Feasibility of a Low-cost MFC for Electricity Generation and Wastewater Treatment

Kartik Sameer Madiraju
McGill University, Department of Chemical Engineering

Lack of electricity and clean water, in many developing parts of the world, has led to the development of unconventional technologies capable of addressing both issues simultaneously; a microbial fuel cell is one such technology. A microbial fuel cell (MFC) is a one or two-chamber device which uses microbes to produce a stable current. Although the concept of using bacteria to produce electricity has been identified many years ago, only recently has this technology been significantly developed for application as an alternative source of energy. In addition to electricity production, microbial fuel cells have also been shown to effectively oxidize organic matter in wastewater, thereby acting as treating agents. The range of power densities obtained from various MFC configurations is anywhere from 0.1 mW/m² to 1.5 W/m², however, an effective balance between costs and current output is required before MFCs can be used on a large scale. This study aims to compare the current producing ability of a low-cost MFC with a conventional MFC; this project also highlights the wastewater treating ability of a low-cost MFC.

Introduction

Clean water and stable sources of electricity are two major needs that must be addressed in the developing world. Conventional resources are polluting and finite, and therefore not ideal avenues to pursue. Research into alternative methods of electricity production in the form of clean fuels or electricity generating batteries led to the development of microbial fuel cells (MFC). A microbial fuel cell is a device typically comprised of two chambers separated by a cation (or proton)-selective membrane: an anode and a cathode chamber. In the anode chamber, microbes oxidize organic matter and release electrons and hydrogen ions. Electrons are transferred to the anode electrode and pass through a circuit, while the hydrogen ions diffuse through the cation-selective membrane into the cathode chamber. Electrons leaving the circuit recombine with hydrogen ions and oxygen in the cathode chamber to form water. An electric current can be measured by applying a resistance to the circuit.

Current and power production in an MFC can be optimized by using sophisticated electrodes (platinum-coated carbon cathodes, for example) and membrane materials (costly Nafion membranes) as well as using a very refined carbon source (i.e. glucose). However, to make this technology cost-effective and accessible to the developing world, it is necessary to reduce costs of building MFCs without sacrificing quality of wastewater treatment or current density. This study uses an uncharacterized sludge consortium as the catalyst releasing electrons in an MFC constructed with low-cost material. The benefit of using a sludge consortium is its ability to mimic the diversity of microbes found in real wastewater treatment systems, as well as those found in the soils of various environments. S. cerivisae and...
E. coli were used in a conventional MFC to compare the performance of an expensive, pure-culture based MFC with the low-cost MFC. These species were chosen for their ease of manipulation (for later studies).

In MFCs, microbes oxidize glucose as follows, a simple reaction which forms the basis of microbial fuel cells:[1]

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$$

Previously, artificial or natural mediators (neutral red, HNQ, methylene blue) were required to transfer electrons from the microbe to the anode surface, but after a breakthrough study it was shown that a mediator-less MFC could be operated as well.[2] The use of MFCs as a means of stable power generation is considered a potential source of energy in the long-term future. MFCs have been shown to produce power densities anywhere from less than 0.1 mW m$^{-2}$ (unit power per unit anode surface area)[3] to more than 1.5 W m$^{-2}$ using a variety of microbes.[2]

MFCs have also been especially designed for secondary applications such as wastewater treatment, in which wastewater is provided as the sole carbon source and electron donor.[4]

**Materials and Methods**

**Growth of S. cerivisiae and E. coli**

Cultures of E. coli K12 (ATCC) were grown at 30°C in batch mode in growth medium made by dissolving 10 g tryptone, 5 g NaCl and 5 g yeast extract in one liter distilled water. The pH was adjusted to seven and the medium autoclaved for 15-20 min. at 121°C. The yeast slurry comprised of 5 ml glucose solution (from an 18% (w/v) stock) along with 3 g of yeast dissolved in 9 ml 0.5 M phosphate buffer. Since E. coli requires an external mediator, this slurry was added to 5 ml of methylene blue before inoculation. Sludge consortiums used were obtained from a waste treatment plant (Ste-Catherine’s, Quebec, Canada) and were kept under anoxic conditions during storage (30°C, N$_2$ sparging) and operation (no headspace).

