Effect on the Process of Biomethanogenesis of Pre-Treatment of Wheat Straw by the High Intensity High-Frequency Electromagnetic Field

Zablodsky N.[1], Klendiy P. [2], Dudar O.[3]
[1]National University of Life and Environmental Sciences of Ukraine,
Kyiv, Ukraine
[2] Separated subdivision "Berezhany Agrotechnical Institute" National University of Life and Environmental Sciences of Ukraine,
Berezhany, Ukraine
[3]Separated structural subdivision “Berezhany professional college of National University of Life and Environmental Sciences of Ukraine”
Berezhany, Ukraine

Abstract. The purpose of the researches is the experimental determination of the effect of pre-treatment with the high-frequency electromagnetic field of high intensity on the appearance of deformations and structural rearrangements in the cells of wheat straw and on the intensity of biogas output.The set goal is achieved by the way of solving the following issues: obtaining chopped straw when it is grinding on a laboratory grinder to the fraction with average sizes of 5.2 mm x 1.5 mm and soaking in tap water for 15 minutes; measurement of distribution of the specific power of the electromagnetic field in the area where the samples of crushed wheat straw are located; comparison of images of the structure of straw under a light microscope for samples after influence by the high-frequency electromagnetic field of high intensity and control samples that were not exposed to such influence; carrying out fermentation experiments and researches of the process of biogas output within 20 days of a mixture of straw and inoculum for options with pre-treatment of wheat straw by the electromagnetic field of a Tesla’s transformer and without treatment by field. The most important results of the researches are: experimental evidence of the effectiveness of the method of pre-treatment of wheat straw by the high-frequency electromagnetic field of high intensity during the production of biogas. The significance of the obtained results is that the proposed approach to the formation of biogas technology with using the pre-treatment of wheat straw by the high-frequency electromagnetic field of high intensity ensures the intensification of biogas output.
Keywords: anaerobic fermentation, biogas, magnetic field water substrates, biomass wastes, lignin, electric field strength.

DOI: https://doi.org/10.52254/1857-0070.2025.1-65.03
UDC: **621.37:631.95**

Efectul asupra procesului de biometanogeneză al pretratării paielor de grâu cu câmp electromagnetic de înaltă intensitate și de înaltă frecvență

[1]Zablodsky N., [2]Klendy P., [3]Dudar O.
[1]Universitatea Națională de Științe ale Vieții și Mediului din Ucraina, Kiev, Ucraina
[2]Subdiviziunea separată "Institutul Agrotehnic din Berejanî" Universitatea Națională de Științe ale Vieții și Mediului din Ucraina, Berejanî, Ucraina
[3]Subdiviziune structurală separată „Colegiul profesional din Berejanî al Universității Naționale de Științe ale Vieții și Mediului din Ucraina” Berejanî, Ucraina

Rezumat. Scopul cercetărilor constă în determinarea experimentală a efectului pretratamentului cu câmp electromagnetic de înaltă frecvență și de intensitate înaltă asupra apariției deformațiilor și rearanjărilor structurale în celulele paielor de grâu și asupra intensității producției de biogaz. Scopul stabilit este atins prin rezolvare a următoarelor probleme: obținerea paielor mărunțite la măcinarea acestora pe un polizor de laborator până la fracția cu dimensiuni medii de 5.2 mm x 1.5 mm și înmuierea în apă de robinet timp de 15 minute; măsurarea distribuției puterii specifice a câmpului electromagnetic în zona în care se află probele de paie de grâu mărunțite; compararea imaginilor structurii paielor la microscopul optic pentru probele după influențarea de către câmpul electromagnetic de înaltă frecvență de intensitate mare și probele martor care nu au fost expuse la o astfel de influență; efectuarea de experimente de fermentare și cercetarea procesului de producere a biogazului în termen de 20 de zile dintr-un amestec de paie și inocul pentru opțiuni cu pretratare a paielor de grâu prin câmpul electromagnetic al unui transformator Tesla și fără tratare prin câmp. Cele mai importante rezultate ale cercetărilor sunt: dovezi

experimentale ale eficacității metodei de pretratare a paielor de grâu prin câmpul electromagnetic de înaltă frecvență de intensitate ridicată în timpul producției de biogaz. Cele mai importante rezultate ale cercetărilor sunt: dovezi experimentale ale eficacității metodei de pretratare a paielor de grâu prin câmpul electromagnetic de înaltă frecvență de intensitate ridicată în timpul producției de biogaz. Semnificația rezultatelor obținute este că abordarea propusă pentru formarea tehnologiei biogazului folosind pretratarea paielor de grâu cu un câmp electromagnetic de înaltă frecvență de intensitate mare asigură intensificarea randamentului de biogaz.
Cuvinte-cheie: fermentare anaerobă, biogaz, substraturi de apă cu câmp magnetic, deșeuri de biomasă, lignină, intensitatea câmpului electric.

Воздействие на процесс биометаногенеза предварительной обработки соломы пшеницы высокочастотным электромагнитным полем высокой напряженности

