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Co-digestion of solid poultry manure with municipal sewage sludge

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HIGHLIGHTS

- Addition of 30% poultry manure to sewage sludge increased biogas yield by 50%.
- Anaerobic mesophilic digestion is inefficient in pathogen inactivation.
- Great contamination of supernatant after the anaerobic digestion was reported.
- No inhibiting effect of ammonia on methanogenesis was observed.

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ABSTRACT

The anaerobic digestion was investigated using mixed sewage sludge and poultry manure. The experiments showed that a 30% addition of poultry manure to the sewage sludge did not increase specific gas yield (376 dm^3/kg VS versus 384 dm^3/kg VS), however gas production rate as calculated per unit volume was 1.5 higher for sludge and manure mixture. The anaerobic digestion turned out to be inefficient in terms of pathogen treatment, since the reduction of *Enterobacteriaceae* reached only two logarithmic units. In the course of the digestion processes, nutrients were released to the supernatant, and longer SRT favored that phenomenon. The liquor after the digestion of sludge alone was rich in phosphates (348–358 gP/m^3) and contained a lot of organic carbon (COD of 2705–6034 gO_2/m^3). Conversely, more ammonium nitrogen was found in the supernatant after co-digestion of sludge with manure (2094–2221 gN/m^3). However, there was no evidence of ammonia inhibition.

1. Introduction

Organic wastes from animal farming represent a big problem in the rural economy. The Polish Act of 10 July 2007 on fertilizers and fertilization (Dz.U. Nr. 147, poz 1033) imposes on entities that conduct poultry breeding or farming of more than 40,000 places, or pig breeding or farming of more than 2000 places, an obligation to dispose of at least 70% of pig or poultry manure on the owners' farmlands. Moreover, it is also required that the storage of manure be in sealed tanks, the capacity of which is equivalent to at least four-months production of that fertilizer. An alternative means of manure management could be via the use of anaerobic digestion and dewatering by which production of organic fertilizer and biogas would be achieved. However, a high concentration of poultry manure (PM) with solids content of more than 20%, and a large content of ammonia and organic nitrogen makes this substrate difficult to digest. Dilution of manure to 3–6% total solids eliminates the problem of ammonia inhibition and provides good mixing conditions in anaerobic tanks but the biogas yield (and the content of methane) is often too low to make production profitable (Bujoczek et al., 2000; Callaghan et al., 2002; Magbanua et al., 2001). According to the cited authors, the biogas yield from diluted manure reaches only 180 dm^3/kg VS added and around 550 dm^3/kg VS removed.

Another option for improving biogas yields is co-digestion of poultry manure with other organic wastes. Apart from increasing biogas production, co-digestion offers several other benefits including: increased loading of readily biodegradable organics, improved balance of nutrients and C/N ratio, dilution of toxic substances, a better quality of a digested product, and reduced costs.

These benefits accrue from the ability to process several substrates in one installation (Khalid et al., 2011; Wang et al., 2012, 2013). Anaerobic digestion of poultry manure with sewage sludge seems to be particularly advantageous since existing digesters operated at wastewater treatment plants are often oversized and hence underloaded (Bujoczek et al., 2000).

Co-digestion of poultry manure with other organic wastes has been examined by many researchers. Gelegenis et al. (2007) performed a series of experiments in continuously stirred mesophilic digesters with various mixtures of diluted poultry manure and

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whey. They reported a 40% increase in biogas production when manure was supplemented with 35% of whey. Chicken manure was successfully treated with rice straw (Wang et al., 2012, 2013) and wheat straw (Roshani et al., 2012). Maibaum and Kuehn (1999) investigated the Plauben/Zobes Biogas Plant for treatment of poultry manure with an organic fraction of municipal wastes (OFMSW) and including some material from the grease separators in the plant. A high biogas production of more than 500 dm^3/kg VS added was achieved in that plant when the reactors were operated at fermentation times below 20 days both under mesophilic and thermophilic conditions. Chicken manure was also treated with other manure types. Magbanua et al. (2001) have reported a 40% increase in biogas production when a 20% of poultry manure was added to hog manure. Esposito et al. (2012) investigated anaerobic digestion of buffalo and poultry manure with OFMSW. They have found, that the methane volume obtained from the mixture of manure with OFMSW (5:1 by dry mass basis) was 30% higher than the sum of the amounts produced from the same substrates digested separately. Wang et al. (2012) investigated co-digestion of the mixture containing 40% of dairy manure, 40% of chicken manure and 20% of wheat straw, which gave the biogas production of 581 dm^3/kg VS, whereas the biogas yield from poultry manure alone was only 311 dm^3/kg VS. Conversely, Callaghan et al. (2002) observed deterioration of the anaerobic digestion performance and a methane yield decrease when a 30% of PM was added to cattle manure, due to the inhibition of free ammonia present in the liquor.

