Appendix 3b

Policy briefs: Executive summary

Introduction

It is generally recognized that institutions such as schools in rural communities in developing countries lack access to electricity produced in cost-effective and "climate friendly" ways. Microbial fuel cells (MFC) can directly produce electricity from biobased compounds in wastewater. An MFC is similar to a fuel cell with anode and cathode electrodes but the difference is that it uses bacteria to produce electrons from soluble biobased compounds (Figure 1). This project aims at developing the MFC with sustainable, efficient and cost effective components such as activated carbon, which is available in many developing countries produced from palm pernel shells.

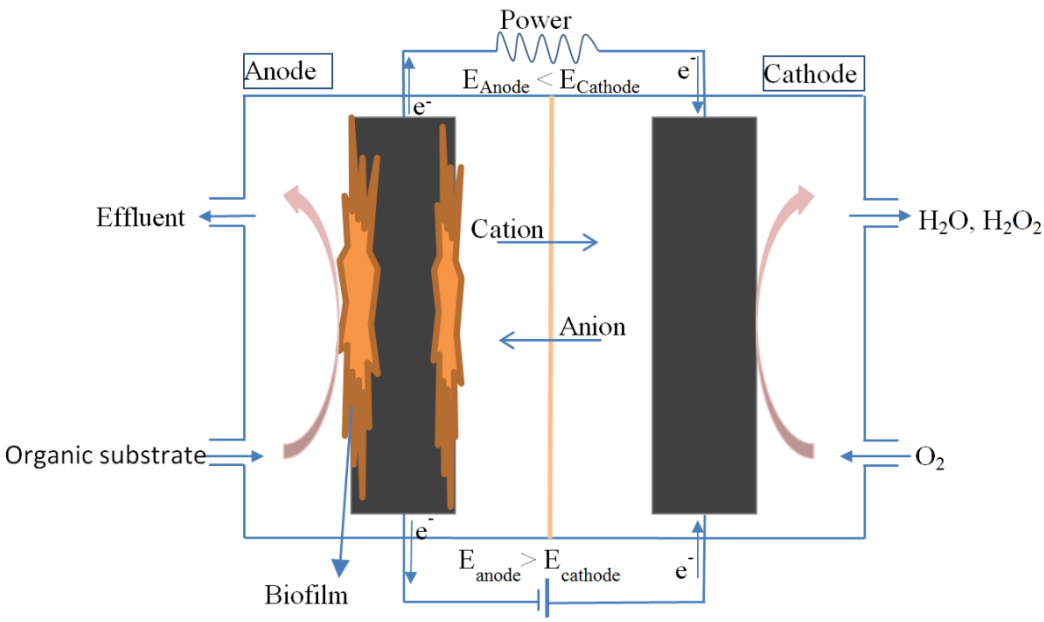

Figure 1. Schematic of microbial fuel cell system containing anaerobic bacteria formed biofilm in anode and chemical cathode.

The knowledge obtained in the project was that activated carbon can be used as electrode material and that clay is useful as separator replacing the membrane. Significant experience on MFC initiation and inoculation was in addition obtained enabling utilization of effluent from the bioethanol process. The main challenges were to make electrode granules by treatment of palm kernel shells and to achieve reproducible inoculation since wastewater contains mixed bacterial populations. The project enabled a more controlled MFC process by improved initiation and inoculation. It can become an aid to wastewater treatment and be an extra source of electricity. The locally produced electrode materials can enable local production of MFC reactors.

Background

A large number of rural communities in Sub Saharan Africa are not expected to have access to grid based electricity within the next 20 years. These communities will in many cases rely on mini-grid systems

supplied by electricity from diesel generators. In communities without access to grid electricity, lanterns and candles are used for lighting while charcoal and firewood is used for heating. Institutions such as schools which are not reached by minigrids can if affordable rely on solutions, such as solar PV systems. Recent research and development has pointed to a new interesting alternative to decentralised electricity production in terms of a microbial fuel cell (MFC), which can provide continuous supply of electricity, while at the same time purifying wastewater from the institution or household. The MFC can be made simple to maintain by usage of cheap materials such as activated carbon.

Electricity is obtained when there is a difference in charge between two electrodes. This can occur in lake sediments by bacterial release of electrons from degraded organic matter. This principle is used in a microbial fuel cell with bacteria colonized on the anode electrode. The electrons then pass through an electrical circuit to the cathode and are here consumed by utilization of oxygen (Figure 1). The chemical reactions that occur in the anode and cathode are shown below.

Anode reaction with xylose: $C_5H_{10}O_5 + 5H_2O \rightarrow 5CO_2 + 20e^- + 20H^+$

Cathode reaction: $O_2 + 4e^- + 4H+ \rightarrow 2H_2O$

The hypothesis of the project is that sustainable MFCs can be established by usage of activated carbon for the anode and cathode, which can be produced from palm kernel shells by local enterprises in Ghana.

Results

<u>WP 1 Reactor design:</u> Three cathode types using dissolved oxygen (DOCs), ferricyanide (FeCs) and air (AiCs) were assessed to improve the reactor design. Electricity generation was evaluated by quantifying current generation response to external resistance. At the lowest resistance of 27 Ohm, FeC-MFC generated highest electrical current of 1630 mA/m^2 followed by AiC-MFC with 802 mA/m^2 and DOC-MFC with 184 mA/m^2. The AiC-MFC was however most sustainable since it is catalysis based in contrast to ferricyanide with the FeC-MFC (Figure 2).

