Facilities and problems of processing organic wastes by family-type biogas plants in Ukraine

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Abstract

The potential of organic wastes in Ukraine for biogas production and the prospects of using the family-type biogas plants for this purpose are shown. In the biogas laboratory of the Ukrainian National Forestry University the efficiency of the anaerobic mesophilic digestion of chicken manure of Poltava poultry farm, Kamianets-Podilsky poultry farm and sewage sludge from Lviv wastewater treatment plant (WWTP) was investigated. Different integral indicators of the biogas production and significantly different dynamics of its formation over time were obtained for three investigated substrates. The value of average specific biogas production from the sewage sludge of Lviv WWTP is 0.494 dm³ (day·kg FM)⁻¹, which is 5.1 times more than the chicken manure of Kamianets-Podilsky poultry farm and 8.0 times more than for the chicken manure of Poltava poultry farm. Strong negative effect of antibiotic treatment of chickens on methane content in the obtained biogas was established experimentally.

Key words: anaerobic digestion, biogas plant, bioreactor, organic wastes, renewable energy

INTRODUCTION

The conditions of Ukraine with the developed animal industry, plenty of renewed organic wastes, dependence on power sources, rather mild climate etc. promotes the necessity of introduction of the technology of biological processing of these wastes.

In accordance with the experts in Ukraine annually more than 125 mln Mg of organic wastes are formed as dry substance in different branches of national economy [Anaerobic Digestion 1994]. Anaerobic method of its processing allows obtaining of effective ecologically pure organic fertilizers and biogas. It is alternative power source ensuring preservation of an environment [ACHINAS et al. 2017; ACHINAS, WILLEM EUVERINK 2020; BATSTONE, VIRDIS 2014; BUDZIANOWSKI 2012]. According to SCARLAT et al. [2018], about 200 m³ of biogas can be extracted from one ton of organic wastes dry mass, which corresponds to 25 bln m³ of this fuel in the scale of Ukraine. On the other hand, for obtaining such amount of biogas using the bioreactors with productivity of 1 m³ of biogas per day per 1 m³ of the reactor [ROSS et al. 1996], it is necessary to operate bioreactors with total volume about 68.5 mln m³.

Using the small family-type plants for the processing of agricultural waste is of special interest [CZEKALA et al. 2017; MYCZKO et al. 2019]. In this case, it is possible to make fuller use of the waste of small agricultural farms, which is practically impossible to realize on high-capacity biogas plants as a result of the logistic problems and high expenditures for the transportation. However, the use of family-type biogas plants causes the risks of not being able to provide constant composition of raw materials during the annual cycle. For this reason additionally to traditional
agricultural wastes, sludge, vegetable raw materials and a combination of different types of organic waste should be used as raw materials [ANGELIDAKI, ELLEGAARD 2003; DONG et al. 2018; KUSHKEVYCH et al. 2018; LI et al. 2013]. Certain types of organic solid waste are also quality raw materials for biogas production [CASTILLO et al. 2006; HILKIAH IGOHI et al. 2008; LINKE 2006].

Big industrial biogas plants are now implementing in Ukraine, including the biogas station at Lviv wastewater treatment plants (WWTP) [Lviv wastewater biogas 2014; ZHUK et al. 2015]. However very small quantity of the small-sized, family-type biogas installations is functioning in Ukraine at this time, and it is important to investigate experimentally the digestion process in the family-type anaerobic plants for different raw materials. Different estimations confirm that depending on a kind of organic wastes, volume of the reactor, technological factors and quality of processing products, such family-type digesters can have investment return period about 6–7 years [CZEKALA et al. 2017]. An important parameter influencing the efficiency of biogas plant is the optimal mode of operation, which is related to the process kinetics [ENITAN et al. 2017; FANTOZZI, BURATTI 2009; LINKE 2006; ZHANG et al. 2015]. The effectiveness of anaerobic digestion of organic substrate strongly depends also on the thickening process effectiveness [POUCHAJDA, OLESZKIEWICZ 2008], that should be taking into account in the maintenance of family-type biogas plants.

The purpose of this research is to study experimentally the dynamics of biogas production at the pilot family-type bioreactor using the mono-digestion of chicken manure from different Ukrainian producers, as well as the sewage sludge of the Lviv WWTP.

