Bioresource Technology 101 (2010) 2657–2664

Contents lists available at ScienceDirect

Bioresource Technology

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

Anaerobic co-digestion of meat-processing by-products and sewage sludge – Effect of hygienization and organic loading rate

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ARTICLE INFO

Article history:
Received 10 July 2009
Received in revised form 19 October 2009
Accepted 26 October 2009

Keywords:
Anaerobic co-digestion
Hygienization
Meat-processing by-products
Organic loading rate
Sewage sludge

ABSTRACT

Anaerobic co-digestion of a mixture of animal by-products (ABP) from meat-processing industry and of sewage sludge was studied at 35 °C for co-digesting such by-products in digesters at wastewater treatment plants. The three reactors were fed with ABP mixture and sewage sludge (1) in a ratio of 1:7 (v/v), (2) in the same ratio but with hygienization (70 °C, 60 min) and (3) in a ratio of 1:3 (v/v). Hydraulic retention time (HRT) was decreased from 25 to 20 days and finally to 14 days, while organic loading rates (OLR) ranged from 1.8 to 4.0 kg VS/m^3 day. The highest specific methane yields were achieved with 20-days-HRT (1) 400 ± 30, (2) 430 ± 40, (3) 410 ± 30 m^3 CH_4/t VS. Hygienization improved methane production to a level above the highest OLR applied (feed ratio 1:3 (3)), while the quality of the digestate remained similar to the other reactors.

1. Introduction

Efficient waste management is increasingly required due to several environmental and economical concerns such as climate change, eutrophication, and the diminishing resources for fossil energy and raw materials. Anaerobic digestion is considered a sustainable option for management of organic wastes and by-products as it produces renewable energy in the form of biogas and enables recycling of materials, especially nutrients. Simultaneously, it enables controlled stabilization and thus decreased emissions from the treated waste materials. By replacing non-renewable energy and materials with the use of biogas and digestate, the greenhouse gas and other emissions from energy production and consumption and from petrochemical and fertilizer industries can be decreased.

Anaerobic digestion of sewage sludge is a usual process in many municipal wastewater treatment plants. Mass reduction, stabilization, methane production and improved dewatering properties are the main features of the process (Mata-Alvarez et al., 2000). However, slow degradation (>20 days) and the relatively low volatile solids (VS) removal (30–40%) are often the disadvantages of the process as the digesters are rarely optimized for biogas production and are operated with too low C/N ratio and organic loading rate (OLR; Murto et al., 2004; Climent et al., 2007). To intensify the process, several pre-treatments (chemical, thermal, biological, mechanical) have been studied (Gavala et al., 2003; Kim et al., 2003; Climent et al., 2007; Lu et al., 2008). Another option is to co-digest the sludge with other, easily degradable materials, which may improve also the degradation of the sludge and thus the stability of the digestate (Mata-Alvarez et al., 2000).

Animal by-products (ABP) from meat-processing industry contain several different materials. Meat and fatty tissue containing materials have high energy potential because of typically high grease and protein content. On the contrary, e.g. digestive tract content consists mainly of partly digested fodder. Anaerobic digestion of both types of ABPs is challenging either due to high possibility for ammonia and/or fatty acid inhibition (Salminen and Rintala, 2002) or the recalcitrance of cellulose and lignin compounds (Rosenwinkel and Meyer, 1999; Buendía et al., 2008; Luste et al., 2009). Lignin compounds act as glue between polysaccharide filaments and fibres thus slowing down their degradation, while 12% of cellulose is estimated to remain in the flotation layer of and biogas reactor and the C/N ratio may be suboptimal (Rosenwinkel and Meyer, 1999).

Co-digestion of different ABPs and sewage sludge could be beneficial due to dilution of inhibitive substrates, improved nutrient content and synergistic effects between the treated materials resulting in better degradation of both (Mata-Alvarez et al., 2000). Moreover, the addition of different ABPs into a sewage sludge digester increases the OLR of the digester, thus resulting in higher methane production. Co-digestion of sewage sludge with grease trap sludge from a meat-processing plant is already reported to be very effective (Luostarinen et al., 2009). As the co-digestion also increases the nutrient content (ammonium nitrogen, potassium, phosphorous, calcium, magnesium) of the digestate as

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0960-8524/$ - see front matter
doi:10.1016/j.biortech.2009.10.071

compared to digesting sewage sludge alone (Field et al., 1985), the digestate may also have better prospects for end-uses in e.g. gardening and agriculture, provided the hygienic quality and low content of harmful substances, such as heavy metals, have been ensured.

Anaerobic digestion eliminates pathogens from the treated materials due to the temperature ranges and the relatively long HRT used. Especially thermophilic digestion (55 °C) is reported to reduce the pathogen content sufficiently (Huyard et al., 2000; Lu et al., 2008), while mesophilic process alone may not be adequate (Iranpour et al., 2004) depending on the feed materials. In order to ensure hygienization of the treated materials, a separate hygienization treatment can be added either before or after the digester. Hygienization treatment (70 °C, 60 min, particle size <12 mm) recommended or demanded for ABPs (1774/2002/EC) and for sewage sludge before the mesophilic digestion (ENV.E.3/LM, 2000) is reported to reduce the pathogen content adequately for fertilizer use of the digestate (Bendixen, 1999).

When hygienization is performed before the digester, it also serves as a thermal pre-treatment possibly increasing the degradability of the treated materials. Thermal pre-treatments differentiate liquid organic material from solids, loosen the structure of the remaining solid particles via pressure changes and concentrate the treated material due to evaporation of water (Bougrier et al., 2005). In previous studies, pre-treatment temperatures below 100 °C have been found more effective in increasing biogas production than higher temperatures (Gavala et al., 2003; Climent et al., 2007), thus indicating the pre-treatment potential of hygienization. In this study, hygienization was studied from the perspective of possible enhanced hydrolysis and pathogen elimination was not verified.

