The Influence of Previous Treatment of Wheat Straw from Bales on the Intensity of Biogas Outlet

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Abstract. The purpose of the research is the experimental determination of the effect of preliminary mechanical and additional magnetic treatment of wheat straw from bales on the intensity of biogas output. This goal is achieved by solving the following problems: determining the physical-chemical properties and component composition of winter wheat straw from packs; obtaining chopped straw by grinding on a laboratory grinder to a fraction of 5–25 mm in length; processing soaked straw in water in an extruder to form 15 pre-treatment samples; calculation the carbon-nitrogen ratio for mixture of straw of certain pretreatment option and inoculum; determination the specific energy intensity of the extrusion process; conducting fermentation experiments and studies of the biogas output process for 42 days for various options for pre-treatment of winter wheat straw from packs, in particular the option with the simultaneous action of constant magnetic field. The most important results of the research are: experimental proof of the effectiveness of the method of preliminary mechanical-magnetic treatment of winter wheat straw from bales in the production of biogas, which forms a synergetic effect; with a one-time extrusion of straw and treatment with constant magnetic field of 1.8 mT, the biogas output increases, which makes it possible to obtain the same amount of biogas as with 5-fold extrusion, but with energy costs for extrusion reduced by 4.28 times. At the same time, sufficient productivity of the biogas production process is maintained, the lag phase is reduced, and the biomethane output increases by approximately 5.5%. The significance of the obtained results is that the proposed approach to the formation of biogas technology with using mechanical-magnetic processing of wheat straw ensures the intensification of biogas output and an increase in the level of production.
Keywords: anaerobic fermentation, biogas, wheat straw, magnetic field, energy costs, synergetic effect.

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Influența tratării anterioare a paielor de grâu din baloți asupra intensității ieșirii biogazului

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Rezumat. Scopul cercetării este determinarea experimentală a efectului tratamentului mecanic preliminar și magnetic suplimentar al paielor de grâu din baloți asupra intensității producției de biogaz. Acest scop se realizează prin rezolvarea următoarelor probleme: determinarea proprietăților fizico-chimice și a compoziției componentelor paielor de grâu de iarnă din baloți; obținerea paielor tocate prin măcinarea pe o râșniță de laborator până la o fracțiune de 5–25 mm lungime; prelucrarea paielor înmuiate în apă într-un extruder pentru a forma 15 probe de pretratare; calculul raportului carbon-azot pentru amestecul de paie cu anumite opțiuni de pretratare și inocul; determinarea intensității energetice specifice procesului de extrudare; efectuarea de experimente de fermentație și studii ale procesului de ieșire a biogazului timp de 42 de zile pentru diverse opțiuni de pretratare a grâului de toamnă din pachete, în special opțiunea cu acțiunea simultană a câmpului magnetic constant de paie. Cele mai semnificative rezultate ale cercetării sunt: dovada experimentală a eficacității metodei de tratare preliminară mecanico-magnetică a paielor de grâu de iarnă din baloți în producerea de biogaz, care formează un efect sinergic; cu o extrudare unică a paielor și tratament cu câmp magnetic constant de 1.8 mT, producția de biogaz crește, ceea ce face posibilă obținerea aceleiași cantități de biogaz ca la extrudarea de 5 ori, dar cu costurile energetice pentru extrudare reduse cu 4.28 ori. În același timp, se menține o

productivitate suficientă a procesului de producere a biogazului, faza de întârziere este redusă, iar producția de biometan crește cu aproximativ 5.5%. Semnificația rezultatelor obținute este că abordarea propusă pentru formarea tehnologiei biogazului cu utilizarea prelucrării mecanico-magnetice a paielor de grâu asigură intensificarea producției de biogaz și creșterea nivelului de producție.
***Cuvinte-cheie*:** fermentație anaerobă, biogaz, paie de grâu, câmp magnetic, costuri energetice, efect sinergetic.

Влияние предыдущей обработки пшеничной соломы из тюков на интенсивность выхода биогаза

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Аннотация. Целью исследований является экспериментальное определение влияния предварительной механической и дополнительной магнитной обработки пшеничной соломы из тюков на интенсивность выхода биогаза. Поставленная цель достигается путем решения следующих задач: определение физико-химических свойств и компонентного состава соломы озимой пшеницы из паков; получение соломы-сечки при измельчении на лабораторном измельчителе до фракции длиной 5–25 мм; обработка замоченной в воде соломы в экструдере с формированием 15 образцов предварительной обработки; расчет углеродно-азотного соотношения для смеси соломы определенного варианта предварительной обработки и инокулята; определение удельной энергоемкости процесса экструзии; проведение опытов ферментации и исследований процесса выхода биогаза в течение 42 суток для различных вариантов предварительной обработки соломы озимой пшеницы из паков, в частности варианта с одновременным действием постоянного магнитного поля. Наиболее существенными результатами исследований являются: экспериментальное доказательство эффективности способа предварительной механо-магнитной обработки соломы озимой пшеницы из тюков при производстве биогаза, формирующего синергетический эффект; при одноразовой экструзии соломы и обработке постоянным магнитным полем 1.8 мТл увеличивается выход биогаза, что позволяет получить то же количество биогаза, что и при 5-кратной экструзии, но с уменьшенными в 4,28 раза затратами энергии на экструзию. При этом сохраняется достаточная производительность процесса производства биогаза, сокращается лаг-фаза, а выход биометана увеличивается примерно на 5.5%. Значимость полученных результатов состоит в том, что предложенный подход к формированию биогазовой технология с использованием механо-магнитной обработки пшеничной соломы обеспечивает интенсификации выхода биогаза и повышение уровня производства.
Ключевые слова: анаэробная ферментация, биогаз, пшеничная солома, магнитное поле, энергозатраты, синергетический эффект.

