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Co-digestion of pig slaughterhouse waste with sewage sludge

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ABSTRACT

Slaughterhouse wastes (SHW) are potentially very attractive substrates for biogas production. However, mono-digestion of these wastes creates great technological problems associated with the inhibitory effects of ammonia and fatty acids on methanogens as well as with the foaming in the digesters. In the following study, the co-digestion of slaughterhouse wastes with sewage sludge (SS) was undertaken. Batch and semi-continuous experiments were performed at 35 °C with municipal sewage sludge and pig SHW composed of meat tissue, intestines, bristles and post-flotation sludge. In batch assays, meat tissue and intestinal wastes gave the highest methane productions of 976 and 826 dm^3/kg VS, respectively, whereas the methane yield from the sludge was only 370 dm^3/kg VS. The co-digestion of sewage sludge with 50% SHW (weight basis) provided the methane yield exceeding 600 dm^3/kg VS, which was more than twice as high as the methane production from sewage sludge alone. However, when the loading rate exceeded 4 kg VS/m^3 d, a slight inhibition of methanogenesis was observed, without affecting the digester stability. The experiments showed that the co-digestion of sewage sludge with large amount of slaughterhouse wastes is feasible, and the enhanced methane production does not affect the digester stability.

1. Introduction

Production and processing of meat in Poland constitutes the largest branch of the national food economy. According to the Central Statistical Office, in 2013 Poland produced 5206 thousand tons (in live weight) of animals for slaughter, of which 2059 thousand tons were pigs (Witkowski, 2014). It is estimated that approximately 25% of the total animal weight slaughtered is not used for food consumption (Hejnfelt and Angelidaki, 2009). This gives around 500,000 tons of slaughterhouse wastes annually generated in Poland. Most slaughterhouse wastes belong to category 2 of animal byproducts, as classified by the Animal By-Product Regulation of European Union, ABPR 1069/2009/EC (EC regulation, 2009). Materials of this category may be processed in biogas plants only after sterilization ongoing at least 20 min without interruption at a core temperature of more than 133 °C and an absolute steam pressure of not less than 3 bar.

Animal by-products are potentially very attractive substrates for biogas production mainly due to the high lipid content. The theoretical biogas yield from fats reaches 1250 dm^3/kg TS with around 67–68% methane content, whereas the corresponding values for carbohydrates are 790–800 dm^3/kg TS and 50% CH_4 (Weiland, 2010). Edstorm et al. (2003) estimated the total biogas potential from waste generated during slaughter of 1300 MJ/cattle and 140 MJ/pig. However, the high solids and nitrogen contents usually preclude the anaerobic treatment of slaughterhouse wastes in their original undiluted form. The anaerobic treatment of these wastes as mono-substrates often leads to the accumulation of ammonia, volatile fatty acids (VFA) and long chain fatty acids (LCFA), which may inhibit methanogenesis and thereby lower or even cease biogas production. Moreover, a high concentration of lipids in SHW may lead to foam formation and sludge flotation in anaerobic digesters as the lipids are adsorbed onto biomass (Cuetos et al., 2008; Hejnfelt and Angelidaki, 2009; Pitk et al., 2013; Salminen and Rintala, 2002). A solution of this problem may be the co-digestion of slaughterhouse wastes with other waste types. Co-digestion is defined as the simultaneous anaerobic treatment of two or more substrates usually of different characteristics in order to improve biogas and methane production. Other benefits achieved by co-digestion include: an improved balance of macro- and micronutrients, dilution of inhibitory or/and toxic substances, increased digestion and stabilization rates (greater VS reduction rates), and often an increased organic loading rate (OLR). Moreover, co-digestion allows to reduce the costs of biogas production as different wastes can jointly be processed in one installation (Mata-Alvarez et al., 2014). Slaughterhouse wastes

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have been successfully co-digested with other organic wastes including pig manure (Alvarez and Liden, 2008; Edstorm et al., 2003; Hejnfelt and Angelidaki, 2009), fruit and vegetable waste (Alvarez and Liden, 2008), organic fraction of municipal solid waste (Cuetos et al., 2008; Zhang and Banks, 2012), pharmaceutical waste (Braun et al., 2003), rendering waste (Bayr et al., 2012) and food waste (Braun et al., 2003; Edstorm et al., 2003). In Poland, most biogas installations have been designed to treat sewage sludge generating at wastewater treatment plants (WWTP). It has been demonstrated that anaerobic digesters located at WWTPs are often oversized, thus providing a free digestion capacity of 15–30% (Braun et al., 2003; Mata-Alvarez et al., 2014). Therefore, treatment of animal by-products together with sewage sludge may provide additional incomes for these plants due to the increased biogas production and gate fees (Luostarinen et al., 2009; Luste and Luostarinen, 2010). The feasibility of co-digestion of sewage sludge with waste grease (as a substrate of similar characteristics to SHW) was demonstrated in the WWTP in Brzeg (Gazda et al., 2012). However, little information is available in the literature regarding the co-digestion of SHW with sewage sludge (Luste and Luostarinen, 2010; Pitk et al., 2013). Generally the cited authors have focused on cattle and bovine manure or its mixture with pig manure, and the manure-to-sludge ratios in the feed were rather low. Therefore, in the following study, the biogas and methane yields of various types of pig slaughterhouse wastes as well as municipal sewage sludge were determined in batch assays. Then the semi-continuous experiments were conducted to assess the feasibility of SHW co-digestion with municipal sewage sludge in order to improve biogas and methane production and to provide stable digester operation. The emphasis was also made to the effect of the co-digestion on digestate quality and the fate of ammonia and volatile fatty acids during the semi-continuous trials.

