Recent advances of microbial fuel cell and its application: a brief review

Naveen,[a] Amit Kumar Sharma,[a,b,*]

[a]*Department of Chemistry, University Institute of Sciences, Chandigarh University, Mohali-140413, Punjab, India*
[b]*University Centre for Research & Development, Chandigarh University, Mohali-140413, Punjab, India*

Email: nahlawat110@gmail.com, amit.e14600@cumail.in

Abstract

Microbial fuel cells, often known as MFCs, are an intriguing device that are capable of producing energy by utilizing the metabolic processes of microbes instead of traditional fuel cells. Because of their capacity to generate energy and effectively eradicate pollutants by converting organic matter that is present in wastewater, MFCs have the potential to be utilized in wastewater treatment plants by virtue of their ability to generate electricity. An oxidation process is carried out by the microorganisms that are present in the anode electrode. This process results in the breakdown of a variety of contaminants. As a consequence of this procedure, electrons are generated and then transported to the cathode compartment by means of an electrical circuit. Additionally, as a byproduct of this process, filtered water is produced, which can either be recycled or returned to the natural environment. By leveraging the power of organic materials in wastewater to generate energy, microfluidic cells (MFCs) provide wastewater treatment plants an option that is more efficient at producing electricity. Multi-fuel combustion engines (MFCs) installed in wastewater treatment plants have the potential to improve energy efficiency, reduce operational expenses, and reduce greenhouse gas emissions, all of which are important factors in achieving sustainability in wastewater treatment operations. The purpose of this study is to provide a brief review of MFCs, including their structure, kinds, construction materials, membrane, working mechanism, and the major aspects that effect their performance in a variety of scenarios. This review investigates the use of this technology in environmentally responsible wastewater treatment and the difficulties that are associated with its widespread implementation.

Keywords: Microbial fuel, electricity, energy, microfluidic cell, micro fuel combustion engine

Introduction

Alternative energy sources are in high demand, which is a fact that is well understood. As a result of the pollution that they generate and the limited amount that is available, the existing reliance on fossil fuels cannot be maintained permanently (1). It is highly improbable that any one solution will be able to replace fossil fuels, even though substantial research is being conducted on a variety of energy options (2). Because of this, it is highly likely that a number of different options will be required in order to generate energy for a specific task in a manner that is distinct from one another depending on the setting (3). An enormous amount of interest has been generated as a result of the discovery that microorganisms possess the capacity to generate power from waste and renewable biomass (4).

A surge of interest and a considerable increase in the number of publications in the field of MFC research have been triggered as a result of the discovering that microbial metabolism can create energy through an electrical current (5). However, in order for these systems to be practicable for widespread usage, major advancements are required. These systems have a big potential to provide us with sustainable energy. Batteries, fuel cells, and supercapacitors are examples of electrochemical systems that are already highly intricate; nevertheless, the addition of living creatures that are responsible for driving electrochemical processes makes these systems far more difficult than they currently are (6). The following are the primary distinctions between MFCs and conventional low-temperature fuel cells: the use of biotic electrocatalysts at the anode; a wider temperature range of 15 degrees Celsius to 45 degrees Celsius with optimal conditions close to ambient levels; neutral pH working conditions; the use of complex biomass as anodic fuel (often waste or effluent); and a promising moderate environmental impact as evaluated through life cycle analysis (7). Over time, researchers and developers have explored and developed a multitude of concepts and advancements in practical application. It is understood the mechanics of electron transfer, constructed successful bio-electrocatalytic interfaces, and developed new electrode materials that are both inexpensive and long-lasting (8). A significant amount of work has been accomplished in these areas. However, further work is necessary to fully utilize MFCs in the industrial sector, as there is still gap for improvement.

According to (9), microbial fuel cells (MFCs) have garnered recognition as a promising and creative technology for the conservation of energy and the treatment of wastewater, hence addressing concerns related to the environment. Biosensors, biohydrogen production, and in-situ power sources are utilized for bioremediation and wastewater treatment in distant places (10). These innovations are especially relevant in these regions since they are used for bioremediation and wastewater treatment.

Wastewater is increasingly gaining recognition as a valuable resource for water reuse and energy savings. On the other hand, traditional treatment methods, such as conventional aerobic activated sludge (CAAS), require a considerable amount of energy and result in the production of residuals (11). According to (12), they are also incapable of capturing and making use of the potential resources that are present in wastewater treatment plants. Anaerobic digester (AD) technology has gained widespread recognition as an essential treatment technique due to its remarkable effectiveness in converting organic chemicals into methane (CH_4) gas (13). This is due to its ability to conserve energy and convert organic chemicals into methane. Two methods to convert this into electrical sources are CH4-driven engines or chemical fuel cells. Nevertheless, some data suggests that treated wastewater may not always fulfill stringent legal standards. This highlights the necessity for more technological developments in the post-treatment process. The technique of water reuse has gained a substantial amount of traction, particularly in areas that have a limited supply of water resources (14). Despite this, it repeatedly necessitates greater energy for treatment, particularly due to the increased water quality criteria for reuse (15).

