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Long-term thermophilic mono-digestion of rendering wastes and co-digestion with potato pulp

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ABSTRACT

In this study, mono-digestion of rendering wastes and co-digestion of rendering wastes with potato pulp were studied for the first time in continuous stirred tank reactor (CSTR) experiments at 55 °C. Rendering wastes have high protein and lipid contents and are considered good substrates for methane production. However, accumulation of digestion intermediate products viz., volatile fatty acids (VFAs), long chain fatty acids (LCFAs) and ammonia nitrogen (NH_4-N and/or free NH_3) can cause process imbalance during the digestion. Mono-digestion of rendering wastes at an organic loading rate (OLR) of 1.5 kg volatile solids (VS)/m^3 d and hydraulic retention time (HRT) of 50 d was unstable and resulted in methane yields of 450 dm^3/kg VS_{fed}. On the other hand, co-digestion of rendering wastes with potato pulp (60% wet weight, WW) at the same OLR and HRT improved the process stability and increased methane yields (500–680 dm^3/kg VS_{fed}). Thus, it can be concluded that co-digestion of rendering wastes with potato pulp could improve the process stability and methane yields from these difficult to treat industrial waste materials.

1. Introduction

In a rendering process, slaughterhouse wastes are treated with heat to meet the treatment requirements of European Union. Raw materials subjected to rendering process include carcasses, parts of carcasses, heads, feet, offal, excess fat, excess meat, hides, feathers, bones and blood, and the final products are mainly used as animal feed ingredients (Meeker and Hamilton, 2006). There are many different rendering waste fractions. Although the physical and chemical composition of these waste fractions may vary, typical for them is the high content of proteins and lipids, which makes them potentially good substrates for methane production. Previously, methane potentials of 351–381 dm^3/kg total volatile solids (TVS) were reported for meat and bone meal in batch experiments at 35 °C (Wu et al., 2009). Similarly, methane potentials of 275, 572, 515, 476, 406 and 287 dm^3/kg volatile solids $(VS)_{added}$ were reported for fat from fat separation, separator sludge, melt, decanter sludge, fat and boneflour, respectively (Bayr et al., 2012). On the other hand, slightly higher methane yields of 834, 607, 390, 978 and 650 dm^3/kg VS_{added} were reported for melt, decanter sludge, meat and bone meal, fat and flotation sludge at 35 °C, respectively (Pitk et al., 2012). However, there are no reported studies under thermophilic conditions. Although rendering wastes have relatively high methane potentials, their digestion process might be unstable due to the production of intermediate compounds viz., ammonia nitrogen (ammonium nitrogen, NH_4-N, and free ammonia nitrogen, NH_3), volatile fatty acids (VFA) and long chain fatty acids (LCFA). These intermediate compounds are formed during the degradation of proteins and lipids. No previous semi-continuous reactor studies have been reported for mono-digestion of rendering wastes. However, methane yields of ca. 720 dm^3/kg VS_{fed} were reported at an organic loading rates (OLRs) of 1 and 1.5 kg VS/m^3 d during mesophilic co-digestion of rendering wastes and slaughterhouse wastes, another protein- and lipid-rich substrate (Bayr et al., 2012).

Due to possible process inhibition during mono-digestion, co-digestion of rendering wastes with other organic materials containing low nitrogen and/or lipid content is one option to improve the process stability and increase methane yields. Co-digestion may improve the digestion process by providing the required nutrient balance and buffer capacity (Mata-Alvarez et al., 2000; Zhang et al., 2013). Moreover, better carbon/nitrogen (C/N)-ratio

Abbreviations: CSTR, continuous stirred tank reactor; Free NH_3, ammonia nitrogen; HRT, hydraulic retention time; LCFA, long chain fatty acid; NH_4-N, ammonium nitrogen; OFMSW, organic fraction of municipal solid waste; OLR, organic loading rate; SCOD, soluble chemical oxygen demand; TKN, total Kjeldahl nitrogen; TS, total solids; TVFA, total volatile fatty acids; VFA, volatile fatty acid; VS, volatile solids; WW, wet weight.

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and lower concentrations of inhibitory substances (reviewed by Appels et al., 2011; Mata-Alvarez et al., 2000; Ward et al., 2008) can be positive consequences of co-digestion. Previously, co-digestion of rendering wastes with manure and sewage sludge has been reported (Pitk et al., 2012, 2013). In the above studies, when 2.5% and 5% (wet weight, WW) of a rendering waste fraction melt was added to the manure, methane yields were increased by 1.75 and 2.7-fold compared to manure alone in batch assays at 35 °C (Pitk et al., 2012). Similarly, co-digestion of sewage sludge with 5% (WW) sterilized mass increased the methane yields by 5.7 times than the yields obtained from mono-digestion of sewage sludge (Pitk et al., 2013). On the other hand, methane yields of 270–500 dm^3/kg VS have been reported during the co-digestion of slaughterhouse wastes with other substrates such as manure, sewage sludge or organic fraction of municipal solid waste (e.g. Alvarez and Lidén, 2008; Cuetos et al., 2008; Hejnfelt and Angelidaki, 2009; Luste and Luostarinen, 2010).

