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METHANE FERMENTATION OF CHICKEN DROPPINGS

Summary

The most troublesome waste from the poultry industry is the manure produced in Poland in the amount of 2.5 million tons per year. It is a substrate with high energy potential whose potential is, however, used very little. Research conducted at the Institute of Biosystems Engineering at the University of Life Sciences in Poznan showed that the biogas efficiency of substrate is 121.40 m³·Mg⁻¹ fresh matter but also point to limitations in the use of the substrate for the purpose of biogas. Observed in the process of continuous fermentation of ammonium inhibition, inhibiting methane fermentation process, it has been defined for the concentration of ammonia nitrogen at 3.7 g·dm⁻³ fresh matter.

Key words: biogas, chicken droppings, ammonium inhibition

FERMENTACJA METANOWA POMIOTU KURZEGO

Streszczenie

Najbardziej uciążliwym odpadem z przemysłu drobiowego jest pomiot kurzy produkowany w Polsce w ilości 2,5 mln ton rocznie. Jest to substrat o dużym potencjale energetycznym, którego potencjał jest jednak wykorzystywany w bardzo niewielkim stopniu. Badania przeprowadzone w Instytucie Inżynierii Biosystemów Uniwersytetu Przyrodniczego w Poznaniu wykazały wydajności biogazową substratu na poziomie 121,4 m³·Mg⁻¹ świeżej masy, ale także wskazały ograniczenia w wykorzystaniu tego substratu na cele biogazowe. Zaobserwowany w procesie fermentacji ciągłej proces inhibicji amonowej, hamującej proces fermentacji metanowej, został zaobserwowany przy stężeniu azotu amonowego na poziomie 3,7 g·dm⁻³ św.m.

Słowa kluczowe: biogaz, pomiot drobiowy, inhibicja amonowa

1. Introduction

Poland is one of the leading producers of poultry in Europe since 2012. Yearly amounts of chicken droppings in Poland, reach nearly 2,5 million tons. According to the information from Agricultural Market Agency (1) consumption of this substrate for biogas production, in the first half of 2016, has amounted to approx. 14 thousand tones, which represents only 0.6% of the total produced poultry manure. The traditional method of use for poultry manure is spreading the unprocessed manure in fields as a natural fertilizer. This method causes great annoyance for local society due to unpleasant odor, and can be hazardous for the environment, due to eluting large amounts of nitrogen, minerals, as well as passing large quantities of pathogens into the soil (10). Additionally, stored and unused poultry excrements emit large amounts of methane, carbon dioxide, and ammonia into the atmosphere. It is important to emphasize, that in the circumstance of storing poultry excrements in heaps, the temperature often rises intrinsically, following the start of the aerobic decomposition process (exotherm) reaching levels of 30-40°C. Such circumstances are followed by rapid oxygen consumption, and the transition to anaerobic digestion of the stored manure (11). During this time, strong emissions of methane gas occur. It is important to state that methane gas has a 21x stronger greenhouse effect than carbon dioxide (9). An effective way to eliminate such nuisance is the use of methane fermentation, led in a controlled environment. However, it turns out that in spite of the advancements in agricultural biogas plant technology, there is

no one high performance technology allowing fermentation, where the majority of the substrate would be poultry manure (12). Moreover, all available western technologies that decrease amounts of nitrogen in the droppings are unprofitable in Polish economic circumstances due to considerably lower governmental subsidies.

2. Methodology

2.1. Analysis of basic physicochemical parameters

Executed analyses of basic physicochemical parameters of the substrates and inoculum, enabled the selection of appropriate proportions of fermentation mixtures. The analyses were conducted according to Polish standards: dry matter (PN-75 C-04616/01), dry organic matter and ash (PN-Z-15011-3). These parameters enabled the subsequent calculation of the biogas efficiency calculated on Mg of fresh matter, dry matter and dry organic matter of the substrate. In case of methane fermentation running in continuous mode, pH analysis has been carried out every single day.