Заблодский Н.[1], Клендий П. [2], Дудар О.[3]
[1]Национальный университет биоресурсов и природопользования Украины, Киев, Украина
[2]Отделенное подразделение «Бережанский агротехнический институт» Национального университета биоресурсов и природопользования Украины, Бережаны, Украина,
[3]Отделенное структурное подразделение «Бережанский профессиональный колледж Национального университета биоресурсов и природопользования Украины», Бережаны, Украина.
Аннотация. Целью исследований является экспериментальное определение влияния предварительной обработки высокочастотным электромагнитным полем высокой напряженности на появление деформаций и структурных перестроек в клетках пшеничной соломы и на интенсивность выхода биогаза. Поставленная цель достигается путем решения следующих задач: получение соломы-сечки при измельчении на лабораторном измельчителе до фракции с средними размерами 5.2 мм x1.5 мм и замачивание в водопроводной воде в течение 15 минут; измерение распределения удельной мощности электромагнитного поля в зоне расположения образцов измельченной пшеничной соломы; сопоставление изображений структуры соломы под световым микроскопом образцов после воздействия высокочастотным электромагнитным полем высокой напряженности и контрольных образцов, не подвергавшихся такому воздействию; проведение опытов ферментации и исследований процесса выхода биогаза в течение 20 суток смеси соломы и инокулята для вариантов с предварительной обработкой соломы пшеницы электромагнитным полем трансформатора Теслы и без обработки полем. Наиболее существенными результатами исследований являются: экспериментальное доказательство эффективности способа предварительной обработки соломы пшеницы высокочастотным электромагнитным полем высокой напряженности при производстве биогаза; при предварительной обработке высокочастотным электромагнитным полем выход биогаза возрастает на 57% по сравнению с контрольным образцом, а скорость процесса метаногенеза в значительной степени изменяется от 7.81 м3/т СВ для контрольного образца до 13.75 м3/т СВ в сутки для обработанных электромагнитным полем образцов; визуально установлено появление деформаций и структурных перестроек в клетках пшеничной соломы. Значимость полученных результатов состоит в том, что предложенный подход к формированию биогазовой технология с использованием предварительной обработки соломы пшеницы высокочастотным электромагнитным полем высокой напряженности обеспечивает интенсификацию выхода биогаза.
Ключевые слова: анаэробная ферментация, биогаз, магнитное поле водных субстратов, отходы биомассы, лигнин, напряженность электрического поля.

INTRODUCTION

Increasing the efficiency of biogas complexes of agro-industrial enterprises and farms is an urgent problem due to the increase in the consumption of biogas for technical and everyday aims [1]. In this regard, works from the study of physico-chemical factors that influence on the biogas potential are relevant. Wheat straw is one of the most spread plant remains, and with the help of anaerobic fermentation, the issue of both regeneration of energy and control of environmental pollution can be solved, to ensure the connection between animal husbandry and crop production, also the formation of self-sufficient eco-agriculture [2].

Pre-treatment- is an important stage of the general conversion of biomass, the main aim of which is increasing accessibility of cellulose for microbes by the way of destruction the compounds of the lignocellulosic complex, removing lignin and hemicellulose, reducing the crystallinity and increasing the porosity of the material [3]. To increase the bioaccessibility of lignocellulose in a biogas fermenter, ultrasound and irradiation, organic solvents and alkaline treatment and mechanical grinding can be used for pre-treatment.

Power inputs during physical processing of biomass depends on the final sizes of the particles and the degrees of decreasing in crystallinity of the lignocellulosic material. For example, for grinding of wheat straw to the size of 0.8 and 3.2 mm, the power inputs is 51.6 and 11.4 kWh/t, respectively, and the maximum level of enzymatic hydrolysis of wheat straw after durable mechanical grinding (14 h) is 80%, while the degree of cellulose crystallinity decreases to 13% [4]. Duration and high power inputs - are the main defect of this method of activation.

Therefore, this type of biomass reveals to be expensive to ensure a high rate of conversion on methane. The complex structure of lignocellulose prevents the penetration into it of cellulolytic enzymes, as a result, a durable time for retention is necessary to increase the accessibility of nutrients. Researches have shown that pre-treatment of maize silage by an impulsive electric field increased potential of biogas [5]. The dependence of the efficiency of the enzyme in enzymatic reactions from the external magnetic field with the participation of an ion- radical - a magnetic isotope of a chemical element [6], also the effect of nanoparticles of iron (Fe) and oxide of iron (Fe_3O_4) with different concentrations on the production of biogas and methane [7] was revealed.

The mechanism of passage of ions into the narrow pores of ion channels is important for understanding the principles of functioning of biological membranes. In the work [8], the effect of magnetic fields of extremly-low frequency on the transport of Ca (2+) in a biological system was investigated and two quantum-mechanical theoretical models were tested, which assume that biologically active ions can be connected with the channel protein and the influence on the state of the opening of the channel. The analysis of stokes flow of an electroconductive viscous incompressible fluid through a spherical part covered by the porous membrane in the presence of the uniform magnetic field is considered in [9]. The theoretical basis of the influence of the magnetic field on the physico-chemical reactions of aqueous solutions of biomass was additionally confirmed by the results of the experiment.Under the influence of the magnetic field, the degree of electrolytic dissociation, the rate of chemical reactions, and the degree of readiness of ions to absorb electrons increases, which is confirmed in research [10].

Works that are devoted to the effect on biomass and processes of biomethanogenesis of the electromagnetic fields are significantly different by the type of electromagnetic field, intensity, duration of influence, long-term/short-term effects, and biological goals (cells and organisms).

For example, it has been shown that impulses are often more effective than sinusoids. There is observed discrepancy in the data and the absence of clear mechanisms of action [11].

The electromagnetic fields as an abiotic stress cause the change in the chemical content of plant cells due to oxidative stress after the increasing of active oxygen shapes, namely, singlet oxygen, superoxide-ions, and peroxides [12,13]. The first consequence of abiotic stress is ionic imbalance and hyperosmotic stresses, which in turn cause cascade of the molecular net with subsequent activation of mechanisms which reacts on stress.

The observations are presented in work [14] show that under the action of the high-frequency electromagnetic field (HF-EMF), occurs changes not only in tissues that are submited to direct influence, but also systemically in distant plant tissues. At the same time, non-thermal destruction of cellular organelles occurs and interaction between HF-EMF and cellular ultrastructural compartments is observed, many metabolic activities are modified.

