STRAW OF THE AGRICULTURAL PLANTS AS AN ALTERNATIVE SOURCE OF ENERGY

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Abstract

Ukraine has significant amounts of land resources for agricultural production. It is able to provide its population not only with food, but as a raw material for bioenergy. As raw materials in bioenergy, waste and agricultural remnants that are formed in the process of harvesting agricultural crops and in the process of their processing can be used, in particular straw of cereals, legumes, corn and sunflower seeds, sunflower husk, rice puddings, pulp sugar beets. For energy needs in bioenergy, agricultural waste is used by direct burning or by processing into solid, liquid or gaseous fuels. In the production of gaseous fuels from agricultural waste, not only the source of energy – biogas, but high quality fertilizers are formed. In addition, biogas is easy to use, store and transport. It can be used on decentralized block heating plants or can be supplied to an existing gas transmission network. The process of biogas production takes place in bioreactors, the constructions of which are quite diverse and differ by form, material, methods of mixing and heating of biomass, volume of processing raw materials. Among the agricultural wastes that bring the greatest energy potential, there are straw of cereals, which is available in large volumes, is actively studied and is increasingly used as a raw material for biogas production.

In this article, for the production of biogas from straw of agricultural plants, the design of a bioreactor is proposed, which allows for efficient mixing and warming up of organic biomass, which allows improve the efficiency and reduce the energy consumption of a bioreactor. Analytical studies to determine the amount of biogas output were used for maize straw, cereal straw and rye straw. Research has shown that the amount of biogas output depends on the type of straw and the time of fermentation. The largest amount of biogas output is generated within 10 days of the day the organic biomass is loaded. It was established that the largest amount of biogas is formed from straw of grain crops, with the maximum value of 1.75 m^3. The smallest amount of biogas is formed from rye straw; the maximum amount of biogas output is 1.3 m^3.

Key words: biomass, straw, biogas, anaerobic fermentation, bioreactor.

Introduction

Ukraine has significant amounts of land resources for agricultural production. It is able not only to provide its people with food, but also to produce raw materials for bioenergy. The main source of energy in bioenergy is biomass, that is, recovered organic matters that can be biodegradable. The waste and the remnants from agriculture, wood waste in forestry, woodworking and pulp and paper industry, energy crops, organic parts of industrial and household waste are used as biomass (Chernukha, Dubrovskaya, & Shklar, 2016; Savchenko, Zhelykh, Yurkevych, Kozak, & Bahmet, 2018). The use of biomass has several advantages: it is a renewable energy source; its use will reduce the amount of waste from various sectors of the economy, during combustion of biomass does not produce gases that contribute to the greenhouse effect, and thus improves the environmental status of the environment. At present, the share of renewable energy sources in the energy balance of Ukraine is negligible at 3 – 4 per cent, but the amount of biomass in renewable energy sources can be up to 20 per cent. In Ukraine, the first place in the use of biomass is wood – 88 per cent. Another important component of the biomass potential in Ukraine is agricultural waste of crop and livestock. Crop waste is divided into primary and secondary (Litvak, 2015). Primary agricultural waste includes straw of cereals, legumes, corn and corn grain waste and sunflower. They are formed directly in the process of harvesting the crops concerned. Secondary agricultural waste includes waste that is formed during the processing of harvest (sunflower husk, rice peel, pulp of sugar beet, etc.).

For the production of thermal or electric energy biomass from agricultural waste is used directly by burning or by processing into solid, liquid or gaseous fuels.

The easiest way to get useful energy from biomass is direct burning. The main drawbacks of this method are the difficulties associated with the provision of automatic fueling, the need for constant attention from users, the pollution of the environment with smoke and soot, that is, requires a special design of boilers (Bodnar, Dakhnovskaya, & Boychuk, 2015).

The agricultural biomass that is pelletized or briquettes is used as a solid biofuel (Niedziolka & Szpryngiel, 2014). The process of pellet formation takes place in pelletizing presses and consists of pressing the crushed biomass into the compression channel as a result of the interaction of the roller and the material layer between the roller and the matrix. Wood, husk, straw and reeds are used as raw materials in the fuel briquettes production, which is pressed in press-brackets.