INTRODUCTION

Wheat straw is one of the most spread vegetative remains, that are produced in the world. Anaerobic fermentation, that is used during the work with wheat straw, is an attractive practice, with the help of which are fixed the issues as energy recuperation, so as control environmental pollution. Biogas technology can secure link between livestock-raising and plant growing, playing an important role in self-sufficient eco-agriculture [5]. Previous treatment is one of the most important stages in the general conversion of biomass, as it directly influence on the economic efficiency of vegetative material processing in a whole. The main aim of previous treatment is increasing the accessibility of cellulose for microbial decomposition by means of destruction the connections of the lignocellulosic complex, removing lignin and hemicelluloses, reducing the crystallinity of cellulose and increasing the porosity of the material [14, 21]. Different types of physical processes, such as grinding, milling, ultrasound and irradiation can be used for increasing the bioaccessibility of lignocellulosic materials in the biogas fermenter. Energy costs during physical processing of biomass depends on the final size of parts and degree of reduction in crystallinity of the lignocellulosic material. The size of the materials as a rule is reduced to 10-30 mm after crushing and to 0.2-2 mm after grinding.

Thus, for grinding wheat straw to grain size of 0.8 and 3.2 mm, the energy costs makes respectively 51.6 and 11.4 kWh/t. According to the literature facts, the maximum level of fermentative hydrolysis of wheat straw after durable mechanical grinding (14 h) is 80%, while the degree of cellulose crystallinity decreases to 13% [9]. The main defect of this method of activation is duration and high energy costs.

The known results of the investigation from the studying of the microbial reaction on straw groups of bacteria that decomposing cellulose in laboratory biogas installations, which work with manure apart or together with straw [18, 20]. Using previous treatment (steam explosion) in four laboratory fermenters at different temperatures, was studying the influence on the structure of the community of bacteria that belong to the phyla Firmicutes and Bacteroidetes and decomposing cellulose. The addition of straw, its previous treatment and work temperature were affecting on the bacteria community, but there were none substantial differences in productivity of installations and outlet of gas. In another investigation was studied, microbial consortium, which consists of bacteria and fungi, which synergistically reveal great capacity to decompose lignocellulose [27]. A method of previous treatment of lignocellulose with using this functional microbial consortium was developed. Increased capacity was found to dissolution into wheat straw and broth which contain amounts of organic materials such as volatile fatty acids and carbohydrates, that can be used for biogas synthesis. Anaerobic fermentation of previous treatment wheat straw showed an increase of total outlet of biogas and methane respectively on 39.24% and 80.34%, and the faster start-up of 20-days production process comparing with the process based on the unwrought system.

However, solid organic substrata, such as energy culture crops, crop remains (including wheat straw) and organic fraction of solid everyday waste, naturally have low content of microelements. This aspect has been underlined by researchers and numbers of investigations have been realized to demonstrate the importance of microelements in anaerobic etching. In the work [26], it has been proved, that iron chloride ($FeCl_3$) as an addition, added to the thermophilic system of bioreactor with sludge, directly increased production of methane.

Trace of metals are important components of cofactors and enzymes, and their addition to anaerobic bioreactor increases production of methane. Many micro- elements are contained in remains of process extraction of herbs [24]. It was shown that the addition of 10% remains of false ginseng during anaerobic fermentation of wheat straw of combined production of biogas and methane increased on 28 and 37% compared to production, achieved in the control.

The efficiency of the enzyme in fermentative reactions depends on the inclusion of an external magnetic field or participation in the ion-radical reaction of a partner with presence of magnetic moment - magnetic isotope of chemical element [11]. In experiments in vitro was revealed that magnetic isotope of magnesium 25Mg, as well as zinc 67Zn and calcium 43Ca in 2-4 times accelerated synthesis of ATP. For understanding the principles of functioning of biological membranes is important mechanism of passage of ions in the narrow pores of ion channels. For calculations, usually the channel is represented in aspect of a set of energy barriers and pit, without giving a concrete physical picture of the structural features of the channel. In work [3], was investigated the influence of magnetic fields of extremely low-frequency on transport Ca (2+) in a biological system which consist of highly purified vesicles of plasma membrane. Two quantum-mechanical theoretical models were tested, which assume that biologically active ions can be connected with the channel protein and influence on state of the opening the channel. In the work [25] is presented the analysis of steady axisymmetric stokes flow of an electroconductive viscous incompressible fluid through a spherical part, covered with a porous husk in the presence of a uniform magnetic field. The theoretical basis of the influence of the magnetic field on the physico-chemical reactions of aqueous solutions of biomass additionally is confirmed by the results of the experiment. Under the influence of the magnetic field, increases the degree of electrolytic dissociation, the speed of chemical reactions, and the degree of readiness of ions to take electrons in our research in 2020 Year .

In the research [1] evaluated the state of fermentation technology of straw for receiving of biogas. The results show that the selection of an adequate process previous treatment is one of the main key factors of the successful receiving of biogas from straw. The analysis of conducted researches shows that is needed further study of the issue of intensification outlet of biogas from the substrate based on cattle manure water (cattle) with the addition to it extruded straw.

The aim of this research is experimental determine of the influence of previous mechanical and additional magnetic treatment of wheat straw from bales on the intensity outlet of biogas with an assessment of the energy intensity of the previous treatment.

RESEARCH METHODS

The used wheat straw from bales of farm's economy of the Koziv district of the Ternopil region of Ukraine is grayish color with the content of spikes - 11%; content of dry matter (TS) – 93%; content of dry organic matter (ODM) is 89%. Humidity of straw was measured with the help highly precise portable hygrometer straw in bale WILE 27 Olli Control FARMCOMP. The humidity of straw was 16%. As a source of methane bacteria (seeding) was been used fermented too much cattle manure water from the fermenter of biogas installation (BGI) of the University: wCP = 1.7%; pH = 7.7. The laboratory fermenter is the gas-tight packet made of polymeric material with a content of 500 ml. To calculated on amount of biomass was added seeding at the rate of 1 part of the sample to 4 parts of the seeding, displaced the air from the fermenter and soldered hermetically the orifice. To soldered packet was hung up weight, and the packet put into the measuring glass tank. In this way, was determined the initial volume of the researched version. The fermenter was hung up in an incubator where it was kept at temperature of +37.5°C for 42 days. The volume of biogas sample was determined by changing the volume of fermenter in which was the researched biomass. The bit of biomethane corrected for the standard conditions of temperature and pressure in the selected volumes of biogas was determined after 42 days by the way of connecting the outlet orifice of bioreactors to containers, which were filled with lime water (450 ml), through which is passed the formed biogas for gathering carbon dioxide. Chopped straw was received by grinding straw from bales on laboratory's grinder into fractions length is approximately 5–25 mm. The productivity of the laboratory's grinder is 2.2 t/h, the specific energy intensity of the grinding process is 5 kW·h·t^(-1). For the preparation of extruded wheat straw, was used the aft extruder EGK-200 with the nominal power of electric drive 18.5 kW, voltage 380 V.

