RESEARCH ON YIELD OF BIOGAS DURING METHANE FERMENTATION OF COW MANURE WITH ADDITION OF GRANULATED STRAW WITH SLAKED LIME

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Abstract. Cattle manure is often used to produce biogas, from which electricity and heat are generated. However, due to presence of a large amount of crude fiber in manure, the yield of biogas when it is fermented using biogas plants is relatively low. Therefore, an urgent task is to increase the yield of biogas from cattle manure through the use of various additives stimulating methane fermentation. Polyethylene bags were used as digesters, which were sealed with special devices. A calibrated cylinder was used to determine the biogas yield. The acidity of the substrate was measured with a pH meter. The novelty of the chosen topic lies in the use of chemical processing of biomass in combination with extrusion. The research results showed that pretreatment of wheat straw with different concentrations of $Ca(OH)_2$ leads to the breakdown of lignocellulose, an increase in biogas yield and electricity generation. The optimal loading at rate of 100 kg $CaO \cdot t^{-1}$ into the reactor in the form of straw pellets has significant advantages and is the optimal solution, since the biogas yield in this case is practically the same as the yield obtained from wheat straw pellets at the rate of 150 kg $CaO \cdot t^{-1}$ of straw, but it is more cost effective. In addition, the year round use of straw pellets with the optimal addition of slaked lime for a biogas plant makes it possible to obtain high quality biological organic fertilizers; ensure high stable and trouble-free operation of the entire system as a whole; to increase gas recovery from bioraw materials of plant origin due to the decomposition of cellulose. This makes it easier to switch to other types of raw materials, and also increases the specific load of the entire line. It can be seen from the calculations that the highest methane yield (0.342 $m^3 \cdot kg^{-1}$ of dry matter) was obtained from wheat straw pellets, which were processed after extrusion with a $Ca(OH)_2$ solution at rate of 100 kg $CaO \cdot t^{-1}$, 40% more than the control experiment.

Keywords: biogas, cattle manure, substrate, extruded straw, methane fermentation.

Introduction

The global energy situation is characterized, on the one hand, by a constant rise in prices for fossil fuels, especially oil, and, on the other, by a decrease in its proven reserves [1]. According to some forecasts, oil reserves will practically run out by 2050 [2]. At the same time, the total use of energy by mankind is constantly growing [3]. The lack of fossil energy resources in the world leads to the expansion of the use of alternative energy sources [4]. Therefore, the production of energy carriers from biomass is becoming one of the most important priorities in solving energy and environmental problems and has a global perspective for further development [6]. As we know [7], cattle manure is often used to obtain biogas, from which electrical and thermal energy is generated. However, due to presence of amount of crude fiber in manure, the yield of biogas during its fermentation using biogas plants is relatively low [8]. Therefore [9], an urgent task is to increase the yield of biogas through the use of various additives stimulating fermentation. If such a stimulating additive is a waste of production, then the problem of its utilization is solved, thereby improving [10].

In order to generate energy for biogas, the joint fermentation of cattle manure with waste from biodiesel production is used: soapstock, which is obtained as a result of neutralizing biodiesel [11], crude glycerin, which is obtained as a result of sedimentation of biodiesel [12], vegetable oil sediment [8], as well as other production wastes: wine waste [13], substandard flour [14]. However, this waste in significant quantities can be used with insignificant transport costs only near large enterprises for the production of biodiesel, vegetable oil, wine, flour, etc. Due to the shortage of industrial waste, at this time, the joint fermentation of cattle manure with corn silage is widely practiced [15]. This raw material can be used as animal feed and human food. Among alternative energy sources, the production of biogas from crop waste, which includes straw, stems, and the like, is becoming increasingly important. In Ukraine, the surplus of straw and stems of all crops is about 20,000,000 tons [16]. Therefore, it is advisable to use cheaper raw materials that stimulate the yield of biogas – waste from collecting wheat (straw), which must be disposed of with minimal costs, while improving ecology [17].

