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Methane fermentation of poultry manure — shortcomings and advantages of the technology: fermentation or co-fermentation?

Abstract
Overcoming of technological barriers in methane fermentation of substrates including poultry manure derived from poultry-breeding industry is regarded as one of strategic trends in biogas-technology development. The essential limitations and possibilities of such substrates for biogas production is presented here. It should be emphasized, that biogas production based on poultry manure from industrial-scale farms is effective solution of important ecological problem with simultaneous production of green energy and efficient solution of odours emission from the poultry breeding farm. Methane co-fermentation of post-processed bedding premixed with poultry manure solves, at least partly, problem of correct C/N ratio in the substrate mixture.

Keywords: methane fermentation, biogas, poultry breeding industry, poultry manure, co-fermentation.

1. Introduction

About 1.2 millions Mg of hen manure and ca. 2.1 millions Mg of hen droppings is annually produced in Poland. One should add to this also turkey, duck and goose manure. Such large amount of poultry manure should be recycled and use as it comes. One of its utilization methods is methane fermentation. The biogas production variant is essential, however not effectively solved, so far, technological challenge. Methane fermentation of poultry manure is hardly ever used at full scale, solely because of high dry mass content together with high ammonium nitrogen content. The standard methane fermentation processes should be thus connected with significant dilution of substrates, in order to effectively reduce inhibiting effect of ammonia (Albertson, 1961; Melbinger et al., 1971; Van Velsen, 1979; Braun et al., 1981; Koster et al., 1988; Nakakubo et al., 2008; Yenigun et al., 2013).

From the economy point of view, dilution of poultry manure makes the process practically unfeasible. However, anaerobic fermentation of diluted manure coupled with controlled ammonia removal provides solution of both technological problems.

It may be realized by removal of ammonia from solution by air stripping or chemical precipitation, e.g. in a form of struvite (Walker et al., 2011; Bharathiraja et al., 2018). Returning the liquid residues back to biogas plant, after separation of digestate, for substrates dilution makes utilization of poultry manure with intrinsic high content of dry mass possible. Methane fermentation of poultry manure of high dry mass content is the most effective within the mesophilic temperature range, with ca. 15–25% dry mass content. Thermophilic fermentation under these conditions is, however, strongly inhibited by ammonia. During fermentation numerous chemical transformations of organic nitrogen are observed, as well as many chemical reactions where ammonia is produced. Outside fermentation chamber, ammonia may be purposefully chemically bound and removed using commonly known and accessible magnesium compounds (Yetilmezsoy et al., 2009).

Many fermentation tests of poultry manure fermentation were done, both as a single substrate and as the mix with other substrates (co-fermentation, especially important for correction of C/N ratio). These processes were driven, taking special attention to large amount of sand, gravel and high contents of ammonium nitrogen, in poultry manure used as the substrate in biogas plant. The co-fermentation of poultry manure with fat and corn silage promotes growth of biogas yield by 22–44%, compared to individual anaerobic fermentation of poultry manure, fats and silage, respectively. Ammonia removal may cause growth of biogas production even by 235%.

Specific problem in poultry-manure fermentation is that in poultry stomachs gravel or sand is present, which is necessary for food rubbing. This sand, excreted together with metabolic products is the main obstacle in process of biogas production, thus it should be separated in early stages of the process. A removal from poultry manure eggshells, soil, gravel, chalk, etc. is also necessary. It is important stage of biogas technology, since these solids in fermentation chamber may even destroy the mixing device. After separation of sand, poultry manure is transported to fermentation chamber. Poultry manure with high content of sand may be also fermented in a special construction chamber, making its continuous removal possible.

Anaerobic fermentation of poultry manure is often carried out with cow manure addition. Because of high content of ammonium nitrogen, fermentation process is also carried out with addition of fresh grass or grass silage. After methane fermentation of poultry manure premixed with grass, straw or maize silage, solid mass can be separated from digestate. Such separated solid mass is regarded to be valuable bedding material. Processed this way material protects the poultry against injury. Moreover, dust generation in the breeding room is effectively prevented or at least diminished. The device for solid-mass separation from digestate is presented in Fig. 1. Especially valuable is biomass separated from post-fermented bedding composed of *triticum spelta* husks.

Fig. 1. Separation of post-fermented biomass

Main factor influencing the performance of poultry breeding farm is limiting its troublesome influences on air, water and soil. Especially odours emission should be prevented by their capture, followed by removal of odours in the system of chemical and biological filters. Thus, in the nearest future one should expect changes in design and operating of gas circulation loops in breeding farms.

The natural solution seems to be reduction of odours and ammonia emissions from poultry manure by its fermentation and production of biogas for energetic purposes — for production of electricity, heat and cold. Poultry manure shows high content of dry mass, as well as high nitrogen and phosphorus contents. Poultry manure has usually 30–70% of dry mass. To be fermentable, it should be 5–10-times diluted. Such large amount of water to be provided creates huge economical and technological problem connected with large amount of post-fermented mass. Thus from digestate a solid fraction should be separated, whereas liquid should be returned for substrate dilution. Returning of post-fermented mass for dilution of poultry manure is possible after ammonia and phosphorus removal. However, the fundamental process parameters are still the amount of biogas produced from unit mass of poultry manure and its decomposition time.

Some analyses results concerning samples of the selected post-processed poultry beddings (poultry manure premixed with bedding biomaterial) tested as the source of substrate biomass for biogas production are presented.

