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Biogas production from chicken manure: Co-digestion with spent poppy straw

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ABSTRACT

Co-digestion of chicken manure (laying hens) and spent poppy straw was investigated in a daily fed laboratory scale mesophilic anaerobic digester. The digester was operated for 240 days and the methane yield was monitored by increasing the organic loading rate (OLR) from 2.78 to 3.56 g VS l⁻¹d⁻¹ and the total ammonia nitrogen (TAN) up to 6650 mg l⁻¹. The highest methane yield of 0.36 l g VS⁻¹ was obtained when the TAN and free ammonia nitrogen (FAN) concentrations were below 4000 and 300 mg l⁻¹, respectively. The results showed that microbial consortia were acclimated to high ammonia concentrations and a methane yield of about 0.28 l g VS⁻¹ was achieved up to 6100 mg l⁻¹ of TAN. When the TAN concentration in the digester increased above 6500 mg l⁻¹, the methane yield sharply decreased below 0.14 l g VS⁻¹.

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1. Introduction

Chicken manure (CM) is an organic material, which is rich in nutrients, such as nitrogen, phosphorus and potassium and traditionally used as organic fertilizer in agriculture. However, its direct application to farmland leads to various environmental problems such as eutrophication in surface waters, pollution of ground water, spread of pathogens, odour and greenhouse gas emissions (Kelleher et al., 2002). In addition, CM has a relatively high energy content when compared to cow and pig manures (Bujoczek et al., 2000). For that reason, CM is very convenient for anaerobic digestion (AD). In this manner, the biogas produced from CM is transformed to electricity and heat and the digestate is recovered as organic fertilizer and/or soil conditioner.

However, during anaerobic digestion of CM, the organic nitrogen existing in the form of protein and uric acid is converted to ammonia which results in a process inhibition and reduction in

biogas production by leading to accumulation of volatile fatty acids (VFAs) (Bolan et al., 2010; Niu et al., 2013; Sun et al., 2016). Therefore, ammonia inhibition is considered as the main problem in biogas production from CM (Bujoczek et al., 2000; Sun et al., 2016).

The factors affecting the ammonia inhibition in AD are total ammonium nitrogen (TAN) concentration, temperature, pH and acclimation of the inoculum (Yenigün and Demirel, 2013). The simplest solution to reduce or eliminate the ammonia inhibition in AD is to dilute the feedstock with water (Nie et al., 2015). However, in this case a large volume of secondary waste is generated and has to be treated before being discharged (Sun et al., 2016). To alleviate the ammonia inhibition in AD, processes such as ammonia stripping, zeolite adsorption, membrane separation, struvite precipitation, microbial acclimation and co-digestion have been studied extensively (Babaei et al., 2013; Huang et al., 2015; Lauterböck et al., 2012; Romero-Güiza et al., 2015; Serna-Maza et al., 2015; Wang et al., 2011).

The most practicable way to alleviate ammonia inhibition is co-digestion of CM with an organic feedstock having low nitrogen content. In this way, the optimal C/N ratio for AD which is in the range of 15–30 may be obtained (Li et al., 2011; Wang et al., 2014). In the literature, anaerobic co-digestion of CM and agricultural

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waste has been investigated using several reactor types and feedstock (Abouelenien et al., 2014; Babaei et al., 2013; Li et al., 2014). The studies have shown that co-digestion of CM and agricultural waste increases the specific methane yield because of better nutrient balance of the substrate mix (Abouelenien et al., 2014; Li et al., 2014). For co-digestion of animal manure and agricultural waste, it is important to use a local waste to make the process cost effective, more applicable and sustainable.

In recent years, significant improvements were achieved in chicken meat and egg production in Turkey in terms of hen's number, production technologies and marketing. Afyonkarahisar is a province in mid-west of Turkey leading in egg production with about 9 million eggs per year. In addition, it is one of the provinces, where opium poppy is cultivated. The harvested poppies are processed in the nearby opium alkaloids factory and approximately 20,000 tons of spent poppy straw (SPS) are generated annually. In this study, the anaerobic co-digestion of CM and SPS, the two waste streams generated in significant amounts in the province of Afyonkarahisar, Turkey was investigated. Although there are many studies about co-digestion of CM and agricultural wastes/crop residues such as wheat straw (Wang et al., 2012), corn stover (Li et al., 2013), rice straw (Gu et al., 2014) and sugar beet pulp (Borowski et al., 2016) in the literature, SPS was used for the first time in this study as co-substrate for anaerobic digestion of CM. This paper presents the performance of the laboratory scale anaerobic co-digester operated for 240 days by feeding with a mix of CM and SPS. The effects of increasing organic loading rates and total ammonia nitrogen (TAN) concentrations on the process stability and methane yield were evaluated.

