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Environmentally Friendly Agricultural Waste Management Technology

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Abstract: As part of this study, the methods were analyzed and developed, aimed at solving the topical environmental issue involving the management of organic waste resulting from human activities. A special attention is given to the issue of organic waste management and minimizing the environmental impact. Organic wastes disposed on landfills pose high-level risks to the relevant ecosystem. The study identified some key factors influencing the intensity of biogas production. They include biomass temperature and humidity, its mixing technique and frequency, and fermentation duration. The key requirement for obtaining biogas is the provision of anaerobic conditions in the bioreactor to maintain the intense life activities of methane-producing bacteria. This paper deals with studying the anaerobic digestion of chicken manure with molasses being added. To produce biogas, we selected the optimal mixing ratios, namely manure-to-water ratio of 1:3 and manure-to-molasses ratio of 1:1. Anaerobic digestion ran in a mesophilic temperature mode. The study has shown that adding molasses into chicken manure leads to increasing the biogas yields by 23.62 %. Using beet molasses to intensify the process of anaerobic digestion is a promising research area solving several tasks simultaneously.

1 INTRODUCTION

In the 21st century, environmental issues gain in strategic importance at enterprises in various industries. Agricultural production is a key factor of satisfying the needs of the population in Russia. It also contributes to increasing the competitiveness of Russia-made goods in the international context and strengthening the national economy. Our home industries are properly equipped to ramp up their production in terms of conditions and resources.

In today’s context, there is escalation of processes disrupting the normal functions of society, that is, the natural reserves of conventional energy sources are being exhausted, their cost-to-produce is increasing, the environment is being contaminated intensively, the biodiversity of our planet is growing down, and huge amounts of organic wastes are being accumulated, produced by industries, agriculture, and households (Araiza-Aguilar et al., 2018). To solve these issues, prompt and decisive actions are required.

In the context of environmental crisis that is characterized by environmental impairment, exhaustion of natural resources, and changes in the planet climate, the humankind is facing the task of looking for new solutions aiming to develop the technosphere. One of such approaches is the use of nature-like technologies based on the principles and mechanisms existing in nature.

Nature-like technologies are those simulating natural processes without inverting natural cycles and flows of matters and energies. They allow creating stable and efficient systems that can provide people with necessary resources without causing harm to the environment (Jamir et al., 2021).

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One example of nature-like technologies is biotechnologies that use living organisms to solve various tasks, including that of processing organic wastes.

Organic wastes disposed in waste landfill deposits represent a serious threat for the ecosystem. In the process of their degradation, harmful gases are evolved, such as CO_2, CH_4, NH_3, and H_2S. These substances deteriorate the air and give rise to acid rains and climatic changes on our planet (El Barnossi et al., 2019). Moreover, filtrate occurring due to the degradation of wastes contains many contaminants and pathogenic microorganisms, which adversely affects surface and ground water and destabilizes natural ecosystems.

Basically, to obtain biogas, organic agricultural wastes are used that contain much cellulose and other polysaccharides. Transforming these wastes into biogas results from complicated chains of biochemical reactions, named *biomass fermentation* (Krekkeitsakul et al., 2023).

This process is only possible when involving bacteria and is implemented in specialized conditions, i.e., in fermenters. Biogas units are also used to process manure and other organic wastes. They allow the efficient waste management and obtaining valuable biofuels (Shih, 2012).

2 MATERIALS AND METHODS

One of the key methods to manage organic wastes is the use of biogas technologies that allow solving multiple environmental problems:

- Managing food-industry (sugar-beet handling) and agricultural (chicken farming) wastes;
- Obtaining an energy product, i. e., biogas; and
- Manufacturing natural fertilizers (Avcı et al., 2013).

