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Integrating bioelectrochemical systems with anaerobic digestion

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Abstract: Microbial bioelectrochemical systems could potentially be used to control or monitor anaerobic digesters. In this study, we investigated two anaerobic reactors with integrated electrodes. In the active reactor, the electrodes were connected to a power source that allowed current to flow and oxidation or reduction reactions to take place at the electrode surfaces. In the control reactor, the electrodes were left in open circuit. We found that reactions on the electrodes did not affect the overall performance of the anaerobic digestion process; however, there was a correlation between the generated current and the state of the reactor. Voltammetry tests also suggested that electrochemically active microbial communities were enriched on both the anode and cathode electrodes in the active reactor.

Keywords: biogas; microbial electrolysis cell; wastewater treatment

Introduction

Currently, anaerobic digesters are typically underutilized in terms of organic loading rate in order to prevent instability. Accumulation of organic acids which lead to inhibition of methanogens can occur in an unstable reactor. A microbial bioelectrochemical systems (BES) could potentially be used for control of the digester by oxidizing excess organic acids at the anode (Bond and Lovley, 2003) and e.g. stimulate hydrogenotrophic methanogens at the cathode (Villano et al., 2010). A BES could potentially also be used to monitor the biological state of the digester in real-time. The output of a BES is either a current or a voltage signal, which is dependent on biological reactions taking place on the anode and cathode electrodes. Voltage and current are very easy to measure in real-time.

The goal of this project is to investigate the integration of BESs with anaerobic reactors. Will the BES affect the performance of the reactor? Is there a correlation between the current generation in the BES and the state of the anaerobic reactor? Will electrochemically active microbial communities develop on both the anode and cathode electrodes?

Material and Methods

Two 1-litre batch-fed anaerobic reactors were set up with two carbon felt electrodes (8x6x0.2 cm^3) submerged in each. The reactors were fed with a nutrient medium containing glucose and bicarbonate. In one of the reactors (*"The active reactor"*), a voltage of 0.8 V was applied over the electrodes. In the other reactor (*"The control reactor"*) the electrodes were left in open circuit. In Run 1, the reactors were fed with 39 mM and 42 mM bicarbonate buffer. In Run 2, the bicarbonate buffer concentration was increased to 83 mM.

Results and Conclusions

At an applied voltage of 0.8 V, a current of up to approximately 10 mA was flowing between the anode and cathode electrodes in the active reactor. The current did not seem to have an effect on the performance of the reactor. As shown in Figure 1, the time profiles of gas production rate, DOC and VFA concentrations, and pH were nearly identical in the active reactor and the control reactor. If VFAs are oxidized at the anode and methane is generated at the cathode, a current of 10 mA corresponds to a VFA oxidation rate of 27 mg/L-d of acetate-carbon and 1.1 mL/h of methane gas production. This is low compared to the total VFA concentration and gas production rate in the reactors and explains why the BES did not have an effect on the performance of the anaerobic reactor.

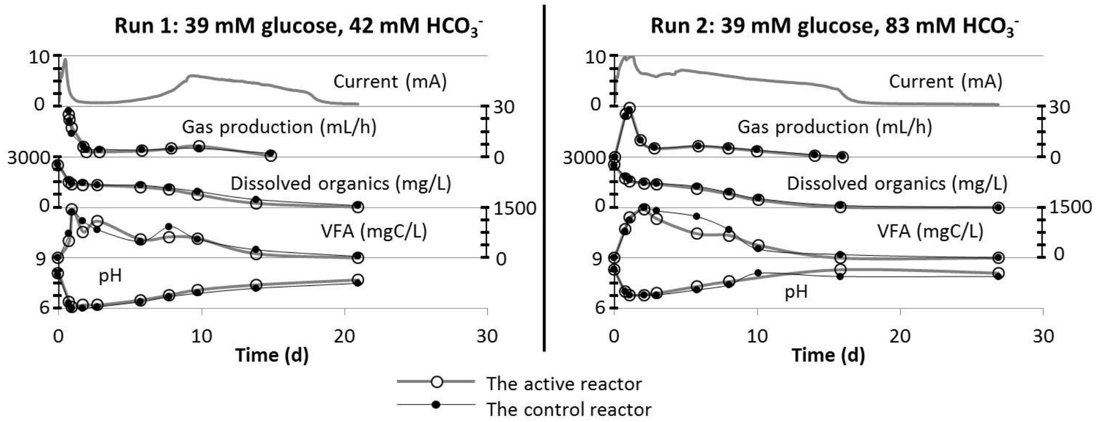

Figure 1. Current, gas production, dissolved organic carbon concentration, volatile fatty acid concentration, and pH in the two anaerobic reactors during Run 1 and 2.

The current generated by the BES was correlated to the state of the anaerobic reactors (Figure 1). Directly after feeding, there is a peak in current which correlates with a peak in gas production in the reactors. After the initial peak, there is a drop in current which correlates with an accumulation of VFAs and a drop in pH in the reactors. The drop in pH and current is more pronounced in Run 1, which had a lower bicarbonate buffer concentration. In the end of the runs, a significant drop in current correlates with depletion of dissolved organics in the reactors.

The electrodes submerged in the active reactor were compared to those submerged in the control reactor using linear sweep voltammetry. The open-circuit potentials were around -0.2 V vs the standard hydrogen electrode for all electrodes in both reactors. In the active reactor the cathode electrode exhibited increasing currents at potentials below -0.3 V whereas a potential lower than -0.85 V was required in the control reactor. The anode electrode showed increasing current at potentials above -0.2 V in the active reactor whereas the current remained low at potentials up to +0.3 V in the control reactor. This suggests that electrochemically active microbial communities catalysing both anode and cathode reactions were enriched on the electrodes in the active reactor but not in the control reactor.

