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# UTILIZATION OF LIVESTOCK WASTE WITH THE PRODUCTION OF USEFUL ENERGY AND FERTILIZERS

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**Abstract:** This study investigates an integrated technological complex for the effective utilization of livestock and poultry waste through combined anaerobic digestion, organo-mineral fertilizer production, and composting processes. The main objective of the research is to develop a resource-efficient and environmentally sustainable system capable of converting organic waste into valuable energy and agricultural products.
The proposed system consists of three interconnected modules: an anaerobic digestion unit for biogas production, a digestate processing module for the production of organo-mineral fertilizers through enrichment and granulation, and a composting module based on a controlled biofermentation process. A key technical feature of the system is the separation of hydrolysis and methanogenesis stages, which improves process stability and prevents acid accumulation in the bioreactor.
The results of the study show that the implemented technological approach ensures stable biogas production and yields high-quality fertilizers with improved agronomic properties. The obtained products are characterized by enhanced nutrient availability, including plant-accessible nitrogen, phosphorus, and potassium, as well as improved soil-conditioning effects. The composting process further contributes to the production of hygienic, odor-free organic material with reduced pathogen content.
The proposed technological complex demonstrates significant environmental and economic benefits by reducing agricultural waste accumulation, lowering environmental pollution risks, and enabling the recovery of renewable energy and valuable fertilizers. Overall, the system supports sustainable agricultural development and contributes to the transition toward a circular bioeconomy model. The presented technological approach contributes to sustainable agricultural development by reducing environmental pollution, enabling efficient resource recovery, and improving the environmental and economic efficiency of livestock waste management.

**Keywords:** livestock waste, anaerobic digestion, biogas, organo-mineral fertilizers, composting, sustainable agriculture.

## Introduction:

One of the directions of economic development of society is the advancement of resource-saving technologies. Such technologies ensure the production of goods with the lowest possible consumption of fuel and other energy sources, as well as raw materials, materials, air, water, and other resources used for technological purposes. They include the use of secondary resources, waste utilization, energy recovery, and closed water-supply systems. These technologies make it possible to conserve natural resources and prevent environmental pollution.

Proper management of agricultural waste is a global and important issue in our world. The problem of disposing waste from livestock complexes is especially urgent and remains unresolved in some regions of the world [2].

Currently, large amounts of manure and litter accumulate around many livestock and poultry enterprises. With proper waste-utilization solutions, these materials can generate additional profit and simultaneously transform farms into nearly waste-free operations. However, for now, the operation of large livestock and poultry farms poses a threat to the environmental well-being of surrounding areas (animal manure and poultry litter contain large amounts of hazardous substances such as $NH_3$, $H_2S$, etc.) due to the absence of organized systems for processing organic waste [3,6]. At the same time, manure and poultry litter are valuable organic fertilizers, as they contain all essential nutrients for plants in a favorable balance. Therefore, finding effective technological solutions for processing livestock waste and obtaining useful energy and products is a highly relevant task today.

At present, the issue of utilizing production and consumption waste generated at livestock enterprises, as well as the preparation and processing of the huge volumes of manure and manure effluents produced at these complexes — which are potential sources of anthropogenic environmental impact — is particularly pressing.

One of the most critical aspects of the environmental pollution problem caused by waste from large industrial-type livestock and poultry farms is the contamination of surface and groundwater.

When wastewater enters natural water bodies, infectious agents can be carried by river currents for distances of up to 200 km. Consumption of water from such sources leads to gastrointestinal and other illnesses in humans and animals [5,9].

In addition to polluting water sources, this waste also affects soils. Therefore, in areas influenced by livestock production facilities, sanitary and hygienic soil assessments must be conducted to ensure their disinfection and remediation.

## Objective

The main objective of this study is to develop and analyze an integrated technological complex for the efficient processing of livestock and poultry waste through anaerobic digestion, composting, and organo-mineral fertilizer production. The study aims to evaluate the environmental and economic benefits of converting organic waste into valuable resources such as biogas and high-quality fertilizers, as well as to assess the effectiveness of the proposed multi-module system in reducing environmental pollution and improving resource recovery efficiency.

## Experimental Methodology

**The anaerobic digestion module for producing biogas** is represented by the following technological scheme: waste accumulator – hydrolysis unit – bioreactor (fermenter) – biogas purification system – gas holder.

The distinctive feature of the anaerobic digestion plant is that the hydrolysis unit is separated from the bioreactor. Agricultural waste is directed into the accumulator and then into the hydrolysis unit, which is located outside the fermenter–bioreactor. In the hydrolysis unit, the hydrolysis process takes place—oxidation under the action of hydrolytic bacteria with the formation of fatty acids. Then the fermentable mass enters the fermenter–bioreactor, where the methanogenic bacteria process the fatty acids, producing biogas [7].

