Treating Swine and Municipal Wastewater with Microbial Fuel Cell Technology

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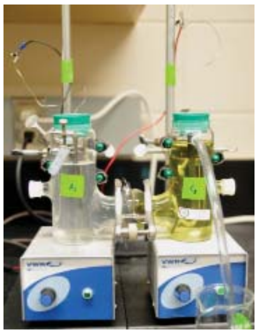

Figure 1. MFC in operation under batch conditions

SUMMARY
Wastewater generated in the agriculture sector contain organic and nitrogenous compounds which represent a valuable source of energy that could be harnessed to offset the energy required for wastewater treatment. The potential use of microbial fuel cell (MFC) technology for treatment of agricultural wastewater was evaluated. Using model compounds (i.e., lactate, acetate, phenol), it was shown that treatment of organic and nitrogenous compounds with concomitant generation of energy can be achieved successfully in microbial fuel cells, with biodegradation rates in continuous mode MFCs significantly higher than in batch systems. Biodegradability of the organic compounds influenced the open circuit potential (OCP), electrical current and power generation, which were higher in continuously operated MFCs. The possibility of biological removal of ammonia and nitrite (nitrification and nitritation processes) in the MFC systems was also demonstrated.

INTRODUCTION
Wastewater can contain organic and nitrogenous compounds (i.e. ammonia) and produced as a result of agricultural activities, including those generated in livestock operations and food processing plants. Conventional treatment processes are costly and livestock producers are increasingly facing challenges with cost of production and environmental impacts of land application of livestock wastewater. As a result there is great interest to find alternatives for the treatment and safe disposal of waste streams and if possible, offset the associated cost through generation of energy.

Treatment of wastewater requires a considerable amount of energy. Organic and nitrogenous contaminants in the wastewater represent a source of energy that if harnessed could offset the energy required for wastewater treatment and even produce a positive net energy.

This project examined the potential use of microbial fuel cell technology in treatment of agricultural wastewater containing organic and nitrogenous compounds. The long term objective was to develop a biotechnology-based treatment of agricultural wastewater to reduce or eliminate the pollutants and potentially convert the energy stored in the organic or nitrogenous compounds into electricity. Specific objectives of this project were to treat wastewater contaminated with organic compounds using microbial fuel cells (MFC) with a biological anode and a chemical cathode, and to develop a complete fuel cell with a bioanode for the removal of ammonia and organics and a biocathode for the treatment of actual wastewaters from a swine barn and municipal wastewater treatment facility.

RESULTS AND DISCUSSION
MFC configuration and operation
Experiments were conducted using H-type configuration fuel cells (Logan, 2008) shown in Figure 1. The two fuel cell chambers (anode and cathode chambers) were separated by a Nafion (NE-1035) high exchange capacity proton exchange membrane (PEM). Electrodes made of graphite rods were fixed into each chamber and chrome wires connect the chambers to complete the circuit. *Pseudomonas putida* was used as the biocatalyst for the MFC.

Two short-chain fatty acids, specifically lactate and acetate at concentrations of 1,000, 2,500 and 5,000 ppm, were tested in an H-type MFC under batch conditions. Figure 2 shows the results in terms of open circuit potential, biomass growth and substrate removal for the tests with 1,000 ppm lactate. It was observed that as the biomass concentration (represented by OD) increased, the concentration of organic substrate decreased over time. As expected, *P. putida* consumed the available organic substrate for their maintenance and growth. With the degradation of lactate, P. putida produced acetate at the same time and then consumed it as well once lactate was depleted. The removal of organic substrate and the corresponding increase in biomass was related to increase in the open circuit potential (OCP) as the bacteria started to grow and degrade the organic substrate.

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Potential, current and power measurements

Under batch conditions, the maximum OCP obtained with lactate ranged from 505-563 mV, while with acetate the range was 393-538 mV, and with phenol was 361-420 mV. For the continuous system, the highest OCP obtained was 705 mV, which was considerably higher compared to that in the batch system. The power and current generated per surface area of the anode electrode were measured in all the tests. In the batch systems using a single graphite rod electrode, the highest power and current densities obtained with lactate as substrate were 3.3 mW/m^2 and 48.2 mA/m^2, while with acetate the values were 1.1 mW/m^2 and 29.5 mA/m^2, and with phenol they were 2.0 mW/m^2 and 36.9 mA/m^2, respectively. In the corresponding continuous system with lactate, the highest power and current densities achieved were 8.1 mW/m^2 and 43 mA/m^2, respectively. The power and current output measured from the continuous system were generally higher compared to those obtained from the batch system.

