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Integrating wood into microbial fuel cell technology

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ABSTRACT

One potentially sustainable method for treating wastewater is the microbial fuel cell (MFC). Maximizing the system's power output is often the primary goal of MFC research. The purpose of this study was to investigate the potential contributions of wood and wood industry effluent as carbon sources for MFC technology. We looked at how using biochar as an electrode may affect power density and the efficacy of wastewater treatment. Because of its porous structure, high electrical conductivity, low cost, and easy one-step manufacturing process of modified electrodes, we found that biochar can be a substitute for conventional graphene felt or carbon felt electrodes when used in MFC. As another example, biochar has been shown to successfully remove heavy meals and organic compounds from wastewater in the wood sector. However, more study is required to improve the manufacturing technique of biochar electrode production and boost its performance.

INTRODUCTION

Microbial fuel cells are a promising technology that uses microorganisms as biocatalysts to transform chemical energy directly into electrical energy. In addition, MFCs have received interest in recent years as a novel method to wastewater treatment (Nimje et al., 2012). A green energy conversion technology, the MFC combines wastewater treatment with energy recovery from the metabolic processes of microorganisms (Hindatu et al., 2017). As can be seen in Fig. 1, MFCs come in a wide variety of shapes, sizes, and designs. In MFCs, bacteria at the anode consume organic matter through metabolism and generate electrons and hydrogen ions, then the hydrogen ions goes under oxygen reduction reaction from cathode side with combination of oxygen with the assistance of electrons which produced in anode side (ElMekawy et al., 2017). Multiple options for cathode and anode electrode construction were investigated with the goal of finding the most efficient and cost-effective combination (Noori et al., 2016). Most studies centered on improving the cathode electrode's durability and oxygen reduction reaction (ORR) and the anode electrode's bacterial adhesion and electron flow (Hindatu et al., 2017). Additional studies have been carried out to determine the impact of various substrates in terms of electron generation and the degree of capability to reduce chemical oxygen demand (COD), including heavy metal reduction (Yuan et al., 2018).

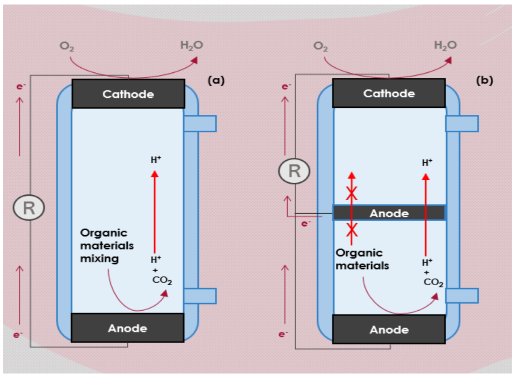

Figure 1: Schematic representation of an ML-MFC (a) single-chamber unit, (b) dual-chamber unit. (Redrawn with modifications from Ref. Kim et al., (2016)). Copyright, Elsevier

The polymer cellulose occurs in great abundance in nature. Water-insoluble fibrous cellulose is essential to the integrity of plant cell walls (Csóka et al., 2022). Wood degradation products, wood extractives, heavy metals, and even surfactants added during cleaning operations can all be present in the water used in the manufacture of wood panels (Toczylowska-Mamińska, 2020). Due to the quantity of wood provided by our planet, it is crucial to emphasize that research and development of MFC technology becomes more cost-effective and viable to everyone if we can combine it with wood goods in any form.
In this paper, we discussed studies that use a wood-based product and a highly contained substrate treated with cellulose and wood extracts as starting points for producing an anode and cathode electrode, respectively.