In the process of extrusion, straw is exposing to short-term, but very intense mechanical influence. Due to the high temperature of 110-180 °C, pressure in 5.1 MPa and efforts in the working parts of the extruder, occur structural-mechanical and chemical changes of the outlet raw materials. Due to the sharp pressure with outlet of the heated up mass, occurs an "explosion" (increase in volume) of the product, which makes it more accessible for the influence of enzymes. During extrusion, to the working area was supplied water with certain correlation of straw-water (R_sw) for removing burning of raw materials in the places of contact with the working surfaces of extruder.

The specific energy intensity of extrusion process was determined as follows:

$$C_e = \frac{\sqrt{3} IU \cos\varphi}{1000G} \tag{1}$$

where C – is specific energy intensity of extrusion process, kW·h·t^(-1); I ; I – consumed current, A; U - voltage of electrical network, V; G – mass productivity of the extruder, t·h^(-1) cosφ – power factor of the electric drive.

Determination of dry matter of DM, organic dry matter of ODM, reaction of medium pH, fractional composition and content of chemical elements was carried out according to appropriate standards and known methods [15]. In table 1 is shown the content of chemical elements of straw from bags.

The main components of straw were determined by standard methods: lignin - by the sulfuric acid method with using 72% sulfuric acid; cellulose - nitrogen-alcohol method; ash - by the method of burning.

In the table 2 is presented the component composition of winter wheat straw. The received results are calculated on the absolutely dry mass of the substance.

The correlation of C/N is an important parameter that should be taken into account during the research. In our case, for samples of wheat straw from bales, the correlation C/N= 81.46.

The determined correlation C/N for cattle manure was 16.1. Depending on the number of stages of straw extrusion, was noted a small increase correlation of C/N to values from 82 to 84.

Each fermenter capaciousness of 515 g contained the substrate in which 20% was sum amount of straw of certain version previous treatment and 80% -was the inoculum.

Table 1

The content of chemical elements in 1 kg of winter wheat straw, g

Nitrogen	Carbon	Phosphorus	Calcium	Iron	Potassium	Magnesiu m	Manganese	Sodium	Zinc
4.8	391.3	4.5	4.9	0.4	28.1	1.25	0.04	0.1	0.02

Table 2

Component composition of winter wheat straw from bales

Content of the component, % from the mass of absolutely dry straw	Indicator for components			
	Cellulose	Hemicellulose	Lignin	Ash
	44.8	31.9	18.4	3.7

The calculation correlation of C/N mixture that is fermented, carried out according to the formula:

$$C/N = \frac{\sum M_n \cdot (C_n(100 - W_n))}{\sum M_n \cdot (N_n(100 - W_n))} \qquad (2)$$

where C/N is the carbon-nitrogen correlation for the converted mixture; Mn-mass of the n-th component of the mixture, kg; Cn- is content of total carbon in the n-th component of the mixture, %; Nn-content of total nitrogen in the n-th component of the mixture, %; Wn- is the humidity of the n-th component of the mixture, %.

Extruded straw in all experiments was soaked before extrusion in water for 15 minutes at temperature of +16°C. Separately was conducted research of fermentation of extruded wheat chopped straw from bales (1-time extrusion) with the simultaneous action of permanent magnetic field. The permanent magnetic field is created by a coil with the amount of turns of 80, reeled on an insulating frame made of copper wire with section of 1.5mm and located near the package with the substrate in the thermostat. The necessary level of magnetic field strength (magnetic induction) in the area where is located the fermenter is regulating in the circuit by the laboratory's autotransformer - rectifier.

Each test was repeated by three times for all variants of previous treatment of winter wheat straw from bales.

Thus, the initial correlation of C/N of mixture was 19.6. For a successful flowing anaerobic fermentation process, correlation of C/N in the mixture should be 20...30 [10]. For the growth of the population of microorganisms, the optimal launching value is correlation of C:N:P of 150:5:1 in our research in 2020 Year . When using mixtures with a lower correlation of C/N, are observed significant losses of nitrogen in the form of ammonia, and when are using mixtures with a higher correlation, decrease rates in cellular growth. During the process CO2, it is consumed much more actively, than nitrogen, and before the end of biofermentation, the given correlation is already in the range of 10 ... 15.

RESEARCH RESULTS

The results of researches the process of outlet of biogas during period of 42 days for various versions for previous treatment of winter wheat straw from bales at temperature of the experiment and without taking into account the dissolved carbon dioxide in substrate are presented in Table 3.

On the Fig. 1 is shown the distribution of parts of extruded straw from bales by fractions. The extruded straw, independently from divisible of extrusion has rather equable distribution parts of straw in the middle fractions (№№. 3, 4, 5). Smaller content of parts from fractions with large size of parts (№№. 1, 2), even smaller - with small sizes (№№. 6, 7).

