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USING OF ORGANIC SLUDGE TO IMPROVE THE EFFICIENCY OF BIOGAS TECHNOLOGIES

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Abstract

Production volumes of organic sludge (digestate) increase as the amount of biogas plants in operation increases and biogas technologies are developed intensively. The rational use of organic sludge is a significant area for improving the efficiency of biogas technologies, since biohumus is an additional valuable product that can be used as organic fertilizer and, accordingly, reduce the cost of biogas production. The more organic material available for decomposition, the higher the biogas yield from the system and the more available organic sludge for plant nutrition. The resulting digestate requires appropriate refinement and quality improvement, primarily its dewatering and removal of harmful substances (including heavy metals). It makes possible to obtain and use an environmentally friendly biohumus as fertilizer for agricultural plants.

Keywords: biogas technologies, organic sludge, digestate, refinement system, dewatering, biohumus.

ИСПОЛЬЗОВАНИЕ ОРГАНИЧЕСКОГО ОСАДКА ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ БИОГАЗОВЫХ ТЕХНОЛОГИЙ

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Реферат

По мере увеличения количества функционирующих биогазовых установок и интенсивного развития биогазовых технологий увеличиваются объемы производства органического осадка (дигестата). Рациональное использование органического осадка является значимым направлением повышения эффективности биогазовых технологий, так как биогумус является дополнительным ценным продуктом, который можно использовать в качестве органического удобрения и, соответственно, удешевлять производство биогаза. Чем более доступный для разложения органический материал, тем выше выход биогаза из системы и тем более доступен органический осадок для питания растений. Полученный дигестат требует соответствующей доработки и улучшения качества, прежде всего обезвоживания и удаления вредных веществ (включая тяжелые металлы). Это позволяет получать и использовать экологически чистый биогумус в качестве удобрения для сельскохозяйственных растений.

Ключевые слова: биогазовые технологии, органический осадок, дигестат, система доработки, обезвоживание, биогумус.

Introduction

The National Strategy for Sustainable Socio-Economic Development of the Republic of Belarus for the period up to 2030 defines the further innovative development for the country's fuel and energy complex [1]. This aim will be ensured by involving nuclear fuel and renewable energy sources in the energy balance. One of the main directions for the development of renewable energy is the production of biogas by creating biogas complexes on livestock farms, food industry enterprises, municipal waste landfills in large cities, as well as its effective technological application [2]. Some progress has been made in this regard. Thus, in 2021, the target for the share of renewable energy sources in the total consumption of fuel and energy resources amounted to 7.4 %, while the installed capacity (MW) of biogas complexes in running increased by 13 %. Electricity generation from biogas increased by 173 %.

According to the Register of Certificates of Origin Energy (Ministry of Natural Resources & Environmental Protection, Republic of Belarus) from 01.11.2021 [3, 4], 29 biogas plants with a total installed capacity by 38.127 MW are operating in the country. Among this quantity, 14 plants operate on the waste of livestock farms, their installed capacity is 18, 772 MW. Accordingly, 15 biogas plants operate using organic waste from municipal and communal services. They are located at municipal solid waste (MSW) landfills near large and medium-sized cities. These plants (using special gas-piston equipment) produce so-called landfill gas. Their total installed capacity is 19.355 MW [5].

An important condition for the effective biogas production is the appropriate structure of biogas plants, including the following technological zones:

1. Substrate management.
2. Composition of the raw material, its pre-processing and loading into the reactor.
3. Anaerobic fermentation process.
4. Storage, refine (cleaning from impurities) and use of biogas.
5. Storage (placement) and refine of organic sludge formed after fermentation.

All zones of biogas plants should be combined into one technological process and have appropriate equipment for successful operation. [6]. First four zones of biogas complexes in running are well studied. However, the fifth zone – the storage (placement) and refinement of organic sludge formed after fermentation – is not payed enough attention in literary sources. Often, there is no information at all. Due to our opinion, this can be explained by the small installed capacity of biogas complexes operated in foreign countries, primarily EU countries, and, as a result, by small volumes of organic sludge production.