Straw is difficult to ferment anaerobically because it contains a strong lignocellulose complex. There are various methods of processing ligninocellulosic materials that make them more accessible to anaerobic microorganisms [18]. One of them is the preliminary chemical treatment of straw with slaked lime. However, for the time being insufficiently studied the possibility of using slaked lime combined with extruded straw for the intensification of the fermentation process [14].

Materials and methods

The determination of the intensity of methane fermentation of wheat straw pellets was carried out depending on the treatment with a solution of $Ca(OH)_2$ of different concentrations (50 kg $CaO \cdot t^{-1}$ of straw, 100 kg $CaO \cdot t^{-1}$ of straw, 150 kg $CaO \cdot t^{-1}$ of straw), the method of soaking in $Ca(OH)_2$ (before extrusion, during extrusion, after extrusion). Soaking was carried out for 5 minutes at a temperature of 20 °C. Measurement of the volume of biogas in all experiments was carried out according to the Krivoruchko method. Thus, the initial volume of the variant under study was determined. After that, the bag was suspended in a thermostat and kept there at temperature of 37.6 °C for at least 34 days. Packet volume was measured every seven days. The objects of the research were: wheat straw from the Kozovsky district of the Ternopil region (dry matter (DM) – 86.94%) and seed (cattle manure), which was previously filtered through a sieve (Fig. 1).

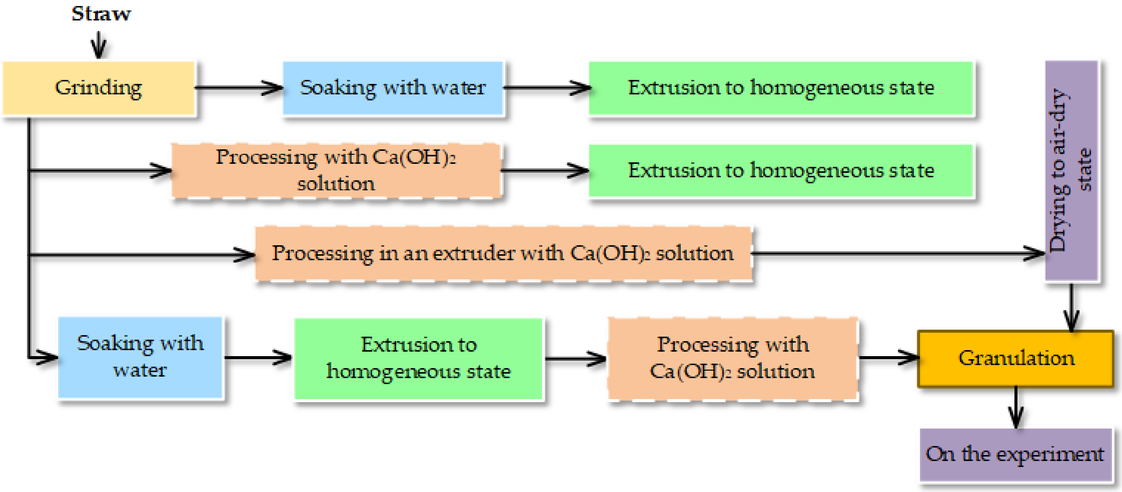

Fig. 1. **Process of preparing raw materials for experiments**

The novelty of the chosen topic lies in the use of chemical processing of biomass in combination with extrusion. During extrusion, it undergoes additional thermochemical treatment. The advantage of using pellets of extruded wheat straw is that such raw materials are better transported over long distances or stored in a warehouse (less volume during transportation and less storage area). Pellets are advisable for the continuous operation of biogas plants, since agricultural waste is seasonal. The research results showed that the pretreatment of wheat straw leads to splitting of lignocellulose, an increase in the biogas yield (Table 1) and electricity generation. Thus, based on the results of the studies, it is necessary to find from the variety of possible options *X* such a technological option for adding slaked lime to straw *x*, which provides the maximum output of biogas and electricity at a given cost of the input substrate *C*.

