Anaerobic digestion of chicken manure as a single substrate by control of ammonia concentration

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Abstract

Anaerobic digestion of high solids chicken manure as a single substrate was conducted at laboratory scale with a reaction volume of 10 l. The organic loading rate was increased gradually from 2.2 to 3.9 gVS l^{-1} d^{-1}. To reduce the amount of inhibiting ammonia in the process technical stripping of ammonia was applied, yielding ammonia-phosphate or ammonia-sulfate as valuable side-products. A high specific biogas yield of 623 ml_N g^{-1} VS^{-1} was produced, despite the high level of free ammonia and of total ammonia nitrogen of up to 1 g/l and above 5 g/l, respectively. The presented results show the technical possibility to use chicken manure as a single substrate for an anaerobic process and demonstrate how to overcome the limitations of the use of substrates with high nitrogen content.

Keywords

Chicken manure; ammonia inhibition; anaerobic digestion; ammonia stripping

INTRODUCTION

Anaerobic treatment is an established method for treating animal manure and biogas production has been widely studied by many researchers (Huang and Shih, 1981; Mackie and Bryant, 1995; Nishio and Nakashimada, 2007). The rising number of biogas plants in Germany treating manure and energy crops has led to an increasing demand of substrates, while on the other hand in many countries chicken manure disposal creates environmental hazards. Chicken manure (CM) is a high potential organic substrate for treatment, but is generally problematic for use in anaerobic digestion. Few studies have been conducted on the anaerobic treatment of CM (Demirci and Demirer, 2004; Liu et al., 2012). Manure contains 20% or more dry matter and is rich in nitrogen. The higher nitrogen content of poultry waste compared to manure from other farm animals makes CM a difficult substrate for anaerobic digestion (Bujoczek et al., 2000). The inhibitory effect of ammonia during anaerobic digestion of animal wastes has been studied by several authors (Salminen and Rintala, 2002 a,b). Different boundaries for tolerable free ammonia (NH_3) concentration can be found, from 55 mg/l (Bhattacharya and Parkin, 1989) to 800 mg/l (Angelidaki and Ahring, 1993). A number of studies have reported inhibitory effects of free ammonia on the metabolism of methanogens (Hashimoto, 1986; Angelidaki and Ahring, 1993; Kadam and Boone, 1996). In some of these studies, CM was diluted with water to decrease the total percentage of solids (Webb and Hawkes, 1985; Bujoczek et al., 2000). Co-digestion of CM with other types of livestock manure was also attempted (Demirci and Demirer, 2004; Nishio and Nakashimada, 2007; Wang et al., 2012). Acclimation of methanogenic consortia to high ammonia levels has proven a useful strategy for improving the process of anaerobic digestion and production of methane from different kinds of wastes (Pechan, 1987). However, only a few studies have been conducted on CM as a single substrate (Abouelenien, 2008; Liu et al., 2012; Niu et al., 2013).

The aim of the research being reported here was to study the performance of digesting CM as a single substrate at mesophilic conditions while controlling the level of ammonia nitrogen. For this purpose the biogas yield under semi-continuous operation was studied. To reduce the amount of inhibiting ammonia in the process technical stripping of ammonia was applied.

MATERIAL AND METHODS

A laboratory-scale semi-continuously operated CSTR with a reaction volume of 10 l was run under mesophilic temperatures. Trials were carried out for 573 days. The reactor was fed once a day, the composition of the substrate mix was changed, as the process seemed to be stable. The organic loading rate was increased gradually from 2.2 to 3.9 gVS l^{-1} d^{-1}. The biogas production and pH were measured daily. Volatile fatty acids, total ammonium nitrogen and gas content were determined twice a week. Volatile fatty acid content was measured by high performance liquid chromatography and the parameter total volatile fatty acids determined by titration (“Kapp-method” (Buchauer, 1998)). The calculation of the NH_4^+/NH_3-values is based on the acid-base equilibrium. Total nitrogen was determined by Kjeldahl method.

To reduce the amount of inhibiting ammonia in the process technical stripping of ammonia was applied. The stripping conditions were 80 °C, 600 mbar absolute pressure for 4 hours during which ammonia was evaporated into the gas phase, withdrawn through condensation and trapped in sulphuric or phosphoric acid. Before stripping the effluent was separated into a solid and a liquid fraction through sieving. The liquid phase (LCM) underwent the stripping process, whereas the solids were dried (DCM). Recirculation of ammonia-depleted LCM into the fermenter was used to lower the total ammonia-concentration in the fermenter. Addition of DCM was used to keep the solids fraction in the fermenter stable and was dosed depending on CM and LCM addition. In Table 1 the characteristics of fresh CM and treated fractions are shown.

