

PREPARATION OF WHEAT STRAW FOR FERMENTATION UNDER THE INFLUENCE OF THE ELECTROMAGNETIC FIELD OF A TESLA TRANSFORMER

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Abstract. *The most common waste of agricultural production is straw of various crops and in particular wheat straw. During energy shortages, straw can be used as an energy resource in two ways: the first is direct combustion and obtaining thermal energy, and the second is its fermentation. In addition to obtaining biogas, highly mineralized organic fertilizer will also be obtained, which, when applied to the soil, will improve its fertility. As can be seen, the second method of using straw is more rational, but requires more complex equipment and a scientific approach to the methanogenesis process, since straw contains lignin, which gives it a rigid structure and makes it resistant to biological decomposition. Therefore, before fermentation, it is necessary to pre-treat the straw to destroy lignin and give microorganisms access to cellulose and hemicellulose polysaccharides.*

There are different methods for the degradation of straw, namely: mechanical, chemical, biological, physical, thermal or combined. The use of one or another method requires a technical and economic justification. That is, it is necessary to take into account the specific energy consumption, the cost of equipment, chemicals and the environmental friendliness of the process.

To change the structure of straw, you can use high-frequency electromagnetic fields generated by a Tesla transformer.

Before processing, straw is crushed and soaked in tap water and then exposed to a high-frequency electromagnetic field. Under the influence of a high-frequency electromagnetic field, the destruction of cell organelles of straw occurs, which will improve and accelerate the fermentation process, since complex compounds such as polymers are broken down and dissolved into monomer units through an enzymatically catalyzed reaction with water. Also, under the influence of a high-frequency electromagnetic field, changes occur not only in the tissues that are directly affected, but also systemically in remote tissues of the stem.

Key words: *high-frequency electromagnetic field, wheat straw, Tesla transformer, energy efficiency*

Introduction. Straw is one of the most common agricultural wastes and is rich in the biodegradable polysaccharides cellulose (approximately 35% by mass) and hemicellulose

(approximately 25% by volume) [1,2]. However, the polymers are interconnected by an anaerobically non-degradable polyphenolic compound, lignin (approximately 10–20%), which gives straw a rigid structure and makes it resistant to biodegradation through a number of different mechanisms, such as lignin-carbohydrate bonds, physical encapsulation of cellulose and hemicellulose, and non-productive adsorption of hydrolyzing enzymes [3]. Cellulose crystallinity and degree of polymerization have also been reported as some of the key factors that negatively affect the degradation process [4]. Therefore, when straw is used as a feedstock in biogas production, low methane yield and low production rate are expected. This can be primarily explained by the difficult hydrolysis, which is the first reaction step in the degradation process, where polymers are broken down and dissolved into monomer units through an enzymatically catalyzed reaction with water [5]. Biogas production from wheat straw is one of the strategies for converting biomass into bioenergy, but pretreatment of the lignocellulosic material is required to make the substrate biodegradable.

Analysis of recent studies and publications. Previous studies have identified different types of methods to reduce the stability of lignocellulose: chemical, physical, thermal, biological and mechanical pretreatments, which were used alone or in combination. Methods propose several strategies aimed at dissolving certain polymers, making others more accessible and/or disrupting the physicochemical structure, thus increasing the bioavailability of the internal structures [4]. Although thermochemical pretreatment, such as steam explosion, has proven highly effective in increasing the digestibility of lignocellulosic materials, it requires high temperatures, the addition of chemicals and subsequent pH neutralization steps and is often designed to suit a single feedstock. Mechanical pretreatment mainly aims at cutting, shredding, grinding or pressing the straw into smaller pieces by grinding, milling, extrusion, pelletizing, briquetting, etc. Extrusion, for example, is based on single or twin screw elements that break the material into smaller fractions by shear force, transporting it forward. Previous studies have shown that such pretreatment of lignocellulosic biomass can lead to an increase in methane yield from 16 to even 99.5% [6, 7]. It is also believed that the reduced particle size increases the surface area of the substrate, which will have a positive effect on

the methane production rate and methane yield, suggesting that the bioavailability of the degradable substrates is simultaneously increased. Several studies have been conducted in which a positive effect of particle size reduction on biogas or methane yield has been observed [8]. but they require significant energy input.

Studies [9] have shown that EMFs from a Tesla transformer cause non-thermal destruction of cellular organelles, and interactions between EM fields and cellular ultrastructural compartments have been observed. Observations [10] show that under the influence of non-thermal effects of HF-EMFs, changes occur not only in tissues that are directly affected, but also systemically in distant plant tissues.

Research objective - assessment and analysis of the impact of high-frequency electromagnetic fields on the structure of wheat straw.

Materials and methods of the study. For the study, wheat straw was crushed in a laboratory grinder and soaked in tap water for 30 min at a temperature of 170 C, after which it was placed in the electromagnetic field of a Tesla transformer. The treatment of wheat straw with a high-frequency electromagnetic field is shown in Fig. 1.