In the research [15] is estimated the state of the technology of fermentation of the straw for getting the biogas. The results show that the selection of an adequate pre-treatment process is one of the main key factors for the successful receiving of biogas from straw. In the most researches, there is absent systematic approach, physical and biochemical argumentation of optimality from the point of view of energy efficiency. There are practically absent works that connect the experimentally achieved results of biomethanogenesis and the results of modeling the process of the influence of the physical field, including works devoted to the preliminary treatment of biomass with the high-frequency electromagnetic field.

The purpose of this work is researching of the influence of pre-treatment of wheat straw with the high-frequency electromagnetic field of high electric intensity on the process of biomethanogenesis.

EXPERIMENTAL RESEARCH METHOD

Wheat straw from the farm of Ternopil district of Ternopil region was used for the research. The straw was crushed on laboratory grinder LZM-1 and soaked in water-pipe water for 30 minutes at the temperature of 17^0 C. After that, it was treated with the electromagnetic field, the source of which was a Tesla's transformer (Fig. 1.).

The specific power of the electromagnetic field was 204 Wt/m^2, the frequency f = 1.514 MHz, the voltage of the secondary winding of the transformer U2 = 2400 B. To determine the power, a PCE-EMF 30 device was used to measure high-frequency electromagnetic fields with a measurement range from 1 MHz to 10 GHz, and the frequency was measured with a Tiny SA ULTRA device.The distribution of the electromagnetic field around the Tesla's transformer is schematically presented in Fig. 2.

With a large value of the high quality of the secondary contour and the creation of resonant conditions of excitation, the conversion ratio of voltage in the Tesla's transformer significantly exceeds the transformation due to the inductive connection between the primary and secondary contours of an ordinary transformer.

The penetration depth of the electromagnetic field into the environment (c) is determined by the formula [16]:

$$h = 1/a \, , \qquad (1)$$

where, a - is the attenuation factor of wave, which depends on the electrical conductivity of the medium σ and the fundamental frequency of the field f:

$$a = \left[\frac{4\pi^2 f^2 \varepsilon_0 \mu_0}{2} \left(-1 + \sqrt{1 + \left(\frac{\sigma}{2\pi f \varepsilon_0} \right)^2} \right) \right], \qquad (2)$$

where, ε_0 and μ_0 - are the absolute dielectric and magnetic permeability of the medium, respectively.

The density of the electromagnetic power that is connected with the electromagnetic waves (measured in watts per square meter) is obtained by the vector product between electric and vectors of the magnetic field (namely the Poynting's vector) for each point of the space. The absorbed electromagnetic capacity (Pd) in the volume (V) during the time period is determined by the expression [17]:

$$P_d = \iiint_v \frac{\sigma \cdot E^2}{2} dV \quad , \qquad (3)$$

where σ is conductivity, S/m; E -is the amplitude of the electric component of the field, V/m.

After treatment with the electromagnetic field of the Tesla's transformer, the structure of the straw was checked under a light microscope Delta Optical BioLight 500 40x-1000x. For comparison, the structure of untreated wheat straw with the electromagnetic field was also determined.

The process of biomethanogenesis of wheat straw was carried out with using the same laboratory fermenters. The laboratory fermenter - is a gas-tight bag made of polymer material with a capacity of 500 ml. The researched biomass and seeding of methane bacteria were placed in the bag in a ratio of 1:4, after which the bag was sealed up and its initial volume of fermenter was determined by immersing it in water. The fermenter was suspended in an incubator at the temperature of +37.5^{0}C for 20 days. The volume of the biogas sample was determined every four days by the value of change in the volume of the fermenter by immersing it in water with the temperature of +37.5^{0}C by the amount of displaced water. For comparative characteristic, fermentation of crushed untreated with the electromagnetic field wheat straw that was also carried out. To analyze the reproducibility of results of the researches, the mixtures were prepared and fermented in 3-e repetitions.

