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Agricultural biogas plants as a future in agricultural waste management

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ABSTRACT

The demand for energy increases with the development of civilization. According to popular opinion, traditional energy resources, mainly fossil fuels (coal, oil, natural gas), are depleted and their use causes an increase in environmental pollution, mainly greenhouse gases. Therefore, renewable energy sources (RES), such as agricultural biogas plants, which are harmless to the world around us, are gaining importance. The European Union pays great attention to environmental protection and soil protection (organic fertilization with digestate, biogas plants) and energy issues. It emphasizes the increase in the share of energy from renewable energy in the total energy consumption. In EU countries, energy issues are regulated by relevant directives and the so-called Green and White Paper [1].

***Keywords*:** Biogas, Biogas plants, Post-fermentation mass, Organic fertilization, Macronutrients, Waste

1. INTRODUCTION AND PURPOSE OF WORK

In order to develop renewable energy, it was decided in Poland to increase the use of renewable energy resources in gross final energy consumption in 2020 to 15%. It was assumed, however, that in 2010 the share of electricity generated from RES in domestic consumption will be 7.5%, in relation to electricity [2, 3].

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Currently in Poland, renewable energy is generated to the largest extent from solid biomass. According to CSO data, in 2008 the share of energy from solid biomass, in relation to total energy from RES, was 87.7%. It was lower than in 2005 by 3.9%, while the share of wind energy increased (by 1%), and a larger amount of biogas and biofuels was produced, by 0.6% and 2.9%, respectively [4].

1. 1. Energy from renewable energy sources and fertilization

Renewable energy sources are a group of commonly available non-fossil sources that arise spontaneously in repetitive natural processes. They are characterized by the lack of negative impact on the natural environment. Energy produced from renewable energy is divided into electricity and heat, and they come from hydro and wind power plants, solar photovoltaic cells and solar collectors for heat generation, as well as geothermal sources and producing energy from biomass, including those producing energy from biogas [4].

Renewable energy production has many benefits. First of all, in the global aspect it helps to protect the environment, because it contributes to the reduction of greenhouse gas emissions, mainly CO_2 and CH_4. Biomass processing also involves the reduction of SO_2, as well as nitrogen oxides (NOx) and carbon monoxide emissions. In addition, such biomass management contributes to the reduction of landfill areas. Installations for obtaining energy from RES are usually of a local nature, therefore it can be argued that renewable energy favors regional economic development and contributes to the creation of new jobs [5].

Post-fermentation mass is produced in the production of biogas as a by-product (it is created from organic matter of plant and animal origin). The composition of the digestate depends on the input material that was used to produce biogas. The digestate in this way differs in qualitative composition and dry matter content. The post-fermentation product is used as a direct organic fertilizer in solid or liquid form, because the elements present in it are in forms available to plants. The digestate contains key chemical elements and is free of pathogens, thanks to which it can be used as a valuable and safe natural fertilizer. The use of digestate causes skipping the process of organic matter decomposition by microorganisms, since organic matter was decomposed in the fermentation process. By-product from biogas plants has a positive effect on all aspects of soil cultivation [6].

The main argument is the limitation of mineral fertilizers (replacing them with digestate), whereby the digestate will enrich the soil with elements such as potassium, phosphorus or nitrogen, but will also increase the amount of organic matter (which will increase the sorption complex of the humus soil layer). The digestate is used because of its special properties; the amounts of organic carbon contained in it increase the balance of organic matter, and the food elements present in it reduce the need for mineral fertilization. The elements found in the digestate are in a form that is available to plants, which causes a fast and even crop emergence and a high yield. When the digestate is used, the ionic structure of the sorption complex changes, which limits the share of acid cations, such as hydrogen or aluminum. However, the share of basic cations, such as potassium, calcium and magnesium, is increased.