Such a division of the biogas plant into two blocks is due to the fact that hydrolytic bacteria represent highly resistant microorganisms that reproduce very rapidly in nutrient media. It is normal for their population to double within a few hours. Anaerobic (methane-producing) bacteria reproduce much more slowly. If hydrolytic bacteria receive a large amount of nutrient substrate, they produce such a quantity of fatty acids that anaerobic bacteria cannot process them in time. This leads to the acidification of the fermenter contents, a drop in pH, and, in critical cases, the breakdown of the entire process [9].

The fertilizer obtained in liquid form can be applied to soil, dried and granulated, or briquetted if necessary. When mixed in specific proportions with various components, it can be used to produce composts, soil mixes for greenhouses, etc. [1,2].

We propose including in the technological complex a module for producing high-quality fertilizers by enriching the sludge obtained from methanogenesis followed by fertilizer granulation.

The use of these fertilizers ensures an increase in crop yield from 20 to 350% depending on the crop. At the same time, the need for mineral fertilizers (which can be completely replaced) and pesticides decreases, allowing agricultural production to become more economically efficient and enabling the cultivation of environmentally clean food products with improved consumer properties [3,4].

Compared to traditionally used manure, the resulting fertilizer is fully disinfected, free of weed seeds, and odorless.

Nitrogen (N) contained in the raw material is almost entirely preserved in the fertilizer in ammonium form, which is more accessible for plant root systems. The utilization rate reaches 80%, compared to 30% for fresh manure.

Phosphorus (P) is present in the form of phosphates and nucleoproteins, which are better absorbed by plants than the salts of mineral fertilizers.

Potassium (K) in these compounds is fully available to plants.

Under the influence of the microbiological cultures contained in the fertilizers, humus materials are formed in the soil, improving soil quality characteristics such as aeration, infiltration, and water-retention capacity. The fertilizer has a complex effect on both plants and soil. The absorption of nutrients by plants increases significantly. The unabsorbed residues represent organic substances containing live microflora, which continue to decompose organic matter, facilitating humus formation and increasing soil fertility. The use of such fertilizer is economically very profitable [5,6].

The second module of the complex represents a technology for Producing Organomineral Fertilizers (Fig. 1).

Based on a literature analysis, a technological scheme has been proposed for the preparation and granulation of organomineral fertilizers obtained from bioreactor sludge.

The fertilizer production technology includes the following stages:

Raw materials are delivered by a loader and unloaded into a mechanized warehouse with a "moving floor" (1).

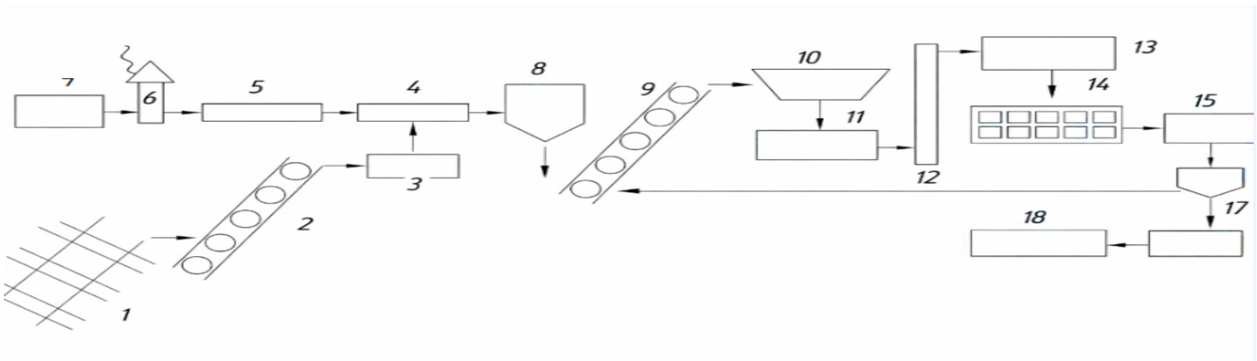


**Figure 1 – Technology of producing organo–mineral fertilizers**
**1-Movable floor, 2-Chain conveyor, 3-Separator, 4-Drying unit, 5-Heat generator, 6-Pipe, 7-Fuel bunker, 8-Settling cyclone, 9-Storage bunker, 10-Granulator bunker, 11-Press–granulator, 12-Pellet cooler, 13-Sorter, 14 -Finished product line, 15-Cyclone, 16 -Finished product bunker, 17-Electronic scales, 18-Weighing of finished products**

The stokers of the moving floor are equipped with a hydraulic drive and perform reciprocating movements under its action. The blades of the stokers have a wedge-shaped design, so as the stokers move, the raw material is fed toward the chain conveyor (2) at a controlled feed rate. From there, the raw material is transported to the disc separator (3).

