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

Ivan VOYTOVYCH[1], Myroslav MALOVANYY[2] ✉, Volodymyr ZHUK[3], Orest MUKHA[2]

[1] Ukrainian National Forestry University, Institute of Woodworking, Computer Technology and Design, Department of Technology of Furniture and Wooden Products, Lviv, Ukraine

[2] Lviv Polytechnic National University, Viacheslav Chornovil Institute of Sustainable Development, Department of Ecology and Sustainable Environmental Management, Lviv, Ukraine

[3] Lviv Polytechnic National University, Institute of Civil Engineering and Building Systems, Department of Hydraulic and Water Engineering, Lviv, 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 $dm^3\cdot(day\cdot kg\ FM)^{-1}$, 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. 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 accounts of 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 m^3 of biogas can be extracted from one ton of organic wastes dry mass, which corresponds to 25 bln m^3 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 m^3 of biogas per day per 1 m^3 of the reactor [ROSS *et al.* 1996], it is necessary to operate bioreactors with total volume about 68.5 mln m^3.

Using the small family-type plants for the processing of agricultural waste is of special interest [CZEKAŁA *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 IGONI *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 [CZEKAŁA *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 [PUCHAJDA, 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'nyy lisotekchnichnyy universytet Ukrayiny – NLTU). Principal scheme of the laboratory installation is presented at the Figure 1. The substrate is fed into the 200-dm^3 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 candle 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.

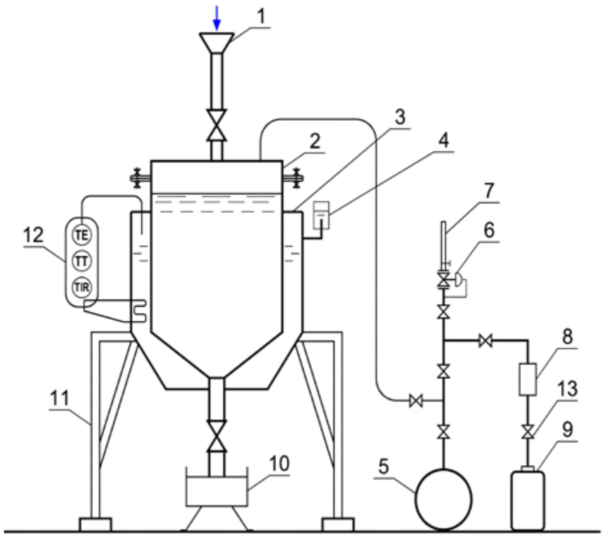


Fig. 1. Pilot family-type bioreactor for the anaerobic digestion of organic wastes: *1* = feeding; *2* = bioreactor (200 dm^3); *3* = water heating; *4* = thermal expansion tank; *5* = experimental gas holder; *6* = pressure reducing valve; *7* = gas candle; *8* = compressor; *9* = domestic gas cylinder; *10* = capacity for digested substrate; *11* = supports; *12* = automation system; *13* = valve; source: own elaboration

The regime factors of anaerobic digestion include:
- humidity of the substrate *W*;
- temperature of the substrate *T*;
- pH-value of the substrate;
- substrate composition.

In the biogas laboratory of the UNFU three series of investigations were carried out using as different substrate for anaerobic mesophilic mono-digestion: chicken manure of Poltava poultry farm, chicken manure of Kamianets-Podilsky poultry farm and sewage sludge from the Lviv wastewater treatment plant (WWTP). Chicken manure in the quantity 150 dm^3 was diluted before the fermentation by the 20 dm^3 of tap water to achieve optimal dry mass content. Main parameters of the substrates, used in these three series are presented in the Table 1. The volume of obtained biogas was measured using the checked experimental gas holder. Methane content in the biogas was defined in the laboratory of Lviv branch of the Institute of Protection of Soils in Ukraine (Ukr. Instytut okhorony gruntiv v Ukrayini).

Table 1. Technical parameters of the substrates, digested in the pilot family-type bioreactor in the biogas laboratory of Ukrainian National Forestry University

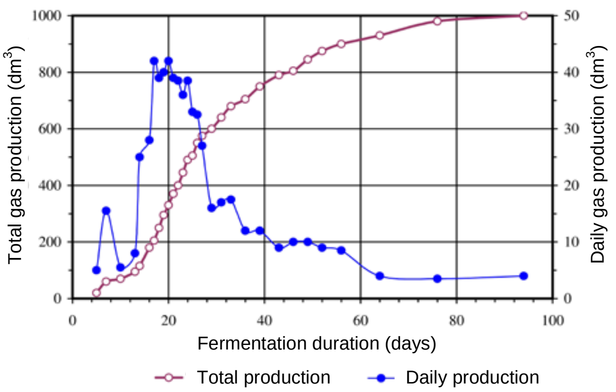
Type of substrate	Volume of digester (dm^3)	Fresh mass (kg)	Dry mass of substrate (kg)	Dry mass content (%)
Chicken manure (Poltava poultry farm)	200	170	13.12	7.72
Chicken manure (Kamianets-Podilsky poultry farm)	200	170	13.12	7.72
Sewage sludge (Lviv WWTP)	200	170	5.04	2.97

Source: own elaboration.