To liquid biofuels are bioethanol and biodiesel (Gelotukha, Zhelyesna, Zhovmir, Matveev, & Drozdov, 2011). The raw material for bioethanol production is products containing starch, sugar or cellulose. Biodiesel fuel is a product of the transesterification of plant oils and is a mixture of methyl or ethyl esters of fatty acids. It can be used in its pure form, or as a mixture with conventional diesel fuel in any proportions. Raw materials for it are plant oils.

The production and use of biogas is an effective way of supplementing and replacing traditional fuel and energy resources. Biogas is very convenient to use and is used on decentralized block heating plants for electricity supply and heat supply or can be supplied to an existing gas transmission network.

Aim of work – to propose the design of a bioreactor for the production of biogas from straw of agricultural plants and to determine the amount of biogas produced in this biogas plant from straw of agricultural plants.

Methodology

Biogas is a flammable multicomponent gas consisting of methane (50 – 75 per cent), carbon dioxide (25 – 50 per cent), water vapor (0 – 10 per cent), nitrogen (0.01 – 5 per cent), oxygen (0.01 – 2 per cent), hydrogen (0 – 1 per cent), ammonia (0.01 – 2.5 mg/m^3) and hydrogen sulfide (10 – 30 mg/m^3) (Panchuk & Shlapak, 2016). Biogas is formed as a result of anaerobic (without access to oxygen) decomposition of organic biomass. The process of biogas production takes place in four stages (Perederiy, 2008):

1. The stage of hydrolysis (splitting) of complex biopolymer molecules into simpler oligo- and monomers.

$$[C_6H_{10}O_5]n + nH_2O = nC_6H_{12}O_6 \tag{1}$$

2. The fermentation stage: the oxidation of the monomers formed in the first stage to the more simple substances, while carbon dioxide and hydrogen are also formed.
3. Acetogenic stage – the reproduction of acid-forming bacteria, in which the direct precursors of methane are formed: acetate, hydrogen, carbon dioxide.

$$C_6H_{12}O_6 + 2H_2O = 2CH_3COOH + 2CO_2 + 4H_2 \tag{2}$$

4. The methanogenic stage is the multiplication of methane-forming bacteria, which leads to the receipt of the final product - methane.

$$CH_3COOH = CH_4 + CO_2 \tag{3}$$

$$4CH_4 + CO_2 = CH_4 + 2H_2O \tag{4}$$

The intensity of the biogas production process is influenced by four groups of factors: biological (composition of biomass, microflora composition, microorganisms' living conditions), physical (fermentation temperature, pressure in the biogas plant, hydraulic regime), chemical (concentration, acidity of the medium, the content of volatile fatty acids in biomass , the volume and composition of the resulting biogas) and organizational and technological (the dose of daily loading of new portions of the organic mass, the load on the ash matter substance, the residual substances).

Anaerobic fermentation of organic matter occurs in biogas plants, the main element of which is a bioreactor. Constructions of bioreactors are quite diverse and are differ:

- from form of the reactor: egg-shaped, cylindrical, trench, cubic, elastic;
- from reservoir placement: with a horizontal or vertical reservoir;
- by the number of chambers: one-chamber and two-chamber;
- from construction material: concrete, glassplastic, metal;
- from mixing method: with mechanical, hydraulic or bubbling mixing;
- from method of heat exchange: heating by hot water, heating by steam, electric heating;
- from volume of processing raw materials: centralized and individual.

When choosing the shape, size and design of a bioreactor, the following factors are considered first and foremost: the mass flow rate of the substrate when filling; the given biogas output or the degree of fermentation of the substrate as a function of the concentration of dry matter, loading of the working space, the time of the digestion cycle and the intensity of mixing; used production system; level of mechanization.

For the production of biogas, you can use any organic biomass, and the technology of anaerobic fermentation can obtain a source of energy in the form of biogas, high quality fertilizers and protein-vitamin feed additives, as well as solves environmental problems in agriculture.