This review article on microbial fuel cells aims to provide a detailed analysis of the numerous applications that can be made use of the technology that is behind microbial fuel cells. The publication's mission is to provide this analysis. This organization's efforts will primarily focus on developing the capability to treat wastewater, generate electric power, remove heavy metals, and maybe manufacture hydrogen energy from organic materials. These capabilities will be the primary focus of the company's activities. The review focuses on the significance of microbial fuel cells in the context of addressing environmental challenges, such as the treatment of wastewater and the production of renewable energy. This is done in order to highlight the importance of these fuel cells. The purpose of this research is to investigate various ways that can be utilized to improve their performance and overcome the limitations that are now present in a number of applications. Additionally, the objective of this review is to serve as a valuable resource that can be utilized to influence future research and technological achievements in the field of microbial fuel cells.

Microbial fuel cell

There are two main types of MFCs used to generate electricity: single-chamber and double-chamber (16). A single-chamber MFC combines all required components, including waste and electrodes (cathodes and anodes), in a single chamber. A double-chamber MFC consists of an anodic and cathodic chamber that are kept separate. One compartment holds wastewater, while the other holds water. The first chamber is sealed to produce an oxygen-free environment and avoid any interaction with it, whilst the second chamber is left open to maximize exposure to air. A salt bridge links the chambers, while a multimeter monitors the current.

Single chamber microbial fuel cell mechanism

The cathode and the anode are not broken up into their own distinct compartments in this configuration. It is possible that proton exchange membranes are not present in the anode compartment, as shown in Figure 1 (17). Additionally, the cathode compartment is unknown. It is possible to absorb oxygen from the air around the cathode chamber by placing a permeable cathode on one side of the wall of the cathode chamber. This also makes it easier for protons to be transferred. In their study, (18) revealed that single compartment MFCs offer a more straightforward and cost-effective alternative.

The design and construction of MFCs have undergone several customizations in addition to these two popular designs. For a variety of construction approaches, there are a great number of single-chambered MFC designs available. Typical single-chamber MFCs is depicted in Figure 1. It is not the makeup of the bacterial community that is the most important component in generating high power densities in MFCs; rather, it is the architecture of the system that contributes to this (19). Both in terms of power density and the efficiency with which contaminants are removed, it has been widely recognized that MFCs that utilize mixed inoculation tend to perform better than those that use pure culture inoculation (20). It is necessary to carefully design MFCs, scale them effectively, manage costs, achieve excellent performance, and integrate them seamlessly with existing wastewater treatment facilities to successfully bring them into the commercial market (21). However, there have been some ingenious designs developed to include MFCs into various wastewater treatment processes. At the moment, MFCs are in the first stages of analysis and evaluation.