RESEARCH RESULTS

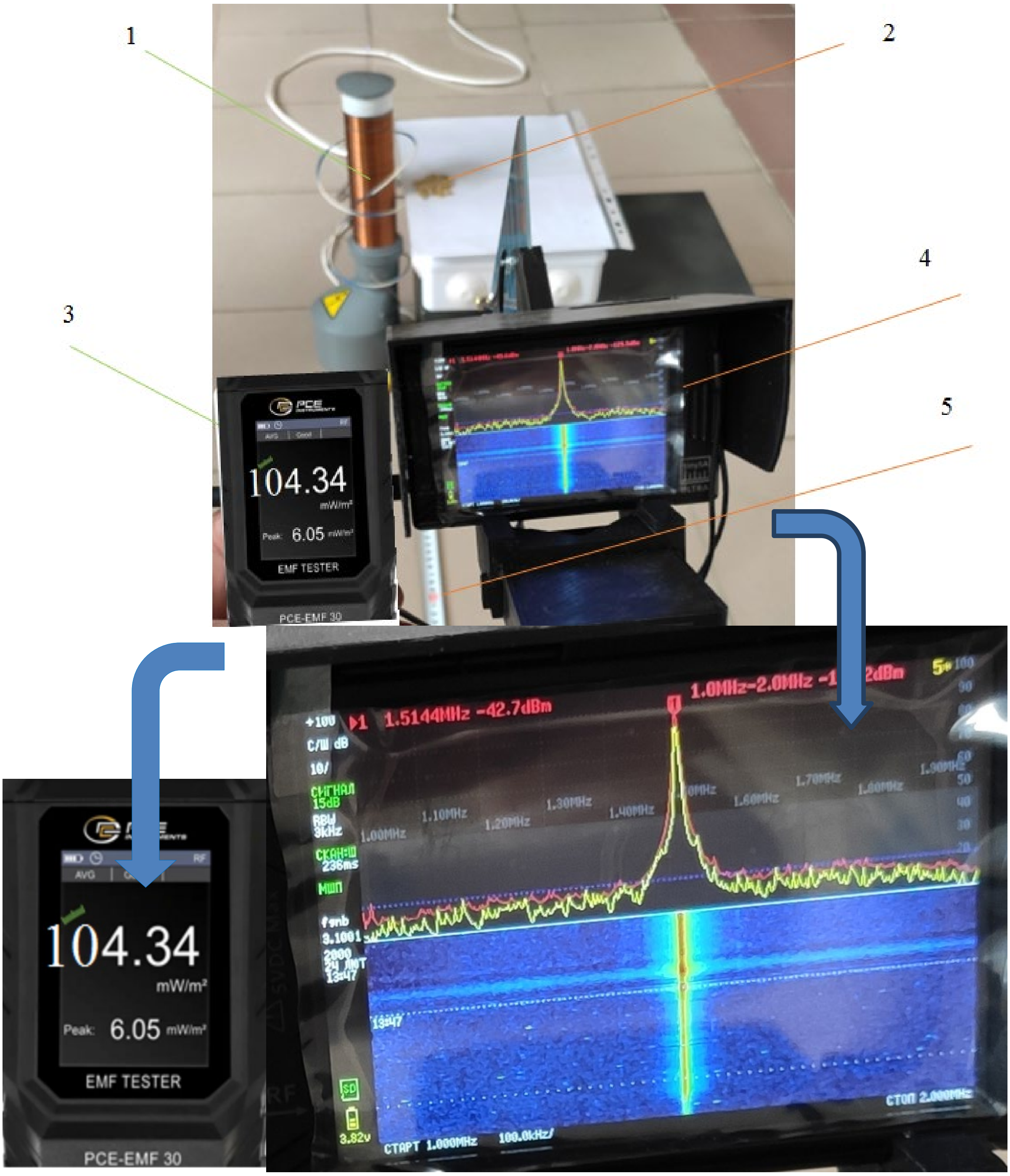
The electromagnetic field created by the Tesla transformer, as shown in Fig 1. has a frequency of 1.5144 MHz, reference 1, in the measurement range from 1 MHz to 2 MHz. , i.e. in this range there is only one frequency emitted by the radiation source.

The penetration depth of the electromagnetic field in wheat straw is shown in fig. 3.

The distribution of the specific power of the electromagnetic field, determined in the area where the samples of crushed wheat straw are located, is shown in Fig. 4.

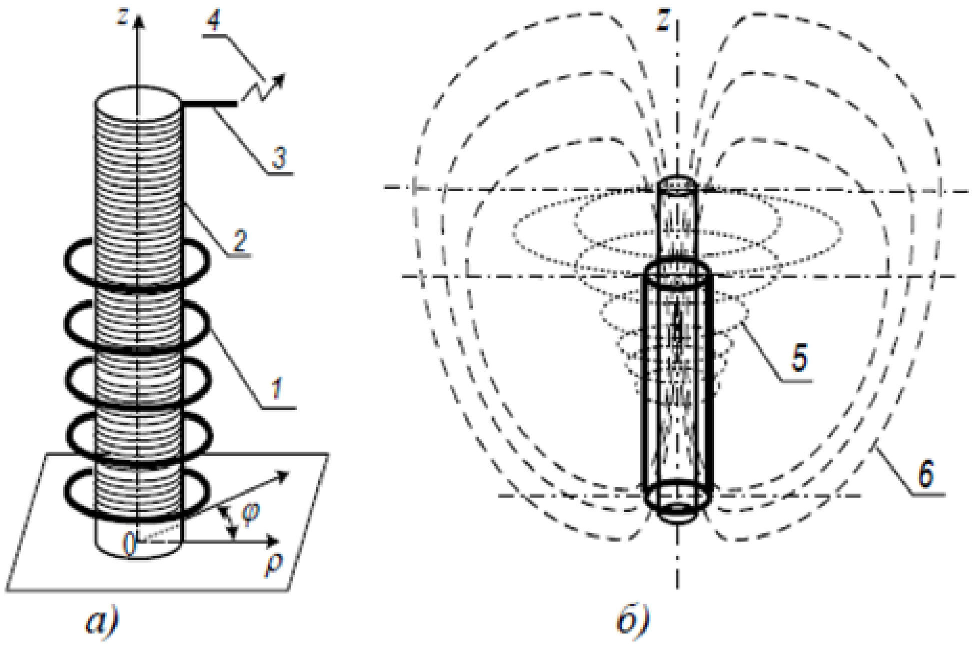
In the Fig. 5 and Fig. 6 are shown images of the surface of crushed wheat straw, respectively, of the control sample and the sample that was exposed to the influence of the high-frequency electromagnetic field of high electric intensity.

In table 1 and in Fig. 7 are presented the results of anaerobic fermentation of crushed wheat straw for the control sample and the sample that was exposed to the influence of the high-frequency electromagnetic field of high electrical intensity.



1 – Tesla’s transformer; 2 – chopped straw; 3 - device PCE-EMF 30; 4 - device Tiny SA ULTRA; 5 – measuring line.

Figure.1. Treatment of wheat straw with the electromagnetic field of Tesla’s transformer.



a) schematic structure of the Tesla's transformer; b) qualitative distribution of E- and H-components of the field 1 – primary winding; 2 – secondary winding; 3 – the rod from which develops the gas discharge; 4 – gas (plasma) discharge; 5 – lines of force of the electric field (E-component) in the z-ρ plane; 6 lines of force of the magnetic field (H-component) in the plane φ.
Fig.2. The distribution of the electromagnetic field around the Tesla's transformer [16].