**MATERIALS AND METHODS**

Pilot family-type bioreactor for the anaerobic digestion of organic wastes was designed and installed in the special laboratory of Ukrainian National Forestry University (Ukr. Natsional’nyi isletekhnichnyy universytet Ukrayiny – NLTU). Principal scheme of the laboratory installation is presented at the Figure 1. The substrate is fed into the 200-dm³ bioreactor 2 through the device 1. Constant temperature in the bioreactor is maintained by the automatic temperature control system 12 using the water heater 3. Biogas, accumulating in the upper part of the bioreactor, through the system of valves, flows to the gas holder 5. Biogas can be either directed to the gas cylinder 7 for burning, or, using the compressor 8, pumped into the domestic gas cylinder 9 for storage.

Experimental biogas installation can operate either in batch or continuous mode. When running in batch mode, the substrate was loaded at 85% of the reactor volume for the entire digestion period. In continuous mode, after initial loading of the 85% of its volume, about 5% of the total volume daily was let out into the capacity 10, and then an appropriate amount of raw substrate was added through the feeding device 1.

<table>
<thead>
<tr>
<th>Type of substrate</th>
<th>Volume of digester (dm³)</th>
<th>Fresh mass (kg)</th>
<th>Dry mass of substrate (kg)</th>
<th>Dry mass content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken manure (Poltava poultry farm)</td>
<td>200</td>
<td>170</td>
<td>13.12</td>
<td>7.72</td>
</tr>
<tr>
<td>Chicken manure (Kamianets-Podilsky poultry farm)</td>
<td>200</td>
<td>170</td>
<td>13.12</td>
<td>7.72</td>
</tr>
<tr>
<td>Sewage sludge (Lviv WWTP)</td>
<td>200</td>
<td>170</td>
<td>5.04</td>
<td>2.97</td>
</tr>
</tbody>
</table>

Source: own elaboration.
RESULTS AND DISCUSSION

Changes in the time of total biogas production and daily biogas production during fermentation of chicken manure of Poltava poultry farm, Kamianets-Podilsky poultry farm, and sewage sludge of Lviv WWTP are shown in Figure 2. The main quantitative results describing the efficiency of fermentation processes in these three series are summarized in Table 2.

Different integral indicators of the biogas production and significantly different dynamics of its formation over time were obtained for all three substrates. Anaerobic processing of chicken manure of the Poltava farm is characterized by a considerable duration of the initial fermentation stage: only 15 days after the start of the process the biogas output reached 25 dm³·day⁻¹, which corresponds to the specific biogas production rate of 0.147 dm³·(day·kg FM)⁻¹. Peak biogas production with an average daily biogas yield of about 40 dm³·day⁻¹, corresponding to 0.235 dm³·(day·kg FM)⁻¹ was observed for only 8 days – from 18th to 25th day from the start of the experiment (Fig. 2a).

Further there was a sharp and then a wave-like decreasing of the rate of biogas production over time. After the 35th day until the end of the process, the daily biogas output no exceeded 17 dm³·day⁻¹ or 0.1 dm³·(day·kg FM)⁻¹. In order to study the dynamics of especially deep fermentation, the series with chicken manure of the Poltava farm was prolonged up to 95 days. Within 42–57 days, the daily biogas output was about 10 dm³·day⁻¹ or 0.059 dm³·(day·kg FM)⁻¹ and then it was stabilized at about 5 dm³·day⁻¹ (0.029 dm³·(day·kg FM)⁻¹). Total volume of biogas obtained in 95 days period was 1000 dm³, which corresponds to the average rate of 10.5 dm³·day⁻¹ and the specific output of 0.062 dm³·(day·kg FM)⁻¹ or 0.802 dm³·(day·kg DM)⁻¹ (Tab. 2).

The total volume of biogas obtained from the chicken manure of Kamianets-Podilsky poultry farm in the period of 60 days is 1010 dm³ (Fig. 2b), which is almost the same as in the first case, but dynamics of the biogas production are completely different. Digestion process of the chicken manure of Kamianets-Podilsky poultry farm had a very short initial fermentation stage. Biogas output was as high as 140 dm³·day⁻¹ in the first 5 days, which corresponds to the specific biogas production rate of 0.824 dm³·(day·kg FM)⁻¹ or 3.5 times more comparing the peak biogas production for the chicken manure of Poltava farm. The peculiarity of fermentation of this type of chicken manure is a sharp decreasing of biogas production since the 6th day, first to 30 dm³·day⁻¹ in the period between 7th and 9th day and then it was changing in the range of 0–12 dm³·day⁻¹ to the end of the process. Another feature of the case at Figure 2b is especially low methane content in the biogas, yielded from the chicken manure of Kamianets-Podilsky poultry farm. It was as low as 10–15% in different days. The reason for this fact can be the treatment of chickens with an antibiotic 2–3 days before the sampling, which could adversely affect on the methanogenesis process.