The digestate has a positive effect on the environment because it reduces methane emissions to the atmosphere through an appropriate production process (collecting methane as the main product) and storage, it does not contain significant amounts of heavy metals, the emissions of nitrogen oxides and sulfur or methane into the atmosphere are reduced, the amount of unpleasant smells is also limited. The digestate is stored in closed silos, reducing odors (and methane) emitted from storage. When using digestate, the fertilizer recycling process is visualized because the use of digestate involves the re-inclusion of elements that were used to obtain the crop (substrates that have been digested in biogas can be used as a processed and safe natural fertilizer) [7].

2. FERTILIZER PROPERTIES OF THE POFERMENTATION MASS

The digestate is a mass rich in phosphorus and potassium, thanks to which biogas was produced in the methane fermentation process, which leads to a reduction in the production of natural gas, potassium salts or phosphorites. The digestate is significantly enriched in nitrogen compounds, which leads toa reduction in the use of nitrogen fertilizers, which in turn results in a reduction in the production of mineral (nitrogen) fertilizers andinhibiting the greenhouse effect [8].

Photo 1. Post-fermentation mass as an example of organic matter
[Own source].

Agricultural biogas plants use farm-derived products, including: cow and pig manure, maize and rye silage, non-compliant cereal seeds (wheat), stillage stocks and manure, or sometimes mushroom charts. The use of different doses and substrates affects the chemical composition and dry matter content. The combination of bovine manure and maize silage in a quantity ratio of 3 : 7 sets the dry matter content at 9%, while the ratio N: P_2O_5 : K_2O at 5.8: 2.3 : 9.1. However, biogas production from maize silage, pig manure and wheat grain in a ratio of 8.5 : 1 : 0.5. The digestate has the following properties: dry solids content was 10.5%, N : P_2O_5: K_2O 7.5 : 3.6 : 10.1, respectively. The exclusive use of bovine manure leads to a decrease in s.m (5.1%) and a decrease in the N : P_2O_5 : K_2O ratio to level 5; 1.8; 6.5. Liquid form has the best fertilizing potential. It has a small amount of dry matter (3-5%) with a high concentration of nutrients (in 1 t of fresh weight). The digestate liquid fraction has a high fertilizer value with fast action. This results in the fact that light soils do not use their full fertilizing potential, their shallow sorption complex does not allow them of organic matter in soils around the world. This is due to, among others decreasin [9].

For light soils, it is recommended to use a solid fraction of digestate, as it enriches the humus level in food elements, but also in significant amounts of organic matter. A larger amount of dry matter causes its compaction, which makes it more useful for light soils (especially rusty soils), as these compounds are not washed away into the soil profile. They undergo gradual, and as a result, completely transition to soil humus level. The digestate liquid fraction can be used on soils with a deeper humus level [10].

Recently, there has been a decrease in the amount quantities of manure produced and used. The unfavorable balance of soil organic matter can be improved by using organic waste materials in fertilization. Such materials include post-fermentation mass (especially the solid fraction), which has a high potential for soil enrichment with biogenic elements and organic matter [11].

3. BIOGAS PLANTS –PRELIMINARY NEWS

Biogas is created as a result of biomass processing, which is one of the basic renewable energy sources. In chemical terms, it consists mainly of methane and carbon dioxide, although its composition largely depends on the type of raw materials from which it is obtained. Table 1 presents the chemical composition of biogas obtained from household waste, sludge from sewage treatment plants, agricultural waste and waste from the agro-food industry. The place of biogas formation is Biogas plant. It consists of: a substrate feeding part, a fermentation chamber, a biogas storage tank, a fermented substrate tank and a device for the use of biogas, e.g. a cogeneration aggregate.

The feeding of the substrate depends on its type. Loose substrates, such as silage from plants, are fed via feeders that are equipped with screw conveyors or piston pumps. Liquid substrates, such as liquid manure or stillage, are transferred to a buffer tank, from which they are immediately pumped into the fermentation chamber. biogas, e.g. a cogeneration plant. The feeding of the substrate depends on its type. The most complicated system of pre-treatment of substrates is the system used for slaughter waste, which must be subjected to pasteurization or hygienization. For sanitary reasons, this waste is collected in a separate, closed building, called the reception hall, equipped with, among others, biofilters to remove odors. Depending on the category, meat waste should be subjected to thermal treatment, with various components, in a pasteurizer. After cooling the pasteurizer to a suitable temperature, the biomass is directed to the fermentation chamber.