Results

The amount of waste in the processing of agricultural plants is very significant (Table 1).

Table 1. Quantity of waste in the processing of agricultural plants

Agricultural plant	Type of waste	Remains of production per 1 ton of finished product
Rice	Straw, husk	1.7 tons of waste
Wheat	Straw, husk	2.0 tons of waste
Maize	Stems, leaves	2.4 tons of waste
Barley	Straw, bran	1.5 tons of waste

Thus, in the process of harvesting, the grain part of the agricultural plant is separated from the stem, with part of the straw is collected, and the other – remains in the form of stubble in the field. The collected straw can be used for livestock (underlay and rough livestock feed), as organic fertilizer, for growing mushrooms in closed soil. The unutilized remnants in Ukraine is often burned in the fields, which leads to the destruction and degeneration of organic matter of the soil, the strengthening of erosion and deflationary danger, the destruction of stubble residues as organic fertilizers and sources of organic matter remediation, the destruction of the natural fauna of the soil and soil microbiological fauna, air pollution basin by products of burning stubble and straw.

Among the waste of plants that bring the greatest energy potential are straw of grain crops, corn waste (stems, leaves) and sunflower waste (stems, baskets), therefore it is expedient to use them as an alternative source of energy in bioenergy (Zhelykh & Furdas, 2011).

For the production of biogas from straw of agricultural plants, the design of a bioreactor is proposed, the scheme of which is shown in Fig. 1 (Xue Li et al., 2017).

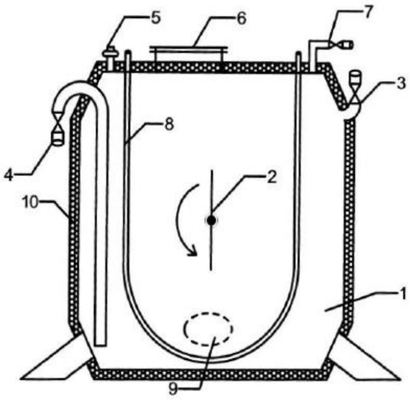

Fig. 1. Bioreactor scheme: 1 – reservoir; 2 – means of mixing; 3 – download branch pipe; 4 – discharge branch pipe; 5 – valve; 6 – hatch; 7 – biogas exit pipe; 8 – heating system; 9 – hatch; 10 – a layer of thermal insulation.

The bioreactor works as follows. The prepared straw of agricultural plants feeds through the branch pipe 3 to the reservoir 1. Inside the reservoir 1, the biomass is mixed by means of mixing 2 and heated using a heating system 8. To maintain the required biomass temperature, the reservoir is insulated with a layer of thermal insulation 10. After the process of anaerobic fermentation in the reservoir 1, biogas is formed, which by the biogas exit pipe 7 flows to the consumer. If necessary, excess biogas is discharged into the atmosphere through the valve 5. Exhausted straw of agricultural plants is removed through the discharge branch pipe 4. Purification and revision of the inner volume of reservoir 1 are carried out through hatches 6 and 9, if necessary. Such a construction of a bioreactor allows for efficient mixing and heating of straw of agricultural plants, which allows increase work efficiency and reduce the energy consumption of a bioreactor.

An important characteristic of bioreactor is the ability to produce a certain volume of biogas. To determine the estimated volume of biogas produced, a method is used to determine the volume of biogas from solid household waste and its adaptation to the straw of agricultural plants. The starting data for the calculation is the biomass temperature, °C; humidity of biomass W, per cent; ash content of dry straw of agricultural plants A, per cent. The calculation is carried out in such a sequence:

1. Determine the concentration of organic substances, kg/m^3:

$$S = \rho_V \cdot (100 - W) \cdot (100 - A) \cdot 10^{-4}, \tag{5}$$

where W – humidity of the substrate, per cent; A – ash content of dry organic raw material, per cent; ρ_V – volume biomass density, kg/m^3.

2. Calculate the density of biomass, kg/m^3:

$$\rho_V = \frac{\rho_{out}}{100 + W \cdot (\rho_{out} \cdot 10^{-3} - 1)} \cdot 100, \tag{6}$$

where ρ_{out} – density of solid biomass fraction, kg/m^3.