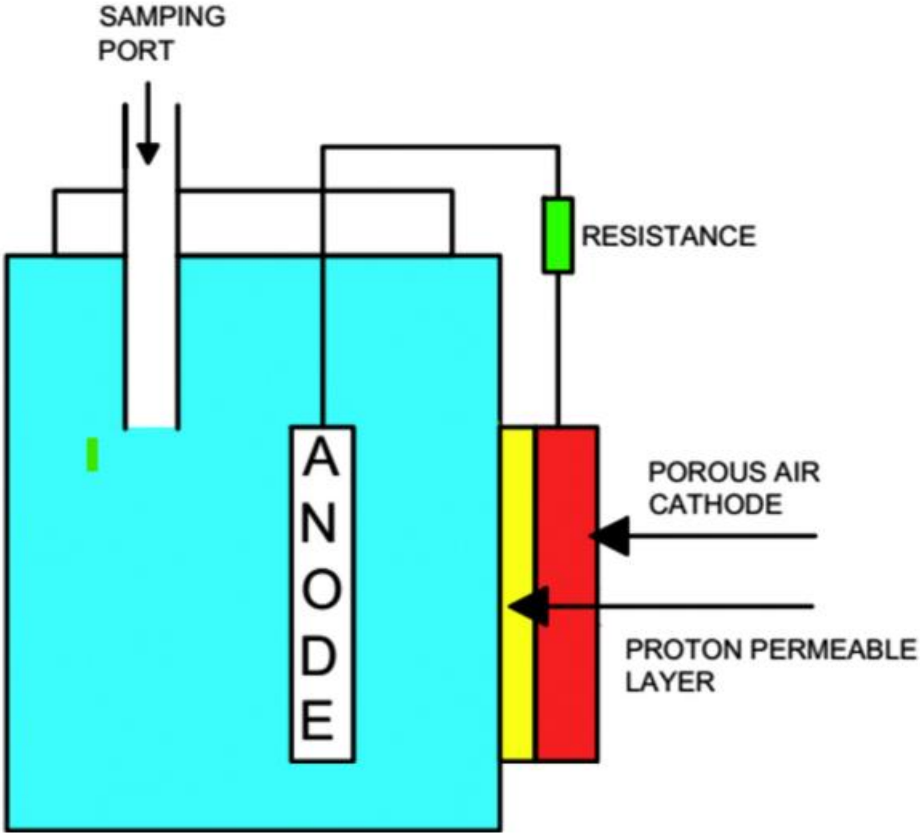

Figure 1: Single chamber microbial fuel cell mechanism (17).

Dual chamber microbial fuel cell mechanism

In recent years, there has been an increase in interest in microbial fuel cell (MFC) technology within the bioenergy sector. The MFC system functions by turning chemical energy into electrical energy. Specific microbes' metabolic activity enables this process, as depicted in Figure 2. Similar to many other bioelectrochemical systems, the MFC constructs a proton exchange membrane (PEM) between the anode and cathode regions. Biological oxidation and oxygen reduction occur at the anode and cathode regions of MFCs, respectively. These processes ultimately generate power in MFCs. Microbes operate as biocatalysts in the anode region, generating electrons and protons via cellular respiration (22). They are responsible for the breakdown of substrates. When electrons move through the external circuit and protons move through the plate electrode material (PEM), a reduction reaction with oxygen occurs in the cathode region, creating water (23). This type of renewable energy generation has numerous advantages, including optimal production conditions, simple procedures, and a wide range of biocatalyst sources (24; 25).

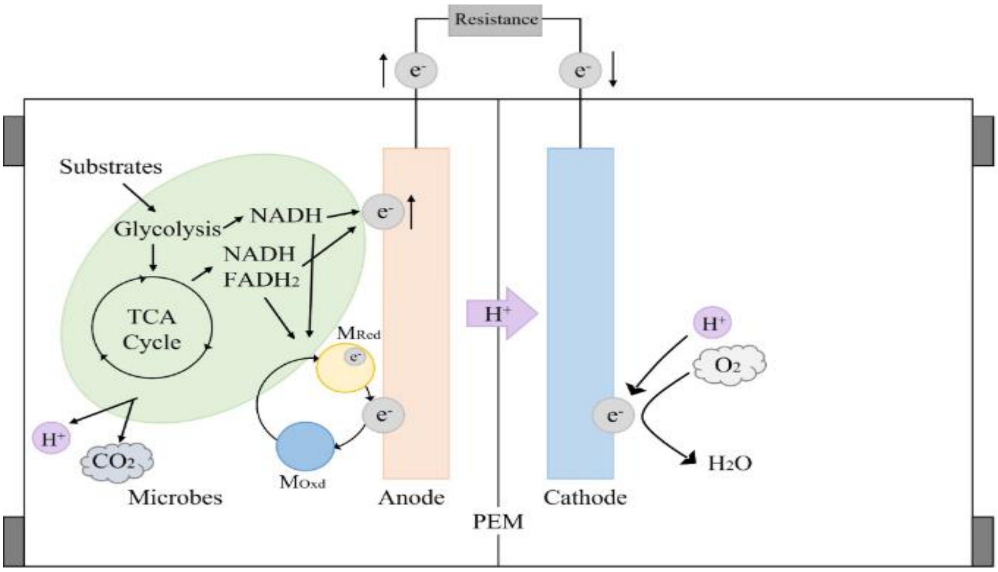

Figure 2: Dual chamber microbial fuel cell mechanism and chemical reaction (26).

Microbial fuel cell: Bioelectricity production

Microbial fuel cells (MFCs) can also use biowaste to generate power. These MFCs are essentially bioreactors in which bacteria turn chemical energy into electrical energy in the absence of oxygen by utilizing carbon from organic waste (27). A salt bridge or membrane separates the two electrodes that comprise a microbial fuel cell (MFC), a cathode and an anode (Figure 3) (28). Microorganisms degrade organic materials to facilitate their development and reproduction. This process consists of a succession of oxidation and reduction processes that yield electrons and protons (29; 30). Microorganisms can transport electrons to a substance in the absence of oxygen, facilitating electron transfer to electrodes during oxidation (31). Once delivered to an electrode, an electron travels through an external circuit, while protons spread through the solution and into the cathodic chamber. This chamber combines with oxygen, producing water (32). As the substrate oxidizes, the potential in the anodic chamber diminishes, leaving a potential difference between the two electrodes (33).