References

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Integrating Bioelectrochemical Systems with Anaerobic Digestion

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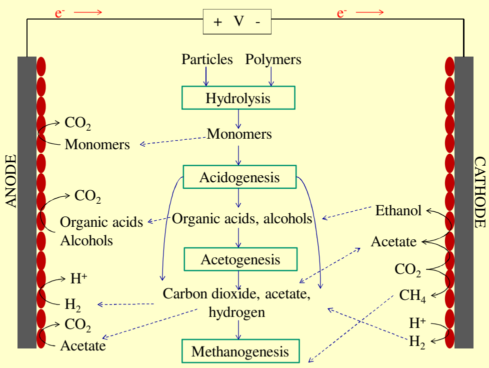
1. Introduction

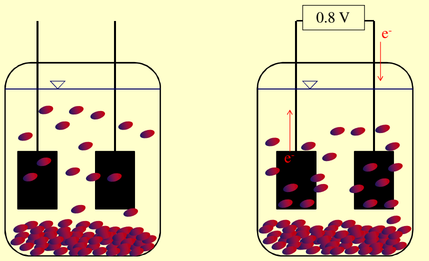
Although anaerobic digestion is an effective technology for converting organic waste into biogas, it is sensitive to process upsets.
Can a bioelectrochemical system be used to control or monitor an anaerobic digester?



A bioelectrochemical system could potentially interact with the anaerobic digestion process in many different ways. Some of the reactions that could take place are illustrated above.

2. Methods

Two anaerobic digesters with integrated electrodes were operated in parallel and fed batchwise with a glucose-containing medium.

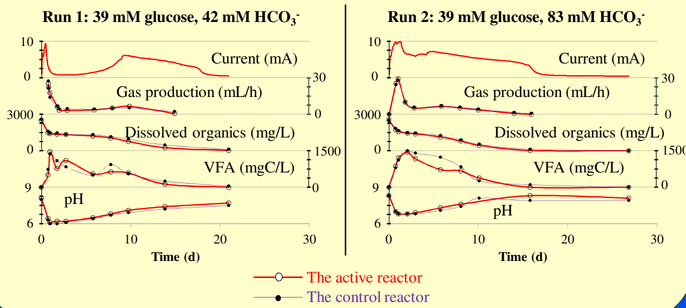


Control reactor (open circuit)   *Active reactor (0.8 V applied voltage)*

Total gas production, volatile fatty acids concentrations, dissolved organic carbon concentration, and current were measured. Electrodes in the two reactors were characterized using voltammetry. The electrodes were made of carbon felt, each with a surface area of 102 cm^2.
The reactors were 1 L in size and operated for a total of 9 months. Results from two batch runs carried out during the last two months of operation are presented here.

3. Results

The performance of the two reactors were investigated in two batch runs with different concentration of bicarbonate buffer.

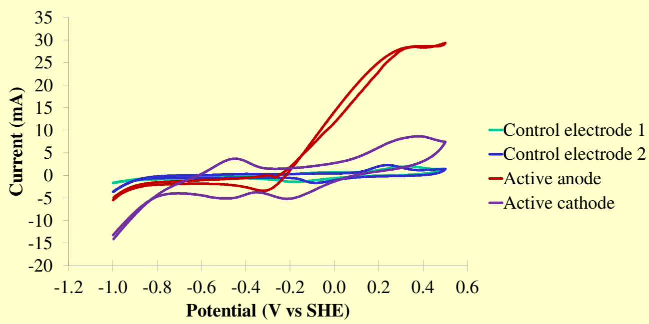


The time profiles of gas production rate, dissolved organic carbon and VFA concentrations, and pH were nearly identical in the two reactors.
This means that bioelectrochemical activity did not affect the anaerobic digesiton process in the active reactor.
On the other hand, the current profiles seemed affected by the conditions in the reactor:

- Peak current corresponded with peak gas production.
- The drop following the initial peak corresponded with a drop in pH.
- The increase in current after the initial drop corresponded with increasing pH, gas production rate, and consumption of VFAs (Run 1).
- Finally, as the dissolved organics were consumed in the reactor, the current approached zero.

This means that the anaerobic digestion process strongly affected the bioelectrochemical activity in the active reactor.

Cyclic voltammograms of the electrodes in both reactors are shown below. At high potentials, the anode in the active reactor shows high anodic current (positive). At low potentials, the cathode in the active reactor shows high cathodic current (negative). ***The voltammograms suggest that microorganisms in the active reactor catalyze electrochemical reactions on both the anode and cathode.***



4. Discussion and conclusions

Theoretically, a bioelectrochemical system could be used to **control** an anaerobic digester by e.g. oxidizing excess VFAs on the anode and contributing to methane generation at the cathode. It could also be used to **monitor** the state of the digester, e.g. a declining current could warn that something is wrong.
In this experiment, when two electrodes were placed in an anaerobic digester and a voltage of 0.8 V was applied across the electrodes, bioelectrochemical activity developed on both electrodes. The reactions on the electrodes **did not control** the digestion process because the generated current (10 mA corresponding to an oxidation rate of 27 mg/L.d of acetate-C) was low in comparison to the organics concentration in the reactor (up to 1500 mg/L VFA-C).
However, the current varied depending on the conditions in the reactor and could therefore potentially be used to **monitor** anaerobic digestion. The magnitude of the current correlated well with gas production rate. Concentration of organics and pH both affected the current and the gas production rate.

Acknowledgements

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