In the separator, stones and impurities are removed from the raw material and discharged into a portable container, while the cleaned raw material flows by gravity into the loading section of the drying–grinding unit (4). Combustion products from the heat generator (5) and cold atmospheric air drawn through the emergency ignition pipe (6) are also supplied here.

Next, the heat carrier mixes with the moist raw material and is drawn into the drying–grinding unit (4). Inside the unit, the material is ground and then dried, rising with the heat carrier flow toward the dynamic classifier located in the head section of the drying–grinding unit.

The ground and dried material (from this point referred to as "meal") is drawn into the settling cyclone (8) due to the vacuum created by the exhaust fan. In the cyclone, the meal settles under centrifugal force and moves downward.

From the cyclone, the meal is discharged through an airlock valve into a screw or chain conveyor (9) and then transferred to the granulator hopper (10).

Inside the hopper, there is a device preventing the meal from caking. From the hopper, the meal is fed by a screw feeder at a controlled rate into the mixer (conditioning chamber) of the press, where water (or steam) is also supplied. In the mixer, the product is conditioned meaning its moisture content is adjusted to the level required for granulation. From the mixer, the moistened meal passes through a ferromagnetic separator and enters the pellet press (11). In the pressing chamber, the meal is pulled between the rotating die and pressing rollers and forced through the radial holes of the die, where the high pressure forms the pellets. The pellets emerging from the holes hit a stationary knife, which cuts them to size. The cut pellets fall downward and are discharged from the press through the housing outlet chute [7].

The pellets exiting the press have a high temperature and low mechanical strength, so they are transported via a bucket elevator (12) to the cooling column (13). Here, air is drawn through the layer of pellets by the cyclone fan (16), cooling the pellets and simultaneously removing some unpelletized meal into the cyclone. During cooling, the pellet moisture decreases due to evaporation, and physical–chemical transformations occur. As a result, the pellets acquire the required hardness, moisture level, and temperature. From the cooling column, as it fills, the pellets are discharged to the screening unit (14), where standard-quality pellets are separated from fines.

The pellets are discharged through the outlet chute and fed to the finished-product bucket elevator (15), while the fines are extracted into the cyclone (16) and then directed, together with the meal, back for re-pelleting. Using the finished-product elevator, the pellets are transported to the finished-product hopper (17). Beneath this hopper are electronic scales (18), and hooks for hanging bags are mounted on the hopper supports. Filled bags are transported to the finished-product warehouse using a loader or a hydraulic pallet truck.

Composting Module: The third module of the technological complex we are developing is the compost production module. Based on a patent search, we have proposed the design of a composter–biofermenter.

The biofermenter is a rectangular structure made of brick, reinforced concrete, or other construction materials. It is equipped with a forced-air supply system that delivers air into the fermenting mixture. The unit operates in a batch (periodic) mode [10].

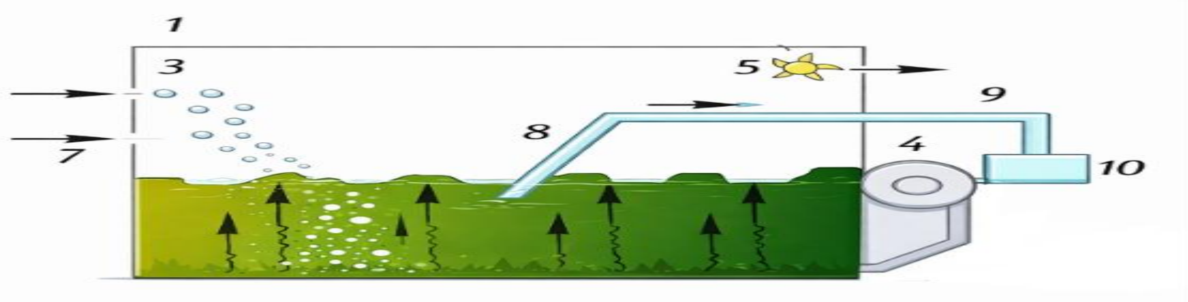


**Figure 2 – Technology of compost production**
**1-Raw material fermentation chamber, 2-Working mixture, 3-Gate / door, 4-Natural ventilation fan, 5-Exhaust (extract) fan, 6-Natural air duct system, 7-Temperature measurement opening, 8-Oxygenometer rod, 9-Flexible hose, 10-Oxygen meter**