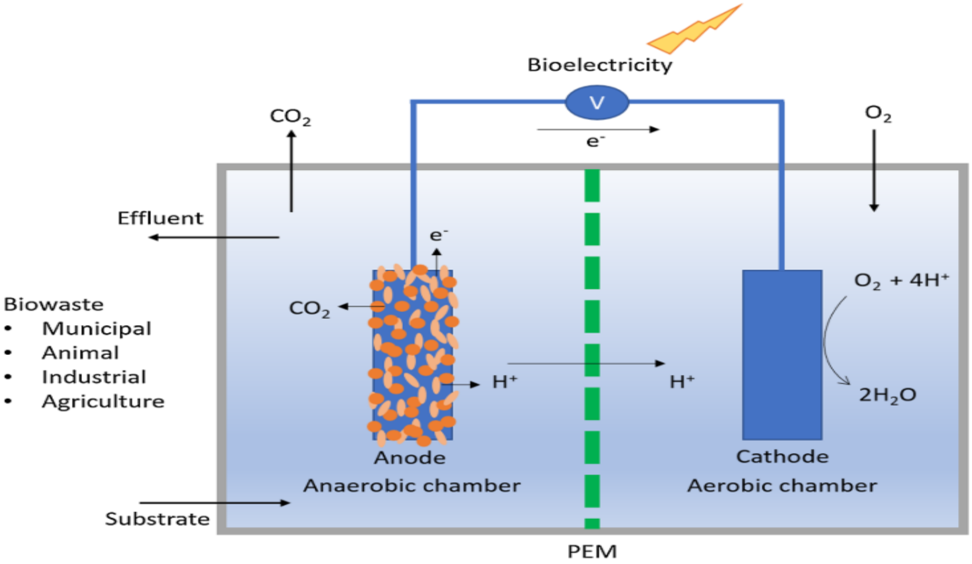

Figure 3: Microbial fuel cell: Bioelectricity production (28).

The type of substrate and microorganisms utilized in the MFC have an effect on current output (34; 35; 36). The electron transport mechanism is an important feature in MFCs. Reports have identified two basic mechanisms: direct electron transfer (DET) and mediated electron transfer (MET) (37; 38). DET can be performed using nanowires or transmembrane-associated proteins, whereas MET can be performed using an electron-transfer mediator (39). Researchers have identified numerous species of bacteria capable of producing power in a microbial fuel cell (40-44). Researchers discovered that many electron mediators, such as natural red and potassium ferricyanide, improve the efficiency of MFCs (45). Using an external mediator can improve the efficiency of an MFC, but it has downsides. These mediators can be toxic, reducing microbial growth and increasing costs. To address this issue, (46) investigated a combination of Lipomyces starkeyi and Klebsiella pneumonia. They used palm oil mill effluent as a starting material and co-cultured the two microorganisms in an anodic chamber. The electron shuttle mediator produced by K. pneumonia was called 2,6-di-tert-butyl benzoquinone. It boosted the performance of L. starkeyi sixfold over a pure culture. It is now not possible to generate considerable current using an MFC for bioelectricity production. Furthermore, because mesophilic bacteria promote most processes, this technique can work at lower temperatures.

Waste valorization

Wastewater treatment commonly employs microbial fuel cells (47). It offers a practical solution to address the challenges of water pollution and energy scarcity. The release and buildup of organic substances in wastewater can lead to significant water pollution. Currently, the commonly used aerobic digestion treatment is highly effective at breaking down organic pollutants in wastewater into carbon dioxide with the help of microorganisms (48). However, similar to other traditional methods of treating wastewater, this treatment still leads to a missed opportunity for harnessing the chemical energy found in organic pollutants. Many strains have recognized the availability of these organic substances in wastewater as substrates (48). Microbes can utilize organic pollutants to fuel their metabolic activities and generate electrons. This allows the MFC system to effectively degrade organic pollutants while simultaneously producing electricity (49; 50). Furthermore, the MFC-based anaerobic digestion technology offers the advantage of lower energy consumption compared to traditional aerobic wastewater treatment methods (49; 51).