Sugar-producing industry is actively engaged in reducing the adverse anthropogenic impact on nature (Paolini et al., 2018). Within this purpose, new technologies are implemented aiming to save resources, equipment is retrofitted, and manufacturing processes are reconstructed. As of November 7, 2024, Russia has a world lead in manufacturing beet sugar. Over one half (51 %) of all cultivated areas is used for this crop in the Central Black Earth Economic Region, 22 % in the Volga Economic Region, and 20 % in the North Caucasus Economic Region, while in Siberia beet is only cropped in its southern part, namely in the Altai Krai (Chen et al., 2024).

After sugar production, considerable wastes remain. At average level of product yield of 12–13 %, the following by-products evolve from the processed beets:

- Beetroot pulp making 80–83 %. It is formed from the reaction of raw juice non-sugars with lime and carbon dioxide. About 40 % of this waste are used fresh in cattle feeding (Afzal et al., 2000), while a part is dried (Hamouda et al., 2016);
- Molasses (‘M’ in our tables and figures) making 5.0–5.5 %. This is a by-product that evolves when centrifuging sugar-bearing massecuite at the last crystallization stage. Ethanol, glycerin, butanol, acetone, and various acids, such as lactic, acetic, citric, and oxalic ones, are made from molasses; and
- Filtration sludge making 10 – 12 %. This waste can be utilized to improve soil structure, manufacture lime and cement, and develop construction materials and asphalt-bituminous pavements. It is also used to consolidate grounds in road engineering.

Molasses evolving in sugar production is categorized as hazard class V and considered practically nonhazardous. However, it is considered to be a large-tonnage waste. In producing 1 ton of sugar, 285.6 to 363.8 kg of molasses are formed depending on the beet sweetness. In 2024, 5.08 million tons of sugar were produced in Russia, which means evolving 1.45–1.85 million tons of molasses (Figure 1).

Molasses contains up to 62 % of sucrose, as well as glucose, fructose, raffinose, and nonprotein nitrogen compounds. It is a valuable raw material for various industries, such as manufacturing of ethanol and new products, and used in agriculture to supplement cattle diets with easily digested carbohydrates, B vitamins, amino acids, and microelements. However, its use is limited due to its low quality, impurities, and perishable nature. Storage of molasses inside-the-fence of sugar manufacturing enterprises is poorly designed, occupies large usable areas, and contributes to secondary environmental pollution.

Authors of this paper propose using molasses as a growing medium for anaerobic bacteria contained in chicken manure (ChM).

In 2024, there were 497 million chickens in Russia (Rosstat, 2024), which means producing 24.85 million tons of chicken manure (Figure 1). Basically, it is used as an organic fertilizer upon composting or pelleting.

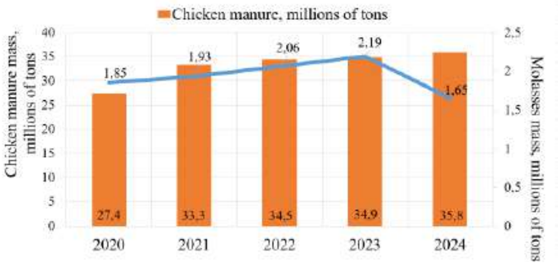

Figure 1: Organic waste formation over time.

Fresh chicken manure is categorized as hazard class III, while rotted manure is class IV. Compositions of chicken manure may vary based on chicken ages and diets. It contains 60 % of water, 4.5 % of nitrogen, 1.5 % of phosphorus, 0.9 % of potassium, and 3.1 % of other microelements, such as calcium and magnesium, as well as 30 % of undigestible roughage and ballast agents (Emmerling et al., 2007).

Key factors of intensifying the process of obtaining biogas are as follows:

- Anaerobic conditions in the reactor;
- Biomass temperature;
- Biomass humidity;
- Biomass mixing;
- Digesting duration;
- Nutrient content; and
- Acid-base balance of the biomass.

The key prerequisite of obtaining biogas is to provide anaerobic conditions in the bioreactor for maintaining the intense life activities of methane-producing bacteria (Tang et al., 2020).

One of the key factors of digestion is to maintain optimal temperature that determines the quantity and quality of biogas to be obtained, as well as the duration of this process (Table 1).

