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# Mono-fermentation of chicken manure: Ammonia inhibition and recirculation of the digestate

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## HIGHLIGHTS

- Mono-fermentation of chicken manure was performed for several hundred days.
- Controlled recirculation of ammonia stripped fermenter-liquid was applied.
- Ammonia-levels during fermentation were steadily controlled.
- Stable process was performed at levels of total ammonia nitrogen of above 6 g/L.

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## ABSTRACT

The effects of ammonia concentration on the performance and stability of mono-fermentation of chicken manure were investigated in a lab-scale continuous stirred tank reactor at 40 °C. Technical stripping was performed to remove ammonia from the liquid fraction of digestate, and the entire product was recycled to the fermenter to control ammonia concentration in the fermenter. Organic loading rate (OLR) of 5.3 gVS/(L d) was achieved with an average free ammonia nitrogen (FAN) concentration of 0.77 g/L and a specific gas yield of 0.39 L/gVS. When OLR was increased to 6.0 gVS/(L d), stable operation could be obtained with an average FAN concentration of 0.86 g/L and a specific gas yield of 0.27 L/gVS. Mono-fermentation of chicken manure was successfully carried out at high ammonia concentrations. Controlled recirculation of treated liquid fraction of digestate could be a solution in large-scale application for both: to avoid ammonia inhibition and minimize digestate.



## 1. Introduction

As commercial opportunities for chicken meat sales expand, rising amounts of chicken are being bred, followed by a huge production of chicken manure (CM). According to the statistics, stocks of chickens in the world were nearly 20 billion in 2010, and stocks in China composed 23% (Food and Agriculture Organization of the United Nations (FAO), 2013). CM is rich in nitrogen and phosphorus, therefore, the traditional utilization of CM is to enrich soil and fertilize crops. However, when CM is produced far more than the local crops can absorb, or poorly managed, significant water pollution will occur. It is not unusual to see ponds covered with algae near chicken farms because of excess nutrients (Pew Environment Group, 2011). Since the good biological degradability of CM, fermentation with CM is considered to be a good choice to minimize waste and recover bioenergy.

However, because of the high content of organic nitrogen and low C/N ratio in CM, ammonia inhibition has been a main problem faced in the practical application. The two main nitrogen sources in CM, undigested protein and uric acid, will be decomposed into ammonia during the anaerobic fermentation process (Nahm, 2005). Nitrogen is an essential nutrient for the growth of bacteria involved in the fermentation, and ammonia is a major nitrogen source in the fermenter. However, excess ammonia will inhibit methanogenesis (Abouelenien et al., 2010; Chen et al., 2008; Fotidis et al., 2013). Ammonia inhibition is a common problem faced in the anaerobic digestion with substrates, such as poultry litter (Gangagni Rao et al., 2008), swine manure (Hansen et al., 1998), municipal solid waste (Mata-Alvarez et al., 2000), etc. Since the 60s in the twentieth century, ammonia inhibition has been on the list of concerns (Albertson, 1961; Melbinger et al., 1971) and henceforth, several researches have been done to explore the reason and find the solution to recover the ammonia inhibited process

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or decrease the ammonia inhibition (Angelidaki and Ahring, 1993, 1994; Nielsen and Angelidaki, 2008; Sasaki et al., 2011). Free ammonia has been suggested to be the main inhibitor (Chen et al., 2008), and the concentration is dependent on temperature and pH since free ammonia and ammonium ions will form a chemical equilibrium in the liquid phase. However, when it comes to the threshold, conclusions are conflicting. It was considered that ammonia will only be a serious problem when free ammonia nitrogen (FAN) concentration exceeds 1.10 g/L (Hansen et al., 1998). But in other processes, concentrations were lower, such as 0.70 g/L (Angelidaki and Ahring, 1994) and 0.60 g/L (Duan et al., 2012). These differences can be ascribed to the nature of substrates, the acclimation of inoculum, and other operating parameters such as hydraulic retention time. Besides that, the judgment criteria for the threshold are not consistent. Melbinger et al. (1971) also thought when the rate of ammonia formation above a threshold limit is faster than the acclimation of methanogens, inhibition or toxicity will occur.

