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Research article

The influence of decreased hydraulic retention time on the performance and stability of co-digestion of sewage sludge with grease trap sludge and organic fraction of municipal waste

Dr. Anna Grosser, Ph.D.

Czestochowa University of Technology, Institute of Environmental Engineering, Brzeznicka 60a, 42-200, Czestochowa, Poland

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ABSTRACT

The effect of hydraulic retention time ranging from 12 to 20 d on process performance and stability was investigated in two anaerobic completely stirred tank reactors with a working liquid volume equal to 6 litres. The reactors were fed with mixtures containing (on volatile solids basis): 40% of sewage sludge, 30% of organic fraction of municipal waste and 30% of grease trap sludge. The change of hydraulic retention time did not significantly affect process stability. However, methane yields as well as volatile solids removal decreased from 0.54 to 0.47 l per kg of added volatile solids and 65% to 60% respectively, with the decrease of hydraulic retention time. Despite the fact that the best process performance was achieved for hydraulic retention time of 20 days, the obtained results showed that it is also possible to carry out the co-digestion process at shorter hydraulic retention times with good results. Furthermore, gas production rate as well as biogas production at the shortest hydraulic retention time were approximately 46% higher in comparison to results obtained at the longest hydraulic retention time. In this context, the proposed solution seems to be an interesting option, because it provides an unique opportunity for wastewater treatment plants to improve their profitability by enhancing energy recovery from sludge as well as full utilisation of the existing infrastructure and hence creates a new potential place for alternative treatment of organic industrial waste such as: fat-rich materials or food waste. However, implementation of the solution at wastewater treatment plants is still a big challenge and needs studies including identification of optimal digesting conditions, information about substrate pumping, inhibition thresholds and processing properties. Additionally, due to the characteristics of both co-substrates their introduction to the full-scale digester should be carefully planned due to a potential risk of overloading of the digester. For this reason, a gradual increase of the share of these wastes in the co-digestion mixture is highly recommended, because it will allow for the acclimatization of bacteria as well as prevent overloading. The results of this study show the importance of gradual acclimatization of microorganisms to the changing environmental conditions. It was found that concentration of long chain fatty acids in effluents increased with the reduction of hydraulic retention time, but this phenomenon did not significantly influence the performance and stability of the process probably due to changes hydraulic retention time being gradual. Although for palmitic acid a moderate negative correlation with volatile solids removal was observed.

1. Introduction

Simultaneous treatment of multiple wastes combined with an enhancement of anaerobic digestion (AD) efficiency fits the new EU policy supporting the increase of the renewable energy share in the general energy balance (Grosser et al., 2013a; Zawieja et al., 2015). Furthermore, the technology allows for improved profitability of wastewater treatment plants (WWTPs) which are energy-consuming (Budych-Gorzna et al., 2016). The produced biogas may cover from 39% to 76% (Silvestre et al., 2015b) electric energy demand of WWTPs which typically ranges from 0.3 to 0.78 khW per cubic meter of treated wastewater (Cano et al., 2015). For this reason, in recent years, the number of publications about the anaerobic co-digestion (AcD) process has increased (Mata-Alvarez et al., 2014). It is understandable consider the fact that in

E-mail address: agrosser@is.pcz.czest.pl.