2. Material and methods

2.1. Chicken manure and spent poppy straw characteristics

Chicken manures (CM) and spent poppy straw (SPS) were obtained from a local egg-laying hen farm and the opium alkaloids factory located in Afyonkarahisar, Turkey. In total, four CM and two SPS samples taken at different times were used. Total solids (TS), volatile solid (VS) and total kjeldahl nitrogen (TKN) content were determined immediately after bringing the feedstock samples to laboratory and they were stored in refrigerator at 4 °C throughout the study. TKN concentration of CM and SPS were in the range of 4.38–5.96% and 0.72–0.86% on dry basis, respectively. TS content of CM and SPS were 23.2–29.7% and 26.3–29.4%, respectively. Characteristics of CM and SPS are shown in Table 1. Because poppy straw was shredded into small pieces (<1 mm) in the alkaloid factory no additional physical pre-treatment was performed before feeding the SPS to digester. CM and SPS were mixed in a ratio of 4.3/1 (w/w) in order to adjust the C/N ratio to 15. The corresponding CM/SPS ratio was approximately 3.6 on VS basis. The TS content of the mixture was adjusted to 9.8–13.5% using tap water.

Table 1
Characteristics of chicken manure and spent poppy straw.

Constituent	Unit	Chicken Manure				Spent Poppy Straw	
		I	II	III	IV	I	II
Total solids, TS	%	29.1	25.2	23.2	29.7	29.4	26.3
Volatile solids, VS	%	18.3	16.8	15.2	20.0	21.9	19.4
VS/TS	%	63.1	66.7	65.5	67.3	74.4	75.4
Total kjeldahl nitrogen, TKN	% of TS	4.80	5.33	5.96	4.38	0.86	0.72

2.2. Anaerobic digester and operation strategy

A laboratory scale continuously stirred anaerobic digester with a total volume of 16 l and a working volume of 14 l was operated under mesophilic conditions for 240 days. The anaerobic digester had been operated for around 5 months before this study. The operating temperature was kept at 36 ± 0.5 °C by using thermostat controlled heating coils that was wrapped around the digester. The daily biogas production was measured by using a volumetric gas counter (Milligas counter, BnC-Ritter) and the biogas was stored in an aluminium-foil gas bag. The digester was agitated at 45 rpm by using a PLC (Programmable Logic Controller) controlled gearbox paddle mixer. The operational period was divided into 6 phases according to influent TKN concentrations (Table 2). Except at Phase 5, the hydraulic retention time (HRT) was 23 days. At Phase 5, it was increased to 28 days to keep the OLR constant at $3.56 \text{ g VS l}^{-1} \text{ d}^{-1}$. The anaerobic digester was fed manually once a day after drawing the effluent from the digester by using a vacuum pump. Experimental set-up was shown in Fig. 1. Operational conditions are summarized in Table 2.

2.3. Analytical methods

Volatile fatty acids (VFAs), alkalinity, total kjeldahl nitrogen (TKN), total ammonium nitrogen (TAN), total solids (TS) and volatile solids (VS) were analyzed 3 times per week according to APHA Standard Methods (APHA, 2005). The temperature of the digester was monitored continuously on-line with a temperature sensor immersed into the digester and connected to a digital controller. The pH was measured every day using a pH meter (Eutech, PCD 6500, Singapore). Total ammonium nitrogen (TAN) concentration was determined by nesslerization method using a spectrophotometer (DR/2800, HACH, USA) and TKN was analyzed according to semi-micro kjeldahl digestion, distillation and nesslerization methods (Standard Methods, 4500 Norg B). VFA analysis was performed using a gas chromatograph (Shimadzu GC-2014, Japan) equipped with a flame ionization detector (FID). One μL of filtrated liquid digestate was injected onto Stabilwax-DA Fused Silica column ($30 \text{ m} \times 0.25 \text{ mm} \times 0.5 \mu\text{m}$). The temperatures of the injection port and detector were 250 and 260 °C, respectively. Helium was used as carrier gas (27.4 ml min^{-1}). The biogas composition was analyzed according to the method described by Yesil et al. (2014) using another gas chromatograph (Shimadzu GC-2014ATF, Japan) equipped with a thermal conductivity detector (TCD). The free ammonia nitrogen (FAN) concentration was calculated using the following formula (Calli et al., 2005).

$$\text{FAN} = \frac{\text{TAN}}{1 + 10^{(\text{pK}_a - \text{pH})}} \quad (1)$$

$$\text{pK}_a = 0.09018 \left(\frac{2729.92}{T + 273.15} \right) \quad (2)$$

Where, pK_a is the dissociation constant for ammonium ion, 8.95 at 35 °C; T is the temperature, °C.

3. Results and discussion

The anaerobic co-digester was operated for 240 days with six different influent TKN concentrations (Table 2) and its performance was summarized in Table 3.

In Period 1 (days 0–48), the digester was operated with an OLR and TKN concentration of $2.78 \text{ g VS l}^{-1} \text{ d}^{-1}$ and 3960 mg l^{-1} , respectively (Table 2). It was started up with a moderately high OLR, because it has been operated with the same feed for about 5

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