Table 1

Biogas output, $m^3 \cdot kg^{-1}$ dry matter

Straw processing methods of extrusion	Mass of straw $Ca(OH)_2$, $kg \cdot t^{-1}$	Week				
		1	2	3	4	5
Wheat straw pellets	177	0.177	0.185	0.228	0.234	0.244
Wheat straw pellets with $Ca(OH)_2$ before extrusion	254	0.254	0.325	0.326	0.326	0.326
Wheat straw pellets with $Ca(OH)_2$ during extrusion	290	0.292	0.392	0.392	0.394	0.394
Wheat straw pellets with $Ca(OH)_2$ after extrusion	282	0.282	0.336	0.341	0.341	0.341

It is assumed that the addition of lime to straw pellets is a controlled N-stage dynamic process, which at each n-th stage is characterized by two types of parameters: control parameters m_n (loading volume of the n-th type of biomass and lime), as well as parameter state $G_n(m_n)$ (output of biogas and electricity at the n-th stage of the technological process). The cost of the input substrate C acts as a limitation. The ultimate goal of the technological process of preparing input raw materials for biogas plant W_N is to obtain the maximum volumes of biogas and electricity. In the general case, the problem of optimizing the technological process for the preparation of pellets from various types of raw materials can be presented as follows

$$\max W_N = \sum_{n=1}^{N} G_n(m_n) \text{ at } S_N \le S\,, \tag{1}$$

where S_N – total cost costs of each type of raw material during N stages of the technological process.

Results and discussion

Dependence of the biogas yield depending on the technology of wheat straw pallet preparation with treatment with $Ca(OH)_2$ solution (before, during, after extrusion) is shown in diagrams (Fig. 2-4). In 35 days, the process of gas formation in most cases ends (see Fig. 2-4). The highest biogas yield was obtained from pellets of extruded wheat straw, which was treated with a $Ca(OH)_2$ solution (at the rate of 150 kg $CaO \cdot t^{-1}$ of straw) during extrusion – 0.399 $m^3 \cdot kg^{-1}$, which is 63% more than the yield of biogas from pellets of extruded wheat straw, which were not treated with a solution of slaked lime. Let us analyze in more detail the methods of processing with slaked lime. When processing wheat straw before extrusion, the yield of biogas increased: at a concentration of $Ca(OH)_2$ solution of 50 kg $CaO \cdot t^{-1}$ by 19%, 100 kg $CaO \cdot t^{-1}$ – 32%, 150 kg $CaO \cdot t^{-1}$ – 28% (Fig. 2).

