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Anaerobic co-digestion of swine and poultry manure with municipal sewage sludge

Sebastian Borowski [a,*], Jarosław Domański [a], Laurence Weatherley [b]

[a] Technical University of Lodz, Institute of Fermentation Technology and Microbiology, Poland
[b] The University of Kansas, Department of Chemical and Petroleum Engineering, United States

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ABSTRACT

The anaerobic digestion of municipal sewage sludge (SS) with swine manure (SM) and poultry manure (PM) was undertaken. It was found that a mixture of sewage sludge with a 30% addition of swine manure gave around 400 dm^3/kgVS of biogas, whereas the maximal biogas yield from ternary mixture (SS:SM:PM = 70:20:10 by weight) was only 336 dm^3/kgVS. An inhibition of methanogenesis by free ammonia was observed in poultry manure experiments. The anaerobic digestion was inefficient in pathogen inactivation as the reduction in the number of *E. coli* an *Enterobacteriaceae* was only by one logarithmic unit. A substantial portion of pathogens was also released into the supernatant.

1. Introduction

Treatment and disposal of manures from livestock breeding creates great economical and legal problems in Poland. According to the Polish Act of 10 July 2007 on fertilizers and fertilization (Journal of Laws No.147, item 1033) farmers that conduct poultry breeding or farming of more than 40,000 places, or pig breeding or farming of more than 2000 places, are obliged to dispose of at least 70% of pig or poultry manure on their own farmlands. Furthermore, farmers are obliged to provide the storage of manure in sealed tanks of the capacity equivalent to at least four month's production of that fertilizer. A solution to these problems can be anaerobic digestion of manure which not only provides stabilization and deodorization of that substrate but also re-categorizes the fertilizer from "natural" into "organic", which can be more easily disposed of. However, anaerobic treatment of manure as a sole substrate is usually unprofitable due to low biogas production and some exploitation problems (Ashekuzzaman and Poulsen, 2011; Fantozzi and Buratti, 2009; Moller et al., 2007; Zhang et al., 2011).

As both swine and poultry manure have higher nitrogen contents compared with other types of organic wastes, many authors report ammonia inhibition of biogas production particularly when digesting manure under thermophilic conditions (Bujoczek et al., 2000; Hansen et al., 1998). To overcome the above problems, manure can be treated with other types of wastes. Mixing of manure with carbon-rich organic wastes improves nutrient balance and the *C/N* ratio, which should be in the range 20–30 as recommended for stable operation of anaerobic digestion. Other co-digestion benefits include: increased loading of readily biodegradable organic matter, dilution of toxic substances, improved buffer capacity of the mixture, greater biogas yield, a better quality of a digested product, and reduced costs (Alvarez et al., 2010; Esposito et al., 2012; Rao and Baral, 2011; Wang et al., 2012). There are several reports on co-digestion of swine manure with other organic wastes including winery wastewater (Riano et al., 2011), food waste (Kafle and Kim, 2013; Zhang et al., 2011), energy crops (Cuetos et al., 2011), agro-wastes (Alvarez et al., 2010; Giuliano et al., 2013), and herbal-extraction residues (Li et al., 2011). Also chicken manure was successfully treated with whey (Gelegenis et al., 2007), fruit and vegetable wastes (Callaghan et al., 2002), organic fraction of municipal solid wastes (Esposito et al., 2012), rice straw (Wang et al., 2013a), and other types of manure including cattle slurry (Ashekuzzaman and Poulsen, 2011; Callaghan et al., 2002; Fantozzi and Buratti, 2009), buffalo manure (Esposito et al., 2012) and sheep manure (Ashekuzzaman and Poulsen, 2011). However, relatively few reports describe co-digestion of multi-component substrates (Ashekuzzaman and Poulsen, 2011; Esposito et al., 2012; Wang et al., 2012, 2013a).

Anaerobic digestion of swine and poultry manure with sewage sludge is of particular interest since most of the digesters at wastewater treatment plants are operated with low loading rates. Due to low solids contents of the sludge delivered to the digesters, poor biogas yields are reported especially when treating waste activated sludge with little or no addition of primary sludge (Bolzonella

* Corresponding author. Address: Wólczańska 171/173, 90-924 Łódź, Poland. Tel.: +48 42 6313484; fax: +48 42 6365976.
E-mail address: sebastian.borowski@p.lodz.pl (S. Borowski).

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et al., 2005; Bujoczek et al., 2000; Rao and Baral, 2011). Polish regulations do not prohibit co-digestion of manure with sewage sludge. The mixture of sludge and manure after anaerobic digestion is treated as sewage sludge alone, which is subject to the Polish Act of 14 December 2012 on wastes (Journal of Laws dated 2013, item 21), and Regulation of the Minister of Environment dated 13 July 2010 on municipal sewage sludge (Journal of Laws No. 137, item 924). These rules define the maximum permissible concentrations of heavy metals and pathogens as well as determine the methods of sludge disposal.

Therefore the aim of this investigation was to evaluate the effectiveness of the anaerobic digestion process for treating sewage sludge with swine and poultry manure. According to the authors' best knowledge, this is the first study dealing with ternary anaerobic digestion of swine and poultry manure with municipal sewage sludge.

2. Methods

2.1. Materials

Sewage sludge (the mixture of primary and waste activated sludge in the average volume proportion of 1:1) was collected from the Municipal Wastewater Treatment Plant at Łódź. Fresh swine manure was obtained from a Bukowie pig farm with a non-bedding breeding system, whereas fresh poultry manure was delivered from a laying hen farm in Zgierz operated using the cage system. The characteristics of substrates used in this study are depicted in Table 1.