2. Materials and methods

2.1. Materials

The following pig slaughterhouse wastes were used in this study: *meat tissue*, *intestinal wastes*, *bristle* and *post flotation sludge*. Other fractions were not investigated due to their low biodegradability and expected operational problems (*bones*) or other way of their use by the slaughterhouse (*blood*). The considered SHW belonged to the Category 2 of animal by-products, according to the EC regulation no. 1069/2009. The slaughterhouse wastes were collected at PINI Polonia Company in Kutno, which is one of the largest plant of this kind in Poland with a capacity of up to 1000 pigs slaughtered per hour. After delivering to the laboratory, all SHW groups were ground and then stored at −30 °C prior to use. For co-digestion experiments, the individual waste fractions were mixed in the proportion (wet weigh basis) of 50% intestines, 21% meat tissue, 21% post flotation sludge and 8% bristle, to reflect the real amounts generated in the PINI pig slaughterhouse. Municipal sewage sludge (the mixture of primary and waste activated sludge) was collected at the Municipal Wastewater Treatment Plant in Kutno. The plant annually produces 30,000 tons of dewatered sludge, which is stabilized by liming. However, lime was not added to the sludge prepared for the purpose of this research. The characteristics of slaughterhouse wastes and sewage sludge are depicted in Table 1.

Sewage sludge and all investigated SHW were abundant in nitrogen showing the C/N ratio lower than 10. Simultaneously, the sludge was rich in phosphorus because this sludge originated from a WWTP operating with an enhanced biological phosphorus removal system. The contents of lipids in slaughterhouse wastes were generally lower that the values reported in the literature (Bayr et al., 2012; Edstorm et al., 2003; Palatsi et al., 2011; Pitk et al., 2012). The SHW mixture composed for co-digestion experiments gave the fat content of around 35% TS.

2.2. Batch experiments

Batch tests were performed to determine biomethane potential of individual substrates as well as the slaughterhouse waste mixture composed as described in Section 2.1. Anaerobically digested sewage sludge sampled at the municipal WWTP in Łódź was used as inoculum. The inoculum had total and volatile solids concentrations of 28.54 gTS/kg and 18.26 g VS/kg, respectively. The batch assays were conducted using glass bottles of 1000 cm^3 volume. Each bottle was closely connected to a 1000 cm^3 gas collecting tank to measure the daily biogas production by a water displacement method. The bottles were filled with 500 g of inoculum and then the substrates were added to meet the inoculum to substrate ratio of 2 (VS-basis). Finally, distilled water was also added into the bottles to reach the liquid volume of 600 cm^3. Before closing, the bottles were flushed with nitrogen gas to ensure anaerobic conditions in the headspace. The reactors were incubated in a thermostat, which maintained a constant temperature of 35 °C. The batch tests were carried in triplicates to achieve reliable results. Additionally, three control (blank) assays were run with inoculum and water only in order to establish the residual methane yield from the inoculum. Net biogas and methane productions were then calculated by subtracting the corresponding values for control and substrate runs.

2.3. Semi-continuous experiments

The co-digestion experiments were performed in a semi-continuously fed reactor with a total capacity of 5 dm^3 and an active volume of 3 dm^3. The reactor was placed in a thermostat to ensure constant mesophilic temperature of 35 ± 1 °C. The headspace of the reactor was coupled with a 4 dm^3 gas collecting tank to control the biogas yield by a water displacement method. Semi-continuous operation was achieved by the daily discharge of digestate, followed by a substrate addition using a peristaltic pump. At the start-up, the reactor was filled with inoculum (the same as in case of batch experiments), and then operated with sewage sludge at an SRT of 30 days for a month to provide a suitable acclimation of anaerobic biomass prior to the experiments. In the first two semi-continuous periods (runs R1 and R2) the reactor was exclusively fed with sewage sludge with SRT values of 20 and 15 days, respectively and at equivalent organic loading rates of 2.15 and 3.03 kg VS/m^3 d. Then, in runs R3 and R4, a mixture of sewage sludge with 30% SHW (w/w) was treated, and the reactor was operated with SRTs of 20 and 15 days and corresponding OLRs of 2.98 and 3.97 kg VS/m^3 d, respectively. Finally, in runs R5 and R6, the content of SHW in the digested mixture was increased to 50% (w/w), and the OLR values were established on 3.10 and 4.10 kg VS/m^3 d, respectively. The mixtures prepared for the semi-continuous experiment were diluted with distilled water in order to increase the moisture content and achieve the OLR values not exceeding around 4 kg VS/m^3 d. For each experimental run, the reactor was continuously operated for at least 4 consecutive SRTs to approximate steady-state conditions and to provide statistically comparable results.

2.4. Analyses

Total and volatile solids (TS,VS), total alkalinity (TAL), chemical oxygen demand (COD) and pH were analyzed according to standard methods (APHA, 2005). The total ammonium nitrogen (TAN) was determined using a HACH-Lange DR2800 spectrophotometer and a modified Nessler method (no. 8038) adopted by HACH. Free ammonia (FAN) concentrations were then calculated using