3. Calculate the kinematic coefficient K according to the formula:

$$K = K_r(\mu_m \cdot S - d)/(B \cdot S - K_r \cdot d), \tag{7}$$

where K_r – coefficient of proportionality.

4. Determine the coefficient of proportionality:

$$K_r = \frac{(38 \cdot S - 205) \cdot P}{100 \cdot (t_B - 17{,}8)}, \tag{8}$$

where t_{in} – temperature of the fermentation process, °C; P – correction factor, (P=1 by t_{in}=33 – 53 °C).

5. Calculate the maximum rate of growth of microorganisms μ_m in biomass, day^{-1}:

$$\mu_m = 0{,}013 \cdot t_{in} - 0{,}129 \cdot \tag{9}$$

6. Determine the daily output of biogas V_B, m^3/m^{3}day :

$$V_B = \frac{B \cdot S}{\tau}\left(1 - \frac{K}{\tau \cdot \mu_m - 1 + K}\right), \tag{10}$$

where B – maximum biogas output, m^3/kg; S – concentration of organic substances in the feedstock, kg/m^3; τ – time of fermentation, days.

The calculation was made for a bioreactor volume of 1.2 m^3. The internal biomass temperature was taken at 50 °C. As organic raw materials, straw of agricultural plants, namely maize, grain crops and rye was used. The bioreactor biomass download was 1 m^3. The daily output of biogas V_B depends on the type of straw of agricultural plants and the time of fermentation τ is shown in Fig. 2.

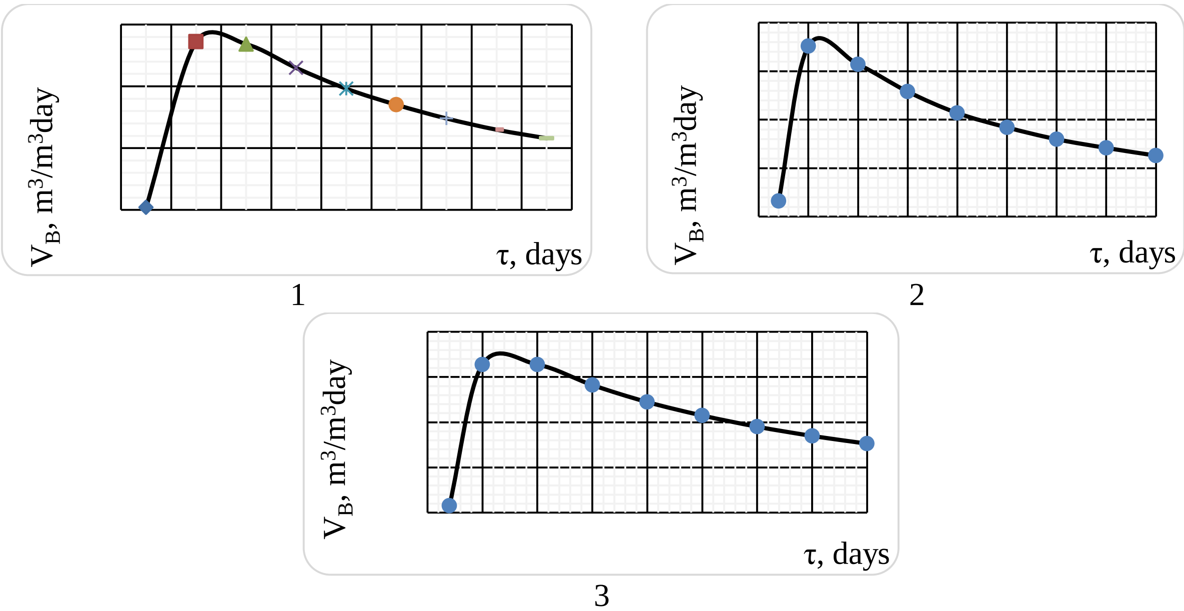

Fig. 2. Daily output of biogas output V_B, m^3 for agricultural plants waste:
1 – maize stem; 2 – straw of cereal plants; 3 – straw rye

As can be seen from Fig. 2 the volume of generated biogas depends on the time of fermentation. Intensive generated of biogas occurs 10 days from the day of loading of organic mass, and then there is a decrease in the output of biogas. The largest amount of biogas is formed from straw of grain crops, with the maximum value of 1.75 m^3. The smallest amount of biogas is formed from rye straw; the maximum amount of biogas output is 1.3 m^3.