A common method to avoid ammonia inhibition is the dilution of the substrate. Fresh CM usually has a high concentration of total solids (TS), ranging from 20% (Huang and Shih, 1981) to 62.4% (Bruni et al., 2013). Before adding it to a fermenter, it is often diluted to a lower TS (for example, 0.5–3.0%) to avoid ammonia accumulation (Bujoczek et al., 2000). The common medium is fresh water (Bruni et al., 2013; Niu et al., 2013b; Huang and Shih, 1981). To dilute CM from 30% (TS concentration) to 3%, the amount of water needed is about 9 $m^3$/t CM. This on the one hand, decreases the biogas production per unit of fermenter volume, on the other hand, it increases the consumption of water and the processing cost for the slurry discharge. Additionally, it leads to a lower hydraulic retention time (HRT) or significantly larger fermenter volumes. Another method to avoid ammonia inhibition is co-fermentation of CM with other substrates, such as cattle manure, straw and other substrates rich in carbon (Abouelenien et al., 2010; Wang et al., 2012). Many biogas plant operators are more willing to use co-fermentation, because this can receive high biogas outputs together with high nutrient content in digestate (Lukerhurst et al., 2010). Compared with mono-fermentation, co-fermentation will increase the complexity of the operation, and increase transportation cost. Also, co-substrates have to be bought in most cases. In the recent decade, ammonia stripping has been applied to reduce ammonia concentration in the fermenter. With slaughterhouse wastes as substrate, partial liquid was continuously separated from digestate, and recycled to the fermenter after ammonia stripping (Siegrist et al., 2005). It was also applied to reduce ammonia concentration in the fermenters treating food waste (Serna-Maza et al., 2014). This approach allowed the process to be successfully operated below concentrations leading to ammonia inhibition.

Besides ammonia inhibition, another problem encountered is how to handle the digestate. Due to the higher rates of mineralization during the fermentation, digestate has an improved fertilizer quality compared with the raw manure (Al Seadi and Lukerhurst, 2012) and is usually used as biofertiliser. Digestate is produced throughout the year and it needs to be stored before field application during periods in which it cannot be applied to the field – this also the case for raw manure. High moisture content of the digestate makes its storage, transportation and application expensive. Furthermore, secondary pollution may even happen during the storage, when uncontrolled anaerobic digestion causes greenhouse gas emissions from open storage facilities.

Exploration of the feasibility of fermentation with CM as the single substrate has been presented in a preceding study (Belostotskiy et al., 2013), with organic loading rates (OLR) between 2.2 and 3.9 gVS/(L d). Stable operation proved to be possible. The aim of the present study was to research the long-term stability of mono-fermentation of CM at higher organic loading rates (5.3–6.0 gVS/(L d)) and higher ammonia concentrations. Furthermore, controlled recirculation of ammonia-depleted liquid fraction of digestate was applied. Digestate was collected and solid–liquid separated. The liquid fraction was treated in a stripping facility to remove ammonia from it. Stripping efficiency and thus total ammonia nitrogen (TAN) concentration in the product were deliberately influenced depending on the needed concentrations by choosing different operating parameters. The TAN-depleted product was recycled to the fermenter. TAN concentration in the fermenter was adjusted by this product and its TAN concentration.

## 2. Methods

### 2.1. Substrates and inoculum

Fresh CM was collected from a biogas plant using CM as feedstock, in Chemnitz, Germany. After collection, it was stored in a sealed-plastic barrel and kept in a cooling room at 4 °C. A plastic container with a capacity of around 10 kg was used to intermittently store CM, for the convenience of feeding preparation. It was also stored at 4 °C. Before the first batch of CM (CM1) was used up, the second batch of CM (CM2) was collected at the same plant. So was the third batch of CM (CM3). To follow possible changes in substrate quality during storage several analysis per substrate batch were performed. Characteristics of CM used are listed in Table 1. The substrate hardly contained any bedding material such as sand or straw.

The original inoculum to start up the fermenter was digested cattle manure. The fermenter had been operated for more than 800 days before this study began.

### 2.2. Experimental setup

The process diagram is shown in Fig. 1. Digestate from the 10-L fermenter was collected daily and stored in a covered tank at room temperature. Once a week, the digestate was centrifuged at 10,000 rpm and 10 °C for 15 min (Sorvall™ RC 6 Plus, Thermo Scientific, USA). The solids fraction was dried to a constant weight at 105 °C, ground to 2 mm (SM 200, Retsch GmbH, Germany), and then termed dried chicken manure (DCM). The liquid fraction was treated in a stripping reactor to remove ammonia, and termed liquid chicken manure (LCM) afterwards. All fractions were used in different ratios according to the need to prepare the feed mixture. DCM was used to maintain the TS concentration of the feed mixture (feeding TS 15%) to avoid any influence that might be caused by TS variation as was observed by Duan et al. (2012). LCM was used to keep HRT and adjust TAN concentration in the fermenter. Fresh CM, DCM and LCM were all stored at 4 °C. Mixtures were prepared daily.

### 2.3. Batch experiments

The biochemical methane potentials of the initial substrates were determined by Automatic Methane Potential Test System (AMPTS II, Bioprocess control, Sweden) according to German standard VDI 4630 (Verein Deutscher Ingenieure, 2006). The seed sludge was mixture of digested manure and straw from lab-scale reactors operated under mesophilic conditions. The tests were carried out in triplicates. Biogas produced passed through sodium hydroxide solution first for $CO_2$ removal, and then methane ($CH_4$) yield was counted by the system's gas flow meter. After the test finished, $CH_4$ potential was calculated according to the actual VS input.