Table 3

Outlet of biogas during 42 days for different versions of previous treatment of straw

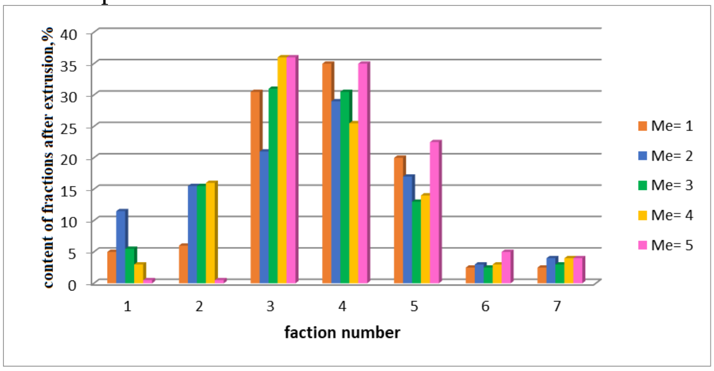
№	Versions of previous treatment of straw	Outlet of biogas, m^3/t VS					
		7d	14d	21d	28d	35d	42d
1	2	3	4	5	6	7	8
1	Seeding of methane bacteria from the fermenter of BGI of the institute; WCP=1.7%, pH= 7.7	0	12	16	16	22	22
2	Raw wheat straw from bales 153 x 3.8 (control sample)	68	197	224	229	248	248/168[1]
3	Wheat chopped straw from bales after shredding 17.5 x 3.3mm[2]	95	204	239	262	263	263/178[1]
4	Fresh wheat chopped straw after shredding 17.5x3.3mm[2]	126	236	272	292	295	295/199[1]
5	Extruded straw from bales (2-times extrusion), 8.6 x 1.4 mm[2]	191	318	336	337	337	337/233[1]
6	Extruded wheat chopped straw from bales (1-time extrusion), 8.4 x 1.4 mm[2]	190	284	331	331	331	331/232[1]
7	Extruded wheat chopped straw from bales (2-times extrusion), 6, Z x 1.4 mm[2]	206	328	344	344	344	344/237[1]
8	Extruded wheat chopped straw from bales (3 times extrusion), 5, Z x 1.4 mm[2]	208	330	356	356	356	356/245[1]
9	Extruded wheat chopped straw from bales (4 times extrusion), 5.2 x 1.4 mm[2]	201	320	374	374	374	374/260[1]
10	Extruded wheat chopped straw from bales (5 times extrusion), 5.0 x 1.4 mm[2]	214	335	377	377	387	387/262[1]
11	Extruded fresh wheat chopped straw (5 times extrusion), 5.0 x 1.4 mm[2]	234	355	397	399	425	425/298[1]
12	Extruded wheat chopped straw from bales (2-times extrusion), water was supplied only during extrusion at +16°C 6.3 x 1.4 mm[2]	212	320	355	368	368	368/255[1]
13	Extruded (5-times extrusion) wheat chopped straw from bales, sifted through sieve with size of closets Zmm 4.5 x 1.2 mm[2]	201	295	336	342	350	350/234[1]
14	Extruded (5-times extrusion) wheat chopped straw from bales, sifted through a sieve with size of closets 2 mm 3.5 x 1.0 mm[2]	201	299	360	360	360	360/251[1]
15	Extruded (5-times extrusion) wheat chopped straw from bags, sifted through a sieve with size of closets 1 mm 2.5 x 1.0 mm[2]	196	313	360	360	360	360/248[1]
16	Extruded (5-times extrusion) wheat chopped straw from bales, sifted through a sieve with size of closets of 0.5 mm; 0.5 x 0.5 mm[2]	174	320	342	342	342	342/229[1]
17	Extruded wheat chopped straw from bales (1-time extrusion), 8.4 x 1.4, irradiation of the substrate in fermenter by the permanent magnetic field of 1.8 mTl	219	329	378	379	380	380/272[1]

[1] Content of methane in selected volumes of biogas was determined after 42 days.

[2] Average size of straw's particles

The results of research in the dependence of outlet of biogas from the average length parts of wheat straw $L_{AV.STV}$, divisible of extrusion M_E, correlation of straw-water (R_{SW}) of raw material during extrusion are presented in the table 4 and on the fig. 2. In the table 4 also brings in an indicators that characterizing power inputs on previous treatment of straw by extrusion, namely: current consumption of electric drive of extruder; duration of extrusion process; specific energy intensity of extrusion process.

When is using straw from bales for extrusion, the average size of parts of straw after 2-times extrusion is 8.6 mm, and when are using chopped straw- 6.3 mm. The outlet of biogas almost did not change (+2%). The current consumption of extruder decreased from 18A to 17A (table 5, Fig. 3).



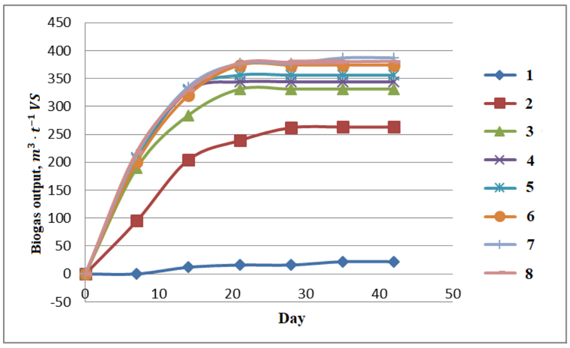
1 - 7 mm x 40 mm, 2 - 5 mm x 25 mm, 3 - 3mm x20mm, 4 - 1 mm x 20 mm, 5 - 0.5 mm, 6- 0.35 mm, 7 - <0.5 mm.

Fig. 1. Distribution parts of straw by fractions.

Table 4

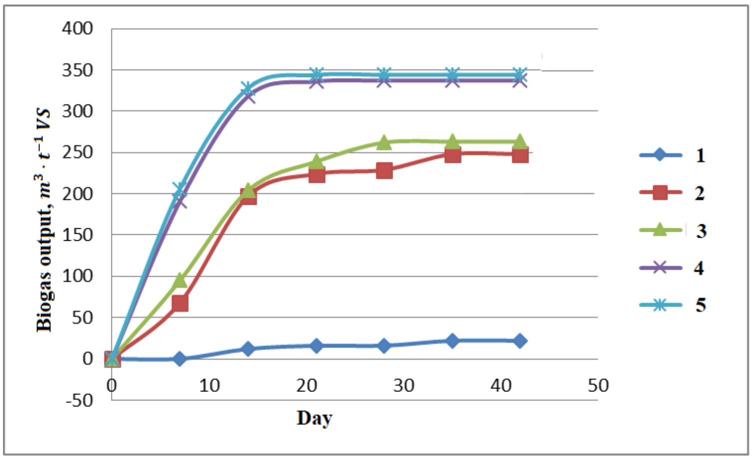
Dependence of outlet of biogas from the divisible of extrusion

