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Elemental and Surface Analysis of Bamboo Charcoal Electrodes in Microbial Fuel Cells

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ABSTRACT

The possibility of using charcoal powder as an inexpensive electrode material for microbiological fuel cells (MFCs) is investigated in this work. Electrodes for MFCs were made by carbonizing bamboo powder in air at 500°C and mixing it with Bokuju ink, with the ratio of charcoal to Bokuju being varied. Power density and current density were used to measure the electrochemical performance. The usefulness of charcoal powder in increasing MFC output was shown by MFC 5, which had a larger charcoal content and reached a maximum power density of 38.02 µW/cm². The results of the SEM elemental analysis showed that the biofilm growth and increased conductivity were due, in part, to the high carbon content and porous surface structure. The charcoal Bokuju electrode's ability to bind microbes was shown by scanning electron microscopy (SEM), demonstrating its promise as a biocompatible and effective MFC electrode. The research calls for further research using cutting-edge spectroscopic methods to investigate the electrical interactions of charcoal electrodes.

Keywords: Microbial Fuel Cell, Charcoal Powder, Bokuju, Electrodes, Power

INTRODUCTION

An exciting new development in renewable energy is the concept of microbial fuel cells (MFCs), which harness the metabolic processes of microbes to produce electricity from organic materials. Because of its great conductivity qualities, low environmental impact, and wide availability, bamboo charcoal has emerged as a promising material for use as an electrode in MFCs. Electrode qualities, such as elemental composition and surface features, have a substantial impact on MFC performance.

Because of the direct impact on its electrical conductivity and biochemical interactions with microbial cells, elemental analysis is essential for comprehending the composition of bamboo charcoal. Because it is produced by a pyrolysis process, carbon is the most abundant element in bamboo charcoal, but hydrogen and oxygen also play important roles.

Charcoal made from bamboo usually has a carbon concentration of 60–80%, making it highly conductive and offering a robust framework for microbes to colonize. Trace elements like phosphorus, sulfur, and nitrogen may coexist with the main components. These components are crucial for improving bamboo charcoal's electrochemical capabilities. As an example, nitrogen has the ability to increase the surface charge density, which in turn makes it easier for electrons to pass from microbial cells to the surface of the electrode. In addition, alkaline metals like sodium and potassium may improve the MFC's overall performance by increasing the electrode's ionic conductivity.

To understand how the physical and chemical properties of bamboo charcoal electrodes affect the adhesion of microbes and the processes of electron transfer, it is necessary to do surface analysis on these electrodes. Surface characteristics of bamboo charcoal are investigated using a number of methods, such as X-ray Photoelectron Spectroscopy (XPS), Energy Dispersive X-ray Spectroscopy (EDX), and Scanning Electron Microscopy (SEM). Bamboo charcoal's porous structure and morphology may be seen in high-resolution images captured by scanning electron microscopy, which examines the electrode surface. Crucial to the electrochemical activity is the porosity, which increases the surface area available for microbial colonization. A web of linked holes, as shown in scanning electron microscopy (SEM) pictures of bamboo charcoal, may house microbial cells and allow substrates and metabolites to diffuse more easily.

When used in conjunction with SEM, Energy Dispersive X-ray Spectroscopy (EDXS) may provide both qualitative and quantitative information on the elemental composition. Researchers may use this method to determine which elements are present on the surface of bamboo charcoal and how they are distributed, which in turn enables them to determine which components are associated with electrochemical performance. As an example, electron density-functional theory (EDX) analysis may show where nitrogen is distributed, which might point to areas with better electron transfer efficiency and conductivity. In order to learn about the chemical condition of the components on the surface of the bamboo charcoal, X-ray Photoelectron Spectroscopy is a useful instrument for surface investigation. Electrode-microbe cell contact may be dramatically altered by the presence of functional groups that XPS can identify, including hydroxyl, carbonyl, and carboxyl groups. Electrode surfaces that have oxygen-containing functional groups are more hydrophilic, which encourages biofilm development and microbial adherence.

An important determinant of the degree of microbial colonization is the surface area and porosity of the electrodes. In order for MFCs to transport electrons effectively, biofilms must accumulate, and a porous electrode with a good structure makes this possible. In addition, functional groups on electrode surfaces may increase microbial binding affinity, which in turn improves power production. The electrochemical behavior of electrodes made of bamboo charcoal is heavily influenced by their elemental makeup. Conductivity is improved with a high carbon content, and electrochemical kinetics of microbial metabolism may be accelerated with the addition of nitrogen and other components. According to research, MFCs may achieve higher current densities and total power outputs by fine-tuning the elemental makeup of their bamboo charcoal electrodes.

