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Anaerobic digestion of sewage sludge with grease trap sludge and municipal solid waste as co-substrates[☆]

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ABSTRACT

The feasibility of simultaneous treatment of multiple wastes via co-digestion was studied in semi-continuous mode at *meso*philic conditions. The obtained results indicated that sewage sludge, organic fraction of municipal waste (OFMSW) and grease trap sludge (GTS) possess complementary properties that can be combined for successful anaerobic digestion. During the co-digestion period, methane yield and VS removal were significantly higher in comparison to digestion of sewage sludge alone. Addition of GTS to digesters treating sewage sludge resulted in increased VS removal and methane yield up to 13% (from 50 to 56.4) and 52% (from 300 to 456,547 m^3/Mg VS_{add}), respectively. While the use of OFMSW as the next co-substrate in the feedstock, can boost methane yield and VS removal up to 82% (300–547 m^3/Mg VS_{add}) and approximately 29% (from 50% to 64.7%), respectively. Moreover, the results of the present laboratory study revealed that the addition of co-substrates to the feedstock had a significant influence on biogas composition. During the experiment methane content in biogas ranged from 67% to 69%. While, the concentration of LCFAs was increasing with the gradual increase in the share of co-substrates in the mixtures, wherein only the oleic acid was higher than some inhibition concentrations which have been reported in the literature. However, it did not significantly affect the efficiency of the co-digestion process.

1. Introduction

Worldwide, the treatment of municipal wastewater produces large amounts of sewage sludge. While at the same time an increase of interest in recovering energy from sewage sludge arises, mainly due to the fact that it can be executed during the same operations comprising of conventional sludge treatments such as landfilling and land application (Cao and Pawłowski, 2012). Sewage sludge is rich in organic matter with a composition comparable to plant tissues and is considered biomass.

However, the first step of anaerobic digestion (hydrolysis) is considered rate limiting. Pre-treating sewage sludge prior to anaerobic digestion aims at enhancing hydrolysis and complete the degradation more fully. Several pre-treatments have been tested for this purpose. These included chemical treatments, alkalization, Fenton and ozonation, thermal, biological, ultrasound, microwave irradiation (Zawieja et al., 2015). Although the abovementioned methods can increase AD efficiency and biogas production, they rely on additional energy inputs. An interesting option for improving anaerobic digestion yield is co-digestion. Co-digestion can be defined as the combined anaerobic treatment of several wastes with complementary characteristics. Apart from increasing biogas production, co-digestion offers several other benefits. These are: increased loading of readily biodegradable organics, improved C/N ratio, dilution of toxic substances and reduced treatment costs. Moreover, wastewater treatment plants (WWTP) may implement co-digestion of sewage sludge with other biodegradable wastes without changing (or with minimal changes) the plant design. This is because existing digesters at WWTP often are over dimensioned (Bień et al., 2010; Neczaj et al., 2012). There are numerous laboratory- and full-scale examples reporting successful co-digestion of sewage sludge and organic fraction of municipal solid wastes (OFMSW) (Borowski, 2015; Grosser at al, 2013). In general, the addition of sewage sludge to OFMSW improves the C/N ratio of the mixtures, and the production of biogas through anaerobic *meso*philic digestion

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increases. Another type of biodegradable wastes, which can be used as co-substrates for sewage sludge co-digestion, are fat rich-materials. For example, fat, oil, and grease (FOG) have been reported to increase biogas production by 30% or more when added to the anaerobic digester (Kabouris et al., 2009). However, during co-digestion of high-strength lipid wastes a wide assortment of operational challenges has also been reported. These are: process inhibition by long chain fatty acids, sludge flotation, digester foaming, blockades of pipes and clogging of gas collector (Worwąg et al., 2011).

Several studies have shown that mixtures of agricultural, municipal and industrial wastes can be digested successfully and efficiently together. However, there is no information regarding co-digestion of sewage sludge with organic fraction of municipal solid waste and grease trap waste. The semi-continuous experiments were conducted to assess: 1) the possibility to digest these wastes together in one reactor; 2) the feasibility of co-digestion of the mentioned wastes in order to improve the efficiency of process (economic aspect).

Therefore, the aim of this investigation was to study the efficiency of the anaerobic digestion of a waste mixture consisting of those three types of waste. The efficiency of the AD was investigated on the basis of biogas production and volatile solids reduction. The emphasis was also put on the fate of long chain fatty acid during anaerobic co-digestion. This resulted from the fact that these compounds may negatively affect the anaerobic process.

2. Materials and methods

2.1. Inoculum and substrate

Sewage sludge (mixtures of primary sludge (PS) and waste activated sludge (WAS) as well as inoculum (digested sewage sludge) for all experiments were obtained from a municipal wastewater treatment plant (WWTP). The WWTP is located in the Silesian region (Poland) and has a treatment capacity of 314 835 population equivalent. The average wastewater flow entering WWTP is equal to 90,000 m^3/d. The sludge was collected at the plant every four weeks and kept at 4 °C prior to use.