The Republic of Belarus has developed specific conditions for the formation of a raw material base using in biogas technologies. First of all, it is the presence of large volumes, the dynamics of formation and the structure of organic raw materials suitable for using in bioreactors. The main source of organic raw materials is livestock, which is characterized by a high level of concentration and specialization. Currently, there are about 100 large cattle fattening farms, 120 large pig farms and about 60 poultry farms, which produce up to 300 thousand tons of liquid organic waste per day [7], or in terms of 30 million m^3 of wastewater per year. The main raw materials for the production of biogas currently are: 1) manure of agricultural animals (secondary biomass), with the addition of other components (green biomass) and 2) solid household waste - this is landfill waste containing an organic fraction - for the production of landfill gas using special equipment [8]. The biogas potential produced from organic livestock waste is 4 billion m^3 of biogas per year, which corresponds to 800 MW of electric capacity. Using this resource would provide savings about 3.87 million tons of equivalent fuel per year [9].

Organic sludge production is increasing as the amount of biogas plants in running increases and biogas technologies are developed all over the world. Thus, effective management of organic sludge and turning it to biohumus is a significant reserve for improving the efficiency of biogas technologies.

Refinery System for Turning Organic Sludge to Biohumus

An organic sludge or digestate (from digestate – fermented deposition) is a stabilized material containing undissolved organic residues of biomass fermentation (cellulose chains most of all), a liquid fraction and necrotic microorganisms. After fermentation processes, which occur at a temperature of about 60 °C, this material is free of weed seeds and pathogenic microorganisms. It does not have an odor.

The composition and properties of the resulting sludge directly depend on the composition and properties of the raw material used for fermentation processes. This is the main determinant of methane yield, as well as the rate of formation and quality of digestate. The more organic material available for decomposition (assimilation), the higher the biogas yield from the system and the more organic sludge available for plant nutrition. In addition, the quality of the resulting sludge can be affected by additional components (including toxic, for example, heavy metal compounds, antibiotics, etc.) contained in initial raw materials. Raw materials used for fermentation may contain mineral components consisting of sand, earth, stones. These components are called raw ash. Such constituents are undesirable for the process of biogas production and organic sludge formation. They can reduce the quality of the resulting digestate and lead to technical problems, namely settling to the bottom of the bioreactor and possible equipment breakdowns.

Anaerobic processes in the bioreactor occur in two ways, which are determined by the content of solid substance part and moisture part in the original biomass. These processes are called dry and wet fermentation. Dry fermentation requires less energy and material costs (for transporting the organic mass and heating the liquid fraction), however, the microbiological process under these conditions is unstable, which leads to uneven formation of biogas, and often to stop the microbiological process. Wet fermentation (with the addition of water to the brooding biomass) requires additional costs for transporting and heating water, which is accompanied by inevitable heat losses and quite high electricity consumption. Despite the fact that the dry fermentation method is cheaper, the wet fermentation process is used more often, since the production of biogas in this case is more stable and guaranteed. With regard to the properties of the digestate obtained by wet fermentation, high water content can be noted as the serious disadvantage. Some authors indicate that up to 92 % moisture and only 8 % dry (useful) fraction may be contained in the organic sludge. Since the main use of digestate is to bring it into soils as an organic fertilizer, it is necessary to improve the applied technologies and carry out the target work to optimize conditions for methane fermentation processes.

Different substrates containing organic compounds and a wet fraction are used in biogas plants. Most organic compounds are decomposed by microorganisms during anaerobic fermentation. Biogas or methane (CH4) and carbon dioxide (CO2) are the most important degradation products in terms of their amount. In addition, initially biogas may contain small amounts of hydrogen sulfide (H2S) and ammonia (NH3). Decomposition processes convert a liquid or solid initial substrate into a liquid or semi-liquid digestate with high water content.

The organic sludge after fermentation of the biomass contains a significant amount of nitrogen, which is easily available for plant nutrition, as well as phosphorus, potassium, sulfur and some micro-elements. Thus, digestate not contaminated with toxic substances can be considered as a high-quality organic fertilizer [10]. The nutritional composition of digestate may vary slightly depending on the substrates used for fermentation. The approximate composition of digestate is given in (Table 1).