Bamboo charcoal is a promising material for MFC applications because to its carbon-rich composition, trace element content, and desirable surface properties. By using advanced imaging and analysis methods like SEM, EDX, and XPS, scientists may better understand the structure and characteristics of bamboo charcoal electrodes. This knowledge will be crucial in creating MFCs with improved efficiency. To increase its efficiency in producing energy from organic substrates, future research should focus on perfecting the manufacture and modification procedures of bamboo charcoal. This would help find long-term solutions to energy problems.

REVIEW OF LITERATURE

Sato, Chikashi et al., (2021) This investigation included the fed-batch operation of three separate and consecutive single-chamber microbial fuel cells (MFCs), with cathodes made of Pt-coated carbon fabric and anodes made of four bamboo charcoal (BC) plates. A mixed bacterial culture was cultured on a substrate of simulated effluent from potato processing. The greatest power production was 1.047 mW when three MFCs were linked in series, up from 0.386 mW when using a single MFC. On the other hand, when three MFCs were connected in series, the maximum power density dropped from 576 mW/m2 (normalized to the cathode area) with a single MFC to 520 mW/m2. Connecting the MFCs in series may enhance power, according to the experimental findings; nevertheless, selecting low resistance BC is critical for achieving a higher power density.

Li, Shuang et al., (2016) As a result of its physiological activity to interact with microbes, carbon materials—which may display a broad variety of morphologies and structures—are quickly becoming electrode materials. Carbon compounds, when used as anode, may hasten the generation of extracellular biofilms and encourage microbial colonization of interfaces, both of which increase electrical power density via the creation of a conductive milieu for electron transfer outside of cells. Using carbon-based materials as the cathode, catalysts for the oxygen-reduction process may be created, and these catalysts are demonstrating gratifying activity and efficiencies that can compete with or even surpass those of Pt catalysts in modern times. The article begins by providing a concise overview of the latest developments in carbon material design for MFC anodes. It then goes on to explain how various carbon materials' structures and surface functionalization affect the immobilization of microorganisms and their electrochemical performance. Following that, a concise overview of the architectures and synthetic methods used to create standard carbon-based cathodes for MFCs is provided. In addition, we outline the new obstacles in taking MFC devices based on carbon electrodes from the lab to an industrial scale and talk about their potential future uses in the energy, environmental, and biological sectors.

Zhang, Jun et al., (2014) The anode material significantly influences the performance of microbial fuel cells (MFCs). This work proposes the bamboo charcoal tube as an innovative anode substrate by the carbonization of natural bamboo. The surface functional groups, biocompatibility, and internal resistance are comprehensively examined. The performance of MFCs with a typical graphite tube anode is compared with that of a bamboo charcoal tube anode. The findings demonstrate that the tubular bamboo charcoal anode possesses benefits over the graphite tube anode, including a rougher surface, enhanced biocompatibility, and reduced total internal resistance. Furthermore, the X-ray photoelectron spectroscopy (XPS) examination of the bamboo charcoal indicates that the incorporation of C–N bonds enhances electron transport between the biofilm and electrodes. The MFC with a bamboo charcoal tube anode attains a 50% enhancement in maximum power density compared to the graphite tube configuration. Additionally, the scalability of the bamboo charcoal tube anode is shown by utilizing a bundle of tubular bamboo charcoal to achieve increased power production.

Zhang, Jun et al., (2014) Microbial fuel cells (MFCs) efficiency depends on anode material. Bamboo charcoal tubes may provide an alternate anode substrate after carbonization, according to this study. Internal resistance, biocompatibility, and surface functional groups have been intensively explored. We also test MFCs using bamboo charcoal and graphite tube anodes. The bamboo charcoal tubular anode has a rougher surface, is more biocompatible, and has a lower total internal resistance than the graphite tube anode. In addition, bamboo charcoal XPS demonstrates that C-N linkages improve electron transport from the biofilm to the electrodes. Thus, the MFC with bamboo charcoal tube anode has 50% greater maximum power density than the graphite tube instance. The anode may be scaled up to produce more power using a bundle of bamboo charcoal tubes.