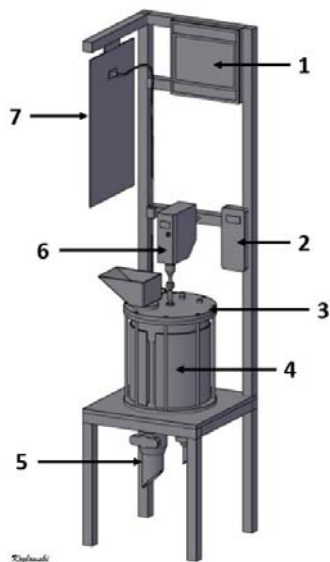
2.2. Biogas efficiency

The research on methane efficiency of the substrates in batch culture technology was carried out in the Laboratory of Ecotechnology at the Institute of Biosystems Engineering at the Poznań University of Life Sciences on basis of internal procedures, based on adapted standards: DIN 38 414-S8 and VDI 4630, commonly used in Europe. Detailed

methodology of performed research was presented by Cieřlik et al. [2016] (4).

2.3. Continuous fermentation

Studying the process in a continuous mode was executed in a glass fermentation BTP-2 reactor of German company Umwelt- und Ingenieurtechnik Dresden GmbH (Figure 1), designed to perform the experiments related to the process of continuous methane fermentation (CSTR). This device belongs to equipment of the Laboratory of Ecotechnology, functioning in the Institute of Biosystems Engineering, at the Poznań University of Life Sciences.



Source: own work / Źródło: opracowanie własne

Fig. 1. The schema of fermentation set-up for continuous process: 1 – steering computer, 2 – temperature regulator, 3 – CSTR reactor, 4 – heating mat with thermal insulation, 5 – outlet valve, 6 – electric mixer, 7 – biogas tank

Rys. 1. Schemat stanowiska fermentacyjnego z reaktorem do prowadzenia procesów ciągłych: 1 – komputer sterujący, 2 – regulator temperatury, 3 – reaktor CSTR, 4 – mata grzejna z izolacją termiczną, 5 – zawór spustowy, 6 – mieszadło elektryczne, 7 – zbiornik na biogaz

The reactor with working capacity of 15 dm³, was equipped with an electric motor with a power of 140 W with a stirrer having a vertical axis, allowing to obtain rotation speed from 0 to 200 rpm (average rotation speed amounted 60 rpm). Produced biogas was collected in a special, plastic sealed gas bag with capacity of 10 dm³, while qualitative and quantitative analysis was performed using gas analyzer from Company GEOTECH GA 5000. Constant temperature of methane fermentation process was possible due to implementation of silicone heating mat with a power of 500 W, equipped with a monitoring and control system for temperature inside the reactor and insulation. The process of continuous fermentation was running under mesophilic conditions, at temperature of 39°C, in accordance with the guidelines published in German standardized biogas guide VDI 4630.

3. Results and discussion

3.1. Analysis of physicochemical parameters

The results of executed analyses of physical and chemical parameters of the materials and inoculum used in the experiment are shown in Table 1.

Tab. 1. Physical and chemical parameters of the substrates and inoculum

Tab. 1. Parametry fizykochemiczne substratów i zaszczepki

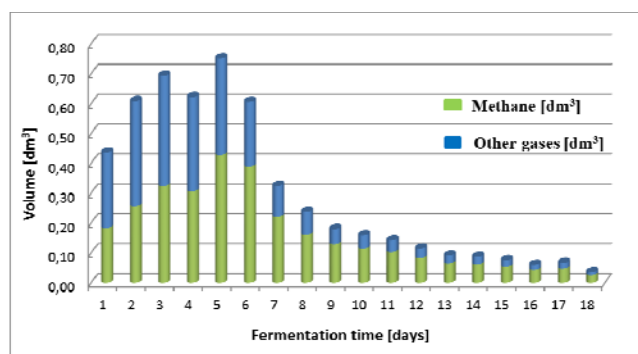
	pH	Fresh matter [%]	Organic dry matter [% FM]	ODM substrate/ODM inoculum
Innoculum	7.87	2.87	65.80	0.49
Chicken droppings	6.55	37.48	75.34	

Source: own work / Źródło: opracowanie własne

Inoculum used in the experiment had dry matter content and organic dry matter content respectively at the level of 2.87% and 65.80% while the substrate used in fermentation experiments amounted 37.48% DM, and - 75.34% organic dry matter.