Table 1 – Composition of organic sludge

Indicators	After fermentation of primary biomass	After fermentation of secondary biomass
Dry matter, %	7.0	6.1
PH	8.3	8.5
Organic substance, kg/t	51.0	42.0
Total nitrogen, kg/t	4.7	4.8
Ammonium, kg/t	2.7	2.9
Phosphorus	1.8	1.8
Potassium	5.0	3.9

The above data on nutrient content in digestate are given for the two main types of feedstocks used in bioreactors - primary biomass, i.e. plant material of various origins (including green mass), and secondary biomass, or organic biological waste, mainly manure of agricultural animals. As can be seen from the table, digestate obtained from different types of raw materials has fairly similar indicators in terms of the content of dry matter and organic fraction, acidity indicator, as well as nitrogen (including ammonium), phosphorus and potassium contains.

Since only a small amount of ammonia leaves the substrate, most of the nitrogen remains in digestate. Decomposition processes reduce the amount of bound nitrogen in the organic substance, while the amount of ammonia increases from 45 % to 76 %, which is present in the ammonium nitrate digestate. This indicates the maximum conservation and accumulation of digestible nitrogen. When brought into the soil, digestate improves the conditions for the functioning of soil microorganisms and increases efficiency of nitrogen fixation. It leads to increased soil fertility in near period of time.

However, it should be noted that when digestate is stored and used, there is a high risk of ammonia releasing into the atmosphere. It is a negative process because ammonia has a high greenhouse effect. It is known that in ammonium form, nitrogen quickly becomes available for assimilation by plants. However, if the needs of cultivated plants are low, then the brought nitrogen can be used inefficiently and lead to denitrification of soils and include greenhouse effect.

The nutritional content of phosphorus in digestate is from 1.8 to 3.5 kg/t, with its content being approximately at the same level for the two main types of feedstock. Other macro- and micro elements added with the initial substrate, such as potassium, magnesium, calcium, also remain in digestate in the same amounts. The dynamics of the biogenic micro element of sulfur in anaerobic decomposition processes is of particular note. Sulfur, in the form of hydrogen sulfide (H2S), partially goes into biogas. Depending on the method used to remove traces of hydrogen sulfide from the biogas (desulfurization process), most of the sulfur can also be returned to digestate [10, 11]. In addition, it is known that undigested cellulose residues contained in the organic sludge reduce the washing-out process of nutrient (including mineral) elements from the soil, and form its optimal water-air regime. All above mentioned qualities of organic sludge are of the high nutritional value for using it as plant fertilizer.

However, the potential use of digestate in our country is limited due to its rather specific physico-chemical properties. The first and main task of digestate quality management is to regulate its moisture content. (Fig. 1) shows theoretically possible uses of digestate [12].

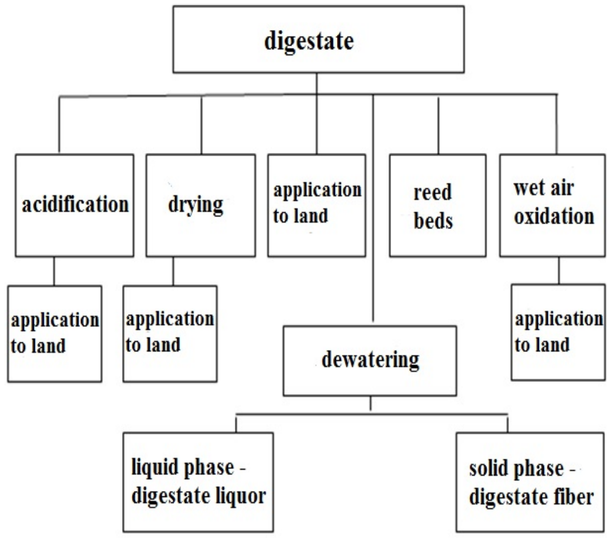

Figure 1 – Methods of digestate management

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Methods of digestate management are:

1. Digestate after fermentation of organic raw materials can be introduced directly into soils, which is a fairly common technique. To reduce ammonium emissions, there are recommendations to add acid salts to it. However, this technique can lead to acidification of soils, so it is used very limited and in compliance with strict regulations.

