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Anaerobic digestion of food waste through the operation of a mesophilic two-phase pilot scale digester – Assessment of variable loadings on system performance

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HIGHLIGHTS

- Two years of operational data of the pilot anaerobic digester system was used.
- 2-Stage digestion for food waste treatment was stable during highly variable loading.
- Methane yield from 2-stage operation was higher than for single stage digestion.

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ABSTRACT

Single and two-phase operations were compared at mesophilic operating conditions using a digester system consisting of three 5-m^3 reactors treating food waste generated daily within the university campus kitchens. When normalizing the methane production to the daily feedstock characteristics, significantly greater methane was produced during two-phase mesophilic digestion compared to the single-stage operation (methane yield of 380 vs 446-L CH_4 kg VS^{-1}; 359 vs 481-L CH_4 kg COD^{-1} removed for single vs two stage operation). The fermentation reactor could be maintained reliably even under very low loading rates (0.79 ± 0.16 kg COD m^{-3} d^{-1}) maintaining a steady state pH of 5.2.

1. Introduction

Disposal of municipal solid waste (MSW) is a growing concern. Between 1988 and 2005, the number of landfills in the U.S. decreased by 380% (EPA, 2006). Of the overall MSW, 13.9% or approximately 35 million tons per year generated in the U.S., is classified as organic food waste (EPA, 2012). Biodegrading organic material in landfills produces greenhouse gases such as methane, resulting in the third largest human-generated methane source after fossil fuel use and agriculture (EPA and Environment Canada, 2013). In addition, the food waste that is currently sent to landfills holds a significant amount of energy that can be recovered using technologies such as anaerobic digestion (AD).

AD systems are capital intensive and their economic viability heavily depends on revenue models for generated biogas, solids, and liquid effluent. Food waste, which has high energy content, could significantly improve the biogas yield of AD systems. However, the high solids content and chemical composition of mixed food waste can pose challenges for AD process operation (Gosh et al., 1985). For single stage systems, even when fed only intermittently, high strength waste may lead to digester overloading, acidification and reactor upset. Alternatively, two stage AD systems may be less susceptible to system overloading. Two-stage AD systems separate acid fermentation and methanogenesis for the purpose of optimizing reactor conditions for the distinctly different microbes that carry out these functions. The first stage (acid fermentation) is maintained at low pH and short hydraulic residence times (HRT; 2–3 days) resulting in a washout of acid-consuming organisms. The second stage (methanogenesis) is operated at HRT of 20–30 days and pH of 6–8, facilitating proliferation of slow-growing methanogenic archaea. Applications of two-stage anaerobic digestion systems for food waste have proven effective

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for resolving the pH inhibition issues of one-stage systems (Cho et al., 1995; Dinsdale et al., 2000; Klocke et al., 2008; Shin et al., 2010; Li et al., 2011; Shen et al., 2013). This process was first proposed more than 20 years ago; yet, very few two-stage digester systems are currently in operation. While the net benefit of improved process efficiency of this system may not offset the extra complexity for low-strength waste municipal solids treatment, the two-stage AD process may provide unique benefits when treating high strength waste such as food waste.

In addition to problems associated with high- vs low-strength waste, variable loading to AD systems is also challenging. For single-stage systems, shock loading (or transient loading) may cause acidification of the digester. As the fermentation reactor of the two-stage AD system is controlled through the washout of acid consuming organisms, low loading conditions may result in prolific growth of acid consuming bacteria in the fermentation reactor causing an increase in pH. This will ultimately result in the reactor operating, essentially, as a series of single staged AD reactors. It is unclear how long a 2-staged AD process can be maintained when exposed to transient loading rates.

The goal of this research was to evaluate single and two staged AD operation for food waste generated at Clarkson University. Clarkson is a private university with 3000 students serving 3700 meals per day during the academic year and approximately 500 meals during the summer months. Given the size of the university, the amount and composition of food waste varies significantly temporarily depending on whether classes are in session, with a peaking factor relative to the mean of greater than seven (Fig. 1). The hypothesis of this research is that shock loadings are rapidly converted to organic acids within the first AD stage, while under low loading conditions, the low pH in the established fermentation reactor will prevent the growth of acid consuming organisms. Overall, we hypothesize that the 2-stage AD process for the treatment of high strength waste exposed to transient loading will be superior over the single-stage system in terms of process stability and biogas yield.