MATERIAL AND METHODS

Preparation of Charcoal

A popular soil conditioner, powdered bamboo, was used in this study. Bamboo powder air-dried overnight at 60°C. Powdered bamboo was air-burned at 500°C for 1 hour to generate charcoal. Our experiment aimed to carbonize bamboo powder at a low cost by calcining it under air rather than nitrogen. Grinding charcoal in a mortar produced a finer powder.

Electrode Preparation

This project made microbial fuel cell electrodes using charcoal powder and liquid Bokuju. Charcoal powder and Bokuju turned the electrode into several shapes quickly. Microbial fuel cell electrodes were made by altering the charcoal powder-Bokuju ratio to obtain the best amount of each. We ordered the matched MFCs 1–5. When the charcoal powder ratio exceeded MFC 5, the Bokuju and charcoal powder mixture became too thick to make the electrode. The cathode electrode was sterilized with 1 g Bokuju and 30 cc copper powder. The anode electrode was 1 × 1 and the cathode electrode was 2 × 2.

Preparation of LB medium

Microbial fuel cells employed LB medium as an electrolyte. Mix sodium chloride (5 g), yeast extract (2.5 g), and filtered water (500 ml). The experiment employed 500 cc of autoclaved LB medium for the microbial fuel cell's electrolyte. Following the processes above, 100 ml of LB medium, 100 ml of tap water, and 1 ml of soil water from a paddy field were mixed to create the electrolyte.

MFC Structure and Operation

This study employed floating microbial fuel cells. The cathode electrode was on the float for air contact. Electrolyte submerged anode electrode. The anode and cathode electrodes were 35 mm apart. The MFC's electrodes were connected to a 4.7 kΩ external resistance. A temperature of 25 ± 1°C was maintained around the MFC. To maintain water level in the MFC electrolyte, tap water was added daily, even when drying occurred.

EXPERIMENTAL RESULTS AND DISCUSSION

Elemental analysis of charcoal powder

Table 1 shows quantitative analysis of the charcoal powder surface elements composition after 500°C fire. Elemental analysis shows the sample's composition: carbon (74.22 wt.%), oxygen (18.70 wt.%), potassium (5.41 wt.%), silicon (1.01 wt.%), magnesium (0.27 wt.%), sulfur (0.19 wt.%) and phosphorus (0.32 wt.%). The powder's high carbon concentration after sintering makes it conductive. Figure 1 shows SEM analysis of charcoaled powder surface morphology. Its large surface area and porous nature make it a viable MFC electrode.

Table 1: Elements of charcoal

Chemical element	Mass percent (wt%)
Carbon	74.22
Oxygen	18.70
Potassium	5.41
Silicon	1.01
Magnesium	0.27
Sulfur	0.19
Phosphorous	0.32

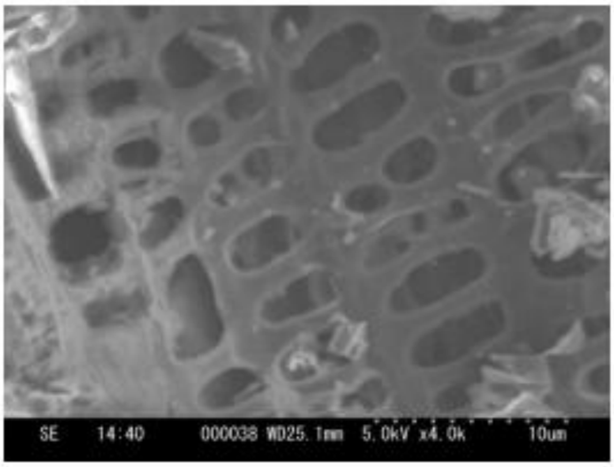

Figure 1: Charcoal SEM

MFC Performance

Power density and current density were measured in an MFC utilizing a charcoal Bokuju electrode to assess the battery. The MFC now has a variable resistor instead of the previously attached 4.7 kΩ external resistor. Adjusting the variable resistor from 4.7 kΩ to 200 was chosen. We determined power and current density by monitoring the MFC's voltage values, which fluctuated with resistance. Besides computing the greatest power densities, we showed the daily maximum value with time (Fig. 2). MFC 4 had the maximum power density at 26.89 µW/cm2, whereas MFC 1, 2, and 3 had the lowest at 0.012, 1.043, and 2.304 µW/cm2, respectively. Compared to Bokuju, MFC 5 showed a higher maximum power density of 38.02 µW/cm2 and enhanced power output with bigger charcoal powder quantities. Microbiological fuel cells consisting of charcoal powder perform nicely. Raman spectra help identify carbon-based electrodes.

