Natural, Cost-Effective Anodes for Optimized Sediment Microbial Fuel Cells: Engineering a Novel Approach to Harvesting Energy and Cleaning Up Oil-Polluted Regions

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***Abstract*:** To address clean energy and pollution issues, microbial fuel cells (MFCs) were hypothesized to simultaneously generate electricity and remediate oil spill pollution. The purpose of this study was to engineer efficient, cost-effective MFC anodes that optimize electrical output and oil remediation using structural and surface coating configurations. For structure, carbonized *Luffa aegyptiaca*, loofah sponges (LS), were tested as cheaper 3-dimensional alternatives to commercial materials (carbon fiber and RVC). Hybrid surface coatings were synthesized to increase electrical properties. Coatings were uncoated, TiO2, graphene, and graphene/TiO2 composite. Nine anode designs were made from these structure/coating combinations. MFCs were implemented in different conditions to assess oil remediation. Electrical outputs were collected; UV-VIS spectroscopy measured oil degradation. Results showed anodes improved oil cleanup. LS-structure groups had significantly higher power densities than standard 2D and 3D anodes. LS-graphene/TiO2 had the highest power density (2087.1 mW/m^2) and oil remediated (93%). This suggests structure and surface coating synergistically improve surface area, biocompatibility, and electrical conductivity for optimized performance. Over 26 times more cost-effective, LS come from accessible, sustainable sources. This MFC design shows potential in remediating oil spills and providing clean energy for industries, remote sensors, and developing nations.

I. Introduction

MFCs are energy-producing devices that use bacteria as catalysts to produce electrical energy via reduction-oxidation reactions in organic matter[1]. In an MFC, the anode functions as the site for extracellular electron transfer (EET) and biofilm growth (Fig. 1). An anode must be biocompatible, electrically conductive, and chemically stable[1][2]. Yet, MFCs produce relatively low power density compared to high cost materials. The use of a natural, sustainable anode and composite surface coating suggests a novel low-cost and effective alternative to standard anodes. A *Luffa aegyptiaca,* or loofah sponge (LS), is a type of cucumber with an open three-dimensional macroporous structure that offers an ideal scaffold for bacterial growth. A graphene-titanium dioxide (G/TiO_2) composite surface coating can increase electrical properties.

It was hypothesized that MFCs can clean up oil spill polluted regions. Often used for wastewater treatment, MFCs may function as alternative electron acceptors to facilitate the oxidation of petroleum hydrocarbons by naturally-occurring oil-eating bacteria in ocean sediment, regions which are especially difficult to clean[1]. The purpose of this project was to develop an efficient, cost-effective MFC anode that optimizes power production and oil spill cleanup.

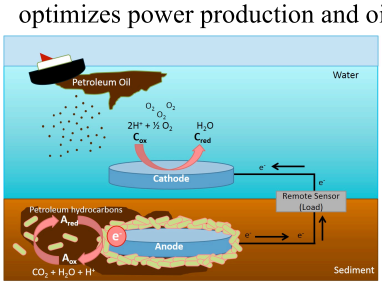

Fig. 1: Diagram of a sediment MFC. Bacteria form on the anode. As they oxidize organic matter, electrons are released and collected by the anode. The electrons then travel through an external circuit to produce and electrical current (Made by authors).

II. Methodology

Nine different anode designs were tested with variations in structure and surface coating. Carbonized LS for electrically conductive carbon were studied as cheaper alternatives to commercial carbon fiber and reticulated vitreous carbon (RVC). Surface coatings of uncoated, G, TiO_2, and G/TiO_2 composite were applied onto these structures. SEM and a capillary action test characterized the anodes.

MFCs were implemented under various systems to study oil degradation. Over a 10k resistor, voltage and current was measured to calculate power density over 10 days. Petroleum hydrocarbons were extracted and measured with UV-VIS spectroscopy to assess the remaining hydrocarbons.

III. Results and Discussion

Anode Characterization: SEM and capillary action test revealed the LS had higher surface area than the carbon fiber and RVC. The pyrolysis caused the shrinking of the plant tissues which created wrinkled channels that increase surface area on LS. This can allow for increased biofilm growth.

Electrical Outputs: Over 10 days, LS had significantly higher (*$p<0.05$) power densities than carbon fiber and RVC, which can be attributed to its high surface area. G/TiO_2 had the highest power density due to a synergistic effect of high electrical conductivity from graphene (G) and increased biocompatibility from H-bonding between anode and bacteria from TiO_2. LS-G/TiO_2 had the highest mean power density (2087.1 mW/m^2), three times greater than the control.

Oil Remediation: MFCs compared to no MFC increased degradation, supporting the alternate hypothesis. Only the LS-G/TiO2 had significant difference among the anode groups with the highest degradation rate of 93%. Enhanced oil cleanup may require a combination of structure and coating.

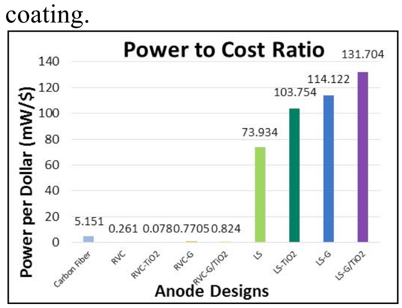

Fig. 2: A power to cost ratio graph of the different anodes for cost-effectiveness analysis. RVC to RVC composite are too miniscule in power to cost ratio to be seen. The LS-G/TiO2 had the greatest PCR.

IV. Conclusion

A novel, low-cost, and highly efficient MFC anode was developed using natural materials. The LS-G/TiO_2 was over 26 times more cost-effective and efficient than the controls. This can be attributed to synergistic effects from the high surface area, electrical conductivity, and biocompatibility from the LS morphology and surface coatings. A patent is currently pending for our novel design. Our research has potential towards providing clean, accessible energy to industries, remote sensors, and developing countries. It also shows an environmentally-friendly, sustainable, and profitable method to cleaning oil spill and polluted regions.

Selected References

[1] Logan, B. E. *Environmental Science and Technology*, 2006. 5181-192.
[2] Morris, J.M. *Journal of Hazardous Materials*, 2 Nov. 2012. 213-214:474-7