wastewater. This technology combines the process of electricity generation with wastewater treatment by using organic matter. Organic matters which act as a substrate have proven to combine the actual treatment of waste streams with electricity generation. MFC also aids in the measurement of the organic carbon in the wastewater. MFC uses microorganisms as biocatalysts. (Vineetha & Shibu, 2013) The bacteria are placed on the anode which decomposes organic matter in the wastewater. The electrons generated via this process flow towards the cathode through an external circuit and aids in the generation of electricity when the protons diffuse from the anode to the cathode. The metabolizes of the substrate via the microbes convert chemical energy into electrical energy. (Abourached et al., 2016)

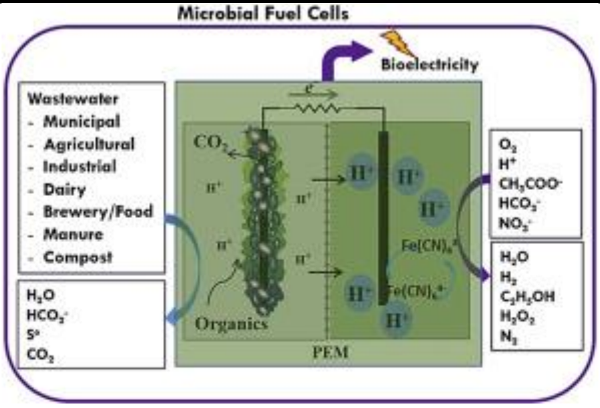

Figure 1 - The figure illustrates the wastewater treatment in MFC for the generation of electricity. (Gude, 2016)

III. METHODS TO ENHANCE MFCS

1.1 Type and source of substrate

Various substrates are used to generate electricity through MFC. However, using organic matter has proven to combine the actual treatment of waste streams with electricity generation. Research has proven that the type of substrate fed to an MFC impact the structure and composition of the microbial community, which subsequently influenced the efficiency of the MFCs. (Zhang et al., 2011) For example, Firmicutes was predominant in glucose-fed or propionate-fed MFCs.

MFCs enriched with **acetate, glucose, sucrose, etc** are efficient in generating stable electricity. The amount of electricity generation varies with the substrate and the mixture of organic matter in the wastewater will be used by the microbes as a source of energy. This mixture can be obtained from various sources such as the chocolate industry, meat processing industries, municipal wastewater, etc. (Prasad & Panda, 2018) Elucidating the response of electricity generation and microbial community composition to substrate changes will assist in the optimization of the MFC technology, for practical applications with varying organic waste streams. (Mohanakrishna, G et al., 2010)

Table 1 – The list of major substrates that can enhance the electricity generation of MFC.

Type of substrate	Concentration	Source of inoculum	Micro-organisms	Reference
Acetate	1 g/L	Pre-acclimated bacteria from MFC	Geobacter metallireducens, Geobacter sulfurreducens	(Min et al., 2005; Logan et al., 2007 ; Pant et al., 2010; Masih & Devasahayam, 2014)
Glucose	6.7 Mm	Mixed bacterial culture maintained on sodium acetate for 1 year (Rhodococcus and Paracoccus)	Actinobacillus succinogenes, Escherichia coli, Desulfovibrio desulfuricans	(Catal et al., 2008a; Park and Zeikus 1999; Park and Zeikus, 2000; Schroder et al., 2003; Ieropoulos et al., 2005; Grzebyk and Pozniak, 2005; Ringeisen et al., 2006; Pant et al., 2010; Masih & Devasahayam, 2014)
Starch	10 g/L	Pure culture of Clostridium butyricum	Clostridium butyricum	(Niessen et al., 2004; Pant et al., 2010)
Sucrose	2674 mg/L	Anaerobic sludge from septic tank	Escherichia coli, Desulfovibrio desulfuricans	(Schroder et al., 2003; Ieropoulos et al., 2005., Grzebyk and Pozniak, 2005; Vega and Fernandez, 1987; Park et al., 1997;

				Pant et al., 2010; Masih & Devasahayam, 2014)
Lactate	18 mM	Pure culture of S. oneidensis MR- 1	S. oneidensis MR- 1	(Manohar and Mansfeld 2009; Pant et al., 2010)

1.2 Reactors

Using wastewater to generate electricity through MFC has various technical difficulties. Research shows that **Sequencing batch reactor (SBR)** combined with MFC has high potential, flexibility and high adaptability to automatic control. (Liu et al., 2011)The biocathode MFCs have greater sustainability than the abiotic cathode system. In an MFC–SBR coupled system, SBR serves as a biocathode chamber of an MFC. The COD loading distribution has a significant effect on the performance of the **MFC–SBR system**. To improve wastewater treatment and electricity generation, we can increase COD uptake in the MFC with prolonged HRT. The COD removal rate increases with an increase in HRT; hence the density increases and maximum voltage is generated. (Wang et al., 2014)

Anaerobic digestion is used in the treatment of sludge because it consumes lower energy, smaller amounts of solids generated, lower nutrient requirement, and potential energy recovery from the produced biogas (methane, CO2, ammonia, etc). Microbial fuel cells (MFCs) can convert organic matter into electricity. MFCs can convert numerous kinds of organic matter into electricity in an oxygen-free environment with the help of interactions from various trophic groups of prokaryotes. (Carter, 1964) For example, simple carbohydrates, such as glucose, acetate and butyrate, and complex organic compounds such as those in swine wastewater. It has also been proven that **sonication has proven to be the most efficient way to liquefy sludge.** (Jiang, Junqiu et al., 2009)