In this study, the anaerobic co-digestion of sewage sludge and a mixture of ABPs from meat-processing industry was studied in a ratio of real middle-sized companies in Finland and in an optimal ratio described in the literature. The aim was to evaluate the possibility to co-digest such by-products in existing digesters at wastewater treatment plants. The effect of different OLRs and hygienization was studied in three semi-continuous reactors at 35 °C.

2. Methods

2.1. Studied materials

The studied materials (Table 1) were chosen according to their annual production rates in middle-sized Finnish wastewater treatment plant and meat-processing industry as well as their availability for treatment in Finland. The ABP materials were received from a slaughterhouse (Lappeenranta, Finland) and a meat-processing plant (Mikkeli, Finland) handling cows and pigs. At the time of sampling, approximately 5300 tons of digestive tract content, drumsieve waste and dissolved air flotation (DAF) sludge were produced annually in the slaughterhouse and 75–100 tons of grease sludge in the meat-processing plant. Digestive tract content and drumsieve waste were mixed (82:18 v/v) in the slaughterhouse according to produced amounts. It was mixed with the other studied materials, DAF sludge and grease trap sludge, according to their produced wet weight (w.w.) ratios (53:34:13, respectively). The resulting ABP mixture was frozen at −18 °C prior to melting for feeding.

Sewage sludge and inoculum (digested sewage sludge) were collected from a municipal wastewater treatment plant (Mikkeli, Finland; Table 1). The plant treats wastewaters not only from residential areas, but also from small and medium-sized industries and produces approximately 36,400 m^3 sewage sludge per year. The sludge was collected at the plant once a month and kept at 4 °C prior to feeding.

2.2. Reactor experiment

The reactor experiment was conducted in three five liter glass reactors with a liquid volume of 4 l at 35 °C. The reactors were constantly mixed using magnetic stirrers (300 rpm; Heidolph MR 3001, Germany). Feeding of reactors was performed once a day, 5 days per week using a 100 ml syringe. The volume of withdrawal was 5% smaller than the feed in order to maintain constant liquid volume in the reactors. The produced biogas was collected into aluminum gas bags (Tesseraux Spezialverpackungen GmbH, Germany) through lead-ins on the reactor top. HRT was reduced from 25 (days 0–43) to 20 days (days 44–126) and finally to 14 days (127–175) with OLR increasing accordingly. Some variation in OLR was also due to changes in the characteristics of the sewage sludge.

The feed ratio of ABP mixture and sewage sludge for reactor 1 (R1) and reactor 2 (R2) was 1:7 (v/v), respectively, and for reactor 3 (R3) 1:3 (v/v; Table 1). The feed for R1 and R2 represented the annual production ratio of the materials, while the feed for R3 represented the reported optimum co-digestion ratio from the literature (sewage sludge with industrial food waste or slaughterhouse waste and/or municipal food waste; Rosenwinkel and Meyer, 1999; Murto et al., 2004; Sosnowski et al., 2008). The feed for R2 was also hygienized (70 °C, 60 min) by firstly heating it to 70 °C using the heater in a magnetic stirrer (Heidolph MR 3001, Germany) and then keeping it in an incubator (Termaks TS 8056, Norway) at 70 °C for one hour. Before the feeding it was cooled to 35 °C.

2.3. Analyses

Biogas volume was measured with water displacement and methane content with gas chromatography (Agilent 6890N: Perkin–Elmer Elite-Alumina column 30 m × 0.53 mm, flame ionization detector 225 °C, oven 100 °C, inlet 225 °C, carrier gas helium

Table 1
Characteristics of the feeds of R1, R2 and R3 and their separate feed materials as determined in previous studies (dtc = digestive tract content; dw = drumsieve waste; Ds = DAF sludge; gts = grease trap sludge; Luste et al., 2009; sewage sludge = ss; Luostarinen et al., 2009).

Reactor/feed material	TS (%)	VS (%)	CODsol (g/l)	CODsol/VS	VFAtot (g/l)	LCFA (mg/l)	NH_4-Nsol (g/l)	CODsol/NH_4-Nsol	pH	CH_4 (m^3 CH_4/t VS)	CH_4 (m^3 CH_4/t w.w.)
R1	6.3 ± 0.7	4.6 ± 0.3	6.6 ± 2	1.4	4.7 ± 1	3.0–42	0.3 ± 0.1	19 ± 2	6.2–6.6	-	-
R2	7.3 ± 0.8	5.4 ± 0.5	9.2 ± 3	1.7	5.8 ± 1	2.7–27	0.4 ± 0.1	24 ± 2	5.9–6.5	-	-
R3	7.2 ± 0.6	5.6 ± 0.3	7.8 ± 2	1.4	5.3 ± 1	3.0–22	0.4 ± 0.1	22 ± 2	6.1–6.5	-	-
dtc	13 ± 1	12 ± 1	4.0 ± 0.1	0.4	–	–	–	–	7.2	400	42
dw	14 ± 2	14 ± 2	0.9 ± 0.1	0.1	–	–	–	–	6.6	230	30
Ds	7.8 ± 0.6	6.8 ± 0.6	5.6 ± 0.2	1.6	–	–	–	–	6.8	340	12
gts	15.9 ± 0.9	15.8 ± 0.8	6.6 ± 0.1	0.6	–	–	–	–	5.6	900	99
ss	4.5 ± 0.8	3.0 ± 0.6	–	–	–	–	–	–	7.2	300	7.8