Table 1. Substrate characteristics.

	TS, %FM	VS, %TS	TKN, g/kg FM	NH_4^+–N, g/l
CM	42.6 – 53.7	61.3–69.0	27.7–33.4	-
LCM	4.4 –6.2	44.1–58.3	2.3–3.9	0.12–1.27
DCM	98.9– 99.4	35.8 – 49.9	19.4–23.7	-

CM chicken manure, LCM liquid chicken manure (after stripping), DCM dried chicken manure, FM fresh matter, TS total solids, VS volatile solids, TKN total nitrogen by Kjeldahl.

RESULTS AND DISCUSSION

At the start of the process fresh chicken manure was used, which was diluted by water to control nitrogen levels. From day 102 on recirculation of ammonia depleted fermenter-liquor was started and instead of water LCM was recirculated and fresh CM was used as the only substrate. LCM and DCM complemented the daily ration of CM such that a constant level of ammonium was achieved. As the pH-value was stable almost completely throughout the experiment, the ratio of free ammonia to ammonium was stable as well.

Using LCM instead of water initially lead to an increased biogas production up to 623 ml_N g^{-1} VS^{-1} (fig. 1). Biogas production deteriorated until day 250 according to substrate quality deterioration. Ratios of CM, LCM and DCM were varied throughout the process, depending on the need for ammonia concentration adjustment, but no significant changes of the process were observed.

As high values of ammonia did not inhibit the process the hydraulic retention time (HRT) was gradually reduced, while the OLR was raised up to 3.9 gVS l^{-1} d^{-1} (fig. 1 and 2). This sometimes lead to instabilities, obviously induced by risen ammonia levels and resulted in decreased biogas production, high levels of total volatile fatty acids and high acetic/propionic acid ratios. In response OLR was reduced for a short time for process stabilization and ammonia reduction. After this procedure OLR was increased repeatedly and parameters became steady.

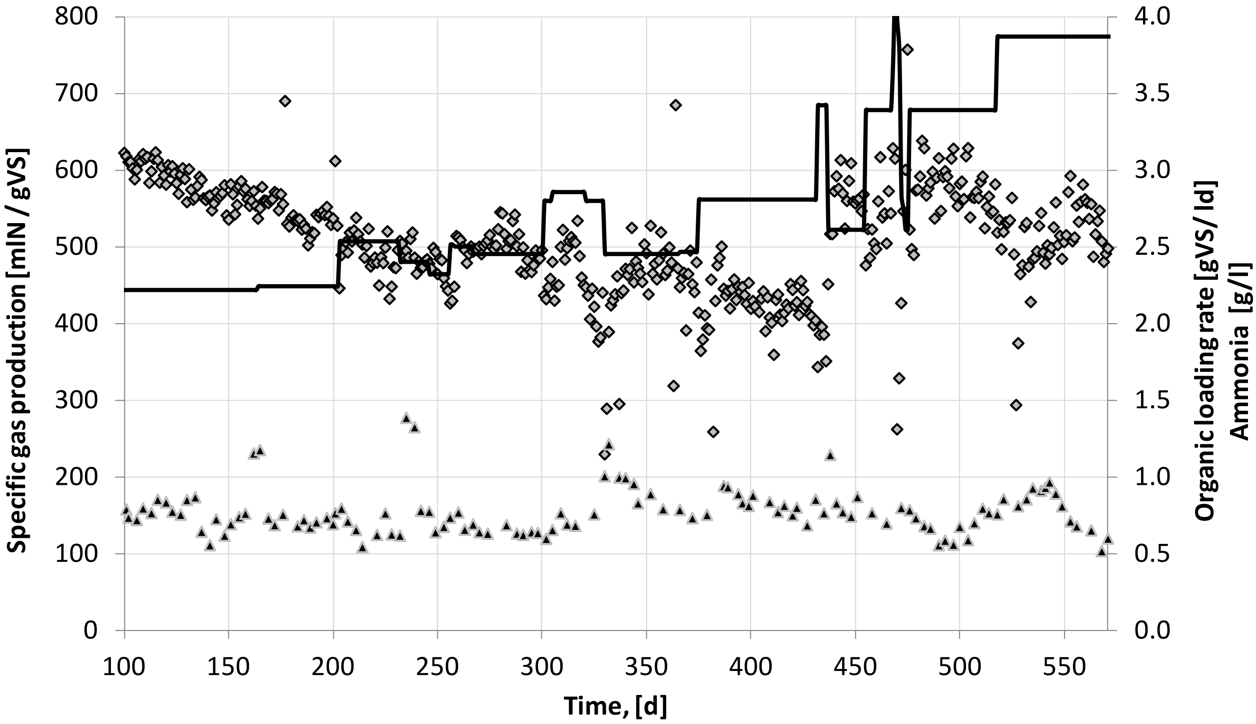

Figure 1. Specific gas production (diamonds), free ammonia nitrogen concentration (triangles) and organic loading rate (solid line) during fermentation of chicken manure.