**Low-cost MFC Construction**

The bottom of a 1 L plastic bottle was cut off and the bottle was placed upside down; 165 holes were made ~10 cm from the spout and graphite rods (d = 0.7 mm, l = 6 mm) were inserted to serve as the anode. Above the anode holes, a 2 cm thick ring was left for a Scotch-Brite filter (emulating a cation-selective membrane), and another 8 cm ring for the cathode chamber. Sixty holes were made to serve as the cathode [Figure 1]. Both electrode areas were sealed with a conductive silver epoxy and copper wires were used for circuitry. Influent and effluent ports were also made for oxygenation and feeding. A Scotch-Brite sponge cut to the size of the bottle was inserted to separate the anode chamber from the cathode chamber. The cathode chamber was oxygenated and controlled using a rotameter. Tubing inserted into the anode chamber was used to feed a nutrient solution simulating wastewater. The volume of each chamber was 600 ml (cathode) and 200 ml (anode). The anode surface area was 0.225 m$^2$ and the cathode surface area was 0.08 m$^2$.

**Conventional MFC Construction**

The anode chamber was built by gluing a plastic endplate with screw holes to a plastic housing chamber fitted with a neoprene gasket. A moist, perforated cloth cut to fit the space within the neoprene gasket was placed on top of the gasket to prevent contact between the cation-selective membrane and carbon cloth electrode. A carbon

![Image of a low-cost MFC during operation](image.png)

**Figure 1: Setup of low-cost MFC during operation**
cloth was cut to fit inside the chamber with a small piece sticking out of the holes provided on top of the chamber. This strip was the piece for circuit completion. The same procedure was used to assemble the cathode component of the fuel cell. The fuel cell was screwed shut by placing both chambers together. Both electrodes had a surface area of 0.15 m².

Experimentation and Data Acquisition
The conventional MFC was always operated in batch mode while the low-cost MFC was operated continuously. All experiments were conducted using a resistance of 1000 Ω (previously determined using a polarization curve (data not shown)) A 5 mL headspace was always maintained in each chamber in the conventional MFC. No headspace was maintained in the anode chamber of the low-cost MFC to ensure anaerobic conditions. The cathode chamber of the conventional MFC contained 10 ml potassium ferricyanide to act as an electron acceptor, while in the low-cost MFC, oxygen served as the electron acceptor. HOBO Data Logger was used in measuring data. After each experiment, which was ~24 h in duration, the conventional fuel cell was cleaned and sterilized by irradiating under a UV lamp for 15 minutes. The electrodes were sterilized by rinsing with 1 M HCl followed by 1 M NaOH. The low-cost MFC was not cleaned throughout the study to emulate field conditions. All experiments were conducted at 21°C.

Chemical Oxygen Demand Measurements
To measure the reduction in organic matter, influent and effluent samples were taken from the low-cost MFC as well as jaggery, an unrefined complex carbon source used in the conventional MFC (to emulate the organic load of agricultural wastewaters). After diluting, each sample was boiled in sulfuric acid, silver sulfate, potassium dichromate and mercuric sulfate successively. The changing color of each sample due to this process was measured using a spectrophotometer at 620 nm. The absorption is correlated to Chemical Oxygen Demand (COD) (mg/L) using a calibration curve.

Results and Discussion
Low-Cost MFC Electricity Experiments
A baseline voltage of 0.01 mA was observed during the ~ eight day acclimatization period. After this, voltage increased exponentially to a peak of 0.17 mA by day 12 using nutrient solution as the sole feed. A glucose ‘spike’ on day 13 increased voltage output to 0.18 mA, which lasted a few hours before decreasing to a stable value of 0.15 mA [Figure 2]. The increase in voltage when a simple sugar was added indicated that the complexity of the nutrient solution played a role in the efficiency of electron transfer in the low-cost MFC. It is also possible that periodic cleaning of the electrodes would have resulted in higher voltage outputs. The maximum current density achieved in the low-cost MFC was 0.76 mA/ m².