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comparison to mono-digestion, regardless of used wastes, AcD offers several advantages such as: the above-mentioned improved economic viability of the plant (e.g. wastewater treatment plant (WWTP)) associated with increased process performance (usually enhanced VS removal, methane yield), improved nutrient balance, increased content of macro- and micronutrients and the biodegradable fraction as well as dilution of toxic compounds (Mata-Alvarez et al., 2014) and the possibility of digesting wastes, which may cause inhibition of the process or can hamper digestion stability, when treated alone (Bień et al., 2010) such as food waste (Kim et al., 2016) or fat-rich materials (Long et al., 2012). Furthermore, simultaneous treatment of organic waste is simpler than their anaerobic digestion alone, because it requires less involvement in the design of the digester (Tandukar and Pavlostathis, 2015) as well as allows to eliminate disadvantages of mono-digestion systems which are linked with characteristics of waste and system optimization (e.g. long hydraulic retention time) (Hagos et al., 2016). Different kinds of substrates can be used as co-substrates in AcD (Shah et al., 2015). According to Mata-Alvarez et al. (2014) the most commonly used substrates in this process are: animal manures, sewage sludge (Ss) and organic fraction of municipal waste (OFMSW). Due to complementary properties of these wastes, addition of Ss and OFMSW as co-substrates to anaerobic digesters is the most documented and confirmed experimentally in co-digestion research (Mata-Alvarez et al., 2014; Grosser and Neczaj, 2016, Pavi et al., 2017; Yalcinkaya and Malina, 2015a,b; Martínez et al., 2016; Budych-Gorzna et al., 2016; Silvestre et al., 2015; Borowski, 2015; Koch et al., 2016) Both the fact that co-digestion is often regarded as a forward-looking direction in energy recovery from food waste (Iacovidou et al., 2012) as well as the possibility of implementing the process in existing WWTP due to the oversized digesters treating sewage sludge which often work at low organic loading rate (OLR), can be used as additional arguments for processing these groups of waste via AcD (Bień et al., 2010). However, on account of their high methane potential (0.7–1.1 m^3 methane/kgVS), fat-rich materials have also been recently acknowledged as an attractive co-substrate for the co-digestion process (Grosser and Neczaj, 2016). Furthermore, due to its high content of volatile solids even a low volumetric addition of this waste to the feedstock leads to a significant increase in organic loading rate and consequently it allows for anaerobic digester operation at slightly reduced hydraulic retention time (Tandukar and Pavlostathis, 2015). Benefits of AcD has been widely reported in a number of studies (Mata-Alvarez et al., 2014). For instance, Kim et al. (2016) for a mixture of food waste (FW) and municipal biosolids (primary sludge and thickened waste activated sludge) at solids retention time of 20 days noted that COD removal as well as specific methane production per influent were higher in a co-digestion system than a mono-digestion system. The achieved results showed a 1.3–1.8x increase of specific methane production and a 47% increase of COD removal from the addition of FW to municipal sludge. In turn Olsson et al. (2014) recorded a 23% increase of methane production for a mixture containing 63% (w/w VS based) of undigested sewage sludge and 37% (w/w VS based) of wet algae slurry. Also, Pavi et al. (2017) recorded a significant increase of biogas yield during the co-digestion process. For a mixture of OFMSW, fruit and vegetable waste(FVW) at a ratio of 1/4 (VS basis) they noted an increase of the mentioned parameter of 130% and 41% with respect to mono-digestion of OFMSW and FVW, respectively. Examples of the positive impact of the addition of the co-substrates on the efficiency of sewage sludge digestion can be multiplied proving that sewage sludge can be successfully used as a co-substrate with a wide range of waste such as OFMSW (Krupp et al., 2005; Ara et al., 2012; Silvestre et al., 2015; Borowski, 2015; Lebiocka et al., 2016), fat-rich materials including fat, oil and grease waste, restaurant grease trap waste (Razaviarani et al., 2013; Yalcinkaya and Malina, 2015a,b; Martínez et al., 2016; Grosser and Neczaj, 2016), micro-algae (Caporgno et al., 2015), glycerol (Jensen et al., 2014; Nartker et al., 2014), strawberry extrudate (Serrano et al., 2015), shredded grass (Wang et al., 2014; Hidaka et al., 2013) or poultry industry waste (Budych-Gorzna et al., 2016).

In most cases the co-digestion process is carried out for a mixture consisting of two components. While, very few systematic studies are available for the co-digestion process using more than two wastes. For instance, Abudi et al. (2016) obtained an improved biogas yield of up to 135.5% for co-digestion of organic fraction of municipal waste with thermo-alkaline pretreated thickened waste activated sludge and H_2O_2 pretreated rice straw using a mixture ratio of 3:0.5:0.5 based on volume. While, Neczaj et al. (2015) and Grosser et al. (2017)) evaluated the feasibility of co-digestion of sewage sludge, organic fraction of municipal solid waste and grease trap sludge (GTS). The authors found that the addition of both waste to the digester treating sewage sludge resulted in an increased methane yield as well as VS removal of up to 82% (from 300 $m^3/Mg\ VS_{add}$ to 547 $m^3/Mg\ VS_{add}$) and 29% (from 50% to 64.7%), respectively in comparison to the control sample – AD of Ss alone. The process was carried out in mesophilic conditions and hydraulic retention time of 20 days which is within operating range values reported in literature for OFMSW (Grosser et al., 2013a). However, there is no information regarding how the change of this operational parameter affects process stability. The proposed scope of this research seems particularly important especially in the context of energy self-sufficiency of the WWTP which could be obtained by increasing OLR (Garrido et al., 2013; Silvestre et al., 2015b), via modification of feedstock composition as well as the reduction of hydraulic retention time. It is worth underlining that among all of the operational parameters, hydraulic retention time (HRT) has been reported as one of the most important parameters significantly affecting microbial ecology in completely stirred tank reactors (CSTR) and it must be optimized for particular feedstock in the bioreactor (Tchobanoglous and Burton, 1991). Moreover, changes of HRT and fluctuations of OLR associated with them, impact the disposal capacity per volume unit of the digester, thereby affecting investment costs (Li et al., 2015).

Therefore, the aim of this investigation was to assess the impact of hydraulic retention time on the performance of anaerobic co-digestion of sewage sludge, fat rich material and organic fraction of municipal waste. Additionally, in this study special attention was paid to the influence of HRT on the concentration of long chain fatty acids (LCFAs) - key intermediate compounds produced during anaerobic decomposition of fat-rich materials (Wallace et al., 2017).

2. Methods

2.1. Substrates

Sewage sludge was obtained from a municipal wastewater treatment plant in the Silesia region of Poland. Samples were collected once every two weeks and kept at 4 °C prior to use. Fat rich materials (GTS) were collected from grease traps which were located within a meat processing plant (Silesian Region, Poland). Which were ground in laboratory conditions using a blender to reduce their particle size and afterwards frozen at −20 °C. Whereas, due to the difficulty of obtaining a representative sample of organic fraction of municipal solid waste, a simulated/synthetic OFMSW with a particle size of less than 1 mm was used as the substrate and was prepared according to Sosnowski et al. (2008). Synthetic OFMSW contained (by weight) the following ingredients: a) potato 55% (potato peelings: boiled potatoes - 80:20 % wt); b) fruits and vegetables 28% (citrus fruit skins and small pieces of: banana

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