Waste Management 34 (2014) 1289–1298

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

High solids co-digestion of food and landscape waste and the potential for ammonia toxicity

Margaret F. Drennan, Thomas D. DiStefano *

Department of Civil & Environmental Engineering, Bucknell University, Lewisburg, PA 17837, USA

ARTICLE INFO

Article history:
Received 14 November 2013
Accepted 27 March 2014
Available online 22 April 2014

Keywords:
High-solids anaerobic co-digestion
Waste biodegradability
Food waste
Landscape waste
Ammonia inhibition

ABSTRACT

A pilot-scale study was completed to determine the feasibility of high-solids anaerobic digestion (HSAD) of a mixture of food and landscape wastes at a university in central Pennsylvania (USA). HSAD was stable at low loadings (2 g COD/L-day), but developed inhibitory ammonia concentrations at high loadings (15 g COD/L-day). At low loadings, methane yields were 232 L CH_4/kg COD fed and 229 L CH_4/kg VS fed, and at high loadings yields were 211 L CH_4/kg COD fed and 272 L CH_4/kg VS fed. Based on characterization and biodegradability studies, food waste appears to be a good candidate for HSAD at low organic loading rates; however, the development of ammonia inhibition at high loading rates suggests that the C:N ratio is too low for use as a single substrate. The relatively low biodegradability of landscape waste as reported herein made it an unsuitable substrate to increase the C:N ratio. Codigestion of food waste with a substrate high in bioavailable carbon is recommended to increase the C:N ratio sufficiently to allow HSAD at loading rates of 15 g COD/L-day.

1. Introduction

Biodegradation of municipal solid waste (MSW) under anaerobic conditions converts organic waste into methane, a valuable energy source. Anaerobic digestion (AD) of municipal solid waste has been employed in Western Europe since the 1980s, where 200 facilities have a total capacity of 6 million metric tons (MMT) per year (De Baere and Mattheeuws, 2010). The United States Environmental Protection Agency has estimated that 2009 production of MSW in the U.S. was 221 MMT, of which 120 MMT was landfilled (U.S. EPA, 2010). Approximately 61.4 MMT (27.8%) of the total MSW was kitchen waste and yard trimmings, of which 18.9 MMT was composted (U.S. EPA, 2010).

In the U.S., substitution of AD for green waste composting processes could result in nationwide net energy production (100–150 kW h/ton) instead of consumption (30–35 kW h/ton) (Hartmann and Ahring, 2006). During one full-scale study, the methane yield from AD of green waste was 0.4 m^3 CH_4/kg VS fed (Bolzonella et al., 2006). In addition to renewable energy production, AD of the organic fraction of MSW (OFMSW) that is currently landfilled in the U.S. could result in significant reduction of CO_2e emissions (DiStefano and Belenky, 2009). However, given the relatively low costs associated with landfilling MSW in the U.S., widespread AD of MSW will only be feasible if the process is cost-competitive with landfilling (Chynoweth and Pullammanappallil, 1996).

The objective of this study was to investigate the suitability of food waste (FW) and landscape waste (LW) for high-solids anaerobic digestion in the US, with the intention of stimulating increased consideration for this process. Knowledge about the consistency of substrates for AD is essential in planning systems, and no long-term characterization of these substrates exists. Therefore, a pilot-scale study of high-solids (20%) anaerobic digestion was completed at low and high organic loading rates (OLR). Long-term substrate characterization and biodegradability studies were completed and reactor performance was determined at the low OLR; however inhibition was observed at the high loading rate. The potential cause and degree of inhibition was subsequently assessed through respirometry.

2. Materials and methods

2.1. Reactor operation

A stainless steel vessel with a horizontally-oriented helical mixer served as the anaerobic digester. Fig. 1 is a diagram of the reactor system. The working volume ranged from 260 to 280 L during high and low organic loading rates, respectively. Seed organisms were obtained from a full-scale upflow anaerobic sludge

* Corresponding author. Tel.: +1 570 577 1647; fax: +1 570 577 3415.
E-mail address: thomas.distefano@bucknell.edu (T.D. DiStefano).

http://dx.doi.org/10.1016/j.wasman.2014.03.019
0956-053X/

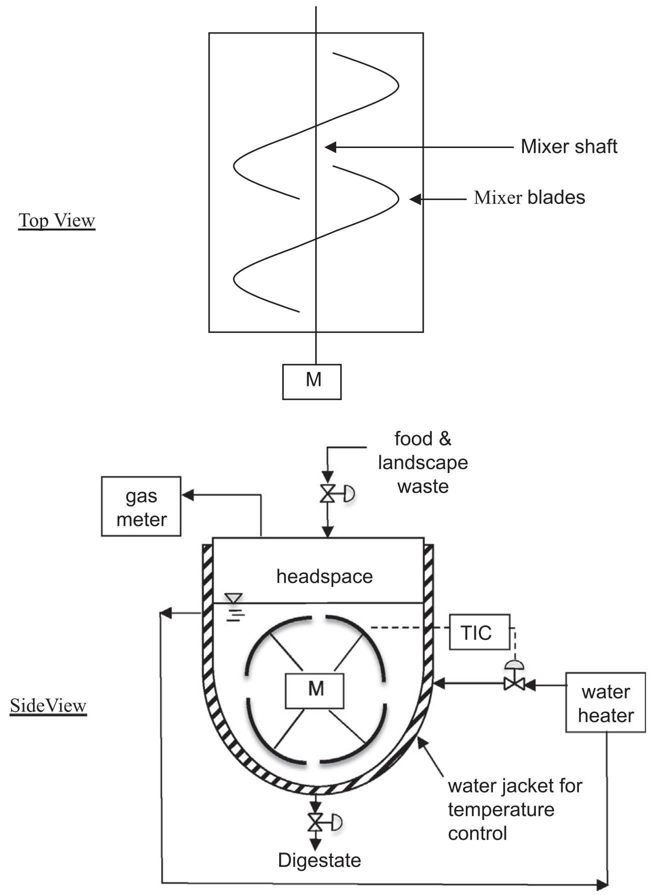

Fig. 1. Diagram of HSAD top view and side view. M = motor; TIC = temperature indicating controller.

