Solution of environmental problems of livestock breeding through intensification of waste treatment processes

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Abstract. Intensification of anaerobic processing of animal waste has a significant effect in comparison with other methods, which is expressed in a significant reduction in the pollution of environmental objects (air, water and soil) with chemicals and pathogenic microflora. The paper shows the developed technology of anaerobic processing of animal products, which allows one, on the one hand, to solve the environmental problems of animal husbandry, and on the other hand, to produce biogas fuel. The design features of the experimental setup for research are considered. The main indicators of the initial and re-loading manure and the properties of the resulting biogas have been analyzed. It was concluded that a promising direction for increasing the yield of biogas, as well as methane in its composition, it is advisable to improve the design of the bioreactor, to increase the productivity of the bioreactor and reduce the HRT through the use of a leaching layer and immobilization of microorganisms. At the same time, preliminary grinding of the raw material allows one to obtain a relatively better result.

1. Introduction
One of the main environmental pollutants in agriculture is animal husbandry. Environmental problems are created by the manure and runoffs that are emerging in livestock complexes, weakening of production and technological discipline, difficulties in organizing control over agricultural objects in view of their dispersal over vast territories [1, 2]. Industrial development of animal husbandry, associated with a large concentration of livestock in a limited area, necessitates the use of a large amount of water from natural water sources. This has a significant impact on the state of the water bodies themselves and the environment as a whole, since industrial livestock farming is one of the largest consumers of water in agriculture [3].

Sanitary and hygienic conditions in livestock complexes are mainly maintained with the help of water, which is used for washing animals and equipment, cleaning premises, preparing feed, manure flushing, etc. [4]. The use of hydraulic systems for cleaning and removing animal excrement leads to the formation of huge volumes of liquid manure, as well as significant amounts of harmful volatile
chemicals, unpleasant odors, etc. associated with the operation of industrial premises. Discharge of even a small amount of untreated wastewater from livestock complexes causes massive fish kill and causes significant damage to water bodies [5, 6].

In general, the issues of environmental protection from pollution, the prevention of infectious, invasive and other diseases of people and animals are associated, first of all, with the effective organization of systems for the collection, removal, storage and processing of manure and manure runoff, the correct placement of livestock complexes and manure treatment facilities relation to settlements, sources of household and drinking water supply [7].

Cattle manure is a cheap and large-tonnage waste suitable for producing renewable energy - biogas. There are numerous approaches to converting biomass energy to produce a fuel suitable for simple conversion to electrical, thermal energy. Nevertheless, all methods and technologies for transforming biomass into liquid or gaseous fuels can be improved [8].

Intensification of anaerobic processing of animal waste has a significant effect in comparison with other methods, which is expressed in a significant reduction in the pollution of environmental objects (air, water and soil) with chemicals and pathogenic microflora.

The efficiency of the anaerobic process largely depends on the correct preparation of raw materials for processing and on the design of the bioreactor [9]. The need for preliminary processing of raw materials is due to the fact that the size of insoluble particles of the original substrate determines the rate of their decomposition during anaerobic fermentation. The process of decomposition of manure can be carried out more intensively by improving the metabolism between microorganisms and the environment. For this, it is necessary to create and maintain the maximum size of the boundary surfaces between the solid and liquid phases by means of preliminary mechanical grinding.

In biogas plants, the solid phase of the substrate partially precipitates, partially forms a surface hard crust. The formation of a crust inhibits the fermentation of manure. The need for constant mixing complicates the design of the bioreactor and requires additional energy consumption [10].

Anaerobic methane fermentation is a complex microbiological and biochemical process. To intensify this process, various factors must be taken into account. In the course of studies of the influence of the main physical and other factors on the growth rate and activity of the biomass of microorganisms, it was determined that to increase the efficiency of their work, heating of the bioreactor is required. This is due to the fact that methanogens are not able to generate heat quickly, but they themselves love a warm environment. Methanogenic bacteria cannot tolerate sudden changes in temperature. The most optimal temperature for the growth of microorganisms can be considered 35-40 °C, and the optimal pH value is 6.5-7.5. To maintain the pH at a constant level, it is possible to regulate the buffer properties of the substrate [11].

When choosing the used method of immobilization, it was taken into account that it is necessary to minimize the contact of cells with substances toxic to them, and to prevent undesirable effects on microorganisms of thermal and osmotic stresses. When testing the selected techniques in the directions of immobilization of methane-forming bacteria on various carriers, it was taken into account that the adsorption interaction of the surface of microorganisms on the surface of polymer systems uses the natural ability of microorganisms to fix on various solid or gel-like carriers and continue their vital activity in such a stationary state. When working with living cells of methane-forming bacteria, an important point is the provision of immobilized microorganisms with nutrients, and the removal of waste products. Thus, the material of the carrier should not create diffusion obstacles to mass transfer processes [12, 13].

