Water Research 95 (2016) 39–47

Contents lists available at ScienceDirect

Water Research

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

Lab-scale demonstration of recuperative thickening technology for enhanced biogas production and dewaterability in anaerobic digestion processes

Jeffrey Cobbledick [a], Nicholas Aubry [a], Victor Zhang [b], Sasha Rollings-Scattergood [b], David R. Latulippe [a, *]

[a] Department of Chemical Engineering, McMaster University, 1280 Main Street West, Hamilton, Ontario, L8S 4L7, Canada
[b] Anaergia Inc., 4210 South Service Road, Burlington, Ontario, L7L 4X5, Canada

A R T I C L E I N F O

Article history:
Received 15 December 2015
Received in revised form
23 February 2016
Accepted 24 February 2016
Available online 26 February 2016

Keywords:
Recuperative thickening (RT)
Anaerobic digestion (AD)
Polymer flocculants
Biogas production
Dewatering performance

A B S T R A C T

There is growing interest in the use of high performance anaerobic digestion (AD) processes for the production of biogas at wastewater treatment facilities to offset the energy demands associated with wastewater treatment. Recuperative thickening (RT) is a promising technique which involves recycling a portion of the digested solids back to the incoming feed. In general there exists a significant number of knowledge gaps in the field of RT because the studies that have been conducted to date have almost exclusively occurred in pilot plant or full scale trials; this approach greatly limits the amount of process optimization that can be done in a given trial. In this work, a detailed and comprehensive study of RT was conducted at the lab scale; two custom designed digesters (capacity = 1.5 L) were operated in parallel with one acting as a 'control' digester and the other operating under a semi-batch RT mode. There was no significant change in biogas methane composition for the two digesters, however the RT digester had an average biogas productivity over two times higher than the control one. It was found that the recycling of the polymer flocculant back into the RT digester resulted in a significant improvement in dewatering performance. At the highest polymer concentration tested, the capillary suction time (CST) values for flocculated samples for the RT digester were over 6 times lower than the corresponding values for the control digester. Thus, there exists an opportunity to decrease the overall consumption of polymer flocculants through judicious selection of the dose of polymer flocculant that is used both for the thickening and end-stage dewatering steps in RT processes.

1. Introduction

Anaerobic digestion (AD) is a well-established process for wastewater (WW) treatment that reduces the total mass of waste solids by breaking down organic matter in the absence of oxygen. It is used both for the stabilization of sewage solids and for the production of biogas (also known as 'offgas' or 'digester gas'), a mixture of approximately 60–65% methane and 35–40% carbon dioxide. The exact ratio of these two components is dependent on several process factors including the methanogenic bacteria population, the food to microorganism ratio, and the digester conditions (e.g. operating temperature) (Kroeker et al., 1979). The produced biogas can be used for electricity generation via combined heat and power (CHP) systems such as internal combustion engine-driven generators or so called 'emerging' technologies such as microturbines and fuel cells (Ely et al., 2014). The produced electricity can be used directly onsite to power the various pieces of equipment (e.g. pumps, blowers) within the wastewater treatment facility (WWTF) or alternatively it can be sold back into the local electricity grid and thus generate a source of revenue.

There is considerable interest in integrating technologies and process improvements that would enable WWTFs to achieve net energy neutrality (i.e. total energy needs are balanced by the amount of energy produced) or even net energy production. One method that has been widely considered is the co-digestion of municipal WW with high energy, easily biodegradable materials

* Corresponding author.
E-mail addresses: cobblejp@mcmaster.ca (J. Cobbledick), aubryn@mcmaster.ca (N. Aubry), victor.zhang@anaergia.com (V. Zhang), sasha.rollings-scattergood@anaergia.com (S. Rollings-Scattergood), latulippe@mcmaster.ca (D.R. Latulippe).

http://dx.doi.org/10.1016/j.watres.2016.02.051

such as household food waste, industrial or agricultural wastes, and/or collections of fats, oils and greases (Schwarzenbeck et al., 2008). A 2014 report summarized the performance of six different WWTFs that incorporated co-digestion processes (Ely et al., 2014); two facilities generated less than 30% of their electricity demand, three facilities generated between 60% and 90% of their electricity demand (close to net energy neutral), and one facility generated nearly 130% of their electricity demand. Thus, the use of co-digestion processes on their own does not guarantee that energy neutrality will be achieved. Also, there may be capacity issues in some WWTFs where the digester volume is not large enough to accommodate the increased organic loading rate (OLR) associated with the use of co-digestion processes. This is a significant concern as the capital costs of new digesters are quite high (Seiger and Parry, 2004).