Wood used for preparing Anode and Cathode electrodes

After undergoing a pyrolysis procedure under nitrogen environment and 800 - 1000 °C heating, biochar chips can be utilized as an electrode (conductive graphite). The biochar was then progressively bathed in ethanol and water for 12 h and dried at 60 °C to ensure its surface was free of any impurities (Chang et al., 2020). Wood biochar may be used to construct the cathode for MFCs, and its high catalytic activity and inexpensive cost make it comparable to granular activated carbon in terms of catalyst capacity. Several studies have demonstrated the suitability of biochar as a substitute electrode for expensive cathode electrodes, and they hypothesized that it can act as both an air diffusion layer and a catalyst for oxygen reduction reaction (ORR) due to its hierarchical structural arrangement and porous channels, which are advantageous for oxygen transfer between the atmosphere and electrolyte (Bataillou et al., 2022). Chang developed a binder-free air cathode using balsa wood biochar chips, achieving a maximum power density of 200 mW/m^2, which was 45% higher than the carbon felt cathode under the same conditions. It was hypothesized that biochar chips are a promising material for the construction of efficient air cathodes (Chang et al., 2020). Biochar made from lodgepole pine wood chips and compressed milling residue produced a greater electric outcome than graphite granules but a lower electric outcome than granular activated carbon. As a consequence, it was discovered that biochar has environmental benefits such as biowaste feedstock, energy positive manufacturing, carbon sequestration potential, and land application as an agricultural supplement (Huggins et al., 2014). Table 1 contains a list of more studies.
A new design for MFCs has arisen in conjunction with the objective of sustainability. A resent study shown to create a cathode out of a bamboo tube by carbonizing it at 900 °C in a nitrogen atmosphere and then heat treating it at 350 °C to increase porosity (Fig. 2). For making the cathode water repellent, it was additionally rubbed with polytetrafluoroethylene solution on the outside area. The anode was a carbon fiber. The cell finally generated an MPD of 40.4 W/m^3 and a CE of 55% (Yang et al., 2017).

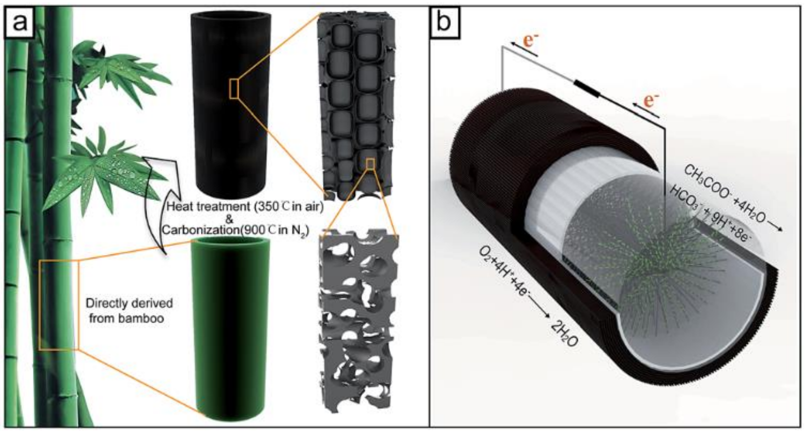

Figure 2: (a) Fabrication process of cathode from bamboo tube; (b) MFC with cathode made from bamboo tube. (Published from Ref. Yang et al., (2017) under CC BY 3.0 license)

Table 1: Further research on biochar electrodes under different conditions

Cathode and anode	Substrate	Wastewater treatment ability	Electric production	Reference
Anode; Cedar wood biochar, cathode; carbon felt functionalized with activated carbon and PTFE	-	-	9.9 ± 0.6 mW/m^2	(Bataillou et al., 2022)
Anode; basswood biochar, cathode; carbon felt and carbon felt	*Shewanella oneidensis* rich influent	completely removed hexavalent chromium (Cr(VI)) in 48 h	62.59 mW/m^2	(Ni et al., 2022)

Evaluation of the properties of the biochar electrode

In comparison to other viable high-cost electrodes, the efficiency of biochar electrodes may be assessed using numerous characteristics, including electric generation and wastewater treatment capabilities. Among the most important parameters are; potentiostat was used to determine total internal resistance of the MFC and ORR performance of the biochar electrode; electrochemical cyclic voltammetry was conducted with a container of 50 mM phosphate buffer solution inside to evaluate catalytic activity towards ORR; Raman spectra shows carbonaceous materials, first-order scattering, crystalline sp2 lattices of the graphitic structure, graphite lattice; EDX analysis revealed the oxygen functional groups; data logger for measuring voltage will read the voltage change throughout the experiment; also data logger with setting resistor reads the current and power output; chemical oxygen demand (COD) can show the capability of wastewater treatment; SEM images are showing the physical structure and homogeneity of the biochar; Brunauer–Emmett–Teller (BET) test for showing the average pore diameter of the materials, etc.

Wood industry wastewater used as substrate

Although MFCs were used to treat a wide range of industrial wastewaters. While the pulp and paper sector is a major user of water, the wood-based panel business requires far less water during manufacturing (Toczyłowska-Mamińska, 2017). Using the treatment of the wood-based panel industry, Toczylowska found a maximum COD removal effectiveness of 94% and a maximum power density of 9 W/m^3 (Toczylowska-Mamińska, 2020). This tells us that cellulose, organic compounds, and extracts abound in the wastewater produced inside the wood-based sector.

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