To intensify the composting process, the use of bioactive additives is proposed. Specialized biological additives may contain EM-preparations, enzymes, microorganisms isolated from compost, or specially selected strains—decomposers of cellulose, lignin, proteins, and other biopolymers. Additives based on native compost microflora can be obtained using the method of enrichment culture on compostable substrates, for example, in devices with forced mixing and aeration. The resulting "starter culture" is introduced into the main compost mass. This method can be used to accelerate composting and to detoxify materials contaminated with xenobiotics (pesticides, petroleum products, etc.). A reduction in composting duration is also possible when compost is irrigated with a water extract from finished compost.

In addition, we propose including in the technological complex a module for producing high-quality fertilizers by enriching the sludge obtained from the methanogenesis process, followed by granulation of the fertilizers. Literature analysis has shown that the use of such fertilizers ensures an increase in crop yield from 20% to 350% for various crops [8].

The novelty of the work lies in the development of the idea of automating the process of preliminary sorting of raw materials and choosing a waste-processing technology (methanogenesis or composting), as well as in the development of scientifically grounded approaches to mixing the resulting product with other organic components and obtaining new modifications of organo-mineral fertilizer complexes. Additional schemes for obtaining organo-mineral complexes based on the use of EM technologies and the implementation of NPV biodeodorization processes have been proposed.

The acquisition of additional resources—fertilizers and biogas—during the waste-processing activities of a livestock complex will offset processing costs and allow the generation of additional profit.

Thus, the proposed technological complex will reduce the anthropogenic impact of agricultural waste on the environment and will make it possible to obtain additional resources that increase its environmental and economic efficiency.

## Conclusion

This study demonstrates that an integrated technological system combining anaerobic digestion, composting, and organo-mineral fertilizer production provides an efficient and environmentally sustainable solution for livestock and poultry waste management.

The separation of hydrolysis and met anogenesis stages improves process stability, reduces the risk of acidification, and ensures more reliable and continuous biogas production.

The proposed system enables the conversion of organic waste into valuable energy and agricultural products. The obtained digestate has high agronomic value, as nitrogen is mainly present in plant-available ammonium form, phosphorus is converted into bioavailable compounds, and potassium remains fully accessible for plant uptake. These characteristics significantly improve soil fertility, enhance humus formation, and increase agricultural productivity.

The composting module further improves the overall process by ensuring additional stabilization and hygienization of organic residues. The final compost product is characterized by low pathogen content, absence of unpleasant odors, and improved soil-conditioning properties, thereby reducing environmental risks such as soil degradation, water contamination, and air pollution.

From an economic perspective, the proposed technological complex provides dual benefits through renewable energy production in the form of biogas and the generation of marketable organic fertilizers. This reduces dependence on mineral fertilizers and improves the overall economic efficiency of agricultural enterprises, supporting the principles of a circular bioeconomy.

Furthermore, the novelty of the study lies in the development of an automated approach for preliminary sorting of raw materials and the selection of the most appropriate waste treatment technology (methanogenesis or composting) based on substrate characteristics. The study also proposes scientifically grounded methods for blending the resulting products with additional organic components to develop new modified organo-mineral fertilizer formulations.

In addition, new technological schemes based on EM (Effective Microorganisms) technologies and biodeodorization processes have been introduced. These innovations enhance process efficiency, improve product quality, and reduce the environmental impact of waste treatment.

The analysis of the three proposed modules shows that the anaerobic digestion module ensures stable biogas production and process reliability. The fertilizer production module provides high-value products rich in plant-available nutrients. The composting module enables the production of a stabilized, hygienically safe organic material that improves soil structure and quality.

Overall, the proposed system significantly reduces the anthropogenic impact of agricultural waste on the environment while simultaneously improving both ecological and economic efficiency through effective resource recovery and waste valorization

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# HEYVANDARLIQ TULLANTILARININ FAYDALI ENERJİ VƏ GÜBRƏLƏRİN İSTEHSALI İLƏ İSTİFADƏSİ