The fermentation chamber (fermenter) is a tank in which organic matter decomposes and produces methane. It is usually a closed steel or reinforced concrete tank. Depending on the substrate used, its physicochemical properties and the amount of the given raw material, biogas plants usually use reinforced concrete, low tanks, which are equipped with side agitators, or steel tanks, high, with a vertical mixer. Appropriate selection of the fermentation chamber is necessary to ensure optimal and stable conditions for the activity of methane bacteria in the entire surface of the tank. Therefore, an extremely important process is mixing, which allows you to distribute evenly subsequent portions of biomass, homogenize the substrate, maintain a constant temperature and pH. Mixing is also important for the release of methane.

An important thing is the thermal insulation of the fermentation chamber (this process can only be carried out effectively at strictly defined temperatures suitable for the development of microorganisms), and heating the contents of the chamber, especially during periods of low temperatures (winter periods) [12].

Photo 2. Example photo of an agricultural biogas plant
[www.wysokienapiecie.pl]

Biogas is produced in a fermentation chamber, while the collection takes place in a storage tank. It is a double-membrane tank, fulfilling two functions: as a roof for the storage of fermented substrate, and a chamber for secondary fermentation (it depends on the technological system of a given biogas plant). The biogas tank also acts as a buffer capacity for the receiving device, among others for a cogeneration aggregate.

This structure allows stable operation of devices despite fluctuations in biogas production, which are everyday occurrences. The cogeneration module is the most popular device for the use of biogas. In the process of biogas combustion in a cogeneration module, it simultaneously generates electricity and heat. The gas that is supplied to the device should be free of hydrogen sulfide and dried. Hydrogen sulfide creates the risk of damage to equipment, because in combination with water vapor it forms hydrogen sulfide. Removal of hydrogen sulfide takes place in the fermentation chamber or in the biogas storage tank, it is removed by biological methods.

Water vapor is condensed between the biogas tank and the cogeneration device, in special elements of the installation, or in a specially installed steam trap. In addition to biogas, the fermentation process also produces a liquid with a content of several to several percent S.M. This substance has high fertilizing properties. It contains elements that are part of the biomass and which do not participate in the production of biogas, such as nitrogen, phosphorus, potassium, magnesium, and calcium. Many of them occur in the form of dissociated salts, which makes them easily accessible to plants. The fermented substrate is most often used as liquid fertilizer. Restrictions on the use of fertilizer make it necessary to install a biomass storage tank. Each biogas plant is obliged to supply such a tank [13].

3. 1. Characteristics of agricultural biogas plants

A biogas plant is a facility for the purposeful production of biogas, in which the substrate is products coming directly from agricultural holdings, such as: agricultural products, production residues from agri-food processing, or livestock excrements [14] (Figure 2).

4. SUBSTRATES AND BIOGAS PRODUCTION TECHNOLOGY

The energy potential of biogas depends mainly on the substrates from which it was produced. When obtaining agricultural biogas, liquid manure is very often used as processed material. It should be noted, however, that it is a substrate with low biogas efficiency: from 290 to 550 dm^3 CH / kg of organic matter, because it is largely composed of water. To increase the efficiency of biogas production from liquid manure, it is subjected to high temperatures and its reaction is changed. Thermal modifications are carried out in the temperature range from 70 to 190 °C, in appropriate equipment and for a specified time. At lower temperatures (100 °C) the process takes longer - about 3 hours and is carried out in a glass reactor equipped with a magnetic stirrer. While at higher temperatures a Zipperclave reactor is used and the process takes 20 minutes. Chemical-thermal modifications are also carried out, which involve the action of high temperatures and a change in the slurry reaction (pH = 10 or 12). Then the so-called Biochemical Methane Production Potential (BMP). Its highest value (up to 48%) is observed at 190 °C. However, optimally the modifications are carried out at temperatures from 135 °C to 190 °C. When heated at temperatures close to 190 °C, thermal hydrolysis of the slurry occurs. It can be stated that in order to increase the efficiency of biogas production from liquid manure, it should be warmed up or its pH first adjusted to 10 and warmed before it undergoes fermentation [15].

