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Monosubstrate fermentation of chicken manure after pretreatment using cold and hot water extraction

Abstract

Simple pretreatmentof raw chicken manureby cold and hot water extractionincreased the crucial for fermentation C:N ratio 2 to 2.7-fold. The pretreated chicken manure thus became suitable for methane fermentation as monosubstrate, this is due to higher C:N ratio. Cumulative methane and biogas production after pretreatment increasedabout 18–40% and 16–45%, respectively.

Keywords: chicken manure, monosubstrate fermentation, pretreatment, water extraction.

1. Introduction

Poland is the leader in poultry farming in Europe. It was estimated that in 2015 the total production of poultry was 950 million birds, which resulted in 5 million tonnes of manure. Intensification of poultry production is associated with a greater amount of biowastes, such as manure, slaughter waste and dead birds as well as increased emission of greenhouses gases, e.g. ammonia, methane and carbon dioxide (Myszograj & Puchalska, 2012).

Therefore, the proper management and reuse of these byproducts is a real challenge. The chicken manure (CM) is rich in important biogens — phosphorus and nitrogen. In some substrates high nitrogen content, mainly in form of uric acids and proteins, is present and may lead to inhibition of fermentation process. During an anaerobic digestion free ammonia, NH_3 (FAN), and ammonium nitrogen (ionized form NH_4^+) are generated, measured as total ammonia nitrogen (TAN), which is a combination of these species (Amanullah, Sekar, & Muthukrishnan, 2010; Nahm, 2005; Rajagopal, Massé, & Singh, 2013; Yenigün & Demirel, 2013).

In order to avoid an accumulation of FAN in a reactor and to ensure an effective, stable process various procedures were proposed:

a) pre-treatment of the substrate,
b) dilution of the substrate, as well as the contents of the reactor,
c) control of the pH value,
d) control of the C:N ratio,

e) acclimation of microflora (Gelegenis, Georgakakis, Angelidaki, & Mavris, 2007; Nahm, 2005; Rahman et al., 2017; Sun, Cao, Banks, Heaven, & Liu, 2016; Yenigün & Demirel, 2013).

To avoid the ammonia accumulation CM manure can be diluted to 0.5–3% of dry matter content. Unfortunately, this causes the formation of large volume of diluted substrate, which makes the method economically unattractive. To dilute one tone fresh mass of chicken manure (40% total solid content) to 2.5% TS, 15 m^3 of water is required. Diluting would reduce the efficiency of biogas production per volume of the fermenter and result in increase of water consumption. Another method, and the most popular, to avoid ammonia accumulation is co-fermentation with other substrates rich in carbon such as lignocelluloses — wheat straw, meadow grass, poppy straw, maize silage, agricultural wastes or organic fraction of municipal solid wastes. The benefits of co-digestion lie in balancing the carbon to nitrogen ratio in co-fermentation mixture (Abouelenien, Namba, Kosseva, Nishio, & Nakashimada, 2014; Bayrakdar, Molaey, Sürmeli, Sahinkaya, & Çalli, 2017; Rahman et al., 2017; Wang, Yang, Feng, Ren, & Han, 2012).

The purpose of the research was to determine an increase of methane production from chicken manure after simple pretreatment (water extraction), by analyzing dynamics of the process and biogas efficiency.

2. Materials and methods

Experiments were carried out according to modified German norm DIN 38 414 S8 and standardized biogas guidance issued by the Association of German Engineers in Dresden VDI 4630.

The inoculum was collected from agriculture biogas plant working in mesophilic temperature range.Chicken manure (CM) was obtained from one of broiler poultry farm located in Pomeranian district, Poland. During poultry farming wheat straw bedding is used.

The water extraction of chicken manure consisted of rising 5 g of chicken manure in 100 ml cold (CW) and warm deionized water (WW). Then samples were centrifuged to separate liquid and solid phase. For biogas experiments solid fraction of pretreated chicken manure was used (CM-CW, CM-WW).

In order to determine the right amount of fresh matter (FM), of inoculum and the substrate, total solids (TS) and volatile solids (VS) were determined according to Standard Methods. The measurements for each substrate and inoculum were necessary to determine the right amounts of VS in each fermentor and biogas efficiency production from the substrates into the units m^3/Mg VS.