blanket reactor treating brewery wastewater. Mixing was supplied by a 5-hp motor equipped with a reducing gear, controlled by a timer to enable 5 min of mixing at 15-min intervals. Temperature was maintained at 35 °C by circulating hot water through the water-jacketed reactor. Manual daily wasting and feeding were accomplished via knife/gate valves in the reactor top and bottom. Biogas production was initially measured using a precision wet tip gas meter (Laboratory Gas Meters, Nashville, TN). Subsequently, a wet-test gas meter (Precision Scientific Petroleum Instruments, Model 63126) was employed to accommodate increased biogas production.

Feedstock chemical oxygen demand (COD) was used to calculate the reactor organic loading rate. After initial startup and testing (days 1 through 141 of operation), the reactor was operated at 2 g COD/L reactor volume-day for 90 days prior to sampling for an examination of digestate curing. Details on reactor performance and the curing process during low OLR operation may be found elsewhere (Drennan and DiStefano, 2010). After the low OLR digestion and curing studies, the OLR was increased stepwise to 15 g COD/L reactor volume-day, with temporary OLRs of 5, 7, 10, and 12.5 g COD/L reactor volume-day for acclimation periods of 13, 24, 36, and 8 days, respectively. Acclimation time was based on indicators of stable digestion (Section 2.3). The reactor was operated at an OLR of 15 g COD/L reactor volume-day for a total of 54 days before instability was observed, at which point feeding was decreased to an OLR of 10 g COD/L reactor volume-day for 6 days and then discontinued.

Food waste and landscape waste were combined to maintain both a consistent OLR, and reactor solids content at 20%. During operation, biomass was wasted from the reactor only for sampling and to maintain the working volume. As a result, at the OLR of 2 g COD/L reactor volume-day, the reactor solids retention time (SRT) was on the order of 175 days. Stable operation was identified by consistent methane production and soluble COD (SCOD) and volatile fatty acid (VFA) content in the digestate. During high OLR operation, the reactor SRT was on the order of 25 days.

2.2. Food and landscape waste characterization

2.2.1. Chemical oxygen demand, solids, TKN, and fats, oil, and grease

Food waste was sampled 38 times and landscape waste was sampled 35 times during the 13-month study. Food waste was collected from food preparation areas in the cafeteria and consisted exclusively of food preparation waste; it was pulped in the cafeteria before collection. Landscape waste was collected from the university composting facility and consisted almost exclusively of deciduous leaves collected from campus; no woody debris and very little grass clippings were collected. Landscape waste was shredded in a lawn chipper/shredder after collection. COD, total solids (TS), and volatile solids (VS) were analyzed in triplicate for each batch of food or landscape waste. For COD analyses, a 12.5-g sample of food waste or landscape waste was homogenized with water (500 mL total volume) at 22,000 rpm in a laboratory blender (Waring Products, model 7010S). For all samples, COD was measured according to the closed reflux colorimetric method (APHA, 1995). Dilutions (20×) were prepared for both food waste and landscape waste COD. TS and VS analyses were conducted on each batch of food and landscape waste in accordance with Standard Methods (APHA, 1995).

Total Kjeldahl nitrogen (TKN) analysis was performed on 28 different food waste batches throughout the study. TKN analysis was completed according to Hach et al. (1985), with the following modifications: 20 mL of the homogenized waste and water mixture was used, and 3 mL of concentrated sulfuric acid and 10 mL of 50% hydrogen peroxide were used (Hach et al., 1985). A TKN calibration curve was prepared by digesting Nicotinic Acid p-Toluenesulfonate in concentrations ranging from 5.12 mg/L to 99.99 mg/L. For COD, a calibration curve was prepared by digesting potassium hydrogen phthalate in concentrations ranging from 200 to 1400 mg/L.

Samples from eight different batches of food waste were analyzed by a contract laboratory for fats, oil, and grease (FOG) content. EPA Method 1664A was used to determine the FOG content using Soxhlet Extraction (U.S. EPA, 1989).

2.2.2. Waste biodegradability

The biodegradability studies were conducted using a Challenge Technologies AER-200 respirometer. Four treatments were studied: control (unfed), food waste (5 g FW COD/L), landscape waste (10 g LW COD/L), and combined food and landscape waste (5 g FW COD/L and 5 g LW COD/L). Digestate from the anaerobic reactor was employed as inocula for the respirometer studies. Six replicates for each treatment were prepared by combining digestate with the appropriate substrate; 0.5 kg of digestate-substrate mixture was used for each replicate. The replicates were incubated in a water bath (35 °C), while biogas production was recorded. Biogas composition of one replicate from each treatment was tested daily to determine the methane content. Each test was continued until the rate of biogas production decreased to about 1 mL/h. On the final day of the study, biogas composition was determined for each replicate in the test (24 total). It was assumed that the final biogas composition accurately reflected the methane proportion throughout the test, and this was used to determine the total methane produced.

For each trial, biodegradability of the FW and LW was determined as follows: the methane produced in each treatment was adjusted for endogenous decay by subtracting the average meth-