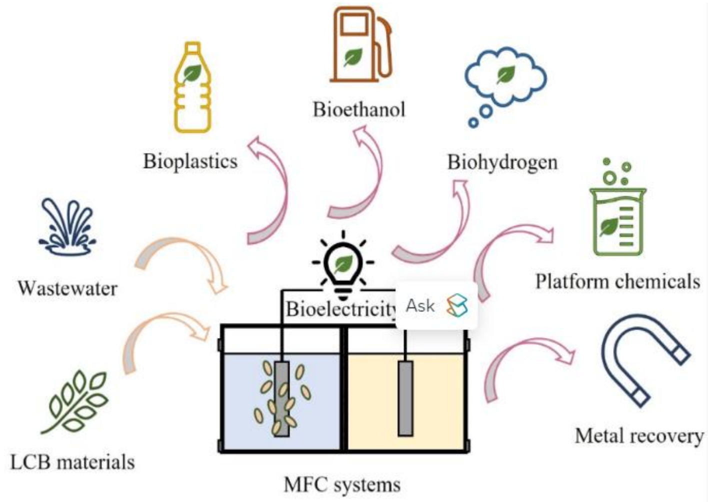

Figure 4: Microbial fuel cell waste valorization system (26).

Currently, people use microbial fuel cells to simultaneously generate electricity and produce valuable products. This is possible because of the wide range of strains and metabolic pathways involved (24; 52). Microbes can generate a range of biofuels, volatile fatty acids, biopolymers, and other platform compounds through the fermentation process during the electricity generation of MFCs (53-56). In addition, MFCs can utilize a variety of substrates, ranging from pure chemicals and organic wastewater to lignocellulosic biomass (LCB), thanks to the wide range of available strains (57). With its impressive annual production reaching about 200 billion tons, LCB stands out as one of the most abundant renewable resources. LCB resources primarily consist of agricultural and forestry wastes. Disposing of and burning such resources can lead to significant resource waste and environmental pollution. Nevertheless, the sugars produced by LCB hydrolysis are excellent carbon sources for microorganism growth and metabolism. Like with organic wastewater, using LCB hydrolysates as a substrate in MFCs can efficiently recycle biomass energy and treat agricultural and forestry wastes (26). Thus, the MFC system shows great potential as a sustainable technology that can generate energy and utilize waste effectively (Figure 4).

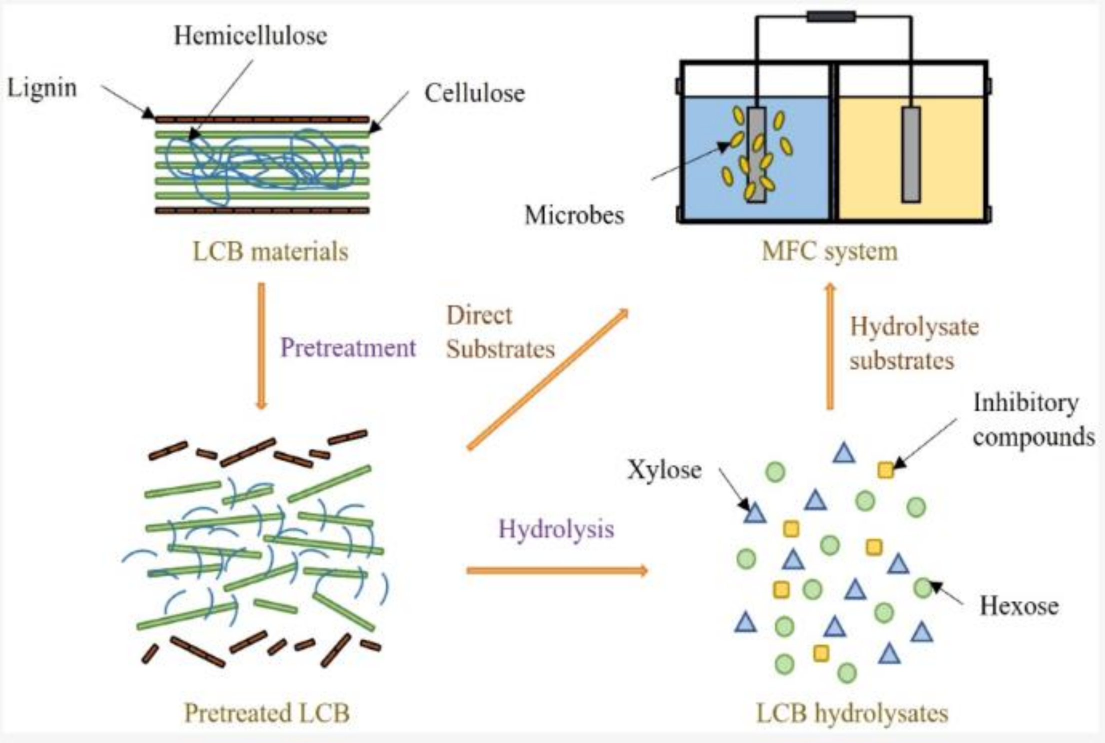

Figure 5: Application of LCB substrates in Microbial fuel cell system (26).