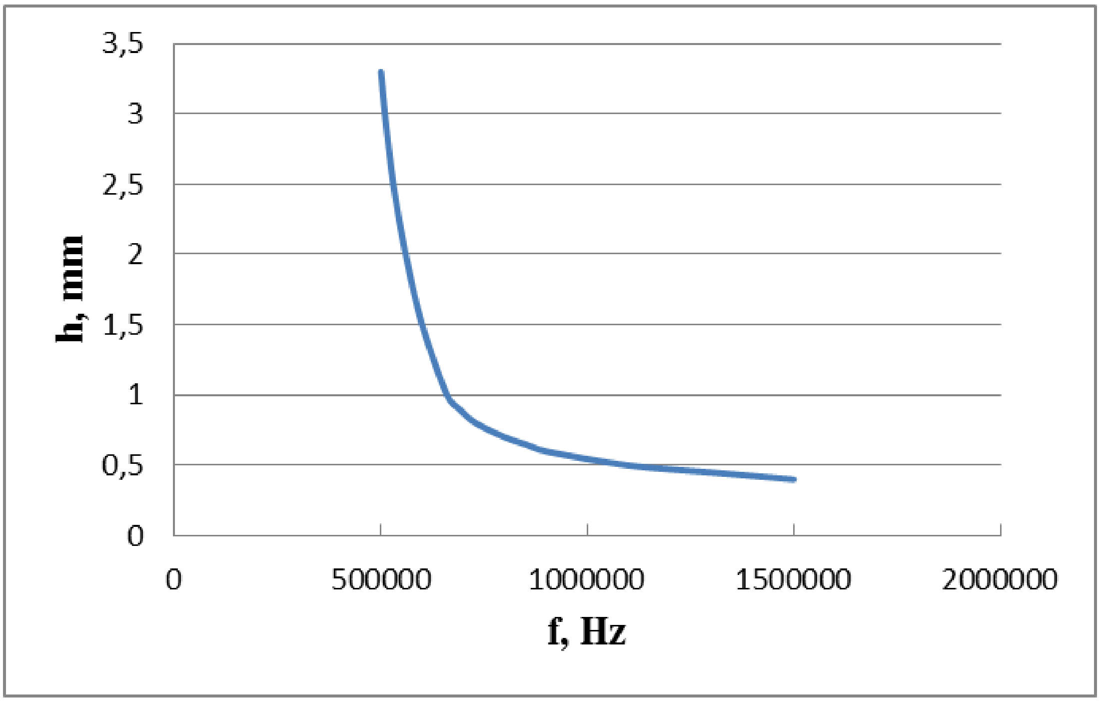


Fig. 3. The depth of penetration of the electromagnetic field in wheat straw depending on its frequency.

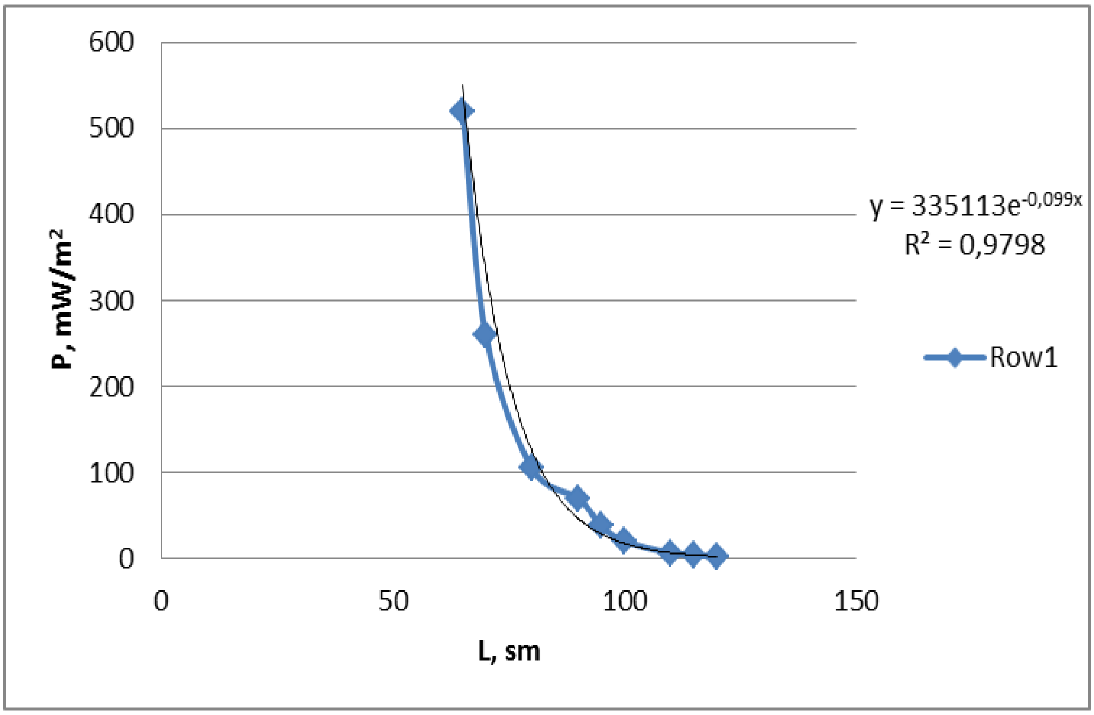


Fig. 4. The dependence of the specific power of the electromagnetic field of the Tesla's transformer from the distance.