To analyze carbon to nitrogen ratio in solid fraction of raw and pretreated chicken manure, Elementar Analyzer Flash 2000 (Thermo Scientific) was used.

Methane fermentation was carried out in 2L reactors. After placing substrates and inoculum in reactor, reactor were purged with nitrogen to remove oxygen and create anaerobic conditions. To create appropriate conditions for mesophilic fermentation, reactors were placed in a water bath under temperature 38±2°C. Biogas produced in each biofermentor was collected in cylindrical vessel filled with barrier liquid to prevent biogas solubility in water. All the experiments were carried out in triplicate.

Biogas measurements were performed every day with an accuracy of 0.01 dm^3. The qualitative and quantitative determinations were determined using portable biogas analyser.The system allows determination of CH_4, CO_2, O_2, H_2 and H_2S in ranges 0–100%, 0–100%, 0–25%, 0–1000 ppm and 0–5000 ppm, respectively.

Batch experiments were continued until daily biogas production was less than 1% of total biogas production.Volume of measured biogas were normalized to standard conditions (0°C and 1.013 bar).

3. Results and discussion

A significant change in C:N ratio was observed. For raw chicken manure was 10, after extraction process in cold and warm water increase to 20 and 27, respectively. As it is known, the ratio C:N in a substrate (optimal 20–30) has a significant impact on biogas and methane production. The higher carbon content results in increased amount of methane in biogas, whereas the low nitrogen content limits the activity of microbes, because they need a sufficient amount of this element to grow, it also causes insufficient use of carbon for methane production.

Characterization data for liquid fraction after water extraction such as pH, oxy--reduction potential (ORP) and conductivity are in Table 1.

Table 1. Characterization of liquid fraction after extraction of chicken manure

Parameters	Cold water	Warm water
pH	6.53	6.81
ORP [mV]	187.2	147.3
Conductivity [mS/cm]	6.989	8.726

During fermentation of raw chicken manure and manure after pretreatment a significant difference in dynamics of methane and biogas production was observed (Fig. 1 and Fig. 2).

During fermentation of raw chicken manure subsequent multiple local peaks were observed, they are due to the complexity of the tested substrate. All fermentation steps were carried out rather in parallel since the first day, only at first day a distinct shift was noted in favour of hydrolysis step when intense production of carbon dioxide takes place. The slight collapse of biogas production between 4th and 8th day can indicate the fermentation-process inhibition.

Dynamics of fermentation processes of chicken manure after pretreatment were similar to this above. During fermentation CM-CW one additional peak in biogas production were observed during 3th day and three lower at 9th, 13th and 19th day. In case of CM-WW three distinct peaks were observed at 2nd, 3th and 4th day and lower in 8th, 9th and 19th day. As with the fermentation of raw manure a slight inhibition can be seen between 4th and 8th day for both CM-CW and CM-WW.

The differences in the dynamics of biogas production of raw chicken manure and chicken manure after pretreatment were evident in the first week of the process.

