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Co-digestion of the hydromechanically separated organic fraction of municipal solid waste with sewage sludge

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A B S T R A C T

This study investigates the anaerobic digestion of the hydromechanically sorted organic fraction of municipal solid wastes (HS-OFMSW) co-digested with sewage sludge (SS). Eight laboratory-scale experiments were conducted under semi-continuous conditions at 15 and 20 days of solids retention time (SRT). The biogas yield from the waste reached 309 to 315 dm^3/kgVS and 320 to 361 dm^3/kgVS under mesophilic and thermophilic conditions, respectively. The addition of SS to HS-OFMSW (1:1 by weight) improved the C/N balance of the mixture, and the production of biogas through anaerobic mesophilic digestion increased to 494 dm^3/kgVS, which corresponded to 316 dm^3CH_4/kgVS. However, when SS and HS-OFMSW were treated under thermophilic conditions, methanogenesis was inhibited by volatile fatty acids and free ammonia, which concentrations reached 5744 gCH_3COOH/m^3 and 1009 gNH_3/m^3, respectively.

1. Introduction

In Poland, municipal and industrial wastes pose great ecological hazards. The most important problems include long-term improper waste management, a poorly developed system of selection, a lack of modern infrastructure, and troubles with the enforcement of laws. According to the Central Statistical Office (Bochenek et al., 2013), Poland produced approximately 135 million tonnes of wastes in 2012, of which 12 million tonnes constituted municipal solid waste (MSW). The amount of collected municipal solid waste was 9.58 million tonnes, from which as much as 90% represented unsorted (mixed) waste. Moreover, approximately 75% of the MSW was deposited in landfill sites, and only 9% was treated by biological processes (mainly by composting). However, approximately 80% of the total municipal waste produced in Poland is organic; and this type of waste is known as the organic fraction of municipal solid wastes (OFMSW) and is suitable for biogas production. These figures indicate the urgent need to reduce the mass of landfilled wastes and suggest the implementation of sorting installations for MSW prior to biological processing via composting or anaerobic digestion (AD).

The literature concerning both laboratory investigations and functioning AD plants focuses on the treatment of separately collected or source sorted municipal organic wastes (SS-OFMSW) (Bolzonella et al., 2006b; Cavinato et al., 2013; Davidsson et al., 2007; Forster-Carneiro et al., 2007; Kim and Oh, 2011; Zhang et al., 2008); whereas little has been published about the anaerobic treatment of the mechanically sorted (MS-OFMSW) and water sorted (WS-OFMSW) organic fraction of municipal solid wastes (Bolzonella et al., 2006b; Dong et al., 2010; Provenzano et al., 2013). The increased popularity of installations processing SS-OFMSW is associated with higher biogas yields and better compost quality produced from these wastes, whereas mechanically sorted municipal organic wastes produce less biogas and a digestate of poorer quality (Bolzonella et al., 2006b). However, implementation of full-scale AD plants treating both types of waste is still limited because of the relatively high costs and technological limitations (Davidsson et al., 2007; Zhang et al., 2008). A solution to this problem may be the co-digestion of OFMSW with other waste types including sewage sludge (SS). Literature data show generally a low carbon to nitrogen ratio in sewage sludges typically ranging from 6 to 16; however, the ratio for OFMSW can be as high as 25–38. Thus mixing sewage sludge with municipal solid waste provides an improved nutrient balance, and the optimal C/N ratio of 15–30 that is suggested for anaerobic digestion can be achieved (Castillo et al., 2006; Forster-Carneiro et al., 2007; Nasir et al., 2012; Zhang et al., 2008).

There are numerous examples of successful SS and OFMSW co-digestion operations at the laboratory-, pilot- and full-scale.

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However, almost all of these cases treated source-sorted municipal organic wastes (Agdag and Sponza, 2005; Bolzonella et al., 2006a, 2006b; Cavinato et al., 2013; Sosnowski et al., 2003). These authors have demonstrated the feasibility of sewage sludge co-digestion with OFMSW in existing digesters at municipal wastewater treatment plants. The digesters treating waste activated sludge are often oversized and work with low organic loading rates. These factors justify the use of additional substrates to achieve co-digestion. Furthermore, previous investigations also showed that wastewater treatment plants could implement the co-digestion of sewage sludge with OFMSW without changing (or with minor changes to) the plant design. These modifications may be economically beneficial (Bolzonella et al., 2006a; Cavinato et al., 2013; Krupp et al., 2005).

In this study, the feasibility of the anaerobic co-digestion the hydromechanically separated organic fraction of municipal solid waste (HS-OFMSW) with municipal sewage sludge was evaluated. The specific objective was to evaluate biogas and methane yield from HS-OFMSW and from the mixture of these wastes with sewage sludge. The emphasis was also put on the stability of the digestion processes, in particular, the role of ammonia and volatile fatty acids was investigated. The experiments were performed in mesophilic and thermophilic conditions with solids retention time (SRT) values of 20 and 15 days. To the best of the author's knowledge, this study is the first to investigate the anaerobic co-digestion of hydromechanically separated municipal organic wastes with sewage sludge.

2. Methods

2.1. Characteristics and origin of materials

Sewage sludge (the mixture of primary and waste activated sludge) was collected from the Municipal Wastewater Treatment Plant in Kutno, Poland. The plant treats 20,000 m^3/d of wastewater and serves an equivalent population of 130,000. In this plant, the primary sludge (PS) and waste activated sludge (WAS) are first pre-thickened together in a gravity thickener to achieve a 2% total solids (TS) content, and then dewatered by centrifugation to approximately 16% TS. In this process, partial stabilization and sterilization (hygienization) is achieved through the addition of lime; however lime was not added to the sludge prepared for the purpose of this study. The annual production of dewatered sludge is 30,000 tonnes.

