Water Research 132 (2018) 158–166

Contents lists available at ScienceDirect

Water Research

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

Post-anaerobic digestion thermal hydrolysis of sewage sludge and food waste: Effect on methane yields, dewaterability and solids reduction

Kine Svensson [a], Oda Kjørlaug [b], Matthew J. Higgins [c], Roar Linjordet [a], Svein J. Horn [d, *]

[a] NIBIO, Norwegian Institute of Bioeconomy Research, P.O. Box 115, N-1431, Ås, Norway
[b] Cambi AS, Skysstasjon 11A, 1383, Asker, Norway
[c] Department of Civil and Environmental Engineering, Bucknell University, Lewisburg, PA, 17837, USA
[d] Faculty of Chemistry, Biotechnology and Food Sciences, Norwegian University of Life Sciences, Ås, Norway

ARTICLE INFO

Article history:
Received 10 October 2017
Received in revised form
21 December 2017
Accepted 3 January 2018
Available online 4 January 2018

Keywords:
Anaerobic digestion
Post-treatment
THP
Steam explosion
Sewage sludge
Biogas

ABSTRACT

Post-anaerobic digestion (PAD) treatment technologies have been suggested for anaerobic digestion (AD) to improve process efficiency and assure hygenization of organic waste. Because AD reduces the amount of organic waste, PAD can be applied to a much smaller volume of waste compared to pre-digestion treatment, thereby improving efficiency. In this study, dewatered digestate cakes from two different AD plants were thermally hydrolyzed and dewatered, and the liquid fraction was recirculated to a semi-continuous AD reactor. The thermal hydrolysis was more efficient in relation to methane yields and extent of dewaterability for the cake from a plant treating waste activated sludge, than the cake from a plant treating source separated food waste (SSFW). Temperatures above 165 °C yielded the best results. Post-treatment improved volumetric methane yields by 7% and the COD-reduction increased from 68% to 74% in a mesophilic (37 °C) semi-continuous system despite lowering the solid retention time (from 17 to 14 days) compared to a conventional system with pre-treatment of feed substrates at 70 °C. Results from thermogravimetric analysis showed an expected increase in maximum TS content of dewatered digestate cake from 34% up to 46% for the SSFW digestate cake, and from 17% up to 43% in the sludge digestate cake, after the PAD thermal hydrolysis process (PAD-THP). The increased dewatering alone accounts for a reduction in wet mass of cake leaving the plant of 60% in the case of sludge digestate cake. Additionaly, the increased VS-reduction will contribute to further reduce the mass of wet cake.

1. Introduction

Anaerobic digestion (AD) is commonly used in waste management for treatment of organic wastes such as sewage sludge and food waste, with the aim of waste stabilization, methane generation and production of a digestate that can be used as a fertilizer. AD processes typically have long retention times, meaning large digesters and thus large plant footprints. The waste stabilization efficiency and digestate quality depends on the characteristics of the waste and the AD technology. Technologies assuring a high hygienic quality of the digestate as well as high waste stabilization rates are key for a successful AD plant, and pre-treatment technologies such as the thermal hydrolysis process (THP) has been extensively used to improve process performance (Barber, 2016; Carrere et al., 2016; Neyens and Baeyens, 2003).

THP has increased degradation rates and biogas yields for a wide range of wastes, including sewage sludge and lignocellulosic biomasses (Bauer et al., 2014; Dereix et al., 2006; Estevez et al., 2012; Horn et al., 2011b; Lizasoain et al., 2016; Vivekanand et al., 2013; Wilson and Novak, 2009). The optimum temperature and time combination during THP pretreatment depends on the type of substrate. THP treatment has resulted in reduced capillary suction time (CST) and filtration time of sludge, both parameters important for the rate of the dewatering process (Dereix et al., 2006; Everett, 1972; Haug et al., 1978). However, CST and filtration methods are not necessarily correlated with maximum cake solids (Kopp and Dichtl, 2001). Technologies that increases the total solids (TS) in dewatered digestate have a large potential for reducing the storage silo footprint as well as transportation costs for disposal of the

* Corresponding author.
E-mail address: svein.horn@nmbu.no (S.J. Horn).

https://doi.org/10.1016/j.watres.2018.01.008

digestate cake. Although improved dewaterability is well documented in sludge after THP (Everett, 1972; Haug et al., 1978; Neyens and Baeyens, 2003; Skinner et al., 2015), the mechanism is not well understood, and the optimum THP treatment conditions for different wastes are largely unknown.

THP-based technologies result in solubilization of organic material and thus release of readily degradable organic matter to the liquid fraction (Dereix et al., 2006). In Norway, pre-treatment of waste is mainly applied to meet health regulations where the minimum requirement is heating for 1 h at 70 °C for sludge and waste of animal origin (Nærings- og fiskeridepartementet, 2007). Although pre-treatment results in a reduction of pathogenic bacteria in the digestate and improved process performance (Bagge et al., 2005; Lang and Smith, 2008; Wang et al., 1997), large fractions of the waste are readily bio-degradable and do not benefit from such treatment. Post-anaerobic digestion treatment (PAD) has recently been suggested as an alternative (Sambusiti et al., 2015; Thygesen et al., 2014). This means that only a fraction of the original waste needs to be treated, while still ensuring a hygienic end-product for land application. In a typical PAD-THP setup, the digestate would be dewatered, treated with THP and then after THP undergo a subsequent dewatering, where the liquid fraction is recirculated to the anaerobic digester. The patented Cambi Solid-Stream™ (Kjorlaug et al., 2015; Kolovos et al., 2016; Solheim and Nilsen, 2014) is based on this idea, and involves post-treatment of digestate cake using THP.