The research took advantage of a food digester system installed on the Clarkson University campus. Kitchen waste was collected over the past 2 years (Fig. 1 shows the last 500 days) and fed to the AD system. The digester was initially operated as a single stage system and switched to 2-staged operation more than one year ago. Results will compare the system performance of the two modes of operation under the transient loading conditions.

2. Experimental methods

2.1. Materials and analytical methods

Food waste generated in three kitchens was collected daily and fed to the digester system. The food waste was collected by the kitchen staff and stored at 4 °C in a walk in refrigerator and collected on a daily basis (every 24 h). Total solids (TS) and volatile solids (VS) were measured according to standard methods (APHA et al., 2012). Chemical oxygen demand (COD) was measured with a Hach DR2700 instrument (Hach, Loveland, CO) using Hach digestion solution vials for COD (20-mg L^{-1} to 1500-mg L^{-1}) following the manufacturer's protocol. Five replicates were analyzed for COD measurements while triplicates were used for TS/VS analyses. Sample variance between replicates was within 15% of the mean for all sampling events. Total volatile fatty acid (VFA) concentrations were measured following standard methods (APHA et al., 2012) and the Esterification method, Hach Method 10240 (Hach, Loveland, CO). The pH of the samples was measured using a VWR symphony pH meter (VWR, Radnor, PA).

2.2. Digester system and operation

The system consists of a grinder (Shred-Tech, Cambridge, Ontario CA), ribbon blender and three neoprene-insulated 5-m^3 reactors that can be operated in series, individually, or in parallel. A fourth 5.7-m^3 polyethylene tank is used for holding the digester effluent until it can be extracted for use as fertilizer.

A Watson-Marlow SPX40 hose pump (Watson-Marlow, Wilmington MA) was used to transfer the diluted and shredded food waste from a ribbon blender to the first-stage reactor. Each of the reactors were hydraulically mixed using a Moyno 500 grinder pump (Moyno, Springfield OH). Reactor temperatures were thermostatically controlled. Biogas flow was quantified using an AC250 gas meter (Elster, Raleigh, NC). Methane content in the biogas was measured continuously using an inline sensor (BlueSens, Herten, Germany).

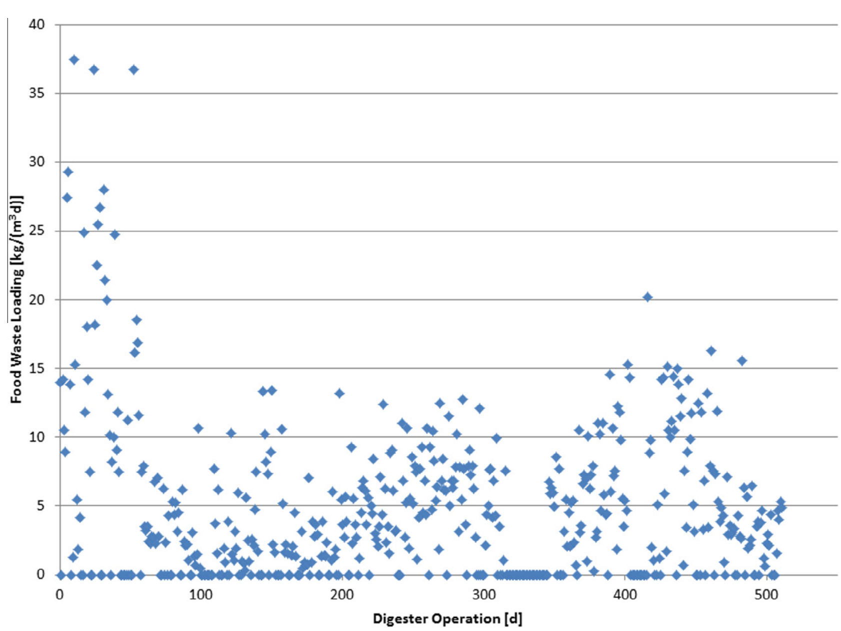

Fig. 1. Daily food waste loading per reactor liquid volume for Clarkson University food digester from February 2013 through June 2014.

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