The organic fraction of municipal solid wastes originated from a sorting plant at the Municipal Services Office in Puławy. In this plant, mixed (unsorted) municipal solid wastes are hydromechanically treated in the BTA® Process, which is the only installation of this type in Poland. The BTA® Process was originally developed in Germany in 1984 by the BTA Biotechnische Abfallverwertung GmbH & Co (now BTA Company GmbH) in cooperation with the University of Applied Sciences, Munich (BTA, 2014), whereas the installation in Puławy was opened in 2001. This process comprises a water pulper to remove heavy materials (bones, stones, glass, etc.) and light components (textiles, wood, fibers, foil, plastics, etc.) from wastes followed by a grit removal system. The capacity of the plant is 22,000 tonnes of wastes per year.

The characteristics of both the SS and HS-OFMSW are depicted in Table 1. Typically, the sludge was rich in nitrogen (average C/N ratio of 9.09) and phosphorus because this sludge originated from a treatment plant operating with a biological nutrient removal system. Additionally, the volatile solids (VS) content was high (approximately 82% of TS) contrasting previously published data (Cavinato et al., 2013; Forster-Carneiro et al., 2007; Sosnowski et al., 2003; Zhang et al., 2008). Conversely, the HS-OFMSW was dilute showing an average total solids content of 3.5% with the volatile fraction not exceeding 53% of the TS. This classifies HS-OFMSW as not-easily biodegradable because the VS/TS ratio was lower than 0.7 (Pavan et al., 2000). Moreover, the waste displayed low quantities of nutrients. The fraction of nitrogen and phosphorus averaged 2.1% and 0.73%, respectively, and these figures were over 3-fold lower than those reported for sewage sludge. This is in agreement with the observations of Dong et al. (2010).

Table 1
Characteristics of sludge and hydromechanically separated OFMSW used for the experiments.

Indicator	Unit	Sewage sludge	HS-OFMSW
TS	g/kg	155.37 ± 9.11	35.33 ± 10.02
VS	g/kg	128.37 ± 10.05	18.79 ± 7.71
	% TS	82.58 ± 3.01	53.17 ± 2.28
COD	gO_2/kg	168.47 ± 22.50	21.53 ± 6.81
	gO_2/kg TS	1084.4 ± 144.8	609.4 ± 164.5
Potassium	gK/kg TS	7.61 ± 0.41	4.52 ± 0.82
Sodium	gNa/kg TS	3.87 ± 0.28	4.14 ± 0.95
Calcium	gCa/kg TS	25.01 ± 1.34	9.80 ± 1.10
Magnesium	gMg/kg TS	5.39 ± 0.72	2.27 ± 0.39
Iron	gFe/kg TS	8.16 ± 1.25	9.03 ± 0.82
Manganese	mgMn/kg TS	532 ± 94	202 ± 58
Zinc	mgZn/kg TS	947 ± 192	157 ± 84
Copper	mgCu/kg TS	343 ± 133	209 ± 19
Lead	mgPb/kg TS	58.8 ± 23.1	39.2 ± 5.1
Cadmium	mgCd/kg TS	31.7 ± 9.8	1.7 ± 0.4
Elemental analysis			
C	% TS	64.30 ± 2.10	66.78 ± 1.39
N	% TS	7.07 ± 0.42	2.08 ± 0.33
P	% TS	2.51 ± 0.23	0.73 ± 0.17
H	% TS	5.27 ± 0.15	5.91 ± 0.52
S	% TS	0.69 ± 0.05	0.05 ± 0.01
C/N	–	9.09	32.18

± Standard deviation.

2.2. Experiments

Four laboratory scale reactors (each with 5 dm^3 of total and 3 dm^3 of active volume) were used in these experiments. Each reactor had a cylindrical shape with an internal diameter of 16 cm, a height of 25 cm and an active volume of 3 dm^3. The reactors were equipped with helix-type mechanical stirrers operated with 80 rpm for 15 min every hour. The reactors were placed in thermostats to ensure constant mesophilic (35 ± 1 °C) or thermophilic (55 ± 1 °C) temperatures.

Each reactor was coupled with a 4 dm^3 gas collecting tank to provide anaerobic conditions and to measure the biogas yield by a water displacement method. The digesters were fed once a day (a semi-continuous operation) using a peristaltic pump. In the nomenclature used in this study, R1 and R2 refer to experiments with HS-OFMSW that were performed in mesophilic conditions, whereas R3 and R4 refer to experiments with HS-OFMSW that were performed in thermophilic conditions (Table 2). The other experiments were performed with a mixture of SS and HS-OFMSW (1: 1 of feed TS) in mesophilic (exp. R5 and R6) and thermophilic (exp. R7 and R8) conditions (Table 3). For each substrate and temperature, two SRT values were implemented to provide different operational conditions.

2.3. Analyses

The analyses of the pH, total and volatile solids, total alkalinity (TAL) and chemical oxygen demand (COD) were performed according to standard methods (APHA, 2005). The total ammonium nitrogen (TAN), free ammonia (FAN), orthophosphates (PO_4^{3-}), and volatile fatty acids (VFA) were analyzed using a DR2800