Potato pulp is a solid by-product from potato industry. It is produced after extraction of starch and mainly consists of water, cell debris and intact starch cells (Mayer, 1998). To the authors' knowledge, there are only a few studies were potato pulp has been used as a substrate for biogas production, although potato pulp is used as a substrate in full-scale biogas plants. In the study of Kryvoruchko et al. (2009), methane potential of 332 dm^3/kg VS was obtained for potato pulp in batch experiments under mesophilic conditions. On the other hand, biogas yields of 300–500 dm^3/kg dry organic matter were obtained for potato pulp in reactor experiments conducted under mesophilic conditions (Weiland, 1993). As potato pulp mainly consists of carbohydrates, and thus has a C/N-ratio of 40–70:1 (Weiland, 1993), it could be a potential co-substrate for treating waste materials rich in protein and lipid content, e.g. rendering wastes.

The objective of the present study was to evaluate the feasibility of anaerobic semi-continuous mono-digestion of rendering wastes and co-digestion of rendering wastes with potato pulp in a long term experiment (472 d) by using a laboratory scale continuous stirred tank reactor (CSTR) at 55 °C. Methane yields and digestate characteristics were monitored to evaluate the process stability.

2. Materials and methods

2.1. Substrates and inoculum

Five different types of rendering wastes were used as substrates in this study. The rendering wastes were obtained from a rendering plant (Honkajoki Ltd, Finland). In co-digestion experiment, potato pulp, a by-product of potato industry (Finnamyl Oy, Finland) was used. Digested material from a full-scale biogas plant (Stormossen, Finland, thermophilic process) treating putrescible organic fraction of municipal waste was used as inoculum. Characteristics of the substrates and inoculum are presented in Table 1.

2.2. Reactor experiments

Anaerobic digestion of rendering wastes alone and co-digestion of rendering wastes with potato pulp was carried out in stainless steel CSTR with a total volume of 13 l and working volume of 10 l. Mono-digestion of rendering wastes was studied during days 1–161 and co-digestion of rendering wastes with potato pulp was performed during days 162–472. Reactor temperature (55 ± 1 °C) was maintained by a heating coil wrapped around the insulated reactor and controlled thermostatically. Reactor content was mixed mechanically with a timer (13 min on/16 min off).

During the start-up, 9.7 l of inoculum and 50 g of separator sludge was added to the reactor. Reactor was flushed with N_2 for 5 min to create anaerobic conditions. Separator sludge was fed twice before actual feeding was initiated on day 14. Reactor was fed manually 5 days per week on days 14–48 and 180–472, and 7 days per week on days 49–179. Feed rate was 200 ml/d, except for 0–100 ml/d on days 84–161. Due to process failure, feeding was withheld during days 185–234 (Table 2). At each feeding, an equal amount of digestate was collected into the digestate storage tank by over-flow. The produced biogas was collected from the head space into aluminum gasbags.

During mono-digestion experiment, feed was prepared by mixing the five rendering plant waste fractions according to the actual amount of each waste fraction produced at the rendering plant (WW basis, Table 1). During co-digestion experiment, relative amounts of rendering waste fractions were the same as in the mono-digestion experiment, but 60% of the feed was replaced by potato pulp (WW basis). The prepared feed was frozen in plastic containers (500 g). Frozen feed was thawed and diluted with tap water to obtain the desired hydraulic retention time (HRT) and OLR (Table 2).

After the initial start-up, feeding was initiated on day 14 at an OLR of 1.5 kg VS/m^3 d and HRT of 50 d. Due to unstable process, feeding was reduced to 0–100 g/d on days 84–161. Thus, the average OLR during this period was 0.5 kg VS/m^3 d and HRT 175 d. In addition, 4 l of the reactor digestate was replaced with water on day 154 to dilute the reactor contents. On days

Table 1
Characteristics of the substrates used during semi-continuous anaerobic mono-digestion of rendering wastes and co-digestion with potato pulp in CSTR at 55 °C. For rendering waste fractions, two batches of each were used during the experiment.

Substrate	Origin	TS (%)	VS (%)	VS/TS (%)	Protein (g/kg VS)	Lipid (g/kg VS)	Methane potential at 35 °C (dm^3/kg VS_{added})	Part of feed (A)[a] (%)	Part of feed (B)[b] (%)
Inoculum	–	3[c]	1[c]	46[c]	nd	nd	–	–	–
Fat from fat separation	Fat separated with H_2O_2 from wastewater of production equipments and rooms	24[c]	22[c]	92[c]	117[c]	892 [c]	275 ± 52[c]	15[c]	6
		78[c]	76[c]	97[c]	nd	nd	nd		
Separator sludge	Water, protein and fat extracted in final purification by centrifuge from sterilized and solids separated fat	2[c]	2[c]	91[c]	100 [c]	800 [c]	572 ± 187[c]	40[c]	16
		22[c]	21[c]	94[c]	nd	nd	nd		
Melt	Sterilized (133 °C, 20 min, 3 bar) mass	98[c]	67[c]	68[c]	644 [c]	330 [c]	515 ± 54[c]	11[c]	4
		98[c]	75[c]	76[c]	nd	nd	nd		
Decanter sludge	Solids, separated by centrifuge from fat separated by pressing from sterilized mass	98[c]	62[c]	63[c]	619 [c]	356 [c]	476 ± 164[c]	13[c]	5
		99[c]	75[c]	75[c]	nd	nd	nd		
Biosludge	Sludge from wastewater treatment	1[c]	1[c]	90[c]	844 [c]	111 [c]	16 ± 23[c]	22[c]	9
		2[c]	2[c]	87[c]	nd	nd	nd		
Potato pulp	–	16	15	93	nd	nd	274 ± 50	–	60

nd = not determined.
[a] Mono-digestion of rendering wastes, days 14–161.
[b] Co-digestion of rendering wastes with potato pulp, days 162–472.
[c] Data published in Bayr et al. (2012).