2.2. Batch experiments

Batch experiments (Exp. 1–6) were carried out in 6 digesters. Each digester had a working volume of 1 dm^3 and was connected to a 3 dm^3 biogas collecting tank to provide anaerobic conditions and to measure daily biogas yields. The following trials were therefore performed: Exp. 1 – 100% SS; Exp. 2 – 90% SS + 10% SM; Exp. 3 – 80% SS + 20% SM; Exp. 4 – 70% SS + 30% SM; Exp. 5 – 60% SS + 40% SM; and Exp. 6 – 50% SS + 50% SM. The mixtures of sewage sludge and swine manure were prepared on a weight (w/w) basis, and no inoculum was used. The experiments were performed with no replicates, however the results were then confirmed in semi-continuous trials. Each experiment was continued to the point at which only residual or zero biogas production rates were measured (no more than 20 cm^3 of biogas per digester daily).

2.3. Semi-continuous experiments

Two identical reactors were operated in semi-batch conditions at 35 ± 1 °C. One reactor was fed with a mixture of sewage sludge and swine manure, SS:SM = 70:30 on a weight (w/w) basis (Experiment A with solids retention time SRT = 30 days, which was followed by Experiment B with SRT = 20 days). The proportions of SS and SM were selected based on the results of the batch tests. The second reactor (Experiments C–E) was operated with a ternary mixture, in which apart from swine manure and sludge, a 10% fraction of poultry manure was added to give the ratio of SS:SM:PM = 70:20:10 (w/w). For that reactor, the experimental procedure was as follows: Exp. C with SRT = 30 days followed by Exp. D with SRT = 20 days and Exp. E with SRT = 15 days.

Each reactor had a working volume of 3 dm^3 and was coupled with a 4 dm^3 biogas collecting tank to provide strict anaerobic conditions and to measure daily biogas production by water displacement. The substrates were added to the reactors and withdrawn once every 24 h with a peristaltic pump. The digesters were operated for at least 3 subsequent SRTs under steady state conditions characterized by stable biogas production and relatively constant pH and volatile fatty acids concentrations throughout the run.

2.4. Analyses

Total and volatile solids (TS, VS), chemical oxygen demand (COD), and pH were analyzed according to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Total Kjeldahl nitrogen (TKN) and total ammonium nitrogen (TAN) were determined using a HACH-LANGE DR 2800 spectrophotometer and a modified Nessler method (no 8038) adopted by HACH®. For determination of TKN, a sample was mineralized beforehand with sulfuric acid at boiling point to convert all ammonium and organic nitrogen into ammonium salts, and then treated with sodium hydroxide. Free ammonia concentrations were calculated according to the following formula, as described by Hansen et al. (1998):

Table 1
Characteristics of municipal sewage sludge and poultry manure used for the investigations.

Indicator	Unit	Sewage sludge[a]	Swine manure[b]	Poultry manure[c]
Total solids	g/kg	48.56 ± 7.98	123.96 ± 28.20	277.18 ± 20.24
Volatile solids	g/kg	36.70 ± 7.35	90.12 ± 24.37	205.32 ± 25.57
	% TS	75.20 ± 3.33	72.20 ± 3.76	73.95 ± 5.55
Chemical oxygen demand	gO_2/kg	41.06 ± 13.30	119.50 ± 7.95	201.39 ± 18.86
	gO_2/kg TS	826 ± 168	964 ± 64	733.21 ± 126.33
Total Kjeldahl nitrogen	gN/kg	2.82 ± 0.61	6.40 ± 2.17	13.09 ± 4.16
	gN/kg TS	58.07 ± 5.93	51.60 ± 17.48	48.69 ± 12.61
Total phosphorus	gP/kg	1.24 ± 0.34	3.08 ± 11.03	4.73 ± 0.91
	gP/kg TS	25.29 ± 3.89	24.88 ± 8.91	17.67 ± 2.64
Sodium	gNa/kg TS	4.17 ± 0.99	4.42 ± 0.22	1.93 ± 0.33
Potassium	gK/kg TS	8.89 ± 0.89	18.33 ± 2.22	23.07 ± 1.27
Calcium	gCa/kg TS	24.42 ± 6.48	53.83 ± 3.34	43.90 ± 11.36
Magnesium	gMg/kg TS	6.36 ± 0.35	12.17 ± 1.65	5.60 ± 0.83
Iron	gFe/kg TS	5.79 ± 1.15	2.54 ± 0.30	0.78 ± 0.33
Zinc	gZn/kg TS	0.74 ± 0.10	1.29 ± 0.42	0.32 ± 0.05
Copper	mgCu/kg TS	204.18 ± 26.96	231.50 ± 30.50	46.63 ± 2.56
Lead	mgPb/kg TS	93.10 ± 16.17	64.84 ± 17.58	41.57 ± 19.38
Aluminium	gAl/kg TS	5.55 ± 1.20	1.75 ± 0.25	0.85 ± 0.61
Cadmium	mgCd/kg TS	43.16 ± 4.77	33.25 ± 6.55	19.23 ± 6.26
E. coli	CFU/g TS	$2.57\times10^6 \pm 1.78\times10^6$	$1.80\times10^6 \pm 1.21\times10^6$	$8.87\times10^6 \pm 1.44\times10^6$
Enterobacteriaceae	CFU/g TS	$5.00\times10^6 \pm 1.84\times10^6$	$2.44\times10^6 \pm 1.61\times10^6$	$1.13\times10^7 \pm 5.48\times10^5$

a,b,c – No. of replicates = 10.