Fat rich material - grease trap sludge (GTS) was obtained from a meat processing plant (Silesian Region, Poland) specializing in meat cutting (cows and pigs) and production of different meat products.

A simulated/synthetic OFMSW with a particle size of less than 1 mm was used as a substrate. OFMSW was prepared just as described in studies by Sosnowski et al. (2008). Both co-substrates were frozen at −25 °C in a laboratory freezer. GTS and OFMSW were thawed for 12 h at room temperature before preparing the feedstock for the reactors.

Synthetic OFMSW contained (by weight): 1) potatoes 55% (potato peelings: boiled potatoes −80:20% wt); 2) fruits and vegetables 28% (citrus fruit skins and small pieces, banana skins, cabbages, apples, lettuce and carrots – of 15%, 10%, 40%, 28%, 2% and 5% wt, respectively); 3) bread 5%; 4) paper 2%; 5) rice, pasta and buckwheat groats 10% (25:60:15% weight).

The characteristics of sewage sludge and co-substrates mixtures used in the presented study are shown in Tables 1–3.

2.2. Experimental procedure

The reported experiment was divided into three stages which were implemented consecutively as shown in Fig. 1. During stage 1, the anaerobic digestion of only sewage sludge was conducted (the data obtained in this stage of the experiment will be considered as the control phase to which the results of the next stages of the experiment will be compared). While in the next stages sewage sludge was co-digested with the addition of different co-substrates. In the 2nd stage, the substrates were fed to the reactor as a mixture of sewage sludge and grease trap sludge (GTS). In this stage the addition of GTS was gradually increased from 5% to 30% on VS basis. The maximum amount of GTS was selected based on literature (Davidsson et al., 2008; Silvestre et al., 2011; Wan et al., 2011; Girault et al., 2012) and unpublished results from own experiments (unpublished data). The amount of GTS was maintained constant until the end of the study. At stage 3, the co-digestion of sewage sludge with GTS and organic fraction of municipal waste (OFMSW), took place. As in stage 2, the addition of waste (OFMSW) was gradually increased up to 30% on VS basis (by 10% every 10 days) and similarly like in the second stage, quantity of waste until the end of the experiment was maintained at this level. Like in the case of GTS the target level of OFMSW in the feedstock was selected based on own experiments (unpublished data). The process was carried out at *meso*philic conditions (37 °C) in two glass reactors filled with 6 l of working liquid. The reactors were constantly mixed (180 rpm) using mechanical stirrers and their temperatures were controlled by a thermostatically regulated water bath. The produced biogas was collected by a gas collector (PVC tube filled with water acidified to pH 3). The reactors were operated in a draw-and-fill mode with a retention time of 20 days. The hydraulic retention time (HRT) was set to 20 d, which is within operating range values reported in literature (spanning from 15 to 25 days) (Hartmann and Ahring, 2006; Nasir et al., 2012; Grosser et al., 2013). Moreover, the 20-day HRT is estimated to simulate future full-scale operating conditions, the exact wastewater treatment plant, where the sludge used in this experiment was obtained.

Experimental procedure was based on our previous works (Grosser and Neczaj, 2016; Neczaj et al., 2012). Gradual addition of the chosen components (GTS, OFMSW) in the subsequent phases of the experiment was done in order to adapt microorganisms to new environmental conditions such as high concentration of LCFAs as well as high organic loading rate. This was essential especially in the case of the second phase of the experiment when the digester was fed with mixtures containing fat rich materials. Despite their high methane potential, due to production of intermediate compounds during anaerobic decomposition, this material is considered in literature as problematic (frequent failure of anaerobic mono-digestion of fat rich material).

At start-up the systems were inoculated with *meso*philic-digested sludge from WWTP. The batch assay used in the first days was applied to promote the development of an anaerobic community. According to Cavaleiro et al. (2009) and Griffin et al. (1998) gradual start-up of the *meso*philic digester promotes sludge acclimation and improves the digestion process as such. Hence (in the first weeks of semi-continues digestion of sewage sludge) aliquots of sewage sludge were added stepwise to the reactors up to the total volume of 300 mL (based on the HRT value and working liquid volume of reactors). Digested material and feed were withdrawn at exact same time daily. The withdrawals were carried out using a peristaltic pump. The sewage sludge mixed with increasing concentrations of GTS and OFMSW were introduced to the reactors using a 100 mL syringe. These mixtures were prepared every 10 days. Feedstock (mixture of sewage sludge and the two other bio-wastes) was stored in sealed plastic bottles, and kept at 4 °C until use. The bottles were equilibrated at room temperature for 24 h prior to introduction into the reactors.

The effluent was monitored every five days while biogas production and composition every day. Influent characteristics were measured once per 10 days.

2.3. Analytical methods

Total and volatile solids, chemical oxygen demand (COD), pH, alkalinity, volatile fatty acids (VFAs), total Kjeldahl nitrogen (TKN), total carbon (TC), fat concentrations and ammonium nitrogen were analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA) (1999). The VFAs, pH, alkalinity, ammonium nitrogen and $COD_{soluble}$ were determined in supernatants after centrifugation at 12100 rcf for 15 min and then filtration through