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Short Communication

Improved anaerobic digestion performance and biogas production from poultry litter after lowering its nitrogen content

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HIGHLIGHTS

- Poultry litter (PL) were pre-treated in a two phase process.
- In the first phase ammonia was produced and accumulated.
- In the second phase ammonia was stripped out.
- PL with lower N content displayed better bio-methane production.

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ABSTRACT

Poultry litter (PL) was pre-treated in order to reduce its nitrogen content and to increase the C/N ratio. The pre-treatment consisted of a first anaerobiosis phase of about 60 days in order to accumulate ammonia nitrogen, followed by an ammonia stripping phase by heating the substrate at 80 °C for 24 h. The digestion was performed with PL and pre-treated PL (TPL) after ammonia stripping as mono-substrate under four total solids loads, i.e. 5%, 10%, 15% and 20%. The TPL after ammonia stripping displayed lower ammonia (62–73%) and VFA (41–65%) concentrations compared to digesters with raw PL, while bio-methane yield increased about 8–124%. Bio-methane yields in the series with TPL after ammonia stripping were about 193, 196, 215 and 147 L_{CH_4}/kg_{COD}, based on the COD added, for 5%, 10%, 15% and 20% TS load, respectively. The results indicate that lowering nitrogen content using the suggested process improves bio-methane yields significantly.

1. Introduction

Poultry livestock is an important agricultural sector which expands over time. In many cases, poultry are produced under intensive conditions, generating vast amounts of poultry litter (PL). PL are organic solid wastes rich in C, N, P, K and other elements. Therefore, PL is used as fertilizers and soil conditioner mainly after its composting (Kelleher et al., 2002). However, an alternative to composting technology is anaerobic digestion, by which the organic matter is degraded down to biogas. The latter is a combustible mixture, which could be used for energy production. In addition, after anaerobic digestion the effluents, which are stabilized and rich in nutrients, could also be used as fertilizers and soil conditioner as like PL compost (Kelleher et al., 2002). Thus, anaerobic digestion is advantageous compared to composting due to the additional gain of biogas.

PL contains about 60–85% (dry basis) of volatile solids, which are highly digestible and could be used as substrate for the production of biogas through the anaerobic digestion technology (Niu et al., 2013). However, a major limitation of using PL for biogas production is its low C/N ratio, which is around 5–8. Substrates with low C/N ratio during the anaerobic digestion tend to accumulate ammonia, which is toxic to the anaerobic microflora. The main parameters that render ammonia toxic is its concentration in combination with the pH of the liquor, which determines the generated amounts of free ammonia (FA). The latter has been considered as the main toxic ammoniac species (Chen et al., 2008; Rajagopal et al., 2013).

For an unhindered anaerobic digestion ammonia concentration should be kept to a level below 3 g/L that do not cause toxicity. To achieve this there are various suggested strategies, such as diluting PL (Bujoczek et al., 2000), adjusting C/N ratio of the digester by co-digesting PL with a carbon rich co-substrate(s) (Abouelenien

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et al., 2014), addition of phosphorite ore (Krylova et al., 1997), removing ammonia by biogas recycle (Abouelenien et al., 2010) and using multiple ammonia stripping phases during dry-digestion of PL (Abouelenien et al., 2009b).

Among the above strategies, ammonia stripping has been investigated by several researchers and seems to be a feasible strategy for removing ammonia nitrogen from the substrate (Jiang et al., 2014; Serna-Maza et al., 2014). Ammonia removal by stripping is based on forcing the dissociation equilibrium of NH_4^+/NH_3 to favor FA (NH_3) formation. FA is a gaseous molecule that is stripped out from aqueous solutions relative easily. The ratio of FA to total ammonia (TA) is a function depending mainly on pH and temperature and can be calculated by the following equation (Niu et al., 2013):

$$\frac{FA}{TA} = \left(1 + \frac{10^{-pH}}{10^{\left(0.9018+\frac{272.92}{T}\right)}}\right)^{-1}$$

To enhance the FA species, the pH of the substrate should be very high (>10) or/and temperature should be raised (Abouelenien et al., 2009b). As can be seen in Fig. 1 the most influencing factor, in the range investigated, is the pH of the substrate, while temperature has lower effect on the FA formation. However, to increase the pH, the addition of alkalis (such as NaOH, CaO, KOH, and $Ca(OH)_2$) is required. The addition of ions in excessive amounts can negatively influence the methanogens lowering the biogas production (Chen et al., 2008). Therefore, in substrates that vast amounts of alkalis are needed, stripping by increasing temperature may be a potential choice, especially when waste thermal energy derived from electrical energy production by combusting biogas is available.