№	M_E	R_{SW}	$L_{AV.STV}$, mm		I, A	cosφ	C_e, kW·h/t	G, t^{-1}	Outlet of biogas, $m^3 \cdot t^{-1}$VS				
			to extru-sion	after extru-sion					7d	14d	21d	28d	35d
1	–	–	17.5 (5-40)	–	–	-	-	-	95	204	239	262	263
2	1	1:1	17.5	8.4	17.0	0.6	70,6	0,095	190	284	331	331	331
3	2	1:1	17.5	6.3	17.0	0.6	134	0,05	206	328	344	344	344
4	3	1:1.2	17.5	5.3	17.3	0.62	195.9	0,036	208	330	356	356	356
5	4	1:1.5	17.5	5.2	17.2	0.61	246	0,028	201	320	374	374	374
6	5	1:1.75	17.5	5.0	17.1	0.605	309	0,022	214	335	377	377	387



1 - seeding of methane bacteria from fermenter, 2 - wheat chopped straw from bales (17.5 mm), 3 - extruded wheat chopped straw (1-time extrusion, 8.4 mm), 4 - extruded wheat chopped straw (2-times extrusion, 6.3 mm), 5 - extruded wheat chopped straw (3 - times extrusion, 5.3 mm), 6 - extruded wheat chopped straw(4 - times extrusion, 5.2 mm), 7 - extruded wheat chopped straw (5- times extrusion, 5.0 mm), 8 - extruded wheat chopped straw (1-time extrusion, 8.4 mm treated by permanent magnetic field of 1.8 mTl).

Fig. 2. Outlet of biogas by 42 days of fermentation in depending on divisible of extrusion of wheat chopped straw.



1 - seeding of methane bacteria from the fermenter, 2 - wheat straw from bales (153 mm), 3 - wheat chopped straw from bales (17.5 mm), 4 - extruded wheat straw (2-times extrusion, 8.6 mm), 5 - extruded wheat chopped straw (2-times extrusion, 6.3 mm)

Fig. 3. Outlet of biogas by 42 days of fermentation depending on the average length wheat straw from bales before extrusion.

Table 5

Dependence of outlet of biogas on the average length of straw before extrusion

№	M_E	R_{SW}	$L_{AV.STV}$, mm		I, A	cosφ	C_e kW·h/t	G, t^{-1}	Outlet of biogas, m³/t VS				
			to extru-sion	after extrusion					7d	14d	21d	28d	35d
1	-	-	153	-	-	-	-	-	68	197	224	229	248
2	2-p	1:1	153	8.6	18.0	0.66	312	0.025	191	318	336	337	337
3	-	-	17.5	-	-	-	-	-	95	204	239	262	263
4	2-p	1:1	17.5	6.3	17.0	0.6	134	0.05	206	328	344	344	344

DISCUSSION

During research №. 10 (Table 3) with extruded wheat chopped straw (5-times extrusion), which was soaked before extrusion in water for 15 minutes at +16°C with sizes of parts of 5.0 mm x 1.4 mm, was got the maximum specific outlet of biogas and biomethane, respectively 387 and 262 m³/t VS. At the same time, in research №16 with analogical conditions of extrusion of straw, but sifted through the sieve with the smaller closet's size (0.5 mm), were got the minimum specific outlet of biogas and biomethane, respectively, 342 and 229 m³/t VS. The result coincides with research of the influence of previous treatment of winter wheat straw that were kept in shelters in ordinary roll bales [7]. The lower sieve selected in this experiment had size of cells 0.5 mm. After sieving, was conducted previous cleaning with hot water. Cumulative production of biomethane was 225 m³/t VS. Dry grinding was chosen as the method of previous treatment because the smaller parts have much larger surface area per unit mass, and thus, the microorganisms and their enzymes have large contact area to work. However, in our research, was established regularity of decrease of specific outlets of biogas and biomethane even with 5-times extrusion in experiments with the length of straw's parts less than 5 mm. That is, grinding really contributes to the availability of substrate for microbial communities, but exists certain limit of sizes to which should be conducted grinding. For the microbial community is necessary also certain area of carriers for immobilization of microorganisms and creation of colonies.

With decreasing the average length of extruded wheat straw (Table 4) from 8.4 mm to 5.0 mm, the outlet of biogas have increased from 331 m³/t VS to 387 m³/t VS, that is on 17%. Compared to initial chopped straw (control experiment), the average length of straw's parts decreased from 17.5 mm to 5.0 mm, and the outlet of biogas has increased from 263 m³/t VS to 387 m/t VS, that is on 47%. Attached to length of extruded wheat straw of 8.4 mm and treatment of substrate with the permanent magnetic field of 1.8 mT (Table 3), the outlet of biogas increased from 331 m^3/t VS to 380 m^3/t VS, that is on 15%, that allows to receive the same amount of biogas, as attached to the length of extruded straw of 5 mm (Me =5), but with smaller power inputs for mechanical treatment (Table 3-5; Fig. 2, Fig. 3). As shown by the summary curves (Fig. 2, Fig. 3), the speed of methanogenesis process considerable measure was depended on the method of previous treatment. A significant difference was given by the results of researches in which respectively were used wheat straw from bales of durable keeping and fresh straw. Thus, with 5-times extrusion, sizes of parts of straw practically converge, but the outlet of biogas in experiment №. 10 (Table 3) adds up 387 m^3/t VS, for methane – 262 m^3/t VS, which is lower by about 10% in comparing with the result of experiment. №.11 – biogas 426 m^3/t VS, methane - 298 m/t VS. This is also confirmed in experiments with chopped straw: the outlet of biogas in experiment №. 3 (263 m^3/t VS) is lower comparing to the result of experiment №. 4 (295 m^3/t VS) on 12%. The difference can be explained by the fact, that deteriorated in store ("gray") straw are washed out the chemical elements and already partly are lost its nutritional properties, since take place partly disintegration of microorganisms by account of additional feeding with nitrogen, which they intercept from the air.