2. Materials and research methods
The studies were carried out on an enlarged laboratory setup with an improved bioreactor with a volume of 50 liters. In addition to the bioreactor, the biogas plant includes a gas holder, devices for preparation and loading of liquid manure for fermentation, auxiliary devices to ensure the functioning of the bioreactor systems (Figure 1).
Bioreactor 13 is a steel vertical cylindrical container with a wall thickness of 7 mm, with a movable lid. Digester height 1.5 m, diameter 530 mm. The bioreactor is equipped with an immobilization device 17 consisting of lower 18 and upper 19 removable gratings and a matrix, which is a layer of rings made of polymer inert materials. A grid 20 is installed in the upper part of the bioreactor to sift the circulated and initial liquids from large particles of the substrate.

The bioreactor is equipped with a heat exchanger (heat exchange area $0.33 \text{ m}^2$), pipelines for supplying and removing the fermentation medium, for supplying and collecting the initial liquid substrate, and a recirculation pump. The upper part of the bioreactor is connected by a pipeline with a gas holder for collecting biogas.

![Figure 1. Biogas installation: 1 - loading and recirculation pump; 2 - storage capacity; 3 - valve on the pressure pipeline; 4 - gas holder; 5 - bell; 6 - guide; 7 - loading valve; 8 - mixing valve; 9 - removable sieve; 10 - water seal; 11 - flow valve; 12 - level plug; 13 - bioreactor; 14 - unloading device; 15 - electric heater; 16 - unloading valve; 17 - matrix - immobilization device; 18 - removable upper grill; 19 - removable bottom grill; 20 - removable grate for sifting circulated and initial liquids.](image)

Manure is fed into the fermentation chamber with a moisture content of 80-85%, where it is anaerobically fermented. Biomass is loaded into the bioreactor daily in the amount of 20% of the original biomass (6.5–7 liters).

The process of anaerobic fermentation of the substrate (hydrolytic retention time) was 28 days in the mesophilic mode (at 40 ± 0.2°C). The experiments were carried out in three repetitions with two runs. The liquid fraction is continuously recirculated towards the top of the reactor by introducing the substrate to be fermented. When the biogas yield from the first pilot run decreases, the next batch of manure is loaded. The fermented mass flows by gravity through the loading device into the drive.

In the second run, the inoculum is not changed or added additionally, that is, the second run is initiated by the lye of the first run. All experimental repetitions of the two launches are otherwise similar. The first launches were initiated with an inoculum taken from a reactor in which cattle manure was fermented over the past few years. The process of anaerobic fermentation of the substrate lasted 28 days of hydrolytic retention time (HRT) in the mesophilic mode (at a temperature of 40 ± 0.2 °C).
Each experiment was performed in three repetitions and two runs. At the first start, 40 liters of manure are loaded into the reactor. The original fraction of manure enters the bioreactor through a pipeline with a valve from the storage tank by a recirculation pump to the level of the upper removable grate of the immobilization device. Next, the process of mixing the liquid fraction is started using a recirculation pump. Circulation flows towards the upper part of the reactor and the liquid is sprayed onto the surface of the solid fraction through the fermentation medium supply line.

Since the use of a bioreactor with an immobilization device makes it possible to efficiently process manure, we used Pall rings made of an inert polymer material (Figure 2).

![Polymer Pall rings for immobilization of microorganisms](image)

The rings are colonized by microorganisms, forming a mucous layer - a biofilm. Microorganisms immobilized in the rings are less susceptible to damage or washout when bubbling or unloading fermentation material. Biofilm protects growing cells from flushing and retains biomass regardless of the duration of fermentation [14].

The experiments were carried out in three repetitions with two runs. At the first start-up, 19 l of inoculum from another continuously operating bioreactor was inoculated into the reactor. After that, liquid manure was charged, which, by introducing the fermentation liquid, is continuously recirculated towards the top of the bioreactor.

As soon as the biogas production from the first pilot run decreases, the reactor lid is opened and the next batch of liquid manure is loaded [15].

In the second run, the inoculum is not changed or added additionally, that is, the second run is initiated by the lye of the first run. The only difference in the second run is that the raw material is pre-ground using a ball mill.

**Determination of waste moisture.** A sample weighing about 15 g was ground in a porcelain mortar. A sample weighing 5 g, weighed on an analytical balance, with an error of not more than 0.001 g, was placed into a weighing bottle, which was preliminarily dried to constant weight and weighed with an error of no more than 0.001 g. heated to 130 ° C and dried for 40 minutes at a temperature of 130 ± 2 ° C. Then the bottle, covered with a lid, was placed in a desiccator for cooling. After cooling, the weighing bottle was weighed and the humidity was found.