In order to address the problem of digester capacity, there is considerable interest in the development of 'high performance' AD processes such as thermophilic digestion for improved reaction rates (Nges and Liu, 2010), thermal pre-treatment of the incoming feed material (Ge et al., 2010), mechanical breakdown of the incoming feed material using ultrasonic conditioning (El-Hadj et al., 2007) or high pressure in combination with chemical addition (Wahidunnabi and Eskicioglu, 2014), and recycling a portion of thickened digested material back into the digester. Various names have been assigned to this recycling process including 'Torpey's process' (to acknowledge the original work in this field (Torpey and Melbinger, 1967)), 'extended solids retention' process, and 'recuperative thickening' (RT) – we chose to use the latter one for this work. Compared to other 'high performance' AD processes, RT is more effective than the feed pre-treatment method at increasing the treatment capacity but does not require the additional energy input to operate at thermophilic conditions (Kelly, 2006); operation at mesophilic conditions can also lead to more stable and robust operating conditions when compared to thermophilic treatment (Labatut et al., 2014). In RT, a portion of the partially digested solids in the digester outlet stream are flocculated, thickened, and then blended with the incoming feed. This operation results in a greater solids retention time (SRT) than the hydraulic residence time (HRT). In a similar way to conventional activated sludge systems, by decoupling these two process parameters the digester is now bound by the solids loading rate and not the volumetric flow into the digester which leads to an increase in capacity. In addition, RT also decreases the volume of waste solids produced; this outcome has the added effect of reducing the amount of polymer flocculant required in an end-stage dewatering process used to create the final solid cake material. Previous studies have shown that the short-term exposure of the anaerobic bacteria to oxygen in the digested solids dewatering step has no significant effect on the activity of the acetoclastic methanogens (Conklin et al., 2007; Batstone et al., 2015).

Various dewatering (aka thickening) technologies have been used to recycle the partially digested solids in the outlet stream. The original RT processes used gravity thickening, centrifugation, anoxic gas flotation, or belt filter press thickening (Kelly, 2006). It has been shown that the overall process can be improved by incorporating a polymer flocculation pre-step. In 2011, Ostapczuk et al. (Ostapczuk et al., 2011) used RT in combination with gravity belt thickeners with a polymer flocculation pre-step to increase the WWTF capacity and thus allow for the co-digestion of dairy whey with municipal sludge; the amount of biogas produced generated 95% of the facility's electrical demand via a CHP process. Between 2009 and 2011, two WWTFs in Australia were upgraded to incorporate RT by adding rotary drum thickeners with pre-injection of polymer flocculants; a significant number of process improvements were realized including improved raw sludge capacity, increased biogas production, and improved end-stage dewatering performance (Tang, 2009; Ireland, 2011).

The incorporation of RT at a WWTF often requires a capital investment to upgrade the mixers (to account for the increased solids content) and to integrate the recycled stream into a dewatering process. Given the importance of the dewatering process to the overall techno-economic performance of RT, it was surprising to find that the studies published to date have almost exclusively occurred in pilot plant or full scale trials at WWTFs. That approach has severely restricted the amount of RT process development work that can be undertaken and thus led to 'knowledge gaps' in the field. For example, a proper techno-economic analysis of the performance and operating costs is required when selecting a polymer flocculant (Kelly, 2006). Also, the potential toxicity associated with excess polymer in the effluent (Bolto and Gregory, 2007) and increased polymer concentrations in the biosolids are a significant concern (Biesinger et al., 1976; Campos et al., 2002). It is generally agreed that the use of polymer flocculants in biosolids dewatering is still one of the most poorly understood and practiced areas in WW treatment. In our previous work, we reported significant variations in dewatering performance for multiple types of polymer flocculants (Cobbledick et al., 2014). A recent study of RT at the lab scale used stainless steel reactors seeded with 20 L of digested sludge to investigate the effect of SRT on digester performance in terms of biogas production and volatile solids destruction (Yang et al., 2015).

In this work, we developed a complete system for the operation of two lab-scale digesters in parallel where one is operated in a semi-batch RT mode (i.e. SRT greater than HRT) and the other was operated as a conventional single pass 'control' (i.e. SRT same as HRT). Both digesters were operated in an automated mixing mode with continuous temperature and biogas production monitoring. This was accomplished with each digester having a volume of 1.5 L and thus the entire footprint was less than 0.5 m^2. Given the number of outstanding issues cited above in regards to polymer-induced flocculation we chose to focus our initial work in that area. However, the system described in this work is ideally suited for studying other process variables for RT operations such as the co-digestion of high strength organics.

2. Experimental

2.1. Feed source

The feed for the digesters was obtained from the Dundas Valley WWTF in Dundas, Ontario at regular intervals (approximately 3 gallons every 2 weeks) and stored at 4 °C. It is a mixture of approximately 60% primary sludge and 40% thickened waste activated sludge. There was a slight variation in the total solids (TS) content of the as-received feed (between 2 and 3 wt% (w/v)) and thus simple gravity settling or low-speed centrifugation processes were employed to increase the TS content to the desired range of 3.5–4 wt% (w/v).

2.2. Polymer preparation

The polymer used in this work is Clarifloc C-6267 (SNF Polydyne) which according to the manufacturer is a very high charge, high molecular weight (3–20 million Da) cationic linear polyacrylamide with a specific gravity of 1.04 and an active solids content of 43%. The as-received stock emulsion of polymer was stored out of direct sunlight and at room temperature. The stock emulsion was diluted with 50 mM sodium phosphate monobasic buffer (pH of 4.8) to a final polymer concentration of 0.25 wt% (w/v) as previously described (Cobbledick et al., 2014). The dilutions were allowed to age at room temperature for at least 90 min, but no