Table 1: Digestion mode conditions.

Mode	Temperature	Time, in days
Psychrophilic	Below 25 °C	Over 30
Mesophilic	25 – 45 °C	20–30
Thermophilic	Above 45 °C	10–20

Biogas is known to be generated within the temperature range of 0–97 °C, while microbiological activity falls at the fermenting mass temperature of below 15 ˚C.

In the countries having the average annual outdoor temperature of about 20 °C, unheated reactors are used in the first operating mode. In the thermophilic digestion mode, a greatly accelerated substrate decomposition rate is observed, which leads to the high yield of biogas and killing pathogenic bacteria. A downside of this mode is that it consumes more energy to heat raw materials and maintain temperature in the reactor, while the methane content decreases. Moreover, rigid temperature control is a must, because a change of 1 °C in temperature leads to the inefficiency of producing biogas.

Optimal process is mesophilic digestion, since biogas yields and quality do not change with potential variations of 2–4 °C in temperature.

In assessing the initial substrate humidity impact, it should be noted that reducing the same leads to an increased duration of the process, maintaining it at the same value causes the efficiency loss due to the lack of nutrients for the bacteria to grow, while the increased humidity results in the lower yields of biogas due to the increased accumulation of volatile fatty acids.

Mixing the fermentation mass is an important factor, as well, since it contributes to increasing the efficiency and stability of biogas obtaining.

Digestion involves various species of anaerobic bacteria, the life activities of which depend on the acid-base balance. Any deviations of pH values from optimal (neutral or weakly basic) ones lead to the system disfunction (Rasool et al., 2024).

Currently, the requirements are defined for the starting materials in accordance with the development conditions of methane bacteria. The raw materials must contain organic and mineral substances in volumes of 75–85 %: 15–25 %, respectively (van Niekerk et al., 2007). The greatest impact on the growth and development of methane bacteria is provided by the carbon-to-nitrogen ratio in the raw materials being processed. If the C:N ratio is improper, lack of nitrogen would lead to nutritional deficiency, while its excess would result in bacterial destruction. Optimal ratio is C:N = 8:20. It is reasonable that bacteria need microelements, such as

S, P, K, Na, Fe, etc., for their life activities, and there must be no inhibitors (Hadidi et al., 2022).

This paper studies the process of the anaerobic digestion of chicken manure with molasses being added. Literature tells us that the process of biogas production requires an optimal manure-to-water mixing ratio equal to 1:3 (Silwadi et al., 2023; Doublali et al., 2024).

To perform the experiment, a biogas producing system was assembled. Two parallel tests were conducted: In one case, 35 g of fresh chicken manure were used as raw material, while in the other case, molasses was added to manure. 200 cm³ of distilled water, 35 g of molasses, and 35 g of fresh chicken manure were poured into a stirred reactor volumed 2 dm^3. The system was made completely leakproof to ensure anaerobic conditions. Initially, the fermentation mass was adapted at the temperature of 20 °C for two days. Then the reaction mass was heated and exposed to the temperature of 30±2 °C. The biogas produced passed through Drechsel bottle where it was cleaned of carbon dioxide. The cleaned biogas fed to Woulff bottle filled with water. The displaced water volume was captured in a cylinder, which corresponded with the volume of the biogas produced. Based on the data obtained, the diagram was built showing the dependency of biogas yields on the reaction mass holding time (Fig. 2).

3 RESULTS

Experimental findings are shown in Figure 2.

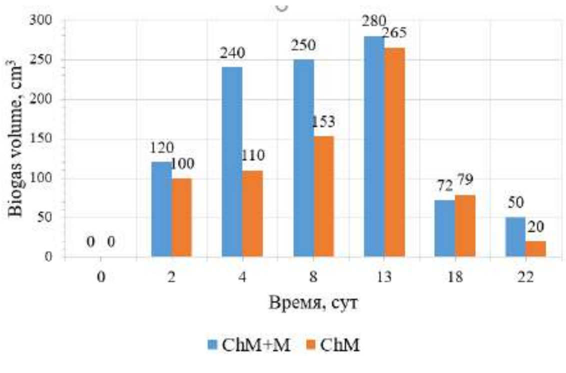

Figure 2: Biogas formation over time.