Waste from agricultural and forestry practices typically contains LCB, making it an abundant and renewable carbon source in the environment. If we perform the appropriate pretreatment, we can utilize LCB as a substrate in the MFC system, either as a hydrolysate or as a direct substrate (Figure 5). An efficient hydrolysis process can convert the cellulose and hemicellulose in LCB into monosaccharides. As substrates for cell growth and metabolism, these LCB hydrolysates, which comprise a variety of hexoses and pentoses, have demonstrated considerable potential. Catal et al., 2019 conducted a study using pinewood flour's sulfuric acid hydrolysate (58). They were able to successfully generate a voltage of 0.43 V in a single-chamber MFC using a 1000 Ω external resistance. Jablonska et al., 2016 achieved a power density of 54 milliwatts per square meter by using hydrolysates from rapeseed straw in their research (59). The researchers utilized a combination of hydrothermal pretreatment and enzymatic hydrolysis to manufacture these hydrolysates. Gurav et al., 2020 conducted a study to investigate the effectiveness of a Shewanella marisflavi BBL25 strain-based microbial fuel cell (MFC) in terms of energy generation (60). They tested the MFC by administering hydrolysates generated from barley straw, miscanthus, and pine. The barley straw hydrolysate demonstrated a remarkable efficiency by achieving a maximum current output density of 6.850 mA/cm^2 and a maximum power density of 52.80 mW/cm^2. In addition, the authors observed that the consumption of barley straw hydrolysates leads to the formation of strain cells that are more elongated. Larger amounts of lactate and formate contribute to this phenomenon. At the same time, there is research that investigates the possibility of using LCB materials as substrates for energy generation. The efforts of numerous strains working together may be necessary for LCB degradation and power generation. Flimban et al., 2020 conducted research using potato peels and rice straw as direct substrates, focusing on energy generation through a dual-chamber MFC unit (61). Potato peels and rice straw have particularly impressive power densities, with values of 152.55 mW/m^2 and 119.35 mW/m^2, respectively. With the help of banana peel, corn bran, and POME, Makhtar & Tajarudin, 2020 conducted an investigation into the generation of electricity in a membrane-less MFC system (62). Using the banana peel as the most efficient substrate, they were able to generate a voltage of 237.1 millivolts and obtain a power density of 23.75 milliwatts per square cm. During their research, Yoshimura et al., 2018 developed a hydrodynamic cavitation system to prepare rice bran for subsequent processing (63). They discovered that using pretreated rice bran resulted in a significant increase of 26% in the total amount of electricity generated. This was due to the efficient utilization of substrates. Jenol et al., 2019 also investigated the power generation by a strain of Clostridium beijerinckii SR1 in a microbial fuel cell (64). The researchers examined the distinctions and parallels between using a direct substrate and a hydrolysate substrate derived from sago hampas. Individually, these two different types of sago hampas can produce a power density of 73.8 mW/cm^2 and 56.5 mW/cm^2. LCB offers a significant amount of potential for MFC-based biomass valorization; nevertheless, the difficulties associated with collecting and transporting it do not allow for its broad application on a large scale.

Performance and efficiency of different types of Microbial Fuel Cells

Table 1 summarizes the various MFC setups, including operational parameters, power outputs, and pollutant removal effectiveness. These configurations include a variety of microbial fuel cells, including sediment microbial fuel cells (SMFCs), wetland MFCs (CW-MFCs), upward continuous flow CW-MFCs, membrane-less biocathode MFCs integrated with sequencing batch reactors (SBR-MFCs), and batch mode membrane bioreactor MFCs.

The upward continuous flow CW-MFCs utilized to treat synthetic wastewater with azo dye had a power output of 0.852 W/m^3 and a hydraulic retention time (HRT) of three days. This layout was more advanced than the last one. Fang et al., 2015 observed that at a concentration of 135 ± 10 mg/L, it achieved an impressive COD elimination effectiveness of 85.66% (65). Malaeb et al., 2013 found that batch mode MBR-MFCs may achieve an excellent power density of 14.5 W/m^3 while running with home wastewater (66). Furthermore, they achieved removal efficiencies of over 97% for soluble COD and NH3-N.

Mohan et al., 2011 found that sediment microbial fuel cells (SMFCs) with residential sewage and fermented distillery effluent as substrates had a high-power density ranging from 211.14 to 224.93 mA/m^2 (67). Furthermore, these SMFCs demonstrated high removal efficiencies of 86.67% for COD and 72.32% for VFA.