2. Drying of digestate under natural conditions. For natural drying, the organic residue is pumped into special settling ponds that occupy sufficiently large territories. Here, moisture evaporates naturally under the influence of solar radiation and air temperature, and organic sedimentation also occurs. Sediment is directed for additional heat drying or introduced into soils.

3. Artificial drying of sediment. Artificial drying of formed organic sediment is carried out using heat energy generated by cogeneration plant of biogas complex. This makes it possible to obtain practically ready organic fertilizer without additional energy costs. The relatively low moisture content makes it suitable for transportation.

4. Target dewatering of digestate is carried out by special technological methods, including physical and chemical methods – coagulation, flocculation, etc., using chemical reagents and physical impacts. This leads to separation of the sludge into a semiliquid fraction containing complete nutrient elements of nitrogen, phosphorus and potassium (NPK), and a fibrous solid fraction consisting of undeposited cellulose fibers, as well as large volumes of water.

5. Oxidation of digestate with wet air. This is the oxidation process of the viscous organic fraction under conditions of increased pressure (4–6 MPa) and temperature (200–300 °C). The efficiency of this method can increase the organic matter content of the sludge to 90 %. The organic substance in this case is represented by a mixture of short chain fatty acids and methanol.

6. Creation of artificial wetlands. This technique is used with small volumes of digestate formation, which is pumped to areas located in low-lying areas. To accelerate mineralization processes, reeds and other swamp plants are planted in these areas. Water flowing from such a system can be used for irrigation. Periodically, sediment is extracted from the bottom of artificial wetlands and used as organic fertilizer [12].

All of the above digestate management techniques have advantages and disadvantages. Heat drying methods are highly efficient, however, they are quite energy intensive, which makes their using limited. Most often, in biogas plants, the generated heat energy is used for other needs, in particular, for the production of electric energy, drying of woody biomass, heating of production buildings and greenhouses. Where the volumes of digestate produced are large enough, heat drying is limited. Drying in settling ponds based on natural evaporation processes is more economically viable and environmentally efficient. This technique can reduce the liquid fraction of digestate from 90 % to 20 %. Significant disadvantages of this technology are the need for large areas, the risk of contamination of adjacent areas, and significant time needed. The process of oxidation of organic sludge with wet air requires economic costs to create high atmospheric pressure and temperature, as well as refinement of the obtained material. The creation of artificial wetlands requires large areas, processes are quite inert and require a long period of time.

Conclusion

One of the main directions of the development of renewable energy in the Republic of Belarus is the production of biogas by function biogas plants on livestock farms and landfills of solid municipal waste. As the amount of biogas plants in operation and the intensive development of biogas technologies increase, the volume of organic sludge production increases too. Biohumus can be obtained from any organic sludge formed by fermentation of biomass.

Digestate is an additional product of biogas production. The more organic material available for decomposition (assimilation), the higher the biogas yield from the system and the more organic digestate available for plant nutrition. Its composition allows to use digestate as a fertilizer, since up to 50 % of organic nitrogen is released in the fermenter in the form of ammonium nitrate, which indicates maximum preservation and accumulation of nitrogen. When brought into the soil, digestate improves the conditions for the functioning of soil microorganisms, nitrogen fixation and other microbiological processes leading to increased soil fertility. Furthermore the nutritional content of phosphorus and potassium is at the same level for the two main types of feedstock which indicates its high value as a fertilizer for agricultural plants.

On the other hand, toxic substances (heavy metal ions, antibiotics, etc.) can be contained in digestate, entering the soil, they are not decomposed by soil microorganisms. Therefore, digestate requires appropriate refinement, improvement of quality to turn it into biohumus for further sustainable use. Effective management of organic sludge and its transformation into high-quality and environmentally friendly biohumus can significantly reduce the payback time of biogas plants and optimize the cost of the obtained biogas.

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