The efficiency of methane production from biomass is also increased by appropriate selection of substrates. As a source of biogas, it used pig manure, which was the base material, while as a so-called co-substrates: maize silage, fruit waste in the form of pomace and cattle manure. The process of fermenting a mixture of liquid manure and fruit waste was characterized by the greatest economic efficiency. However, the biogas production efficiency from these substrates was 18.0 and 112.7 m^3/h, respectively. In the case of cattle manure, biogas efficiency was 35.3 m^3/h. Satisfactory process efficiency was also found in the fermentation of maize silage. The biogas production efficiency from maize silage was 132.7 m3/h and was the highest among the analyzed cases. However, the high price of this substrate makes its fermentation unprofitable [16].

4. 1. Raw materials for biogas production

Various types of organic material are used to produce methane in biogas plants. For the use of organic material to be profitable, the material must meet the following conditions:

- fast biodegradation
- parts of plants that are woody, feathers and bones are not suitable for use in biogas plants.
- a large amount of biogas obtained from a given organic material
- biomass transport to biogas plants should be as short as possible
- substrate availability throughout the year or storage in a form suitable for carrying out the methane fermentation process.

Photo 3. Maize silage
[http://www.blending.pl]

Photo 4. Rye for silage
[www.agrofakt.pl]

Only a small amount of biomass types can ferment independently, many of them require the addition of substrates that will support the process or balance the biochemical balance in the fermetation process. The right composition of substrates should be developed by an experienced technologist, while in more complicated cases, composition creation should also be preceded by specialized laboratory tests that will condition stable and optimal biogas production and will allow optimal operation of the biogas plant over the next years of production. Main substrates used in food biogas plants: faeces from animal production, plant biomass, industrial waste [17].

Photo 5. Slurry
[www.topagrar.pl]

Photo 6. Cow manure
[www.stajniatrot.pl]

Table 1. Biogas production potential for selected substrates of the methane fermentation process [22].

Type of material	Characteristic		Biogas efficiency	
	Dry matter content [%]	Organic matter content in dry matter [%]	Dry organic matter dm^3/kg	Content of CH_4 In biogas [%]
Cow manure	8	86	280	55
Pig manure	6	80	400	60
Manure	25	80	450	55
Ensilage from corn	32	95	600	52
Ensilage from whole cereals	40	95	520	53
Ground corn cobs	65	98	680	55
Grain	86	98	700	55

4. 2. Biochemical basics of biogas production

The result of the process in which biogas is formed is called methane fermentation. Anaerobic bacteria are responsible for its course. The methane fermentation process consists of four stages. The first is hydrolysis, during which organic compounds under the influence of water and enzymes are lysed to simple organic compounds. The second stage is acidogenesis, i.e. the organic acid formation phase. Then, the hydrolysis products are further broken down into fatty acids, such as acetic, propionic or butyric acid. The third phase is the acetic acid production process, this phase is also called acetogenesis. In this phase, higher fatty acids break down into acetic acid. During the decomposition of organic matter, the following are released: carbon dioxide and hydrogen. From these newly formed compounds, methane bacteria synthesize methane, more commonly known as biogas. This is the last phase of this four-step process, called methanogenesis. All four stages proceed in parallel in the fermentation chamber. In one place and time, microorganisms exist that are responsible for particular stages of methane production. They co-exist in symbiosis. Each group of microorganisms must appear in the fermenter in the right amount to carry out the process as efficiently as possible, which also results in the quality of the biogas produced. Destruction of the balance between microorganisms in the fermentation chamber can even result in complete cessation of methane production. However, these are extreme situations and do not happen often [18].