According to the findings of a study conducted by Zhao et al., 2013, wetland-MFCs (CW-MFC) using swine wastewater as a substrate had a power output of 9.4 mW/m^2 when running in continuous mode (68). Furthermore, these MFCs demonstrated a significant COD removal efficiency of 76.50%, which is an impressive finding. Nonetheless, membrane-less biocathode MFCs paired with sequencing batch reactors (SBR-MFC) demonstrated a lower power output of 2.34 W/m^3 and a low COD removal efficiency of 18.7%, showing that there are some operational efficiency challenges (69). This means that some efficiency concerns must be addressed. This material demonstrates the wide range of possibilities and limitations associated with various MFC designs. It also emphasizes the influence of substrate type, system setup, and operating circumstances on performance results.

Table 1: Performance and efficiency of different types of Microbial Fuel Cells

MFC Type	**COD and VFA Removal Efficiency**	**Power Output**	**Substrates and Inoculum**	**Source**
CW-MFC in Upward Continuous Flow	85.66% at 135 ± 10 mg COD/L with 30% dye	0.852 W/m^3 for anode volume, HRT 3 days, 135 ± 10 mg COD/L (30% dye)	Synthetic wastewater with azo dye	(65)
Batch Mode MBR-MFCs	>97% removal for both soluble COD and NH_3-N	14.5 W/m^3	Domestic wastewater	(66)
Sediment Microbial Fuel Cells (SMFCs)	86.67% COD and 72.32% VFA	211.14-224.93 mA/m^2	Domestic sewage and fermented-distillery wastewater	(67)
Wetland-MFCs (CW-MFC)	76.50% in continuous mode	9.4 mW/m^2 anode area in continuous mode	Swine wastewater	(68)
Membrane-less Biocathode MFCs in SBR (SBR-MFC)	18.70%	2.34 W/m^3	Synthetic wastewater	(69)

Table 2: Challenges of Microbial fuel cell

Challenges	**Details**	**References**
High Capital Costs	MFCs are 30 times more expensive than traditional systems due to costly electrode materials.	(70)
Low Power Output	Power generated is often insufficient for continuous operation of sensors/transmitters without additional management.	(33)
Operational Temperature Limitations	Inefficient at low temperatures due to slow microbial reactions.	(71)
Material Costs and Stability	High cost and instability of electrode materials hinder practical application.	(72)
Biofilm and Structural Challenges	Large surface areas and durable structures are needed to support biofilms.	(73)
Membrane Fouling	Biofouling of membranes disrupts performance and increases costs.	(74)
Scalability Issues	Power densities in larger MFCs are much lower than chemical fuel cells, limiting practical use.	(75)
Innovative Integration Needs	Integration with other processes (e.g., anaerobic digestion, membrane bioreactors) can improve performance.	(70)

Discussion

A direct influence on the amount of power that can be generated by MFC systems is the efficiency of the cathode-based oxygen reduction process (76). Cathode catalysts that are effective increase power output by facilitating the transfer of electrons and boosting the reduction of oxygen during the process (77). In spite of the fact that platinum-based catalysts have demonstrated encouraging results in terms of improving oxygen reduction activity, the fact that they are both expensive and unstable makes it difficult to have widespread application (78). Furthermore, in order to enhance the electrochemical activity of MFCs, research has been concentrated on the development of cathode catalysts that are based on nanocomposite materials.

The remarkable peak power density of 16.12 W/m^2 was achieved by (79), who were able to successfully improve the performance of an activated carbon cathode by combining Cu2O and Cu. In order to contribute to the improved performance of the cathode, the authors highlighted the catalytic activity of Cu2O in oxygen reduction as well as the high electrical conductivity of copper. A remarkable power density of 180 mW/m^2 was reported in a study that was carried out by (80). Carbon fabric cathode, which has been reinforced with α-MnO_2 nanowires and carbon Vulcan, was utilized in order to accomplish this goal. It was also discovered by Chiodoni et al., 2019 that the utilization of cathode catalysts that were based on manganese oxide led to improvements in the performance of modular fuel cells (81).

An investigation into the combination of several materials was carried out by Rout et al., 2018, which led to the development of a nanocomposite that resulted in a considerable increase in the volumetric power density by 2.7 points (82). A four-electron oxygen reduction route was shown to be facilitated by this nanocomposite, which also improved electron transfer; this was reported. In their study, Mecheri et al., 2018 demonstrated that the utilization of a cathode catalyst that is composed of FePc and GO has the potential to improve the electrochemical performance of MFCs (83).

