Hybrid Anaerobic Digester-Microbial Fuel Cell for Waste Water Treatment

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Here report results of a phase I project funded by the Bill and Melinda Gates Foundation.The ultimate goal of the project is to catalyze effective treatment of human waste in developing communities to reduce the burden of diarrheal disease and childhood mortality. Successful treatment methods must 1) realize human waste as a resource, the treatment of which yields valuable products, thereby incentivizing waste treatment, 2) be appropriate-level technology, whereby the apparatus can be constructed from low-cost, mostly locally sourced materials and maintained by trained local residents, 3) realize a high rate of decentralized sludge treatment/elimination, and 4) occupy a small footprint. To achieve this goal, the University of Maryland and the US Naval Research Laboratory set out to determine feasibility of primary waste treatment using laboratory-scale (1.5 L) anaerobic digesters (AD) and secondary treatment using laboratory-scale (0.1 L) microbial fuel cells (MFC). The results indicate the capability to generate electrical power with the MFCs (7 mW/L) even after high levels of methane-enriched biogas was extracted by AD (0.2–0.3 L CH_4 per kg COD), resulting in an effluent that meets international standards for safe environmental discharge (e.g. < 300 mg BOD/L, < 105 CFU/100 mL), with nitrogen levels appropriate for agricultural application (1-1.2 g NH_3-N/L).

Biogas potential, evaluated for 40 identical 1.5 L batch AD reactors over the course of four trials, produced on average 250 m^3 methane per kg COD removed, equivalent to 60% conversion efficiency (industry standard). Approximately 80% of the biogas was captured within the first 5-days of digestion, suggesting that standard retention times for AD (e.g. 30-d at 30℃) can be s ignificantly reduced without sacrificing energy. Removal of organic matter, in all trials, was masked by the addition of recalcitrant material associated with the methanogenic inoculum (previously digested domestic wastewater). Greater than 99% removal of fecal coliforms, however, was achieved by Day 5, supporting the hypothesis that greater removal of organics (COD, TS, VS) can be achieved in flow-through, pilot systems. By Day 10 of digestion, effluent fecal coliform levels were < 40 MPN/100 mL, meeting international regulatory guidelines for safe discharge (< 105 CFU/100 mL). Nitrogen was solubilized to ammonia (NH_3-N) during digestion, with an effluent containing 1-1.2 g NH_3-N/L, which is appropriate as a high-value organic fertilizer. Importantly, ammonia concentrations in the 30-day digestate neared inhibitory levels for methanogenic organisms, and thus, the digestion period will be kept less than 30 days for the field-scale treatments, with the additional treatment provided by the MFC. When scaling-up the AD system, considerations should be given to the addition of secondary carbon sources, such as e.g. food scraps, leaves and/or urine diversion efforts to increase the C:N ratio and avoid ammonia inhibition.

By employing MFC as secondary treatment, we furthered waste treatment and increased energy capture. Our 0.1 L bench scale MFCs produced approximately 10 W/m^3 of power (equivalent current of 50-90 A/m^3) when fed with digested latrine sludge. Undigested sludge yielded higher power (~14 W/m^3; 65 A/m^3). Importantly though, in all cases the MFC power was cathode limited. When the MFCs were operated in a 3-electrode configuration (no power output) with a fixed anode potential, we were able to generate > 200 A/m^3 from undigested sludge, which, to date, represents the upper limit of current production from waste-fed MFCs.

It is increasingly recognized that the oxygen reduction reaction (ORR) at MFC cathodes is the greatest impediment to scaling and implementation of MFCs. The circum-neutral pH and temperatures required for biological growth are at odds with the thermodynamics of cathodic oxygen reduction, and result in dramatic reductions in cathode potential, and thus in MFC voltage and power. Known oxygen reduction catalysts (e.g. platinum) are easily fouled by organic waste by-products (e.g. hydrogen sulfide), and further, are not suitable for scalable cost-appropriate systems. We performed over 20 iterations of cathode designs in the Phase I project. The addition of low cost high-surface area graphite granules to the cathodic chamber tripled power outputs. Even then the overall MFC power output was still constrained by the cathode reaction suggesting that the ratio of anode-to-cathode surface area can be further optimized in the Phase II project. Since completing the Phase I project, we subsequently evaluated the use of a low-cost manganese oxide (MnO) catalyst to further accelerate ORR at circum-neutral pH, and have found it effective at reducing the cathode overpotential at low current/power densities (i.e. dilute waste streams). Additional testing is underway to optimize MnO loading rates and cathode configurations for high-current (i.e. high-strength) wastes, such as latrine sludge.