2. Results of measurements

In this section the characteristics of the biogas derived from laboratory tests are presented. The controlled isothermal methane fermentation of selected, typical and representative for the poultry breeding industry, multicomponent waste mixture, including poultry manure premixed with sawdust or poultry manure premixed with the straw is performed. Different chemical compositions represent post-processed bedding material derived from broiler poultry breeding in rooms with floor heating. Moreover, application of further pre-processing may effectively influence biogas production. The post-processed poultry beddings collected in a poultry breeding room with heated floor is dry and represents higher content of ammonium nitrogen. Proteins from the fodder were not thoroughly decomposed due to unfavourable conditions.

2.1. Poultry manure premixed with sawdust

Batch methane fermentation of poultry manure premixed with sawdust was carried out in temperature of 38°C. After 1071 hours of anaerobic fermentation biogas production was (mean value based on 3 independent, parallel tests) ca. 426 m^3/Tdm (tone of dry manure mass), where:
- methane content in biogas was 53%,
- carbon dioxide content in biogas was 46%,
- total nitrogen content was 3.85%,
- ammonium nitrogen content was 2.08%,
- CaO content was 2.883% of dry mass, what corresponds to 5.174% of dry mass of $CaCO_3$,
- pH value of solution after fermentation was 7.53.

2.2. Poultry manure premixed with the straw

The volume of biogas produced after 44 days of batch fermentation of poultry manure premixed with the straw bedding was 668.5 m^3/Tdm. Biogas biosynthesis runs intensively during ca. 10 first days, then biogas production rate have slowed down:
- methane content in biogas was 56%,
- carbon dioxide content in biogas was 43%,
- total nitrogen content was 3.95%,
- ammonium nitrogen content was 3.11%,
- CaO content was 4.007% of dry mass, what corresponds to 7.155% of dry mass of $CaCO_3$,
- pH of solution after fermentation was 8.03.

It was observed, however, that after fermentation some fraction of the straw was not decomposed.

2.3. Post-processed poultry beddings derived from broiler poultry breeding on the heated floor

As the bedding in the poultry breeding such substances are used, which prevent birds injury. The most often bedding is made of *triticum spelta* husks, straw pellets, crumbled straw or separated, post-fermented mass. In breeding room with the heated floor and straw bedding totally different conditions are met than in case of chicken coop without any heating system. In the floor-heated rooms thorough decomposition of poultry manure correlated with ammonia emission is not observed. The manure is dry, thus decay processes are strongly inhibited. Traditional chicken coop heated with oil is presented in Fig. 2.

Fig. 2. Conventional room for industrial-scale broiler poultry breeding with oil heating, straw used as the bedding biomaterial and high dusting level

After chemical analysis of bedding the following data were provided:
– dry mass — 53.77%,
– organic mass — 88.32%,
– ash — 11.16%.

After 1745 hours of methane fermentation biogas volumes in different test reactors were different. Large biogas volume is especially produced from fine fraction of mixture (of straw bedding). Prolongation of fermentation process is mainly affected by straw content and degree of its preliminary decay.

2.4. Post-processed poultry beddings derived from broiler poultry breeding with additional preliminary preprocessing

In industrial-scale farm where broiler poultry breeding runs with heated floor the resulting mixture of poultry manure and bedding (crumbled straw) is dry. Decay process is strongly inhibited. As it results from the previous tests, methane fermentation of poultry manure runs with high rate provided that manure is appropriately preprocessed towards fermentation. For fermentation process some samples of manure from the current bedding exchange, after 6 weeks, as well as after 12 weeks of its external exposition to aeration on a prism were prepared.

One should pay special attention on the amount of biogas produced from the samples of post-processed bedding material aerated during 12 weeks on a prism. It should also be emphasized, that biogas production rate in these test conditions is higher, especially at the beginning. In next experiments the prism was sprinkled with liquid digestate after separation of solid fraction, as a form of preprocessing of the post-processed “dry” poultry beddings.

Its analysis showed following parameters: dry mass — 53.77%, organic mass — 88.32% and ash — 11.16%.

In the case of post-processed poultry beddings after 6 weeks of exposition to oxygen on a prism these indicators were as follows: dry mass — 47.61%, organic mass — 88.84% and ash — 11.16%.

For post-processed poultry beddings after 12 weeks of exposition to aeration on a prism analytical tests provided the following values: dry mass — 43.44%, organic mass — 85.44% and ash — 14.56%.

Biogas production from post-processed "dry" poultry beddings is slower at the beginning than in the case of post-processed poultry beddings "wet — aerated". Nevertheless, it was observed, that after ca. 900 h of batch process the amount of produced biogas is practically identical. However, further course of fermentation process should be carefully observed, since for the prolonged process times some further quantitative changes are possible.

Analysis provided the following results. Biogas composition: CH_4 — 57%, CO_2 — 42%, CO — 142 ppm, H_2S — 2050 ppm.

Post-processed "dry" poultry beddings characterized by (3 samples): dry mass — 74.828, 74.856 and 74.929%, organic mass — 88.020, 88.996 and 88.786%, inorganic mass — 11.979, 11.004 and 11.214%.

Analysis of post-processed "wet — aerated" poultry beddings provided the following values: dry mass — 39.831 and 39.775%, organic mass — 89.814 and 89.347%, whereas inorganic mass — 10.185 and 10.653%.

3. Conclusions

Presented results show, that composite substrates including poultry manure premixed with remainder of bedding biomaterial (which is the subject of biological partial decay processes during poultry breeding cycle) may represent valuable group of biodegradable materials — substrates suitable for anaerobic fermentation process. It should be highlighted, that decomposition (fermentation) of metabolic products of poultry breeding is possible; wastes which in the opposite case could represent troublesome problem for natural environment and economy, requiring recycling according to appropriate norms and sanitary regulations.

Combination of metabolic products of poultry breeding with post-processed poultry beddings can also provide some practical method of C/N ratio adjustment in multicomponent substrate, essentially influencing the complex biochemical transformations of agricultural biogas-production technology.

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