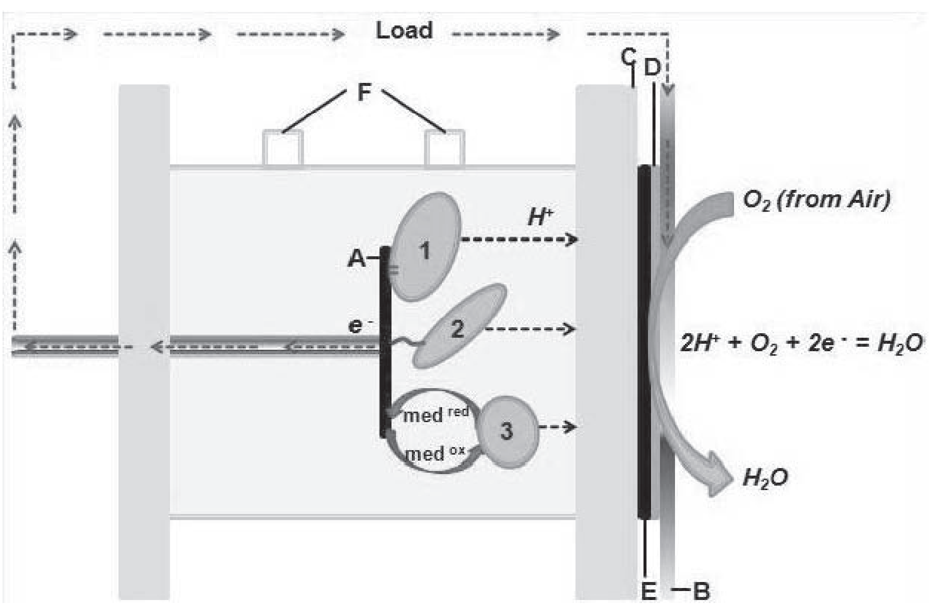
Development of a Microbial Fuel Cell for Sustainable Wastewater Treatment

Wastewater treatment is an energy intensive process to remove contaminants and protect the environment. While some wastewater treatment plants (WWTPs) recover a small portion of their energy demand through sludge handling processes, most of the useful energy available from wastewater remains unrecovered. Microbial Fuel Cells (MiFCs) that generate electricity are a promising renewable energy technology; however their low power densities hinder practical applicability.

This WERF study focused on two major research objectives to enhance the usefulness of MiFCs as a wastewater treatment technology that simultaneously allows for energy recovery. The first objective focused on using nitrifying cultures to capture energy associated with ammonia and other reduced nitrogen chemicals found in wastewaters. The second evaluated whether or not addition of carbon nanostructures (CNS) to stainless steel anodes in anaerobic microbial fuel cells enhanced electricity generation.

Results from the first research objective were not successful during this study, despite promising preliminary experiments. Researchers concluded that while the concept of a nitrifying MiFC remains attractive, due to the availability of treatment plant sidestreams with high ammonia concentration, the fact that significant electrical power was not produced by the nitrifying cultures tested suggests that the nitrifying microbial fuel cell is a technology that will require considerable research.



Description of Transport Processes: Microorganisms deposit electrons on the anode (A) by direct electron transfer via membrane bound cytochromes (1), through the use of bacterial nanowires (2) and/or through interaction with a chemical mediator (3). These electrons flow through the circuit to a conducting plate (B) where they meet with hydrogen ions migrating through the proton exchange membrane (C) and oxygen diffusing from the air through a gas diffusion layer (D) at the platinum catalyst layer (E) where they react to make water. Two sampling ports (F) allow for the addition/removal of fluid during batch operation.

Figure 1. Schematic of a Batch, Single-Chamber MiFC.

BENEFITS

- Demonstrates a microbial fuel cell with 500 mW/m^2 power density using anaerobic sludge with glucose as the electron donor.
- Demonstrates that CNS-enhanced anodes can lead to more than a 20-fold improvement in power generation in microbial fuel cells when compared to stainless steel anodes.

RELATED PRODUCTS

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However, findings from the second research objective were very promising. Those findings suggest that CNS-enhanced anodes, when coupled with more efficient MiFC designs than were used in this research, may enhance the possibility that MiFC technologies can move to commercial application.

Microbial Fuel Cell Basics

Microbial fuel cells operate by utilizing exoelectrogenic microorganisms (those which have the ability to transfer electrons outside of the cell) to transfer electrons from an electron donor in an influent feed to an insoluble electron acceptor (the anode). The multiple processes of electron transfer, as well as the path of electrons and protons in a batch, single-chamber MiFC are outlined in Figure 1.

Developing Microbial Fuel Cells

Key challenges to the development of microbial fuel cells include inefficiencies inherent in recovering energy from microbial metabolism (particularly carbon metabolism) and ineffective electron transfer processes between the bacteria and the anode. This project explored the prospects for constructing microaerobic nitrifying MiFCs which could exhibit advantages over carbon-based metabolism in particular applications (e.g., potential use in ammonia-rich recycle streams). In addition, this work evaluated nanostructure-enhanced anodes which have the potential to facilitate more efficient electron transfer for MiFCs because carbon nanostructures, such as nanofibers, possess outstanding conducting properties and increase the available surface area for cellular attachment.

The first phase of the work focused on the development of a nitrifying microbial fuel cell. Preliminary batch testing showed that power was produced by a nitrifying MiFC which used an anode structure coated with carbon nanostructures (CNS). However, a second round of testing with pure cultures of *Nitrosomonas europaea* exhibited very low power generation. Additional testing with mixed nitrifying cultures also exhibited very low power, though cells with CNS anodes continued to exhibit better performance than bare stainless steel anodes. After a final set of MiFC tests using mixed nitrifying cultures also demonstrated very low power, the research focus shifted to an investigation of MiFC anode enhancement using CNS coatings.

The second phase evaluated whether or not the addition of carbon nanostructures to stainless steel anodes in anaerobic microbial fuel cells enhanced electricity generation. The results demonstrated that CNS-coated anodes produced up to two orders of magnitude more power in anaerobic microbial fuel cells than in MiFCs with uncoated stainless steel anodes. The largest power density achieved in this study was 506 mW m^{-2}. The average maximum power density of the CNS-enhanced MiFCs using anaerobic sludge was 300 mW m^{-2}. In comparison, the average maximum power density of the MiFCs with uncoated anodes in the same experiments was only 13.7 mW m^{-2}, an almost 22-fold reduction. Electron microscopy showed that microorganisms were affiliated with the CNS-coated anodes to a much greater degree than the noncoated anodes. Sodium azide inhibition studies showed that active microorganisms were required to achieve enhanced power generation.

Study Conclusions

The researchers concluded that future studies into the use of CNS-coated anodes in MiFCs are needed to understand better the effect of CNS on power production. They suggest that CNS-enhanced anodes, when coupled with more efficient MiFC designs than were used in this research, may enhance the possibility that MiFC technologies can move to commercial application. They offer some suggestions for future research:

- Experiments should be done to determine the actual surface area of CNS-coated anodes so that the current and power density produced relative to uncoated anodes per unit true surface area can be compared.
- Research to understand how carbon nanostructures alter the surface properties of stainless steel mesh, and how these alterations enhance cellular attachment.

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