The VS removal ratio showed a reducing tendency along with HRT reduction (Figure 2). Apparently it depends on feeding substrate composition. LCM after stripping process contained low amounts of fermentable organic materials, which had not been digested completely when added as fresh chicken manure. This effect may have been caused since the hydraulic retention time was gradually decreased. Despite this biogas production and methane concentration were increased.

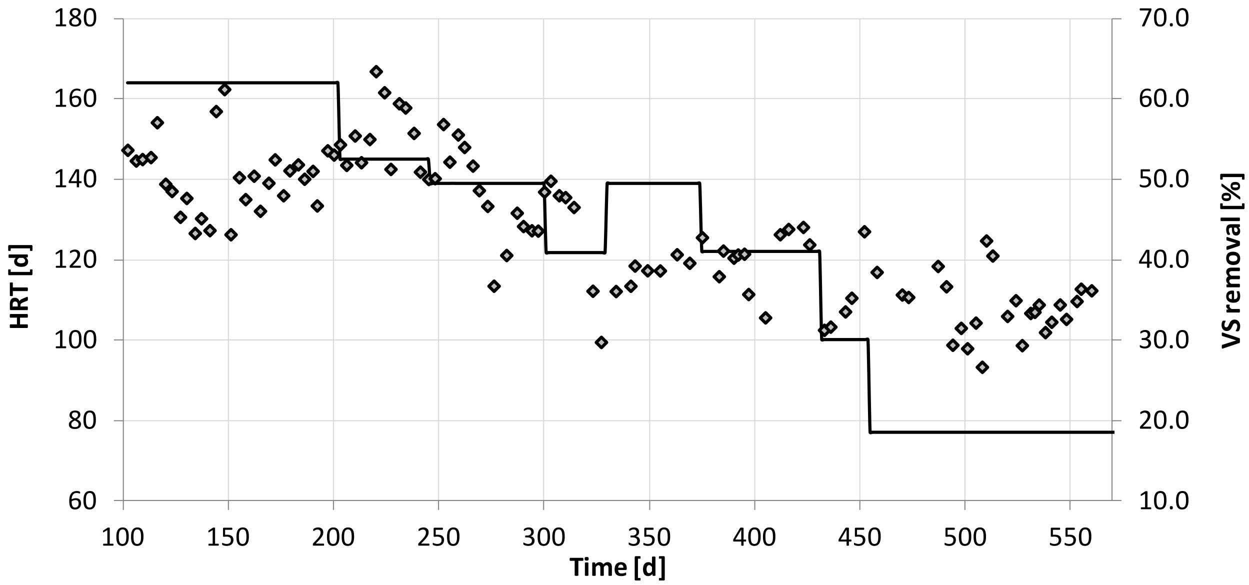

Figure 3. Hydraulic retention time (solid line) and volatile solids removal ratio (diamonds) during fermentation of chicken manure

The pH value was 7.9 – 8.0 and did not change during the experiment (not shown). Fig. 2 shows free ammonia (NH_3-N) content was high, usually ranging between 0.6-1 g/l, allowing a stable process. The use of LCM with high ammonia concentrations (e.g. around day 325) lead to values of up to 1.4 g\l. Due to this the process became inhibited in the following days, as can be seen from the declining specific biogas production rate.

CONCLUSION

The data presented show that even under high ammonia concentrations (up to 1 g/l) it is possible to maintain a stable anaerobic digestion process obtaining high biogas yields. Achieved biogas yields were up to 620 $ml_N\ g^{-1}\ VS^{-1}$ at an OLR of 3.4 $gVS\ l^{-1}\ d^{-1}$ and 77 days HRT. The possibility to use chicken manure as a single substrate for an anaerobic process was proven. Furthermore, a procedure is demonstrated, allowing to overcome the limitations CM-digestion. The use of substrates with high nitrogen content and the control ammonia levels during fermentation, while producing ammonia-phosphate or -sulphate as valuable and commercially usable side-products seem feasible according to the results shown.

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