The results of the given research coincide with the results of work [17], in which investigated the bioconversion of lignocellulosic waste (wheat straw) after physical and chemical previous treatment and cattle manure in the process of anaerobic joint fermentation in mesophilic bioreactors of periodical operation. Increases biogas production with increasing of the content volatile matter (VS) in wheat straw and decreasing correlation of inoculum-substrate. (ISR). On the level of total content of solid matter (TS) 3% and correlation of inoculum-substrate (ISR = 1), outlet of biogas and methane were respectively 510 and 307 m/t VS. Some difference in the productivity of biogas in the work [17] and the given researches caused by 12% difference correlation of inoculum-substrate, and also the chemical previous treatment of wheat straw, which, by the way, complicates the technological process of biogas production. The results of this research on outlet of biomethane also coincide with the results of work [13], in which investigated the influence of three different methods of previous chemical treatment of wheat straw with using: N-oxide of organic solvent at 120 °C for 3 hours; ethanol as an organic solvent at 180 °C during 1 hour; alkaline treatment with NaOH at 30 °C during 24 hours. The three methods of previous treatment had different influence on the chemical content of straw. Thus, previous alkaline treatment was the most effective for removing the lignin’s fraction. The influence of different scales of mechanical fragmentation binding of different concentrations of NaOH on lignocellulosic components and removal of lignin from wheat straw is shown in [8]. The content of lignin rapidly decreased with increasing concentration of NaOH and then reached stable value of about 13% when the concentration of NaOH was higher than 6%. Are known that lignins straw of grass plants are structurally different from lignins of soft or hard wood, and lignins of straw have characteristic solubility in alkalis. The solubility of alkalis is explained by the presence of alkali-labile complicated ethereal links between hydroxycinnamic acids and hemicelluloses (arabinoxylans) in complexes of lignin/phenolic substances–carbohydrates. The action of permanent magnetic field in the process of anaerobic fermentation manifests itself in significant decrease of level of oxidizing-renewable potential and increasing of pH substrate and corresponding increasing of the rate of chemical reactions in our research in 2020 Year . It should also be emphasized the fact that inoculum itself, as component of mixture, also has lignin up to 10% from the mass of dry matter [23]. Assuredly, the concentration and effect of alkaline environment (increasing pH) in the given research were much smallerr, but the synergistic effect from increasing the rate of chemical reactions and some dissolution of lignin in substrate was manifested.

It is interesting to compare the results (Table 3) with the results achieved in [5, 16, 19, 22], which demonstrate the synergistic effect in fermentation of mixture of waste and, accordingly, the possibility of adding to wheat straw various nutritional remnants. In work [5], mixture of cow’s hem waste with blood (SB), various nutritional remnants (VC) with content of straw (37.5%), foods for animals (37.5%), and waste of fruits and vegetables 12 (25 %). The outlet of biomethane of 452 m/t VS indicates on the achievement of the synergistic effect even with low launching value of correlation C/N= 11.8. In work [16], were used mechanically previous treated lignocellulosic remnants (wheat and rice straw, pulp and wheat straw, bagasse and rice straw, pulp, wheat and rice straw) in anaerobic bioreactors of periodical mode under mesophilic mode. The synergistic effect formed maximum value of 339 NmLCH4/gVS and stable production of biomethane at correllation of substrate to inoculum (S/I) of 1.5 by the way of joint decompose of wheat and rice straw. At the same time, the lowest outlet of biomethane of 15.74 NmLCH4/gVS was observed for mixture of bagasse and rice straw at correlation of substrates to inoculum of 2.5. Besides, all studied mixtures had demonstrated significant by duration (up to 20 days), lag-phase which was not observed in this research (Fig. 2, Fig. 3). Strategies for biological previous treatment of lignocellulosic resources of second-generation for increasing of biogas production are demonstrated in works [19, 22]. However, strategies of chemical and physical previous treatment demonstrate natural defects, including the formation of inhibitory products, biological previous treatment, more often propagandize as ecologically pure process with low energy consumption, low outlays on utilization, and milder conditions of exploitation. Polyporus brumalis BRFM985 was cultivated on wheat straw to investigate the simultaneous influence of previous treatment parameters on anaerobic fermentation, including initial moisture of substrate, temperature, duration, and adding of metal. For quantitative judge importance of each parameter and also synergistic effect between them was used methodology reaction of surface. First of all, the addition of metal and secondly, the duration of previous treatment led to the positive influence. Nevertheless, the promising potential of methods of biological previous treatment has not been fully realized yet, and the highest achieved production of methane 182 m^3/t TS during 20 days that is rather low result in comparison with the given research (Fig. 2, Fig. 3).

In this work, it is possible to compare the anaerobic joint fermentation of cattle manure with crushed wheat straw with the results of research [23], in which, with an average length of parts of wheat straw, crushed straw of 20 mm, the outlet of methane on 42 day was 250 m/t VS. which exceeds the result of experiments №.3 and №.4 (Table 3). But this is explained by the fact that the research [23] was carried out in laboratory's reactors in thermophilic mode (50 °C).

At the same time, the results of this research significantly exceed the results of experiments [18, 20] that were carried out in laboratory's reactors (5 l) that worked with organic loading of raw straw or straw subjected to steam explosion, during (joint processing) joint digestion with cattle manure. Processes over 25 days at operating temperatures of 37, 44, or 52 °C showed stable productivity but low outlet of methane (0.13–0.21 N L CH4/kg VS) for as separete manure and so as joint digestion with straw.

An evaluation of three versions of previous treatment, i.e., mechanical treatment, steam explosion, alkaline treatment, shows that mechanical previous treatment is economically more beneficial than the other versions, even if the expected outlet of biogas is evidently lower [1]. This is connected with that the previous chemical or thermal treatment leads to high investment costs due to high pressure, temperature or long processing time of treatment. In this research, the specific energy intensity of the extrusion process has proportional dependence on $C_E = 65.2 \cdot M_E$ divisible of extrusion (Table 4). When the length of the extruded wheat straw is 8.4 mm and treatment of substrate by permanent magnetic field of 1.8 mT (Table 3), the outlet of biogas increases, which allows to obtain the same amount of biogas as with 5-times extrusion, but with smaller amount in 4.28 times the power inputs for extrusion (Fig. 2, Fig. 3). At the same time, is kept sufficient productivity of the process of biogas production and the output of biomethane increases by approximately on 5.5%.