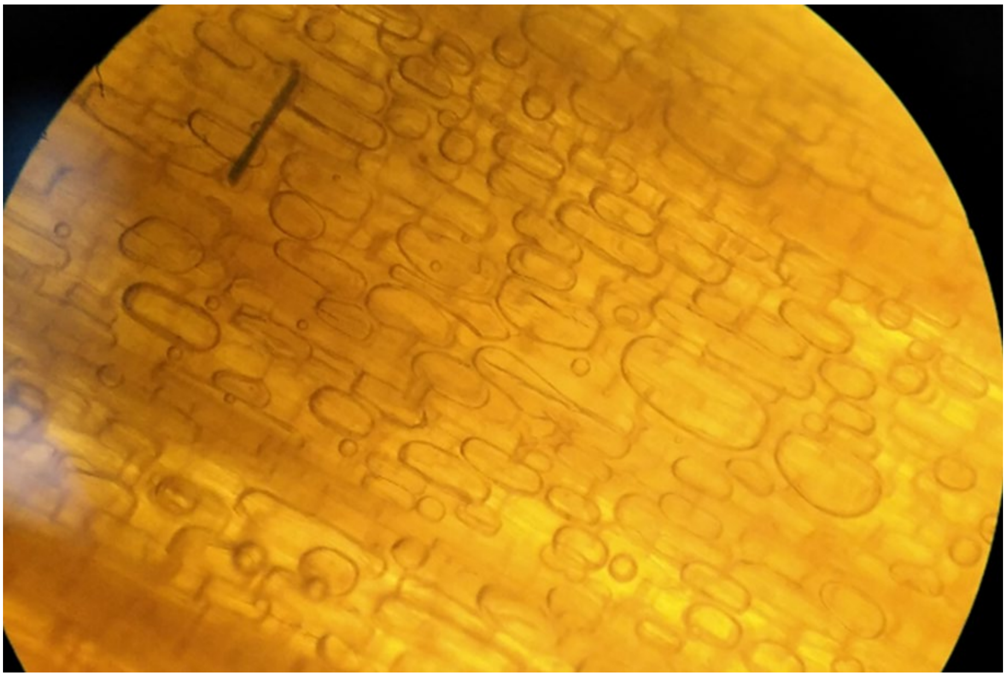


Fig.5. Image of untreated straw with the electromagnetic field.

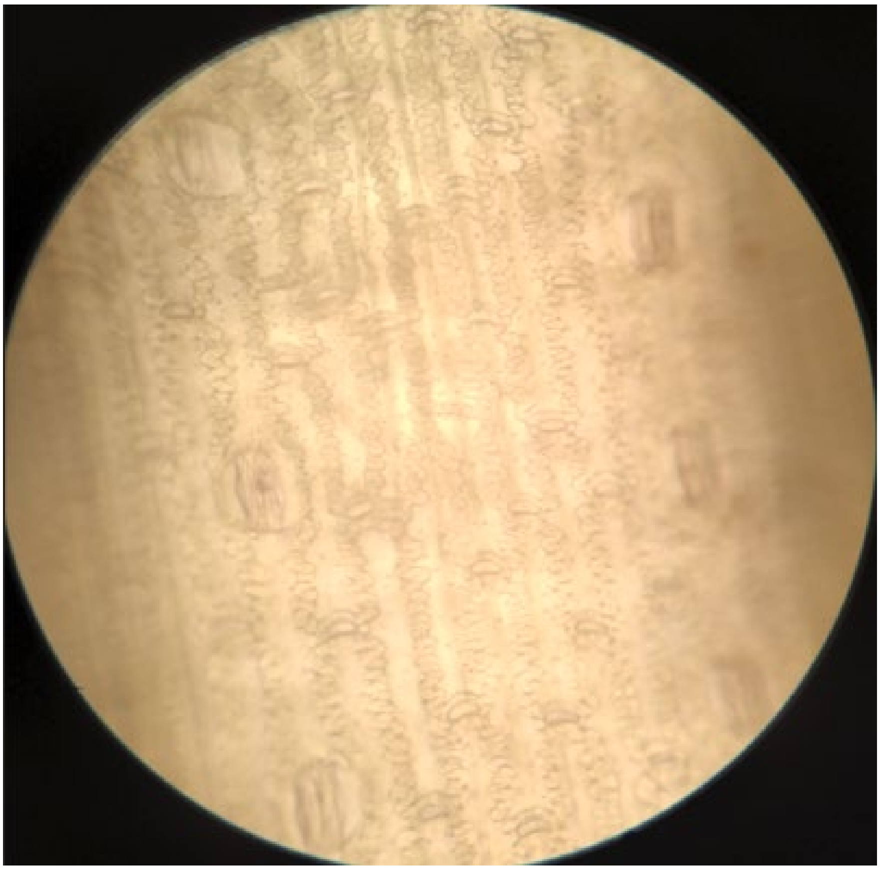


Fig. 6. Image of wheat straw after the influence of the high-frequency electromagnetic field of high electrical intensity.

Table 1

Output of biogas from chopped wheat straw untreated and treated by the electromagnetic field of the Tesla's transformer

№	Versions	Output of biogas m^3 /t DM				
		4	8	12	16	20
1	Chopped wheat straw, average size 5.2 mm x 1.5 mm, which is pre-soaked for 15 minutes in water-pipe water at the temperature of (+17^{0}C), + seeding of methane bacteria	120	195	220	238	240
2	Treated chopped wheat straw with the electromagnetic field of the Tesla's transformer, average size 5.2 mm x 1.5 mm), which is pre-soaked for 15 minutes in water-pipe water at the temperature of (+17^{0}C), + seeding of methane bacteria	165	250	303	345	377