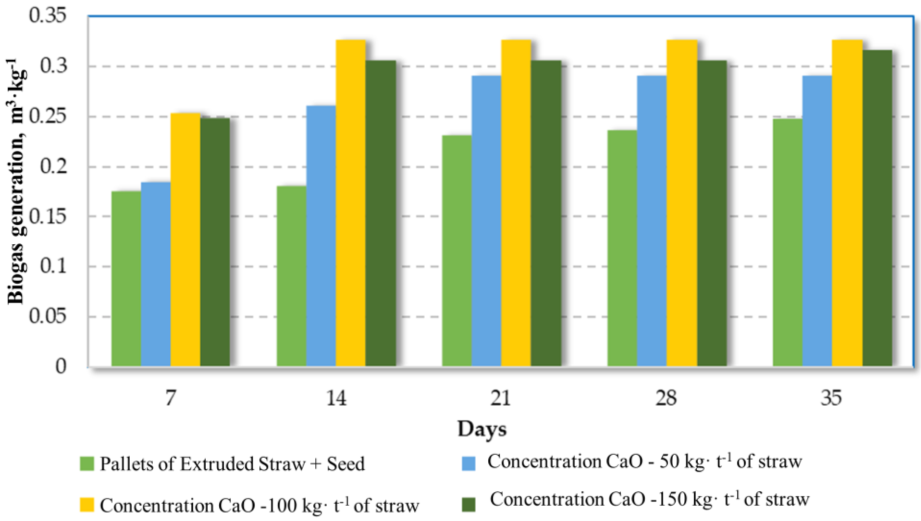

Fig. 2. **Dependence of biogas yield on pretreatment**

Fig. 2 shows that the highest methane yield (0.327 $m^3 \cdot kg^{-1}$ DM) was obtained from wheat straw pellets, which were processed before extrusion with a $Ca(OH)_2$ solution at rate of 100 kg $CaO \cdot t^{-1}$ (32% more than the control experiment). The biogas yields increased: at a concentration of $Ca(OH)_2$ solution of 50 kg $CaO \cdot t^{-1}$ – by 53%, 100 kg $CaO \cdot t^{-1}$ – 60%, 150 kg $CaO \cdot t^{-1}$ – 62% (Fig. 3). That can be seen in the above diagram that the highest methane yield (0.399 $m^3 \cdot kg^{-1}$ DM) was obtained from wheat straw pellets, which were processed during extrusion with $Ca(OH)_2$ solution at rate of 100 kg $CaO \cdot t^{-1}$ (62% more than the control experiment). Processing wheat straw after extrusion with $Ca(OH)_2$ solution with different concentrations increases the biogas yield: at $Ca(OH)_2$ solution concentration with a calculation of 50 kg $CaO \cdot t^{-1}$ – by 34, 100 kg $CaO \cdot t^{-1}$ – 39%, 50 kg $CaO \cdot t^{-1}$ – 34%. It should be noted that the dynamic programming method is such a directed sequential enumeration of options, which necessarily leads to a global maximum and an optimal solution of problem (1).