Understanding that in water under the influence of magnetic field, eventuating its structural rearrangement, and on some chemical elements and compounds also influence magnetic field, it is possible to trace the influence (direct or mediated) on specific technological result. A few examples will insert clearness in this statement. Many researches have shown that water that has been previously suffered influence of electromagnetic, electrical, vibrational or magnetic fields kepts its biological activity during long periods of time. At the same time, is observed change on specific electrical conductivity, magnetic susceptibility, surface tension, and viscosity [12]. The water kepts and transmits information that is concerned to dissolved substances with the help of the hydrogen net. The evolution of physical-chemical parameters over r the time provide for trigger effect of the structure of molecular aggregates after the potentiation procedure [6]. The magnetic system, is configured for mode of water destructuring, ensures increasing of monomolecules in its structure to 30%. Since water monomolecules have minimum size in comparing to clusters, they easily penetrate into cells. Besides, they are anomalously polar and, therefore, able to quickly dissolve microcrystals of salt and ensure the unobstructed supply of nutrients to cells of microorganisms. The concentration of hydrogen ions (pH) significantly effects on the development of microorganisms already in the of process fermentation in the bioreactor.

Taking into account the high concentration of magnesium, iron and calcium in straw (Table 1) and substrate, including the magnetic isotope 25Mg, Ca (2+), we can assume that their participation in the process of intensification of methanogenesis [3, 11]. Existing models of functioning of biological membranes [6, 12] represent ion channels as water pores of atomic's sizes, formed by macromolecules with active charged centers. At the same time, the charge centers create a constant electric field, perpendicular to surface and is external to ratio to parts of the interphase region. The direction action of the force is determined by the sign of charge of the part. In the biological membranes exists channels, the properties of which change on the applied influence, for example, of electric or magnetic field.

These effects are called "gates", since by opening and closing the pore under the influence of field, they control by the movement of ions. The proposed theoretical models in [4, 6, 12] and experimentally determined characteristics of the physical-chemical processes in bioreactor give good qualitative convergence of the influence of magnetic field on activation of the methanogenesis processes which were considered in the given work. The effects of change in oxidizing-restoration potential and pH are shown for different substrates both under the influence of rotating electromagnetic field with level of magnetic induction of 0.0035 T, and when substrate is moved in field of permanent magnets with the level of magnetic induction of 0.065 T. The industrial implementation of the method of activation of anaerobic fermentation processes is eventuated by the way of using multifunctional electromechanical converter with an external massive hollow rotor on which are located the pallets, intended for mixing the substrate. The magnetic field of interharmonic frequencies is formed in the zone of contact of rotor and substrate in our researches in 2017-2019 Years. The methodology of activation of anaerobic fermentation processes by magnetic field can be also used by the way of influencing on the catalyst process nickel [28] and synthetic magnetite. Schematically, the process of obtaining of synthetic magnetite can be written as follows:

$$FeCl_2 + 2FeCl_3 + 8NH_3 \cdot H_2O \rightarrow$$
$$Fe_3O_4 + 8NH_4Cl + 4H_2O$$

Iron chloride practically is almost always dissolved in water, and ammonia hydrate is present in the process of bioconversion of cattle manure water or bird droppings.

CONCLUSIONS

Biogas technology with using mechanically processed wheat straw can provide link between livestock and crop production, thus playing an important role in self-sufficient eco-agriculture.

Was conducted an experimental analysis of the possibilities of using and proposed acombined method of previous mechanical-magnetic processing of deteriorated in store ("gray") winter wheat straw from bales in production of biogas in which is formed synergistic effect.

When the length of extruded wheat straw is 8.4 mm and treatment of substrate with permanent magnetic field of 1.8 mT, the outlet of biogas increases, which allows obtaining the same amount of biogas as with 5-times extrusion, but with less on 4.28 times power inputs for extrusion. At the same time, is kept sufficient productivity of the biogas production process, and the outlet of biomethane increases by approximately on 5.5%.

Extrusion and influence of magnetic field not only shorten the lag- phase and activate the rapid growth of the microbial community in bioreactors, but also significantly shorten the stationary phase of their development.

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REFERENCES

[1] Andersen L.F., Parsin S., Lüdtke O., Kaltschmitt M. Biogas production from straw–the challenge

feedstock pretreatment. *Biomass Conversion and Biorefinery*, 2022, vol. 12, pp. 379-402. https://doi.org/10.1007/s13399-020-00740-y

[2] Arthur R., Antonczyk S., Off S., Scherer P.A. Mesophilic and Thermophilic Anaerobic Digestion of Wheat Straw in a CSTR System with 'Synthetic Manure': Impact of Nickel and Tungsten on Methane Yields, Cell Count, and Microbiome. *Bioengineering*, 2022, vol. 9, no. 1, 13.

[3] Bauréus Koch C.L.M., Sommarin M., Persson B.R.R., Salford L.G., Eberhardt J.L. Interaction between weak low frequency magnetic fields and cell membranes. *Bio Electro Magnetics*, 2003, vol. 24, no. 6, pp. 395-402. https://doi.org/10.1002/bem.10136

[4] Block S. Brownian motion at lipid membranes: a comparison of hydrodynamic models describing and experiments quantifying diffusion within lipid bilayers. *Biomolecules*, 2018, vol. 8, no. 2, p. 30. https://doi.org/10.3390/biom8020030

[5] Diaz J.P, Reyes I.P, Lundi M., Horvath I.S. Co-digestion of different waste mixtures from agro-industrial activities, kinetic evaluation and synergetic effects. *Bioresource Technology*, 2011, vol. 102, pp. 10834-10840.