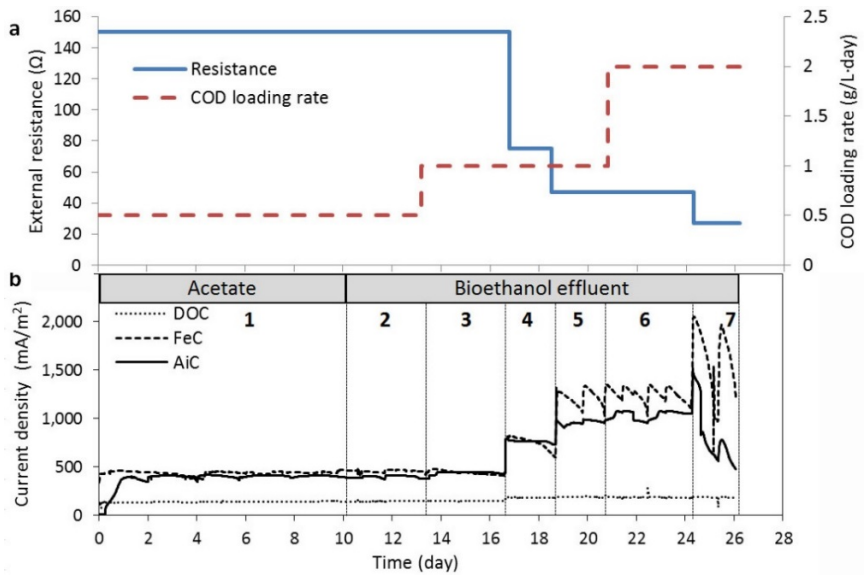

*Figure 2. Continuous MFC processes experiment: **a**) External resistance (——, left Y-axis) and chemical oxygen demand load (- - - -, right axis) applied during the 7 periods for the total 26 days of experiment; **b**) Current density responses recorded for the MFCs with different cathode types: DOC, FeC and AiC, during the 26 days of experiment.*

WP 2 Bacterial inoculation: The MFC process requires anode electrode biofilm with a microbial community rich in electrogenic bacteria. Usually this microbial community is established from inoculation with naturally occurring anaerobic inocula. The microbial community was optimized by testing three inocula including domestic wastewater, lake sediment (LS) and biogas sludge. The electrogenic bacterium *Geobacter sulfurreducens* was identified in all inocula and its abundance was positively correlated to the MFC performance. The LS inoculated MFCs showed highest abundance of *G. sulfurreducens* (18%), maximum current density and highest electricity yield (coulombic efficiency) (29%). The data obtained improved the understanding of the positive link between electrogenic bacteria abundance and electricity generation.

WP 3 Substrate: This study assessed electricity generation and anode electrode microbial community composition in response to initial substrate. The MFCs initially fed with acetate showed shorter initiation time (1 day) and higher cell voltage (634 mV) than those initially fed with xylose. The acetate-initiated MFCs exhibited longer adaptation time (21 h) when the substrate was switched to bioethanol effluent (BE) in the acetate-initiated MFCs. The microbial community in acetate-initiated MFCs contained most electrogenic bacteria (14%) including *G. sulfurreducens*. After switching the substrate to BE, the microbial community became more diverse. The initial substrate thereby affected the power generation. Acetate-initiated MFCs showed best performance in utilizing BE and BE could not be used in the initiation phase.

WP 4 Cheap electrode materials: This study introduced a simple and efficient electrode material in the form of palm kernel shell activated carbon (AC). This can be produced in rural communities to improve the viability of MFCs. The maximum voltage and power density obtained (under 1000 Ω load) using an H-shaped MFC with AC as both anode and cathode electrode material was 0.66 V and 1.74 W/m^3, respectively. The power generated with AC was as high as 86% of the value obtained with the extensively used and imported carbon paper which proves that there is a great potential.

Conclusions

The initiation of a microbial fuel cell (MFC) is important for the final power generation. If complex substrates such as bioethanol effluent are used, it is therefore required to start with simple substrates such as acetate. Inoculum is important due to varied presence of electrogenic bacteria such as *G. Sulfureducens*, which need to form a biofilm on the anode electrode. Optimal cathode electrode materials can in addition improve the performance. Membrane electrode assembly gave the best performance due to low internal resistance. For use in Ghana it is optimal to use locally obtained electrode materials such as activated carbon since it gives local employment and is not imported. The project forms thereby the foundation for establishment of an upscaled MFC in Ghana useful for rural communities with poor grid connection.

Implications

If the MFC process shall be implemented in Ghana it requires much teaching and supervision on university level. The education will enable utilization and improvement of the technology in Ghana. Since the MFC process also depends on inoculation it is important to write protocols explaining how to assemble reactors, initiate and use the MFC technology. The government and community leaders also need information about how to implement the technology through meetings with professors on the topic from Ghanaian universities.

Recommendations

1. Up-scaled MFC units should be developed and tested at the research level before dissemination to schools and communities
2. Establish university courses in MFC technology.
3. Educate high school teachers in MFC technology and renewable energy.
4. Collaborate with electricians and the electricity sector to implement the MFC technology.
5. Rural areas have low education levels and need significant training to learn using the technology.