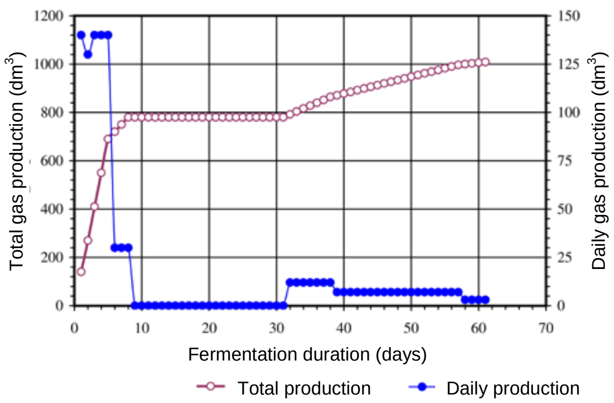
RESULTS AND DISCUSSION

Changes in the time of total biogas production and daily biogas production during fermentation of chicken manure of Poltava poultry farm, Kamyanets-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.

a)



b)



c)

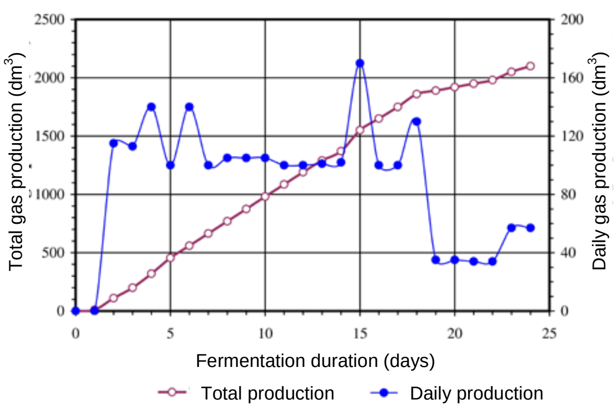


Fig. 2. Biogas production from: a) Poltava poultry farm, b) Kamianets-Podilsky poultry farm (chickens of the breed “Loman white”, aged 5 days), c) sewage sludge from Lviv wastewater treatment plant; source: own study

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 dm^3·day^{-1}, which corresponds to the specific biogas production rate of 0.147 dm^3·(day·kg FM)$^{-1}$. Peak biogas production with an average daily biogas yield of about 40 dm^3·day^{-1}, corresponding to 0.235 dm^3·(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 dm^3·day^{-1} or 0.1 dm^3·(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 dm^3·day^{-1}or 0.059 dm^3·(day·kg FM)$^{-1}$ and then it was stabilized at about 5 dm^3·day^{-1} (0.029 dm^3·(day·kg FM)$^{-1}$). Total volume of biogas obtained in 95 days period was 1000 dm^3, which corresponds to the average rate of 10.5 dm^3·day^{-1} and the specific output of 0.062 dm^3·(day·kg FM)$^{-1}$ or 0.802 dm^3·(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 dm^3 (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 dm^3·day^{-1} in the first 5 days, which corresponds to the specific biogas production rate of 0.824 dm^3·(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 dm^3·day^{-1} in the period between 7th and 9th day and then it was changing in the range of 0−12 dm^3·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 dm^3, or 84 dm^3·day^{-1}, and daily biogas production at the 25th day was still high enough: about 55 dm^3·day^{-1} (Fig. 2c). Average specific biogas yield is equal to 0.5 dm^3·(day·kg FM)$^{-1}$ or 16.9 dm^3·(day·kg DM)$^{-1}$. The start of the fermentation process was fast enough, already in the third day 110 dm^3 of biogas were yielded. In the period from 3rd to 18th day specific biogas production was in the range of 100−160 dm^3·day^{-1} with the weighted average value 125 dm^3·day^{-1} which corresponds to 0.74 dm^3·(day·kg FM)$^{-1}$ or 24.8 dm^3·(day·kg DM)$^{-1}$.

Table 2. Main results of the digestion in the pilot family-type bioreactor of Ukrainian National Forestry University

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

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

CONCLUSIONS

Three different substrates were digested in pilot family-type biogas plant (W = 200 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 $dm^3 \cdot (day \cdot kg\ FM)^{-1}$, 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.

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