[6] Elia V., Baiano S., Duro I., Napoli E., Niccoli M., Nonatelli L. Permanent physico-chemical properties of extremely diluted aqueous solutions of homeopathic medicines. *Homeopathy*, 2004, vol. 93, no. 03, pp. 144-150.

[7] Fjørtoft K., Morken J., Hanssen J.F., Briseid T., Pre-treatment methods for straw for farm-scale biogas plants. *Biomass and Bioenergy*, 2019, vol. 124, pp. 88-94.

[8] Gao C., Yang J., Han L. Systematic comparison for effects of different scale mechanical-NaOH coupling treatments on lignocellulosic components, micromorphology and cellulose crystal structure of wheat straw. *Bioresource Technology*, 2021, vol. 326, 124786.

[9] Ghizzi D., Silva G. Effects of grinding processes on enzymatic degradation of wheat straw. In: *Bioresource Technology*, 2012, vol. 103, no. 1, pp. 192-200.

[10] Habiba L., Hassib B., Moktar H. Improvement of activated sludge stabilisation and filterability during anaerobic digestion by fruit and vegetable waste addition. *Bioresource technology*, 2009, vol. 100, no. 4, pp. 1555-1560. https://doi.org/10.1016/j.biortech.2008.09.019

[11] L'etuta U.G., Tikhonova T.A. Magnetic Fields and Magnetic Isotope 25Mg Effects on Biofilms Formation by Bacteria E. coli. *Doklady Biochemistry and Biophysics*, 2019, vol. 484, no. 1, pp. 85-87. https://doi.org/10.1134/S160767291901023X

[12] Lobyshev V.I. Water is a sensor to weak forces including electromagnetic fields of low intensity. *Electromagnetic Biology and Medicine*, 2005, vol. 24, no. 3, pp. 449-461.

[13] Mancini G., Papirio S., Lens P.N., Esposito G. Increased biogas production from wheat straw by chemical pretreatments. *Renewable energy*, 2018, vol. 119, pp. 608-614.

[14] Mani S., Tabil L.G., Sokhansanj S. Grinding performance and physical properties of wheat and barley straws, corn stover and switchgrass. *Biomass and bioenergy*, 2004, vol. 27, no. 4, pp. 339-352.

[15] Mehrabani R.T., Mosavi M.A. Determination of chemical composition and gross energy of cereal straw (Wheat & Barley) in Kermanshah province, Kermanshah Agricultural and Natural Resources Research Center, 1998.

[16] Meraj S., Liaquat R., Raza Naqvi S., Sheikh Z. Zainab A., Khoja A.H., Atabani A. Enhanced Methane Production from Anaerobic Co-Digestion of Wheat Straw Rice Straw and Sugarcane Bagasse: A Kinetic Analysis. *Applied Sciences*, 2021, vol. 11, no. 13, 6069. https://doi.org/10.3390/app11136069

[17] Ranjbar F.M., Karrabi M., Shahnavaz B. Bioconversion of wheat straw to energy via anaerobic co-digestion with cattle manure in batch-mode bioreactors (Experimental investigation and kinetic modeling). *Fuel*, 2022, vol. 320, 123946. https://doi.org/10.1016/j.fuel.2022.123946

[18] Risberg K., Sun L., Levén L., Horn S. J., Schnürer A. Biogas production from wheat straw and manure–impact of pretreatment and process operating parameters. *Bioresource Technology*, 2013, vol. 149, pp. 232-237.

[19] Rouches E., Zhou S., Sergent M., Raouche S., Carrere H. Influence of white-rot fungus Polyporus brumalis BRFM 985 culture conditions on the pretreatment efficiency for anaerobic digestion of wheat straw. *Biomass and Bioenergy*, 2018, vol. 110, pp. 75-79.

[20] Sun L., Müller B., Schnürer A. Biogas production from wheat straw: community structure of cellulose-degrading bacteria. *Energy*, Sustainability and Society, 2013, vol. 3, no. 1, pp. 1-11.

[21] Sun Y., Cheng J. Hydrolysis of lignocellulosic materials for ethanol production: a review. *Bioresource technology*, 2002, vol. 83, no. 1, pp. 1-11.

[22] Wagner A.O., Lackner N, Mutschlechner Prem E.M., Markt R, Illmer P. Biological Pretreatment Strategies for Second – Generation Lignocellulosic Resources to Enhance Biogas Production. *Energies*, 2018, vol. 11, no. 1779, pp. 1- 14.

[23] Xavier C.A., Moset V., Wahid R., Møller H.B. The efficiency of shredded and briquetted wheat straw in anaerobic co-digestion with dairy cattle manure. *Biosystems Engineering*, 2015, vol. 139, pp. 16-24.

[24] Xi Y., Liu Y., Ye X., Du J., Kong X., Guo, D.,

Xiao Q., Enhanced Anaerobic Biogas Production From Wheat Straw by Herbal-Extraction Process Residues Supplementation. *Frontiers in Bioengineering and Biotechnology*, 2021, vol. 9, no. 623594, pp. 1-8. https://doi.org/10.3389/fbioe.2021.623594

[25] Yadav P.K., Deo S., Singh S.P., Fillipov A. Effect of magnetic field on the hydrodynamic permeability of a membrane built up by porous spherical particles. *Colloid Journal*, 2017, vol. 79, pp. 160-171. https://doi.org/10.1134/S1061933X1606020X

[26] Yu B., Zhang D., Dai X., Lou Z., Yuana H., Zhu N. The synthetic effect on volatile fatty acid disinhibition and methane production enhancement by dosing FeCl3 in a sludge thermophilic anaerobic digestion system. *RSC Adv.*, 2016, vol. 6, 21090–21098. https://doi.org/10.1039/C5RA26245C.

[27] Zhong C., Wang C., Wang F., Jia H., Wei P., Zhao Y. Enhanced biogas production from wheat straw with the application of synergistic microbial consortium pretreatment. *RSC advances*, 2016, vol. 6, no. 65, pp. 60187-60195.

[28] Zipes D.P., Jalife J., Stevenson W.G., Cardiac Electrophysiology: From Cell to Bedside E-Book. Elsevier Health Sciences. 2017.

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