So far, only one full-scale plant has installed a PAD-THP process, which is the Cambi SolidStream™ (Amperverband in Olching, Germany). No laboratory scale studies have been published on this topic. Thus, many of the mechanisms of the technology are not well documented and understood. For example, recirculation of the centrate from the post-treated digestate can result in a reduction of sludge retention time (SRT), which could reduce the efficiency of the AD process (Jang et al., 2014), possibly counteracting the beneficial effect of post-treatment. In addition, optimal THP conditions found for other substrates will not necessarily apply to biogas digestates, and studies of how digestate cakes of different origin respond to THP are lacking. A third unknown factor of THP is the effect on digestate dewaterability. Up to now, the effect of THP treatment on different digestate cakes is not described in the literature.

The objectives of this study were to evaluate the effect of:

1) thermal hydrolysis conditions (time and temperature) on the solubilization of COD and resulting biogas production from digestate cakes using biochemical methane potential (BMP) tests; and
2) PAD-THP on digester performance and overall solids reduction using semi-continuous anaerobic digesters.

2. Materials and methods

The experimental work was in part performed at the Biogas Laboratory at the Norwegian University of Life Sciences (Ås, Norway) and at the Environmental Engineering Laboratory at Bucknell University (Lewisburg, PA, USA). Due to differences in the laboratory equipment at the two locations, it was not possible to use the same methods for all analyses; however, we consider the methods used compatible.

2.1. Experimental design

This study is based on two experiments. The first experiment was designed to find the optimal THP conditions for two digestate cakes using the biochemical methane potential (BMP) test. The second experiment was designed to investigate how the Solid Stream approach affects the performance of semi-continuous anaerobic digesters operated until steady state conditions were achieved.

2.2. Materials for THP conditions experiment

We obtained centrifuged digestate cake from two different full-scale AD plants. One cake was from a food waste anaerobic digester operating in the thermophilic range (52–53 °C; Hadeland and Ringerike waste company (HRA), Ringerike, Norway), and source separated food waste (SSFW) was its sole substrate. HRA pretreats the SSFW according to Norwegian regulations at 70 °C for 1 h. The second cake was from an anaerobic digester operating in the mesophilic range (35 °C) treating sludge and collected at Hampton Roads Sanitation District's (HRSD) Nansemond Treatment Plant (Suffolk, Virginia, USA). HRSD's plant treats a mix of primary and waste activated sludge (WAS) from a Bio-P process. Both plants use high solids centrifuges for dewatering.

2.3. THP conditions experiment

The digestate cakes (HRA and HRSD) were used for testing different post-treatment conditions. The post treatment of HRA digestate cake was performed in Norway, using a small Cambi mini test steam explosion unit with a reactor volume of 1 L (CAMBI GROUP AS, Asker, Norway), while the HRSD digestate cake was post-treated in a larger Cambi mini test steam explosion unit at Bucknell University with a reactor volume of 5 L (CAMBI GROUP AS, Asker, Norway). The characteristics of the two cakes prior to post-treatment are presented in Table 1.

To examine the effect of different THP conditions on BMP and dewatering properties of digestate cakes, a set of seven different pre-incubation times and temperatures, spanning from 134 °C to 175 °C and from 20 min to 30 min, was applied. The lowest temperature was not tested with the 20 min treatment because this combination of time and temperature does not fulfill the current regulations for sanitation. Pre-incubation time was measured from the time the desired temperature in the reactor was reached. The post-treated digestate cakes were separated in a centrifuge at 2000 relative centrifugal force (RCF) for 30 min and the liquid and solid fractions were used in BMP and dewatering tests. The BMP results for the liquid fraction is presented on the basis of COD and the solid fraction on the basis of TS, because much of the liquid COD was volatiles that would result in falsely low TS measurements, and the solid fraction contained particulates making COD-measurements

Table 1
Characteristics of digestate cakes from HRA and HRSD. Standard deviations are listed in parenthesis. All percentages are on the basis of TS with the exception of Ash which is on the basis of wet weight.

	Unit	HRA	HRSD
TS	%	18.5 (0.3)	21.8 (0.1)
VS	%	73.1 (0.4)	68.4 (0.4)
Ash	%	5.0 (0.7)	6.9 (0.1)
COD	g/L	226 (2.6)	183 (17)
COD:VS		1.7	1.2
C	%	42.7 (0.3)	32.7 (0.2)
H	%	5.45 (0.09)	5.47 (0.08)
N	%	2.43 (0.05)	4.70 (0.1)
S	%	0.49 (0.02)	1.95 (0.01)
C:N		17.6 (0.5)	7.0 (0.2)
ADF[a]	%	54.6 (0.3)	31.4 (1.3)

[a] ADF = Acid detergent fiber.