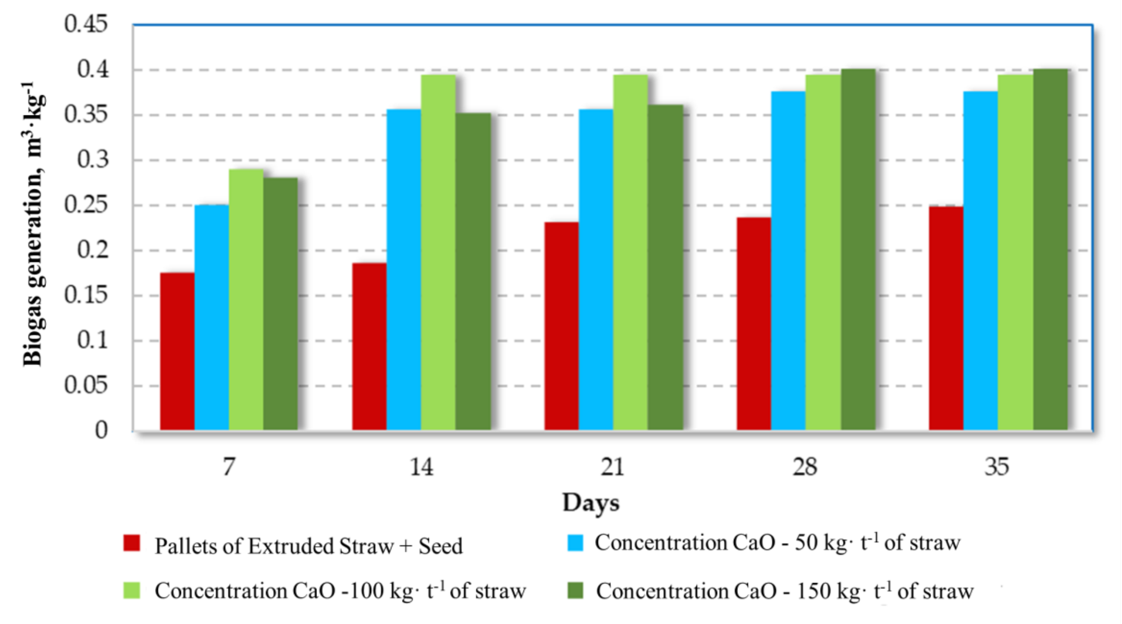

Fig. 3. **Biogas yield on direct processing in extruder to homogeneous state**

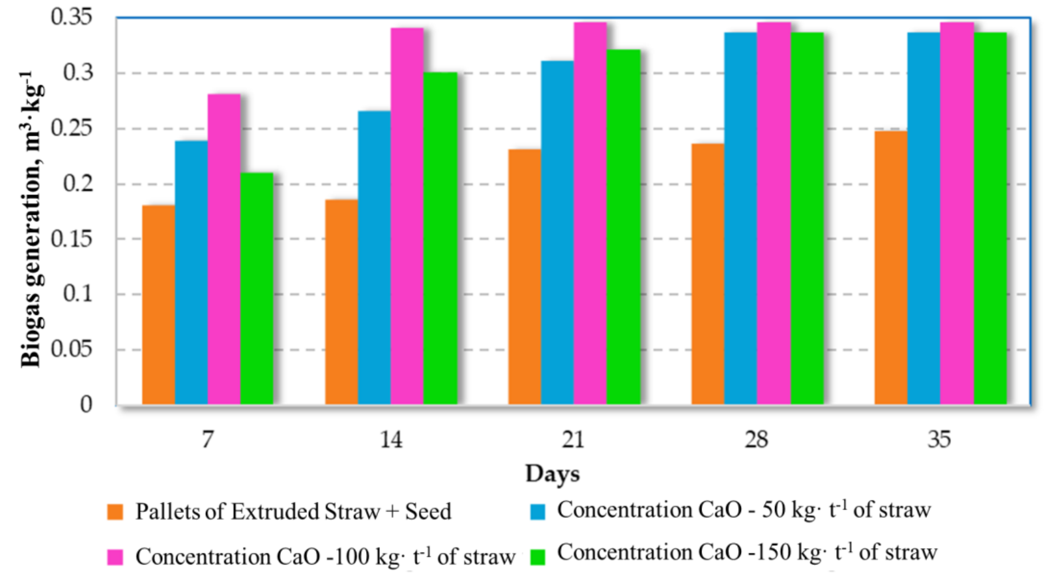

Fig. 4. **Dependence of biogas yield on homogeneous state**

The optimal loading at the rate of 100 kg $CaO \cdot t^{-1}$ into the reactor in the form of straw pellets has significant advantages and is an optimal solution since the biogas yield in this case practically does not differ from the yield obtained from wheat straw pellets at the rate of 150 kg $CaO \cdot t^{-1}$ of straw but is more cost effective. In addition, the year round use of straw pellets with an optimal addition of slaked lime for biogas plant allows obtaining high-quality biological organic fertilizers; ensuring high stable and trouble-free operation of the entire system as a whole; increasing the gas recovery from biological raw materials of plant origin (straw, grass, fodder waste, etc.) due to the decomposition of cellulose. At the same time, the transition to other types of raw materials is easier, and the specific load of the entire line also increases. The calculations show that the highest methane yield (0.342 $m^3 \cdot kg^{-1}$ DM) was obtained from wheat straw pellets, which were processed after extrusion with a $Ca(OH)_2$ solution at rate of 100 kg $CaO \cdot t^{-1}$ (39% more than the control experiment).

At the same time, the yield of biogas from cattle manure is 0.25-0.34 $m^3 \cdot kg^{-1}$ DM with a biomethane content of 65% [26]. That is, the yield of biomethane during fermentation of cattle manure (without the use of pellets) is 0.16-0.22 $m^3 \cdot kg^{-1}$ DM. The significance of the research results is that the optimal use of straw extruded with lime as cosubstrate will increase the yield of biogas and electricity by more than 60% compared to the fermentation of untreated straw, and by 30-50% compared to the fermentation of cow manure.