When it comes to lowering oxygen, it has been discovered that a three-dimensional composite made of carbon nanotubes and molybdenum disulfide is extremely effective. An excellent maximum power density of 1177.31 mW/m^2 and a current density of 6.73 A/m^2 were both achieved by Li et al., 2019 in their research (84). This was accomplished by the researchers. Using a bacterial cellulose cathode that had been doped with phosphorus and copper led to an increase in the number of active sites for oxygen reduction, which was the reason for this extraordinary performance. PANI and an iron-based metal-organic framework were combined in a study that was carried out by Kaur et al., 2021, which resulted in the composition of a potent composite catalyst (85). The catalyst that was produced from this process exhibited a remarkable power density of 680 milliwatts per square meter and a high limiting current density of 3500 milliamperes per square meter. It has also been established that metal-organic frameworks based on nickel are efficient catalysts that facilitate the reduction of oxygen (86).

Improvements in specific surface area and surface characteristics are the primary focuses of the MFC anode improvement process. An increase in the specific surface area of the anode can be accomplished through the application of a number of different techniques, such as heat and acid treatments.

Furthermore, electrochemical oxidation techniques has the capability to enhance the surface area of the anode and augment the presence of novel functional groups on the surface of the anode (87). The combination of these therapies helps to improve the electrical connections between cells, which in turn fosters the production of biofilms that facilitate the flow of electrons. There has been a substantial amount of research carried out on a variety of materials in order to improve electrode modification. This has resulted in an improvement in the adhesion of the strain cell and has made it easier for electrons to transfer to the surface of the anode. Both metals and metal oxides are frequently utilized in the process of anode modification. The generation of power in dual-chamber MFCs with carbon cloth anodes that were increased with various materials was investigated by Xu et al., 2018, as an illustration (88). Under the influence of MnO2, Pd, and Fe3O4 alterations, respectively, they were able to accomplish maximum power densities of 824, 782, and 728 mW/m^2. According to their findings, a number of modifications result in the enhancement of particular strains on the anode surface. A considerable increase in power densities was reported by Yu et al., 2019 when changed anodes were utilized (89). Anodes changed with bentonite-Fe were able to obtain maximum power densities of 29.98 mW/m^2, while anodes modified with Fe3O4 were able to achieve 18.28 mW/m^2. In comparison to graphite felt anodes that were left bare, these alterations led to an increase in stable voltage as well as a reduction in the internal resistance. It has been discovered that the generation of energy from MFCs can be greatly improved by the use of modifications utilising cobalt oxide (90) and nitrogen-doped carbon nanorods with Co-modified MoO2 nanoparticles (91). The inclusion of zero-valent iron was shown to have a beneficial impact on the maximum power density, as was discovered by (92). By boosting the diversity of functioning microbial communities and arranging biofilms, it was able to accomplish this goal. The generation of power was, however, hampered by the presence of zero-valent iron at concentrations that were excessively high. Graphene oxide (GO) and carbon nanotubes (CNT) are two examples of carbon compounds that have been shown to be effective in the modification of anodes, according to study as well.

Future directions

The concept of microbial fuel cells began as a scientific curiosity, and in many ways, this remains the motivation for their existence today. The Microbial Fuel Cell (MFC) is a unique device that can swiftly analyze and convert microorganisms' chemical and metabolic processes into electrical output. This technology has an intrinsic sensing capability that may be used in a wide range of applications and is compatible with the desired microorganisms. It has been established that using ceramic materials for the chassis and ion exchange membranes causes the generation of catholyte, a disinfectant liquid. Disinfectants are exposed to the MFC's environment, therefore the biofilm on the anode electrode can destroy them. Two of these examples have the potential to increase cleanliness, which is a critical problem for developing countries and regions.

Conclusion

In conclusion, microbial fuel cells, also known as MFCs, are devices that harness the natural metabolic processes of bacteria to generate energy and cleanse wastewater. MFCs have potential uses in wastewater treatment facilities, where their purpose is to produce electricity and remove contaminants.There are two primary types of MFCs: single-chamber and double-chamber designs. In double-chamber MFCs, the anode and cathode chambers are kept separate, while single-chamber MFCs house all of their parts within a single chamber. Microbial fuel cells have the ability to utilize different types of substrates, such as organic waste and lignocellulosic biomass found in the environment, in order to generate energy and purify wastewater. However, MFCs come with a range of advantages and disadvantages. These include initial expenses, limited power generation, and temperature limitations within which they can operate. In order to effectively tackle these challenges and enhance the performance and efficiency of MFCs, further research and development are necessary. Microfluidic cells (MFCs) are widely recognized as a technology that prioritizes environmental safety and sustainability in the treatment of wastewater and power generation.

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