However, ammonia nitrogen concentration in raw PL is relative low and the most nitrogen contained is in the organic form of proteins and uric acid. In order to remove nitrogen from PL by ammonia stripping, proteins or uric acid should be first degraded down to ammonia. For this reason, PL could be stored under dry anaerobic conditions for protein and uric acid degradation to convert organic nitrogen to ammonia (Abouelenien et al., 2009b; Kirchmann and Witter, 1989), followed by ammonia stripping to reduce the nitrogen content. Reducing the nitrogen content it is hypothesized that the anaerobic digestion of PL would be enhanced. Since, to the best knowledge of the author, there is no available information about the anaerobic digestion of PL treated by this approach, aim of this study was to investigate the anaerobic digestion performance of PL with low nitrogen content derived by the above mentioned two phase treatment.

2. Methods

2.1. Poultry litter collection and treatment

PL was collected from an egg laying poultry farm in Megara, Attiki, Greece. PL was transferred to the lab and stored in a freezer at −26 °C. Some physiochemical characteristics of PL are listed in Table 1. Since the ammoniac nitrogen in PL was about 20% of the TKN, in order to increase the ammoniac nitrogen content, the PL was stored under anaerobic conditions (Kirchmann and Witter, 1989) for a period of about 60 days under room temperature 17–22 °C. The process of anaerobiosis of PL was not monitored and therefore it was not be optimized. At the end of the anaerobiosis the physiochemical characteristics of treated PL (TPL) are listed in Table 1. For the removal of ammonia, the TPL was placed inside an oven and heated at 80 °C and aerated for 24 h. The physiochemical characteristics of TPL after the ammonia stripping are listed in Table 1.

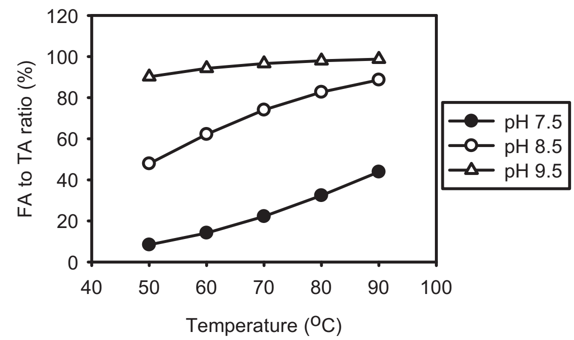

Fig. 1. Effect of pH and temperature on the ratio of free ammonia to total ammonia.

2.2. Anaerobic digestion

The anaerobic digestion was accomplished in 500 ml poly(ethylene terephthalate) (PET) bottles with working volume of 300 ml. Digesters were placed on a water-bath with constant temperature (35 ± 2 °C) and were intermittently stirred with magnetic stirrers with agitation cycle of 15:15 min on:off. As inoculum, sludge from mesophilic anaerobic digestion of swine manure and corn silage was used with PL substrate in a ratio of 3:1. After about two weeks, the digestion was switched in the semi-continuous mode and the hydraulic retention time (HRT) was set at 30 days. The feeding of the substrate was performed every two days. The digestion was considered as steady after about 2 times the HRT (60 days of operation). Digesters were run in duplicates.

2.3. Analytical methods

Total ammonia, total Kjeldahl nitrogen (TKN), total solids, ash and chemical oxygen demand (COD), were determined by standard methods (APHA, 1995). Volatile fatty acids (VFA) were determined on the supernatant of centrifuged (10 min in 5000 rpm) samples according to Montgomery et al. (1962). Organic carbon was measured according to Yeomans and Bremner (1988). The ratio of carbon to nitrogen (C/N) of the samles was calculated as the ratio of the organic carbon to the TKN, which represents the total nitrogen (organic and inorganic) content of the samples. Biogas was trapped inside a vessel contained aqueous solution, which was replaced during biogas production. Solution of 0.1 N H_2SO_4 was used in order to avoid the dissolution of CO_2 into the solution. Bio-methane was measured by passing biogas into a solution 5% NaOH. The NaOH solution absorbed the CO_2 of the biogas and the difference between the volume before and after CO_2 absorption was considered as the volume of produced bio-methane. The pH values were measured with a pH 209 (Hanna Instruments) pH meter. All analyses were made for two continuously feds in

Table 1
Physicochemical characterization of raw poultry litter, after their anaerobiosis, and after ammonia stripping.

Parameter	Raw	After anaerobiosis of 60 days	After ammonia stripping
pH (1:10 H_2O)	6.74	8.29	6.63
Total solids (%)	23.3 ± 0.55	19.71 ± 0.34	–
Ash (% TS)	27.6 ± 1.51	30.2 ± 1.90	32.6 ± 1.51
COD (mg-O_2/g)	990 ± 55	960 ± 26	860 ± 173
TKN (mg-N/g)	52.5 ± 0.1	51.0 ± 0.5	25.3 ± 0.1
Ammoniac nitrogen (mg/g)	11.2 ± 1.1	36.4 ± 1.7	1.86 ± 0.31
Organic carbon (mg/g)	336 ± 26	312 ± 12	296 ± 11
C/N ratio	6.4	6.11	11.7

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