Conventional MFC Electricity Experiments
Using glucose as a carbon source and yeast as the microbial catalyst, peak currents of 0.43 mA were observed within ~2h of inoculation. The low acclimatization period can be attributed to the use of a pure culture as well as the presence of a cation-selective membrane and catholyte. As the carbon source was depleted, current discharged to 0.1 mA within 20 h, and negligible amounts after 24 h. The peak current density achieved was 2.87 mA/ m² [Figure 3a]. When jaggery was used as the carbon source a lower peak current of 0.25 mA was observed, which discharged to 0.15 mA within 15 h, and negligible amounts in 24 hours [Figure 3b]. Rather than a depletion of the carbon source, the lower peak current can be attributed to the microbes being unable to digest the complex carbon source completely. Using jaggery, maximum current densities of 1.67 mA/ m² were achieved. When using E. coli as the microbial catalyst and glucose as the substrate, a peak current of 0.28 mA and peak current...
density of 1.87 mA/m² was achieved [Figure 3c].

To establish the need for live microbes to produce stable current, a pre-prepared yeast slurry was ‘broken’ (cells membranes were lysed) by passing the sample through a French Press at 20,000 psi; this mixture produced a stable peak current of ~0.2 mA using glucose as a substrate, followed by a decrease to almost nil within 12 h [Figure 4]. The peak current density was 1.3 mA/m². The stability of the current can be attributed to the lack of carbon source depletion; the current itself can be attributed to enzymes and cellular mediators shuttling electrons in solution, as well as bacterial residue that did not break under the French Press.

Finally, the sludge consortium was also tested in the conventional MFC using glucose as a substrate. A stable current of ~0.25 mA was achieved, with a peak of almost 0.3 mA [Figure 5]. This is almost twice as what was observed in the low-cost MFC, indicating the effect of a cation-selective membrane and catholyte in improving current outputs. The maximum current density achieved was 2 mA/m², also twice what was observed in the low-cost MFC.

**COD Experiments**

The influent sample and effluent sample from the low-cost MFC yielded COD readings of 83 mg/L and 67 mg/L respectively [Figure 6]. This corresponds to a 20% reduction in organic matter over 15 days continuous operation of the low-cost MFC. It is possible that a reintroduction of effluent into the fuel
cell as a feed would have further reduced the organic load of the solution, thereby treating the solution over repeated cycles. The influent COD is comparable to tertiary filtered municipal wastewater\(^5\) indicating that the low-cost MFC is an effective oxidizer of organic material. The COD of jaggery was 947 mg/L (data not shown), indicative of organic loads in less refined agricultural wastewaters.

**Conclusion**

The low-cost MFC has an average construction cost of $<10USD, while the conventional MFC cost more than 150USD (including catholyte and membrane costs). At 10% of the cost, assuming comparable electron transfer efficiencies, the low-cost MFC was able to achieve 25% of the peak current obtained using the conventional MFC. Use of salt bridge as a membrane and electrodes of higher surface area would have dramatically increased current outputs in the low-cost MFC, without affecting the cost greatly\(^6\). The materials used to build and operate the low-cost MFC are obviously not feasible in real-world applications, however, this study has shown that expensive materials are not necessary to achieve respectable current densities.

COD studies support the use of an MFC to perform one stage of wastewater treatment. A system involving several microfiltration and chlorination steps as well as MFC treatment is conceivable. Such a system could lead to the development of MFCs capable of self-powered wastewater treatment, in which wastewater influents serve as the source of carbon and microbial catalysts.

The benefit of using a sludge consortium as opposed to pure cultures extends beyond the economy: simple reactors can be constructed in developing regions by taking advantage of the microbial ecosystems present in lakes and agricultural soils. A low maintenance, low-cost MFC is ideal for providing cleaner water and stable electricity to developing regions. Obstacles that must be addressed before MFC technology is viable in real world applications include cleaning of electrode fouling, maintaining high current outputs under varying climates, and ensuring electrodes are colonized by the most efficient microbial catalysts.

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**References**


About the Author

Kartik Sameer Madiraju is an undergraduate student at McGill University, studying for his Bachelor’s of Engineering degree at the department of Chemical Engineering. He has competed for over five years in science competitions at all levels and currently organizes science fairs in his hometown of Montreal. When not conducting fuel cell research, Kartik enjoys playing badminton, cricket, and is an experienced debater.