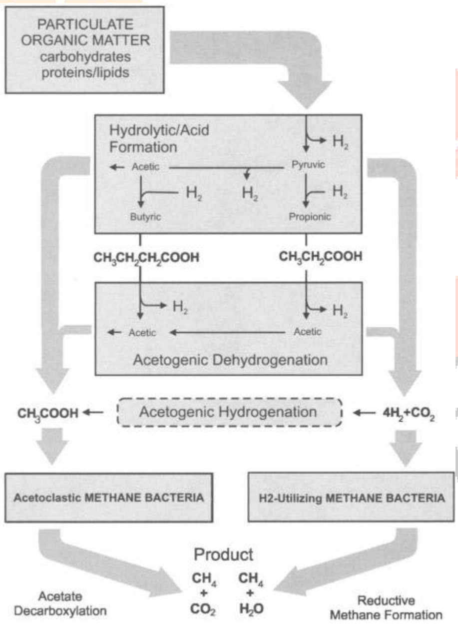

Figure 2 – Conversation of organic matter into biogas (methane and CO2) during anaerobic digestion. (Woodard & Curran, 2006)

1.3 Fuel cells

The voltage of MFC doesn't exceed a theoretical open-circuit voltage. So, their practical application is very limited. **The voltage can be increased by connecting the fuel cells in series or parallel.** (Zhuang, Li et al., 2012) The use of **plug-flow microbial fuel cells (PF-MFC)** can aid in improving power generation. The driving force for the PF-MFC is the gradient of organic substrate concentration. While complete mixing microbial fuel cell **(CM-MFC) is more efficient in the removal of COD**. (Karra, Udayarka et al. 2013)

The usage of **ferricyanide catholyte** could elevate power generation through the MFC. The use of **H2** along with consortia as the anodic biocatalyst can enrich the production of the MFC. **Selectively enriched consortia and fuel cell** configurations will favour the generation of electricity. (Venkata Mohan, S. et al., 2008)

The use of **Tungsten oxide** as the electrocatalyst improves power generation by nearly 5%. This suggests that the WO3 can be used as the electrocatalyst in the MFC instead of platinum. This will also decrease the cost and increase the efficiency of the MFC. (Das et al., 2020)

Table 2 - Materials that can be used in the components of the MFC.

Components	Material	Reference
Anode	H2 along with consortia, graphite, reticulated vitreous carbon (RVC)	(Venkata Mohan, S. et al., 2008; Du et al., 2007)
Cathode	**ferricyanide catholyte, graphite, RVC**	(Venkata Mohan, S. et al., 2008; Du et al., 2007)
Electrolyte	**Tungsten oxide, Platinum, polyaniline**	(Das et al., 2020; Du et al., 2007)
Proton exchange system	**Polymers like Nafion, ultex, polyethylene, etc. and salt-bridge**	(Basene & Gothalwal, 2019; Du et al., 2007)

1.4 Using graphite and aluminium electrode

Research shows that MFCs that have graphite and aluminium **electrodes of 64 cm2 produced a greater voltage, electric current, and conductivity,** with peak values of 0.22 volts, 0.08 milliamperes, and 1.05 milli siemens per cent, respectively. Also, the pH of the substrate in each MFC exhibited a moderate degree of consistency, with values ranging from 7.39 to 6.49. Additionally, efficiency was reached in the removal of the concentration of COD by 70%, Thermotolerant Coliforms were reduced by 73%, and Turbidity was reduced by 36%. (AgÜero QuiÑones et al., 2023)

1.5 Installation of MFC in the treatment system

MFC can be used to modify the secondary waste and sludge treatment processes in a biological treatment system. This can be done by **replacing the AS system or the filters (as MFC is more efficient in the removal of the biofilm), using MFC as a membrane bioreactor, using sediment MFC, or fabricating MFC to remove heavy metals and nutrients.** These replacements will not only increase power generation but will also reduce waste aeration, decrease solids production, and is a potential for odour control. (Tsekouras et al., 2022)

Industrial-size waste treatment via MFC involves the treatment of a larger quantity of waste. Using methods such as **increasing the size of each chamber, and using individual MFC in stacks can help in the development of MFC system.** (Tsekouras et al., 2022)

IV. Discussion

With the increase in energy demand and the decrease in the availability of fossil fuels, the need for an alternative source of energy is increasing. (Pandey, Prashant et al.,2016) Additionally, there is a rapid increase in the amount of waste generated due to urbanization worldwide. The MFC acts as a potential solution for this crisis. Microbes produce energy while converting the organic substance into CO2 and water. MFC uses this for its work. In the anode, microbes undergo oxidation and, in the cathode, they are under reduction. The electrodes are separated by the proton or cation exchanger membrane, and an electric circuit with an external resistor interconnects the electrodes. (Rabaey et al., 2005) Substrates from molasses, biodiesel, and cellulose wastewater agricultural, brewery, domestic, and food wastewaters have a high potential for bioelectricity generation. Efficient alteration of the system according to the substrate used will help in the enhancement of electricity generated.

V. Conclusion

With the increase in wastewater generation, there is a need for a system that can efficiently convert the waste into a usable form of energy which is also not harmful to the environment. MFC can be a revolutionary development for the treatment of wastewater and the generation of electricity. It can be an alternative source of renewable energy. MFC has the potential to work on various substrates and has the potential to remodel the system based on the substrate. But the primary disadvantage of the system is the low amount of electricity generation. The system requires various developments to improve the quality and quantity of electricity generation. Identification of the right type of substrate, fuel cell, reactor, etc can help in the enhancement of the MFC.

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VII. Conflict of Interest

The authors declare no conflict of interest.

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