3.2. Dynamics of biogas production and biogas efficiency of chicken manure

The process of methane fermentation in "batch culture" system was running smoothly and without any pH interference. In the eightieth day, the volume of biogas was 0.9% of the total produced biogas which, according to DIN 38 414 / S8 provisions, determined the last day of fermentation. The following Figure 2 shows the daily dynamics of biogas production for tested substrate.



Source: own work / Źródło: opracowanie własne

Fig. 2. Daily biogas and methane production from chicken droppings

Rys. 2. Wykres dobowej produkcji biogazu i metanu dla pomiotu kurzego

During the fermentation process of chicken manure there have been observed two distinct peaks of biogas production in the third and fifth day (Fig. 2). Increased biogas production in the first days of the experiment is related to intense degradation of simple organic compounds (in particular, carbohydrates and proteins) of the substrate, by the hydrolysis phase bacteria (3).

The following table 2 presents the biogas efficiencies and percent concentration of methane in biogas from tested silages from maize subjected to methane fermentation under mesophilic conditions.

The obtained results proved that this substrate has a good biogas potential. Relatively high content of dry matter of the substrate (37.48%) caused to obtain the biogas in the amount higher than 121 m³ Mg⁻¹ of fresh matter of the substrate.

Moreover, produced biogas had also high methane content (approx. 57%) resulting from high-protein poultry diet, Tab. 2. Biogas efficiency of substrate in mesophilic fermentation
Tab. 2. Wydajność biogazowa substratu w fermentacji mezofilowej

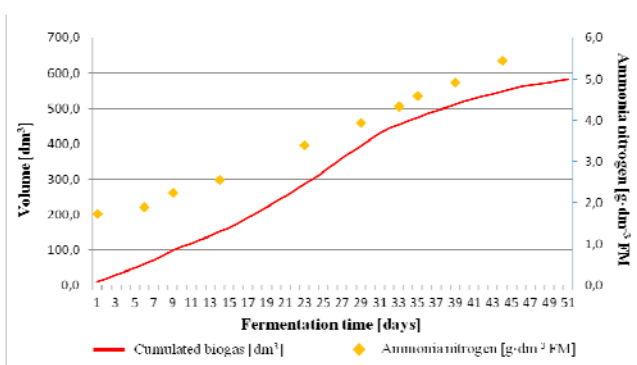
which significantly increases the biogas calorific value.

Sample	Methane content [%]	Fresh matter		Dry matter		Organic dry matter	
		Cumulated methane [m ³ Mg ⁻¹ FM]	Cumulated biogas [m ³ Mg ⁻¹ FM]	Cumulated methane [m ³ Mg ⁻¹ DM]	Cumulated biogas [m ³ Mg ⁻¹ DM]	Cumulated methane [m ³ Mg ⁻¹ ODM]	Cumulated biogas [m ³ Mg ⁻¹ ODM]
Chicken droppings	57.38	69.66	121.40	185.84	323.89	246.67	429.90

Source: own work / Źródło: opracowanie własne

3.3. Dynamics of biogas production in continuous mode

The next research step was to run the continuous fermentation of chicken manure in order to check the inhibitory properties of the nitrogen contained in it. The cumulative biogas production and changes in the concentration of ammonia nitrogen in the reactor are shown in the following figure 3.



Source: own work / Źródło: opracowanie własne

Fig. 2. Cumulated biogas production and ammonium nitrogen changes in bioreactor for fermentation

Rys. 2. Wykres skumulowanej produkcji biogazu oraz zmian stężenia azotu amonowego w reaktorze fermentacyjnym

The process of continuous fermentation of chicken manure was performed for 50 days. Around day 27, it was observed that despite the continuous daily load of digester chamber with a substrate – at the level of 2.5 kg ODM m⁻³ day⁻¹ the biogas production began to decrease heavily. Analysis of ammonia nitrogen in the fermenting pulp showed a concentration amounted 3.7 g · dm⁻³ fresh matter. Referring to the literature data (13, 7, 6; 5), it has been observed a presence of ammonium inhibition, which resulted in decrease of biogas production and methane content in produced biogas from 62% in 21. day to 41% at day 50.