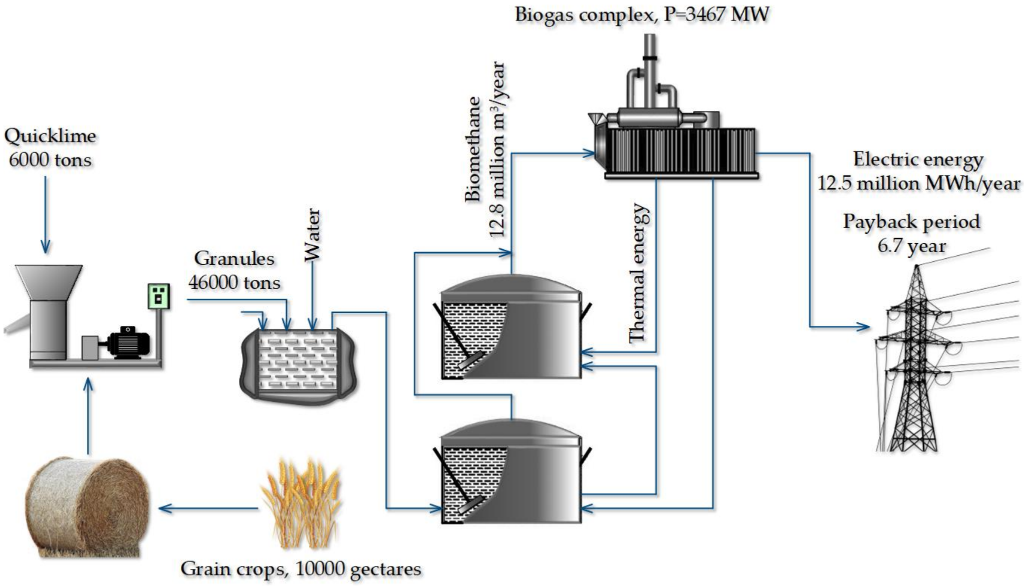

Fig. 5. **Biogas production from granulated straw with production of thermal and electrical energy**

When fermenting pellets with lime made from straw collected from an area of 10,000 hectares, the payback period of the biogas complex will be 6.7 years (Fig. 5), which is lower than the payback period of the biogas complex, which operates only on extruded straw (8.2 years) or on chopped straw (11.2 years).

Conclusions

1. Preliminary alkaline treatment of ligninocellulose materials is a promising treatment for introduction into biogas production. The best biogas yield was obtained from pellets of extruded wheat straw, which were treated with a $Ca(OH)_2$ solution (at the rate of 150 kg $CaO \cdot t^{-1}$ of wheat straw) during extrusion (~0.4 $m3 \cdot kg^{-1}$ DM), which is 63% more than the yield biogas obtained from the control sample (untreated straw). The yield of biogas from pellets of wheat straw, which was treated with a $Ca(OH)_2$ solution at rate of 50 kg $CaO \cdot t^{-1}$ of straw in extrusion, in comparison with other concentrations, is the lowest. Based on the use of the dynamic programming method, the optimal concentration of $Ca(OH)_2$ solution for introduction into production was found – 100 kg $CaO \cdot t^{-1}$ of straw (+63%), but it is more cost effective.
2. The most significant result of the research is that the optimal ratio of extruded straw with lime as a cosubstrate was found, which will increase the yield of biogas by more than 60% compared to the fermentation of untreated straw, and by 30-50% compared to with fermentation of cow manure.

Author contributions

Conceptualization, T.V.; methodology, T.V. and V.P.; software, T.V.; validation, T.V. and V.P.; formal analysis, T.V. and V.P.; investigation, T.V. and V.P.; data curation, T.V. and V.P.; writing – original draft preparation, T.V.; writing – review and editing, T.V. and V.P.; visualization, T.V. and V.P.; project administration, T.V.; funding acquisition, T.V. and V.P. All authors have read and agreed to the published version of the manuscript.

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