Results of digestion of the sewage sludge from Lviv WWTP are much higher, comparing the chicken manure. The total biogas production for the 25-days period is equal to 2100 dm³, or 84 dm³·day⁻¹, and daily biogas production at the 25th day was still high enough: about 55 dm³·day⁻¹ (Fig. 2c). Average specific biogas yield is equal to 0.5 dm³·(day·kg FM)⁻¹ or 16.9 dm³·(day·kg DM)⁻¹. The start of the fermentation process was fast enough, already in the third day 110 dm³ of biogas were yielded. In the period from 3rd to 18th day specific biogas production was in the range of 100–160 dm³·day⁻¹ with the weighted average value 125 dm³·day⁻¹ which corresponds to 0.74 dm³·(day·kg FM)⁻¹ or 24.8 dm³·(day·kg DM)⁻¹.

Fig. 2. Biogas production from: a) Poltava poultry farm, b) Kamianets-Podilsky poultry farm (chickens of the breed “Loman white”, aged 5 days), c) sewage sludge from Lviv wastewater treatment plant; source: own study.
Table 2. Main results of the digestion in the pilot family-type bioreactor of Ukrainian National Forestry University

<table>
<thead>
<tr>
<th>Type of substrate</th>
<th>Duration of digestion days</th>
<th>Total volume of biogas $\text{dm}^3$</th>
<th>Methane content %</th>
<th>Average biogas production $\text{dm}^3\text{day}^{-1}$</th>
<th>Average specific biogas production $\text{dm}^3\text{day}^{-1}\text{(day-kg FM)}$</th>
<th>Average specific biogas production $\text{dm}^3\text{day}^{-1}\text{(day-kg DM)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken manure (Poltava poultry farm)</td>
<td>95</td>
<td>1 000</td>
<td>73</td>
<td>10.5</td>
<td>0.062</td>
<td>0.802</td>
</tr>
<tr>
<td>Chicken manure (Kamianets-Podilsky poultry farm)</td>
<td>61</td>
<td>1 010</td>
<td>10–15</td>
<td>16.6</td>
<td>0.097</td>
<td>1.262</td>
</tr>
<tr>
<td>Sewage sludge (Lviv WWTP)</td>
<td>25</td>
<td>2 100</td>
<td>70</td>
<td>84.0</td>
<td>0.494</td>
<td>16.670</td>
</tr>
</tbody>
</table>

Explanation: WWTP = wastewater treatment plant.
Source: own study.

CONCLUSIONS

Three different substrates were digested in pilot family-type biogas plant ($W = 200 \text{ dm}^3$), constructed in Ukrainian National Forestry University: 1) chicken manure of Poltava poultry farm, 2) chicken manure of Kamianets-Podilsky poultry farm, 3) sewage sludge from the Lviv wastewater treatment plant (WWTP).

Different integral indicators of the biogas production and significantly different dynamics of its formation over time were obtained for three investigated substrates.

The value of average specific biogas production from the sewage sludge of Lviv WWTP is 0.494 $\text{dm}^3\text{day}^{-1}\text{(day-kg FM)}^{-1}$, which is 5.1 times more comparing the chicken manure of Kamianets-Podilsky poultry farm and 8.0 times more than for the chicken manure of Poltava poultry farm.

A significant difference in the initial time of fermentation process is obtained: from two weeks for the chicken manure of Poltava poultry farm to 3 days for the sewage sludge from the Lviv WWTP and only 1 day for the chicken manure of Kamianets-Podilsky poultry farm.

Methane content in biogas, yielded from the sewage sludge and chicken manure of Poltava farm is high enough and equal 70% and 73% respectively. Instead methane content in biogas, obtained from the chicken manure of Kamianets-Podilsky poultry farm, was only 10–15%, and this fact can be explained by treatment of chickens with antibiotic 2–3 days before the sampling.

It is necessary to carry out additional investigations of the co-digestion of the different types of organic wastes to find the most effective compositions for anaerobic fermentation in small-sized family-type biogas plants.

REFERENCES