The formation of ammonia during methane fermentation process is related to pH in fermentation mixture. Along with increase of the afore-mentioned parameter, the balance between the ammonium ion and ammonia moves toward ammonia [8]. The influenced on NH₃ concentration has also the process of temperature growth as well as use of substrates with high protein content, such as chicken manure [14]. According to Hashimoto (7), as well as Angelidaki and Ahring (2), the process of methane fermentation can be adapted even to the tolerance of 4 g NH₃ dm⁻³, however it requires a very slow gradual habit of bacteria to adapt to such conditions.

4. Conclusions

1. Chicken manure is an energy valuable substrate allowing production of methane at the level of 70 m³ · Mg⁻¹ of fresh matter of the substrate.
2. Mono-substrate fermentation of chicken manure is impossible to run in traditional fermentation process due to the presence of ammonium inhibition caused by too high nitrogen content.
3. The limit concentration of nitrogen beyond which reported the inhibition of ammonium is 3.7 g·dm⁻³.
4. Effective and economic technology of reduction of nitrogen content should be developed in order to effectively exploit the potential of chicken manure as a biogas, or it should be added only as supplement to control C:N ratio in the feed and fermenting pulp.

5. References

- [1] Agencja Rynku Rolnego: Wykaz surowców zużytych do produkcji biogazu rolniczego w 2015 r. – korespondencja prywatna z ARR, 2016.
- [2] Angelidaki I., Ahring B.K.: Thermophilic anaerobic digestion of livestock waste: effect of ammonia. *Appl. Microbiol. Biotechnol.*, 1993, 38: 560-564.
- [3] Chandra R., Takeuchi H., Hasegawa T.: Methane production from lignocellulosic agricultural crop wastes: A review in context to second generation of biofuel production. *Renewable and Sustainable Energy Reviews*, 2012, 16: 1462-1476. doi:10.1016/j.rser.2011.11.035.
- [4] Ciešlik M., Dach J., Lewicki A., Smurzyńska A., Janczak D., Pawlicka-Kaczorowska J., Boniecki P., Cyplik P., Czekala W., Józwiakowski K.: Methane fermentation of the maize straw silage under meso- and thermophilic conditions. *Energy*, 2016, In Press. DOI: http://dx.doi.org/10.1016/j.energy.2016.06.070
- [5] Gelegenis J., Georgakakis D., Angelidaki I., Mavris V.: Optimization of biogas production by co-digesting. *Renewable Energy*, 2007, 32: 2147-2160.
- [6] Hansen K.H., Angelidaki I., Ahring B.R.: Anaerobic digestion of swine manure: inhibition by ammonia. *Water Research*, 1998, 32: 5-12.
- [7] Hashimoto A.G.: Ammonia inhibition of methanogenesis from cattle wastes. *Agric. wastes*, 1986, 17: 241-261.
- [8] Kroiss H.: *Anaerobe Abwasserreinigung. Wiener Mitteilungen Bd*, 1985, 62, Wien.
- [9] Lelieveld J., Crutzen P.J., Brühl C.: Climate effects of atmospheric methane. *Chemosphere*, 1993, 26: 739-768.
- [10] Rodríguez Carmona P. C., Witaszek K., Janczak D., Czekala W., Lewicki A., Dach J., Pilarski K., Mazur R.: Methane fermentation of the poultry manure as an alternative and environmentally friendly technology of its management. *Archiwum Gospodarki Odpadami i Ochrony Środowiska*, 2014, 16: 21-26.
- [11] Rzeźnik W.: Ograniczanie emisji zanieczyszczeń gazowych z tuczarni poprzez zastosowanie instalacji do odzysku ciepła. *Inżynieria Rolnicza*, 2013, 3(146): 331-339.
- [12] Sun C., Cao W., Banks C., J., Heaven S., Liu R.: Biogas production from undiluted chicken manure and maize silage: A study of ammonia inhibition in high solids anaerobic digestion. *Bioresource Technology*, 2016, 218: 1215-1223.
- [13] Van Velsen A.F.M.: Adaption of methanogenic sludge to high ammonia-nitrogen concentrations. *Wat. Res.*, 1979, 13: 995-999.
- [14] Weiland P.: *Grundlagen der Methangärung – Biologie und Substrate. VDI Berichte*, 2001, 1620 (Biogas als regenerative Energie – Stand und Perspektiven): 19-32.

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