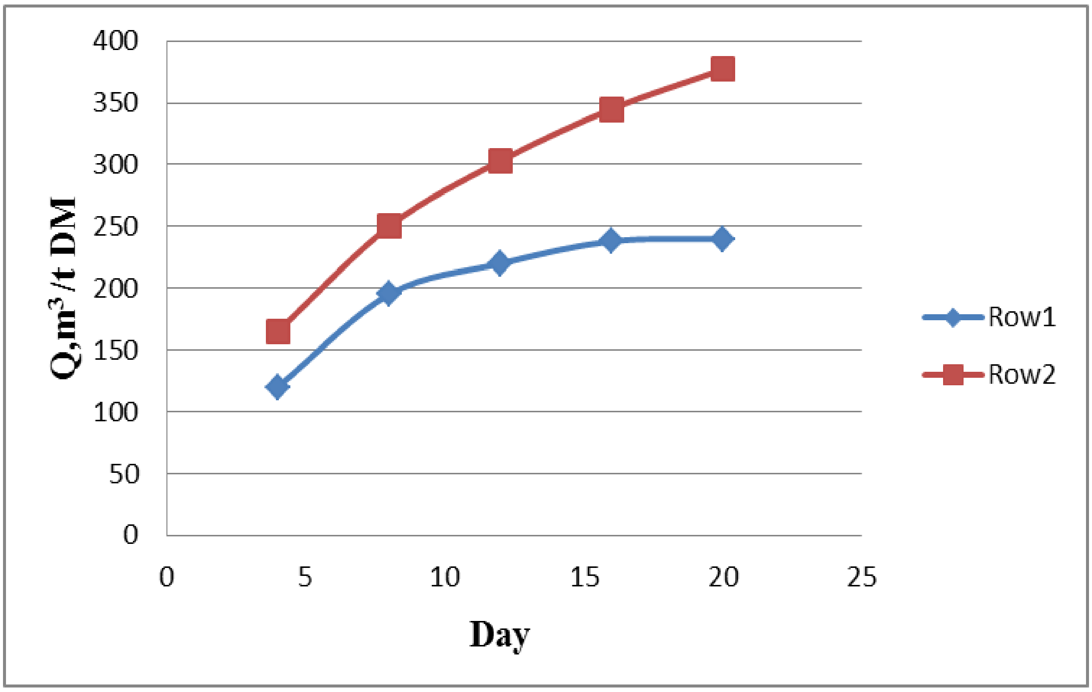


Fig. 7. Output of biogas from chopped wheat straw: 1 – preliminary untreated; 2 - pre-treated with the electromagnetic field of the Tesla's transformer.

DISCUSSION OF RESULTS

As shown by the summarized data (Fig. 7, table. 1), during preliminary treatment with the high-frequency electromagnetic field, the yield of biogas increases by 57% in comparing with the control sample, and the rate of the methanogenesis process changes significantly: from 7.81 m^3 /t DM for the control sample up to 13.75 m3 /t DM per day for samples treated with the electromagnetic field.

The results of this research due to biomethane yield exceed the results of work [18], in which evaluated the influence of three different methods of chemical pre-treatment of wheat straw, among which alkaline pre-treatment was the most effective for removing the lignin fraction and reducing the crystallinity of cellulose . Alkaline pre-treatment uses bases, from which NaOH is the most popular, that to make the lignocellulosic matrix readily decomposed for microbes by removing parts of the lignin and hemicellulose. But the toxicity of reagents or the high cost of organic solvents creates certain limitations in the application of this method. Combined mechanical and chemical treatment can effectively compensate the shortcomings of a single method of treatment, thus achieving the goal of energy saving and environmental protection [19]. While chemical and physical pre-treatment strategies show inherent disadvantages, including the formation of inhibitory products [20].

For the formation of their cells, bacteria need nutrients (microelements and minerals), which come to the bioreactor together with waste of animal and plant origin. The interaction of electrolytes with water leads to the destruction of ionic or molecular crystals or molecules and the formation of hydrated ions. Since bacteria consume mineral elements in the dissociated state, in the form of ions, this helps to stimulate their growth [10]. Under the influence of the electromagnetic field leads to the structural rebuilding of biomass, and some chemical elements and compounds can be traced the influence (direct or indirect) on the specific technological result.

In Fig. 5 and Fig. 6 visually can be traced the appearance of deformations and corresponding structural rebuildings in cells of wheat straw for the control sample and the sample that was exposed to the influence of the high-frequency electromagnetic field of high electric intensity. Such changes can be partially explained as the consequences of "explosions" from instantaneous vapor generation in the structure of wheat straw when exposed to a high-frequency electromagnetic field of high electric intensity.

The water stores and transmits information which concern to dissolved substances with the help of the hydrogen net and provides the trigger effect of the structure of molecular aggregates after the potentiation procedure [21].

Since monomolecules of water have the minimum size, unlike clusters, they easily penetrate into the cells of wheat straw. They are abnormally polar, so they are able to dissolve quickly microcrystals of salt and ensure the unobstructed supply of nutrients to the cells of microorganisms. There are channels in biological membranes, the properties of which change under the applied influence, including the electromagnetic field. These effects are called "gates" because, by opening and closing the pores under the influence of the field, they control the movement of ions [21].

During the preliminary preparation of straw for fermentation, the power measurement of the grinder and Tesla's transformer was conducted.

The specific energy consumption for preliminary treatment of wheat straw for methanogenesis was 39.7 kWh/t, of which 7.5 kWh/t was for mechanical grinding, and 32.2 kWh/t was on the influence of the electromagnetic field. For soaking - 100 l/t of water.

The specific energy consumption for grinding of wheat straw with a sieve mill with the size of sieve 0.8 and 3.2 mm was 51.6 and 11.4 kWh t^{-1}. For the size of the sieve 1.6 mm, the total specific energy that is consumed for grinding of wheat straw was twice as high as in the case of the sieve of 3.2 mm [22].

The energy that is consumed during grinding of the straw depends on the moisture content, initial size of the particles, material feed rate, properties of the material and variable parameters of the machine.

As shown above, the specific energy consumption during combined (mechanical grinding and influence of the electromagnetic field) pre-treatment of wheat straw is lower than mechanical.