Conclusions

The bioreactor construction for obtaining biogas from straw of agricultural plants was proposed and the amount of biogas produced in bioreactor from straw of agricultural plants for different values of the duration of the fermentation process is determined. Analytical studies were conducted for three types of straw, including maize stem, cereal straw and rye straw. Research has shown that the amount of biogas output depends on the type of straw and the time of fermentation. The largest amount of biogas output is generated within 10 days of the day the organic biomass is loaded. It was established that the largest amount of biogas is formed from straw of grain crops, with the maximum value of 1.75 m^3. The smallest amount of biogas is formed from rye straw; the maximum amount of biogas output is 1.3 m^3.

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ŽEMĖS ŪKIO AUGALŲ ŠIAUDAI KAIP ALTERNATYVUS ENERGIJOS ŠALTINIS

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Anotacija

Ukraina turi didelį kiekį žemės išteklių žemės ūkio produkcijai. Ji gali aprūpinti savo gyventojus ne tik maisto produktais, bet ir bioenergijos žaliavomis. Kaip bioenergijos žaliava galima naudoti atliekas ir žemės ūkio liekanas, susidariusias derliaus nuėmimo metu, bei derliaus perdirbimo procese, ypač javų, ankštinių augalų šiaudus, kukurūzų ir saulėgrąžų perdirbimo atliekas, saulėgrąžų ir ryžių lukštus, cukrinių runkelių išspaudas. Energijos poreikiams bioenergijoje naudojamos žemės ūkio atliekos, kurios susidaro tiesioginio deginimo būdu arba perdirbant į kietą, skystą ar dujinį kurą. Gaminant dujas iš žemės ūkio atliekų susidaro ne tik energijos šaltinis – biodujos, bet ir aukštos kokybės trąšos. Be to, biodujas patogu naudoti, saugoti ir transportuoti. Jos gali būti naudojamos decentralizuotuose elektros ir šilumos tiekimo blokuose arba gali būti tiekiamos į esamą dujų perdavimo tinklą. Biodujų susidarymo procesas vyksta bioreaktoriuose, kurių konstrukcijos yra labai įvairios ir skiriasi savo forma, medžiaga, biomasės maišymo ir kaitinimo metodais bei perdirbamų žaliavų kiekiu. Tarp žemės ūkio augalų atliekų, kurios suteikia didžiausią energijos potencialą, aktyviai tiriami javų šiaudai, kurie prieinami dideliais kiekiais, ir vis dažniau naudojami kaip žaliava biodujų gamybai.

Šiame straipsnyje biodujų gamybai iš žemės ūkio augalų šiaudų siūloma bioreaktoriaus konstrukcija, kuri užtikrina efektyvų organinės biomasės maišymą ir šildymą, gerina darbo efektyvumą ir mažina bioreaktoriaus energijos suvartojimą. Siekiant nustatyti pradinį biodujų kiekį, buvo atlikti kukurūzų, javų ir rugių šiaudų analitiniai tyrimai. Tyrimai parodė, kad biodujų kiekis priklauso nuo šiaudų tipo ir fermentacijos laiko. Didžiausias pradinių biodujų kiekis susidaro per 10 dienų nuo organinės biomasės pakrovimo dienos. Nustatyta, kad didžiausias biodujų kiekis susidaro iš javų šiaudų, kurių didžiausia vertė – 1,75 m^3. Mažiausias biodujų kiekis susidaro iš rugių šiaudų, kurių didžiausia vertė – 1,3 m^3.

Reikšminiai žodžiai: biomasė, šiaudai, biodujos, anaerobinis fermentavimas, bioreaktorius.

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