In order for the methane fermentation process to be carried out with high biogas production efficiency, it is necessary to mix substrates in fermentation heaps. This allows the substrate temperature to be kept uniform, ensures a homogeneous process flow throughout the entire pile stack as well as a homogeneous material consistency. First of all, mixing means that the bacteria and the medium have more contact. It also allows for easier degassing and reduction of dissolved CO_2 content, as well as the release of supernatant (intermolecular) water, which causes the concentration of biomass. However, too intensive mixing can reduce the efficiency of the process, so they are usually carried out in a batch manner, using low-speed mixers with low cutting force have shown that to increase the efficiency of biogas production under thermophilic conditions, biomass containing acetogenic, methanogenic and degrading polymers should be inoculate with cultures of thermophilic, acetogenic and hydrogen producing bacteria, e.g. *Caldicellulosiruptor saccharolyticus*. The addition of bacteria took place before or during the fermentation process. The proposed method also resulted in an increase in the methane content of the obtained biogas [19].

4. 3. Chemical composition of biogas obtained from various types of raw materials

Biogas can be divided according to the way it is obtained, e.g. landfill gas, obtained as a result of waste fermentation in landfills, as well as gas from sewage sludge, produced as a result of anaerobic digestion of sewage sludge. Agricultural biogas is also isolated, which is obtained in the process of anaerobic fermentation of biomass from energy crops, residues from plant production and animal excrements or from waste in slaughterhouses, breweries and other food industries [20].

Table 2 Chemical composition of biogas obtained from various types of raw materials [22].

Ingredients	Unit	Agricultural waste	Waste from the agro-food industry
CH_4	[%] vol.	60–75	68
CO_2		19–33	26
N_2		0–1	–
O_2		< 0,5	–
H_2O	[%] vol. (in 40 °C)	6	6
H_2S	[mg/m^3]	3000–10 000	100
NH_3		50–100	400
Aromatic compounds		–	–
Organohalogen or fluoroorganic compounds		–	–

As previously mentioned, biogas is produced in the methane fermentation process. It is an anaerobic process that involves four stages: hydrolysis, acidogenesis, acetateogenesis and methanogenesis. In the first stage, the insoluble organic compounds, such as proteins, fats and carbohydrates are broken down. As a result, amino acids, monosaccharides, polyhydric alcohols and fatty acids are formed. The process takes place with the participation of extracellular enzymes. The acidogenic phase produces volatile fatty acids, methyl alcohol and ethanol, aldehydes as well as CO_2 and H_2, as well as acetates. The resulting acids (formic, acetic) as well as methanol, CO_2 and H_2 can already be used at this stage by methane bacteria in the methanogenesis process. On the other hand, acetogenic bacteria process ethanol and volatile fatty acids into CO_2 and H_2 in the next stage - octanogenesis. Their activity affects the next stage of the process. As a result of inhibiting the growth of these microorganisms, volatile fatty acids accumulate, which in turn slows down or stops the growth of methane bacteria. They are responsible for generating methane from acetates or alcohols, as well as CO_2 as a result of its reduction with hydrogen. The course of methane fermentation depends on many factors - temperature, reaction of the fermented material, content of nutrients (more precisely the C/N ratio) and mixing. Because methane bacteria are more sensitive to changes in temperature and pH than acetogenic bacteria, the fermentation process is carried out under more favorable conditions for their development and activity. Table 2 presents the parameters for conducting the methane fermentation process [21].

5. CONCLUSIONS

Biomass and the resulting biogas are a valuable source of electricity and heat, and biogas plants are an alternative to conventional methods that pollute the environment. The types of technological solutions for biogas production are closely related to the availability of substrates for the process. Nowadays, we are aiming to increase the consumption of energy generated from biogas in relation to energy generated from conventional sources. Therefore, governments of many countries support the development of pro-ecological technologies, stimulate the construction of installations for biogas production. Technological solutions for obtaining biogas are constantly being improved.

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