**Determination of the content of DM, ODM, ash and moisture.** Three replicates of the manure samples were tested for dry matter (DM), organic dry matter (ODM), ash and moisture. Moisture content, dry matter and organic dry matter were determined according to the methodology [16].

**Measurement of pH of the medium.** The pH values of the substrate in the reactor were measured every 3 days using a portable pH meter [17].

**The biogas volume** was measured with a Ritter TG gas flow meter. The temperature was controlled using a DTS-105-50M thermal sensor and was regulated by a TRM-202 microprocessor controller. Biogas analysis data and date, time, reactor temperature, air pressure at which measurements were taken were recorded to determine biogas production [18].
3. Results and discussion

Prior to the start of the experiments, manure samples were analyzed for dry matter (DM), organic dry matter (ODM) and ash content using standard APHA (1995) techniques. Three samples from each substrate were dried overnight at 103 °C in an oven to determine the DM and moisture content. Firing of the dried samples was carried out at 505 °C for 12 hours in an oven to determine the content of ODM and ash. The properties of cattle manure of primary and secondary loading are presented in table 1, and the quantitative characteristics of raw materials are given in table 2.

| Indicators                      | First run manure | Second run manure |
|--------------------------------|------------------|-------------------|
| Content of DM (in DM), %        | 18,9±0,50        | 19,1±0,65         |
| Content of ODM (in DM), %       | 68,3±0,60        | 68,1±0,65         |
| Ash (in fresh material), %      | 2,32±0,50        | 2,37±0,55         |
| Humidity, %                     | 91,4             | 91,2              |

| Indicators                      | First run manure | Second run manure |
|--------------------------------|------------------|-------------------|
| Raw weight, kg                 | 15,5             | 15,5              |
| Dry matter, kg                 | 4,33             | 4,56              |
| Organic dry matter, kg         | 3,87             | 3,73              |
| Duration of fermentation (HRT), days | 28               | 28                |

In the course of the research, the productivity of the reactor with an immobilization device was analyzed from the point of view of the specific yield of methane and the kinetics of the manure fermentation process. The research results showed that the maximum percentage of methane in biogas is reached on the seventh day (68%), and a stable mode of biogas formation is established on the 9-10th day of fermentation. Recirculation of the fermentation medium and immobilization of microorganisms in polymeric carriers makes it possible to initiate methanogenesis within 1-2 days and to reduce the hydrolytic retention time (HRT) due to the formation of biofilm.

Average total methane production is shown in Figure 3.

The daily methane yield reaches 0.002 Nm³/kg ODM by the second day, and decreases to 0.001 Nm³/kg ODM at the end of the second day. After the third day, it increases to 0.006 Nm³/kg ODM on the seventh day and gradually decreases until the end of the cycle, showing the methane yield between 0.006 Nm³/kg ODM and 0.004 Nm³/kg ODM. The average total cumulative methane yield is 0.148 Nm³/kg ODM. The percentage of methane after 3 days of launch was 26.5%, on the 5th day it increased to 50% and was above 55% by the end of the sixth day. The peak methane percentage at the first launch was 56.1% (on the 8th day).

The second run, initiated by the liquor of the first run, showed intense biogas production (Figure 4). At the same time, the formation of methane reaches 0.004 Nm³/kg ODM every other day, decreases to 0.002 Nm³/kg ODM at the beginning of the second day, and gradually rises to a maximum on the fifth day (0.009 Nm³/kg ODM). After that, in the process of methane formation, a gradual decrease to 0.003 Nm³/kg ODM is observed.

The total average cumulative methane yield is 0.150 Nm³ / kg ODM. The percentage of methane in the biogas after the second day is 35%, which gradually increases to 68% on the seventh day, while reaching the peak of the percentage of methane in the biogas.

The high initial production of biogas and methane in all starts up to the third day is explained by the fact that, due to selective fermentation of rapidly decomposing organic matter, it can lead to a temporary decrease in biogas and methane production between the third and fourth days.
Figure 3. Average cumulative methane yield and percentage of methane for the first launch

Figure 4. Total average cumulative methane yield and methane content for the second launch

4. Conclusion
In general, we can conclude that a promising direction for increasing the yield of biogas, as well as methane in its composition, it is advisable to improve the design of the bioreactor, to increase the productivity of the bioreactor and reduce the HRT through the use of a leaching layer and immobilization of microorganisms. At the same time, preliminary grinding of the raw material allows one to obtain a relatively better result.

The more complex the structure of the substrate, the longer the digestion will take. Cellulose and hemicellulose are widely branched and decompose slowly. Lignin, woody substance in plants, the amount of which increases with the age of the plant, is decomposed very poorly by bacteria, since it is resistant even to acids.

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