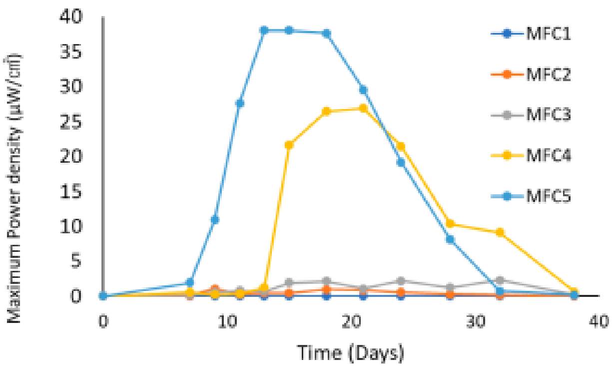

Figure 2:Maximum MFC power density using charcoal Bokuju electrodes

Elemental Composition Analysis of Charcoal-Bokuju Electrode Surface

SEM-EDS elemental analysis of charcoal Bokuju electrodes by ratio is shown in Table 1. Carbon components increased with ink use. However, MFC electrodes depend on charcoal since their electrical output increases with charcoal consumption. To prove the charcoal powder's unambiguous electronic interactions and synergistic effects, XPS and other experiments on the charcoal Bokuju electrode and other carbon electrodes are needed.

Table 1:Elemental Composition Analysis of Charcoal-Bokuju Electrodes

MFC	(Mass%)						
	C	O	Na	Mg	Si	K	Ca
MFC 1	77.98	19.05	0.42	0.49	0.48	1.25	-
MFC 2	77.20	19.83	0.50	0.18	0.53	0.08	1.26
MFC 3	76.06	20.80	-	-	-	2.31	-
MFC 4	73.59	22.42	0.40	0.30	0.75	2.44	0.26
MFC5	71.90	22.71	0.82	-	0.49	3.62	-

Surface Characterization of Charcoal-Bokuju Anode

Charcoal Bokuju electrode surface was SEM-imaged. After the MFC 5 procedure, the anode was carefully removed and stored in hand sanitizer at 4°C to kill and repair bacteria. Submerging the anode in ethanol dried the electrode. Sputtering gold on the electrode surface made it more noticeable. Figure 4 shows bacterial cell biofilms on the anode. The charcoal Bokuju electrode appears to appeal to microorganisms.

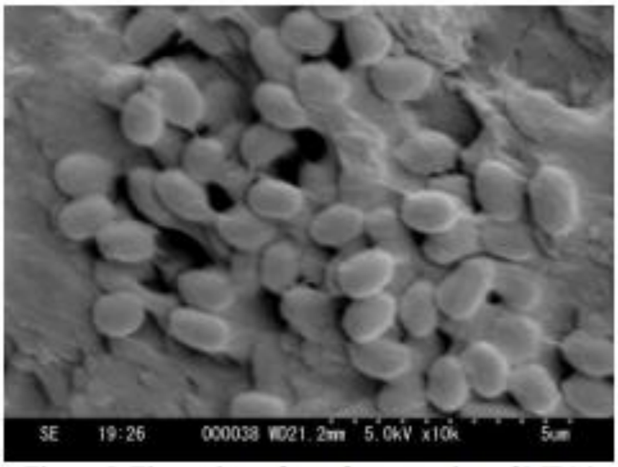

Figure 4: MFC4-Operated Electrode Surface

CONCLUSION

This study suggests bamboo charcoal might be a cheap Microbial Fuel Cell anode. The study indicated that increasing charcoal content improves MFC performance by modifying the charcoal-Bokuju ratio. MFC 5 achieved the maximum power density of 38.02 µW/cm². SEM-EDS elemental and surface examinations demonstrated a high carbon content and porous structure, highlighting electrode surface biofilm formation and increased conductivity. Bamboo charcoal improves microbial activity and power generation in MFCs and is biocompatible. To understand electronic interactions and improve charcoal-based electrodes in microbial fuel cells, further study is needed, including sophisticated spectroscopic methods. Bamboo charcoal electrodes show promise for sustainable energy applications.

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