As mentioned above, co-digestion of sewage sludge with other organic wastes is of considerable interest, since it allows the use of existing digesters at wastewater treatment plans to increase their biogas production and overall performance. In most studies, sewage sludge as a predominant substrate was co-digested with organic fraction of municipal solid wastes (Krupp et al., 2005; Sosnowski et al., 2003). The addition of around 25% of OFMSW to the sludge considerably increased the biogas yield especially in a two-stage system comprising a thermophilic hydrolysis reactor followed by a mesophilic methane digester (Sosnowski et al., 2003). In other work, sewage sludge was also co-digested with other organic wastes including fruit and vegetable wastes (Gomez et al., 2006), pig and cow manure (Murto et al., 2004), fat, oil and grease (Luostarinen et al., 2009; Wan et al., 2011), and meat processing wastes (Luostarinen et al., 2009). The investigation undertaken by Murto et al. (2004) is of particular interest since they studied co-digestion of sewage sludge with pig manure and other organic wastes. The maximal biogas production of 1000 dm^3/kg VS was measured when pig manure was digested with industrial and slaughterhouse wastes as a predominant substrate (66% of the reactor volume). The authors also reported high stability of the anaerobic digestion system, which was not affected by the high concentrations of volatile fatty acids (VFA, up to 3400 mg/dm^3 as acetic acid) due to production of ammonia, which kept the pH at a neutral level.

There is very little information regarding co-digestion of municipal sewage sludge with solid poultry manure. Yilmazel et al. (2011) investigated anaerobic co-digestion of poultry manure and sewage sludge but the purpose of their study was to evaluate nutrient recovery from digester effluents via struvite precipitation. Anaerobic digestion of chicken manure and sewage sludge in a batch screening assay was examined by Bujoczek et al. (2000). They reported the most complete digestion of all when a mixture of 40% fresh manure and 60% anaerobically digested sludge was employed.

Therefore, the aim of this investigation was to compare anaerobic digestion of mixed (primary and secondary) raw sewage sludge with co-digestion of this sludge but in the presence of poultry manure. The efficiency of the anaerobic digestion processes was investigated on the basis of biogas production and volatile solids reduction as well as on the release of ammonia and the production of volatile fatty acids. Moreover, the substrates and digestion products were also determined for *Enterobacteriaceae* and *Esherichia coli* to evaluate the impact of anaerobic digestion on pathogenic bacteria present in sludge and poultry manure.

2. Methods

2.1. Materials

The experiments were conducted using mixed, primary and secondary sewage sludge in the average volume proportion of 1:1. The sludge was collected from the activated sludge treatment system at the Municipal Wastewater Treatment Plant at Łódź, serving a population equivalent of 820,000 inhabitants. Before the experiments the sludge had been pre-thickened by passage through a belt thickener giving approximately 5% TS. Poultry manure was obtained from a non-litter poultry farm in Zgierz breeding 50 thousand layers. Both fresh sludge and manure were collected at the plants 7 times and delivered to the laboratory. The substrates were stored at 4 °C prior to use.

The characteristics of municipal sewage sludge (mixture of primary and secondary), and poultry manure used for the investigation are shown in Table 1. The composition of both substrates differed considerably. Poultry manure was far more dense than sewage sludge, however the percentage of volatile solids in TS for both wastes were similar. The mean concentrations of nutrients and trace elements (N, P, K, Mg, Ca) were comparable to the typical values stated in literature referring to European and US poultry farms (Nicholson et al., 1996). A relatively high content of calcium with a maximal value of 60.65 gCa/kg TS was due to the presence of eggshells in poultry manure. Sewage sludge was rich in nitrogen and phosphorus with maximal values of 139 gN/kg TS and 71.31 gP/kg TS as it was derived from a treatment plant operating with an enhanced biological nutrient removal system. The concentrations of heavy metals were also higher in sludge than in poultry manure, whereas the numbers of *E. coli* and *Enterobacteriaceae* were at comparable levels for both substrates.

2.2. Experiments

Semi-batch experiments were conducted in two reactors, one was fed with sewage sludge alone, another with a mixture of sludge and poultry manure (70:30% of feed VS). The proportion of sewage sludge to poultry manure was selected as the optimal one based on previous batch experiments.

Each reactor had a working volume of 3 dm^3 and was coupled with a 4 dm^3 gas collecting tank to enable anaerobic conditions and to control daily biogas production. The reactors were operated at 35 ± 1 °C with mixing performed by mechanical stirrers (80 rpm for 15 min every hour). The raw substrate (sewage sludge or its mixture with poultry manure) was fed into the reactor once every 24 h with a peristaltic pump. Prior to each feeding, a volume equal to that which was fed was discharged to maintain a constant reactor volume. Two solids retention time (SRT) values of 20 and 30 days respectively were used. Similar retention times were also applied by other authors who performed experiments with sewage sludge digestion, and with co-digestion of different types of manure (Ashekuzzaman and Poulsen, 2011; Bolzonella et al., 2005; Forster-Carneiro et al., 2010; Gelegenis et al., 2007; Sosnowski et al., 2003).

2.3. Analyses

The raw sludge and manure were analyzed for total and volatile solids (TS, VS), chemical oxygen demand (COD), total Kjeldahl