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**Xülasə:** Bu tədqiqat heyvandarlıq və quşçuluq təsərrüfatlarında yaranan tullantıların anaerob parçalanma, orqanomineral gübrələrin istehsalı və kompostlaşdırma proseslərinin birləşdirilmiş tətbiqi əsasında səmərəli utilizasiyası üçün inteqrasiya olunmuş texnoloji kompleksin işlənməsini araşdırır. Tədqiqatın əsas məqsədi üzvi tullantıların enerji və kənd təsərrüfatı üçün dəyərli məhsullara çevrilməsini təmin edən resurs effektiv və ekoloji baxımdan dayanıqlı sistemin yaradılmasıdır.
Təklif olunan sistem üç əsas moduldan ibarətdir: biogaz istehsalı üçün anaerob parçalanma qurğusu, fermentasiya qalığının zənginləşdirilməsi və qranulyasiyası yolu ilə orqanomineral gübrələrin hazırlanması modulu və nəzarət olunan biofermentasiya prosesinə əsaslanan kompostlaşdırma modulu. Sistem daxilində hidroloz və metanogenez mərhələlərinin ayrılması texnoloji sabitliyi artırır və reaktorda turşulaşmanın qarşısını alır.
Tədqiqat nəticələri göstərir ki, tətbiq olunan texnoloji yanaşma sabit biogaz istehsalını təmin edir və yüksək aqronomik göstəricilərə malik gübrələrin alınmasına imkan yaradır. Alınan məhsullar bitkilər üçün əlçatan formada azot, fosfor və kaliumla zəngin olmaqla yanaşı, torpağın strukturunu yaxşılaşdıran xüsusiyyətlərə malikdir. Kompostlaşdırma prosesi isə patogenlərin azaldıldığı, qoxusuz və sanitariya baxımından təhlükəsiz üzvi materialın əldə olunmasını təmin edir.
Təklif olunan kompleks kənd təsərrüfatı tullantılarının ətraf mühitə mənfi təsirini azaldır, çirklənmə risklərini minimuma endirir və bərpa olunan enerji ilə yanaşı qiymətli gübrələrin əldə olunmasına şərait yaradır. Ümumilikdə sistem dayanıqlı kənd təsərrüfatının inkişafına və dairəvi bioiqtisadiyyat modelinə keçidə töhfə verir. Təqdim olunan texnoloji yanaşma ətraf mühitin çirklənməsinin azaldılması, resurslardan səmərəli istifadənin təmin edilməsi və heyvandarlıq tullantılarının idarə olunmasının ekoloji və iqtisadi səmərəliliyinin artırılması vasitəsilə davamlı kənd təsərrüfatının inkişafına töhfə verir.
**Açar sözlər:** heyvandarlıq tullantıları, anaerob parçalanma, biogaz, orqanomineral gübrələr, kompostlaşdırma, dayanıqlı kənd təsərrüfatı.

# УТИЛИЗАЦИЯ ЖИВОТНОВОДЧЕСКИХ ОТХОДОВ С ПОЛУЧЕНИЕМ ПОЛЕЗНОЙ ЭНЕРГИИ И УДОБРЕНИЙ

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**Резюме:** Данное исследование посвящено разработке интегрированного технологического комплекса для эффективной утилизации отходов животноводства и птицеводства на основе сочетания процессов анаэробного сбраживания, производства органоминеральных удобрений и компостирования. Основной целью работы является создание ресурсосберегающей и экологически устойчивой системы, обеспечивающей преобразование органических отходов в ценные энергетические и аграрные продукты.
Предлагаемая система состоит из трёх основных модулей: установки анаэробного сбраживания для получения биогаза, модуля переработки дигестата с целью получения органоминеральных удобрений путём обогащения и грануляции, а также модуля компостирования на основе контролируемой биоферментации. Важной технологической особенностью системы является разделение стадий гидролиза и метаногенеза, что повышает стабильность процесса и предотвращает закисление в биореакторе.
Результаты исследования показывают, что предложенный технологический подход обеспечивает стабильное производство биогаза и получение высококачественных удобрений с улучшенными агрономическими свойствами. Полученные продукты характеризуются повышенной доступностью питательных элементов, включая азот, фосфор и калий в формах, усвояемых растениями, а также положительным влиянием на структуру почвы. Процесс компостирования дополнительно обеспечивает получение гигиенически безопасного, обеззараженного и беззапахового органического материала.
Разработанный технологический комплекс способствует снижению негативного воздействия сельскохозяйственных отходов на окружающую среду, уменьшению уровня загрязнения и одновременному получению возобновляемой энергии и ценных удобрений. В целом система поддерживает устойчивое развитие сельского хозяйства и переход к модели циркулярной биоэкономики. Предлагаемый технологический подход способствует развитию устойчивого сельского хозяйства за счёт снижения загрязнения окружающей среды, обеспечения эффективного использования ресурсов и повышения экологической и экономической эффективности управления отходами животноводства.
**Ключевые слова:** отходы животноводства, анаэробное сбраживание, биогаз, органоминеральные удобрения, компостирование, устойчивое сельское хозяйство