4 DISCUSSION

Adaptation of microorganisms takes about 48 hours, both when using chicken manure as a source of raw material and with the addition of molasses. This is when bacteria grow and get ready for dividing. Nucleic acids, protein, and other key components are actively accumulated in this period.

As can be seen from Figure 2, exponential growth, i. e., the period of intensive bacteria division, lasts approximately 2 to 8 days. This is when the cells are most vulnerable, which is due to high sensitivity of the metabolic components of a growing bacterium. As can be seen from the biogas production over time, adding molasses to chicken manure at a ratio of 1:1 contributes to increasing the biogas yield by 23.62 %. This process is observed due to the presence of additional nutrient rich, easily digested carbohydrates contained in the substrate, contributing to the more intense growth of microorganisms.

Exponential growth phase is followed by the stationary growth phase, where the number of viable cells remains unchanged and reaches its maximum. Duration of this phase depends on the species of bacteria.

Bacteria growth process is completed by the death phase, in which they die away due to the depletion of nutrient sources and accumulation of their metabolism products. This phase comes up after 13 days.

Thus, the experiments conducted resulted in finding the process parameters of organic waste management:

- Manure-to-molasses-to water ratio: 1:1:3;
- Temperature of 30±2 °C; and
- Regular mixing of the digesting mass.

A basic block diagram is also proposed for producing biogas and a biofertilizer developing from digesting of the mass consisting of chicken manure and molasses (Fig. 3).

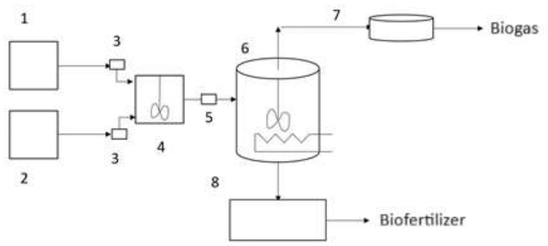

Figure 3: Schematic of the integrated treatment of chicken manure and molasses: 1 – chicken manure bin; 2 – molasses bin; 3 – dispensing sewage pump; 4 – substrate preparation bath; 5 – dispensing sewage pump; 6 – bioreactor; 7 – gas holder; 8 – finish stock storage.

Integrated treatment of chicken manure and molasses includes several stages. Chicken manure is loaded into a special bin (1), while molasses (2) into another one. With a dispensing sewage pump (3), the components are fed to a substrate preparation bath (4) where they are thoroughly mixed with water to the proper consistency. Then the mixture prepared is fed to a bioreactor (6) where it is fermented at the temperature of 30–35 °C for 15–20 days, and its organic substances undergo anaerobic oxidation producing biogas. The biogas obtained is accumulated in a gas holder (7), from where it can be used or stored. The processed material is fed to a finish stock storage (8) where it is pre-packed and prepared for sale as an organic fertilizer.

5 CONCLUSIONS

Livestock sector and industry contribute considerably to the increasing environmental impact of organic wastes. Since the demand for meat products and sugar keeps growing, it is necessary to develop stable methods to manage organic wastes and reduce their environmental impact.

As part of this study, we developed and tested the methods to manage organic wastes using nature-like technologies, not least obtaining biogas. It is shown by experiments that adding extra nutrients, such as molasses, into organic wastes (manure, in our case) helps intensify anaerobic digestion in a mesophilic temperature mode and increase the yield of biogas.

Using beet molasses to intensify the process of anaerobic digestion is a promising area that solves multiple tasks simultaneously. The nature-like technology proposed may become a basis for developing the anthropogenic environment in the context of environmental crises.

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