CONCLUSIONS

The main result of the researches is the experimental confirmation of the hypothesis of the synergistic effect from the previous mechanical grinding and processing of wheat straw with the high-frequency electromagnetic field of high intensity, which formed the maximum value of the biogas yield of 377 m^3 /t VS and its stable production.

The appearance of deformations and corresponding structural rebuildings in cells of wheat straw was visually determined for samples that exposed to the influence of the high-frequency electromagnetic field of high electric intensity.

The task of the next stage of researches should be establishing the dependences of deformations and corresponding structural rebuildings of biomass, levels of high-frequency electromagnetic field and biogas output

.

ACKNOWLEDGMENTS

With the support of the National Fund of Researches of Ukraine competition "Science for the reconstruction of Ukraine in the war and post-war periods", grant No. 202/0129.

REFERENCES

[1] Krzystek, L., Wajszczuk, K., Pazera, A. et al. The Influence of Plant Cultivation Conditions on Biogas Production: Energy Efficiency. Waste Biomass Valor (2019) doi:10.1007/s12649-019-00668-z

[2] Diaz J.P, Reyes I.P, Lundi M., Horvath I.S. Codigestion of different waste mixtures from agroindustrial activities, kinetic evaluation and synergetic effects. Bioresource Technology, 2011, vol.102, pp. 10834-10840

[3] 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.

[4] 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.

[5] Szwarc, D.; Szwarc, K. Use of a Pulsed Electric Field to Improve the Biogas Potential of Maize Silage. Energies 2021, 14, 119. https://doi.org/10.3390/en14010119

[6] 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

[7] Abdelsalam, E.; Samer, M.; Attia, Y.A.; Abdel-Hadi, M.A.; Hassan, H.E.; Badr, Y. Influence of zero valent iron nanoparticles and magnetic iron oxide nanoparticles on biogas and methane production from anaerobic digestion of manure. Energy 2017, 120, 842–853.

[8] 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

[9] 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

[10] Zablodskiy M., Kozyrskyi V., Zhyltsov A., Savchenko V., Sinyavsky O., Spodoba M., & Klendiy G. (2020, April). Electrochemical characteristics of the substrate based on animal excrement during methanogenesis with the influence of a magnetic field. In 2020 IEEE 40th International Conference on Electronics and Nanotechnology (ELNANO) (pp. 530-535). IEEE.

[11] Magnetic Fields and Magnetic Isotope 25Mg Effects on Biofilms Formation by Bacteria E. coli. U. G. Letuta, T. A. Tikhonova Dokl Biochem Biophys. 2019 May; 484(1): 85–87. Published online 2019 Apr 22. doi: 10.1134/S160767291901023X

[12] Shabrangy A, Majd A (2009) Effect of magnetic fields on growth and antioxidant systems in agricultural plants. PIERS Proc 2:23–27.

[13] Ahmad P, Jaleel CA, Salem MA, Nabi G, Sharma S (2010) Roles of enzymatic and nonenzymatic antioxidants in plants during abiotic stress. Crit Rev Biotechnol 30:161–175. https://doi.org/10.3109/07388550903524243

[14] Plant Responses to High Frequency Electromagnetic Fields Alain Vian, Eric Davies, Michel Gendraud and Pierre Bonnet. Hindawi Publishing Corporation BioMed Research International Volume 2016, Article ID 1830262, 13 pages. http://dx.doi.org/10.1155/2016/1830262

[15] Andersen L.F., Parsin S., Lüdtke O., Kaltschmitt M. Biogas production from straw–the challenge feedstock pretreatment.. Umwelttechnik und Energiewirtschaft V-9 Biomass Conversion and Biorefinery, 2022, vol. 12, pp. 379-402. http://hdl.handle.net/11420/7453

[16] Kolomiets, R. O., Morozov, D. S., & Grek, O. V. (2017). A medical generator of cold plasma based on the Tesla's transformer. Bulletin of the Zhytomyr State University of Technology. Access mode: http://eztuir.ztu.edu.ua/jspui/bitstream/123456789/6692/1/177.pdf

[17] Vian, A., Davies, E., Gendraud, M., & Bonnet, P. (2016). Plant responses to high frequency electromagnetic fields. BioMed research international, 2016.

[18] Mancini G., Papirio, S., Lens, P. N., & Esposito, G. (2018). Increased biogas production from wheat straw by chemical pretreatments. Renewable energy, 119, 608-614.

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

[20] Wagner A. O., Lackner, N., Mutschlechner, M., Prem, E. M., Markt, R., & Illmer, P. (2018). Biological pretreatment strategies for second-generation lignocellulosic resources to enhance biogas production. Energies, 11(7), 1797.

[21] 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.

[22] Pretreatments Applied to Wheat Straw to Obtain Bioethanol. Carmen Otilia Rusănescu, Maria Ciobanu, Marin Rusănescu, Raluca Lucia Dinculoiu. Faculty of Biotechnical Systems Engineering, National University of Science and Technology Polytechnica Bucharest, 313 Spl. Independentei, Bucharest,

Romania. *Appl. Sci.* 2024, *14*(4), 1612; https://doi.org/10.3390/app14041612]

Information about authors.

Zablodskiy Mykola, doctor of technical sciences, scientific interest is technologies conversion of biomass into high-quality biogas with a shortened fermentation period under the influence of electromagnetic field.
E-mail: zablodskiynn@gmail.com

Klendiy Petro, associate professor of the department of power engineering and automation, candidate of technical sciences, scientific interest is renewable sources of energy.
E-mail: pklendii@gmail.com

Dudar Oksana, teacher of the cycle committee of special electrical engineering disciplines", scientific interest is renewable sources of energy.
E-mail: oksana-dydar@ukr.net