Wastewater treatment in MFC

Batch trials using wastewater as substrate in the MFC were also conducted. The reactor was filled with 250 mL of municipal or diluted swine wastewater. Concentration of organics in the wastewater was measured in terms of chemical oxygen demand (COD) using Hach COD reactor digestion method. COD removal of municipal wastewater was 75% and physical appearance of wastewater was clearer (less turbid) after the test period of approximately 165 h. For swine wastewater, initial COD readings were significantly high (> 6000 ppm) hence, a 1:5 dilution with McKinney`s medium was done to make a less concentrated substrate of around 2200 ppm COD. As shown in Figure 3, removal of organics from swine wastewater was considerably fast (<12 h). The amount of COD removed was 73%. Swine wastewater has been chosen as substrate for subsequent MFC experiments, anticipating potentially larger range for removal of organics.

Microbial fuel cells used for ammonia and nitrite removal

Medium containing 7, 18 and 36 mM NH_4^+-N were tested to evaluate the effect of ammonia concentration on oxidation of ammonia (nitrification) and generation of electricity. A number of batch runs was carried out using resazurin as an electron mediator. Results clearly demonstrated the possibility of biological oxidation of ammonia and nitrite (nitrification and nitritation processes) in MFC systems. In the presence of resazurin as an electron mediator, the oxidation of ammonia was much faster, though the nitrification characteristics (oxidation of ammonia to nitrite and consequently to nitrate) did not change. Nitrite oxidation in the MFC was much more consistent and reproducible compared to ammonia. In sequential batch runs with either ammonia or nitrite, the performance of the MFC improved after consecutive trials to the point where the oxidation rate was comparable to that in an aerated conventional reactor. This highlights the importance of maintaining the microbial population in the MFC and repeated use of cells.

CONCLUSION

Results revealed that treatment of organic and nitrogenous compounds with concomitant generation of energy can be achieved successfully in microbial fuel cell type bioreactors. In continuously operated MFC system, the removal rate of lactate, phenol or combination of lactate and phenol were significantly higher than that in the batch systems regardless of type of electrode (single graphite rod vs. granular graphite), while performance of the MFCs packed with graphite granules were much better than MFCs with single rod electrode.

The biodegradation (removal) of lactate, acetate and phenol was accompanied by rise in open circuit potential (OCP) and current generation, with the extent of generated power being influenced by biodegradability of the organic compound. The OCP, power and current generation were higher in the continuously operated MFCs when compared to those obtained in the batch MFCs. Experiments with municipal and swine wastewaters were successful, indicating the potential use of MFCs for treating wastewater. Investigating the biological removal of ammonia in bioreactors provided valuable biokinetic data regarding the process of nitrification.

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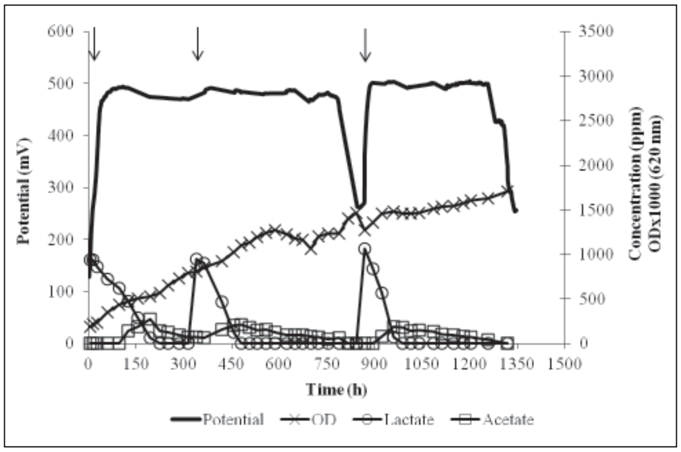

Figure 2. Open circuit potential and organic degradation in an MFC by P. putida fed with 1000 ppm lactate. Arrows indicate the time of lactate addition.

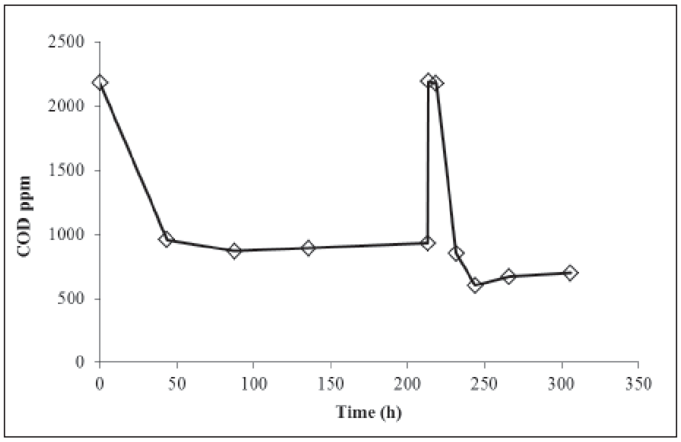

Figure 3. Removal of organic compounds in swine wastewater operated under batch conditions.