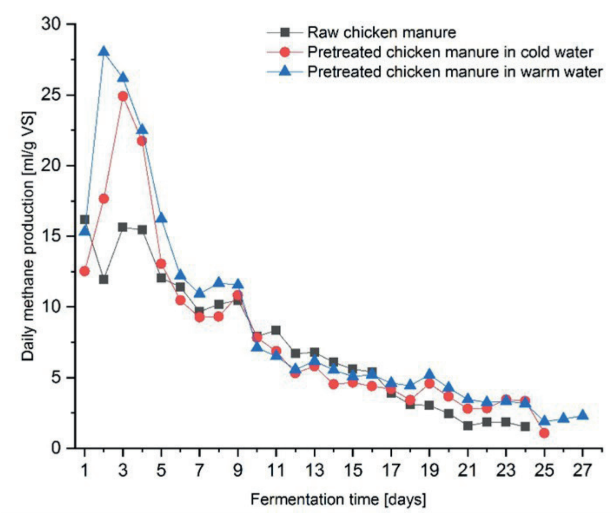

Fig. 1. Daily methane production — raw chicken manure and pretreated

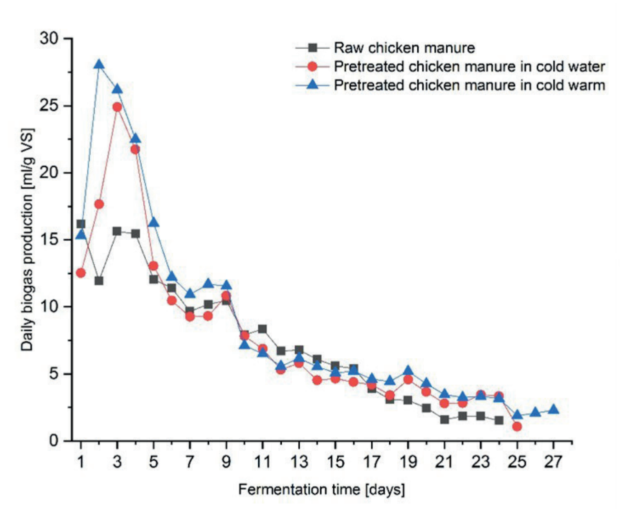

Fig. 2. Daily biogas production — raw chicken manure and pretreated

An increase of water-extraction temperature had also influenced the rate of biomass decomposition. Total time required for fermentation of raw chicken manure and CM-CW were comparable — 24 and 25 days, respectively. In the case CM-WW the fermentation time was 3 days longer compared to chicken manure without pretreatment, which means 12%.

Such long hydraulic retention time is economically not viable, because the last period of fermentation, characterized by low production of biogas, can last very long.

Longer retention times result in larger fermenter volumes and higher energy inputs to heat reactor under low biogas production. Time required to decompose 80 and 90% of the CM-CW is shortest, 11 days and 16 days, respectively, the same for raw manure. In case of CM-WW, both times are longer (14 and 18 days).From economic point of view the differences are significant.

Figure 3 summarizes biogas and methane efficiency from chicken manure with and without pretreatment in units m^3/Mg VS.

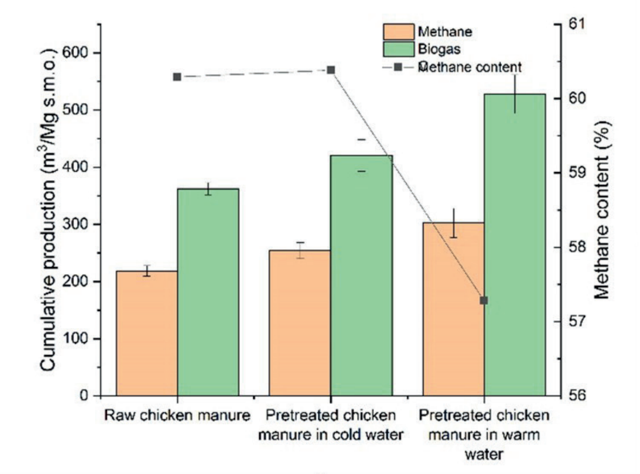

Fig. 3. Cumulative biogas and methane production for raw and pretreated chicken manure

Methane content in biogas, during fermentation of raw CM and CM-CW was comparable, while in the case of CM-WW methane concentration decrease of about 5% was noted.

The largest productivity (volume of biogas per Mg VS) was obtained for CM-WW (527.8 m^3); for CM-CW it was 420.6 m^3; for raw CM it was 362.5 m^3, it was about 31% less than for CM-WW.

As a result of water extraction, the cumulative production of methane per Mg VS was 254.0 m^3 for CM-CW and 302.3 m^3 for CM-WW, which was about 18 and 40% higher compared to manure without pretreatment, respectively.

Significantly higher productivity of methane and biogas resulted from an increase C to N ratio, which for CM-CW and CM-WW was 20 and 27, while for raw CM only 10.

Reduction of volatile solids for all samples was at comparable level. No effect of pretreatment on VS reduction was observed. For all samples it was about 27%.

4. Conclusions

Anaerobic digestion of raw CM after water extraction is a promising way of enhancing biogas and methane production compared to raw chicken manure; this is due to improving C:N ratio. Water extraction successfully increased C:N ratio from 10 to 20 and 27. About 16–45% and 18–40% more biogas and methane was produced from CM-CW and CM-WW than from raw CM, respectively.

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