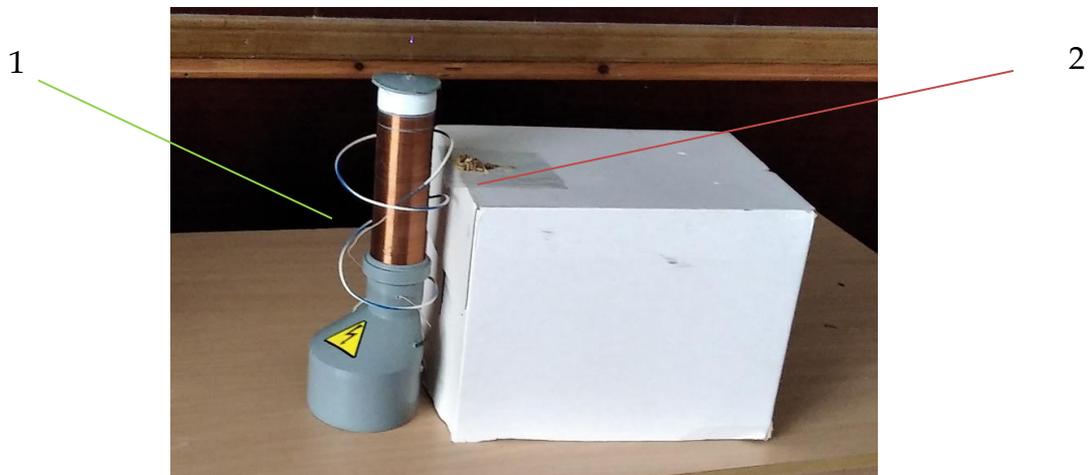


Fig.1. Processing of wheat straw by the electromagnetic field of a Tesla transformer:

1 – Tesla transformer; 2 – crushed straw

The electromagnetic power density associated with electromagnetic waves (measured in watts per square meter) is characterized by the Poynting vector . The Poynting condition in differential form states that at any point of the source, its energy per unit time is spent on heating the conductor, on changing the energy of the electromagnetic field, and on

transferring energy in the form of the divergence of the positive Poynting vector $\Pi^{\bar{}} = [(\mathbf{E},)^{\bar{}} \mathbf{H}^{\bar{}}]$, which is equal to the vector product of the electric and magnetic field strengths [11]. It is directed at each point in space in the direction of energy transfer and is numerically equal to the energy transferred per unit time through a unit area located perpendicular to the direction of energy transfer. Thus, the energy produced by sources in a certain volume is spent on heating conductors in this volume, on the movement of free charges, on the change of energy in the electric and magnetic fields and, in addition, part of the energy of the sources is transferred beyond this volume through the surface S that limits it, into the surrounding space. The specific power of the electromagnetic field was measured with a PCE-EMF 30 device, and the frequency with a Tiny SA ULTRA.

Research results and their discussion. The voltage equation on the capacitance of the secondary circuit, excited by the field of the primary circuit winding, can be written in the form [11]:

$$\frac{d^2 U_2(t)}{dt^2} + 2\delta_2 \cdot \frac{dU_2(t)}{dt} + \omega_{20}^2 U_2(t) = (\omega_{20}^2 \cdot k_1) \cdot U_{1m} \cdot \sin(\omega_1 t), \quad (1)$$

where $\omega_{20} = \frac{1}{\sqrt{L_2 C_2}}$ and $\delta_2 = \frac{R_2}{2L_2}$ are the natural frequency and the decay decrement of the secondary winding of the Tesla transformer, respectively.

The general integral of equation (1) can be represented as the sum of the general solution of the homogeneous $-U_{20}(t)$ and the partial solution of the corresponding inhomogeneous equation $-U_{21}(t)$

$$U_2(t) = U_{20}(t) + U_{21}(t), \quad (2)$$

where $U_{20}(t) = e^{-\delta_2 t} \cdot [C_1 \cdot \cos(\omega_2 t) + C_2 \cdot \sin(\omega_2 t)]$; $\omega_2 = \sqrt{\omega_{20}^2 - \delta_2^2}$;

$$U_{21}(t) = \frac{(\omega_{20}^2 \cdot k_1) U_{1m}}{(\omega_{20}^2 - \omega_1^2)^2 + (2\delta_2 \omega_1)^2} \cdot [(\omega_{20}^2 - \omega_1^2) \sin(\omega_1 t) - (2\delta_2 \omega_1) \cos(\omega_1 t)].$$

Expression (2) is checked by the limit transition at $t \rightarrow \infty$ with the further assumption $-\delta_2 \rightarrow 0$. From the point of view of physics, this is a stationary regime, since there are no active losses in the secondary circuit.

From (2) we determine that:

$$\lim_{\substack{t \rightarrow \infty \\ \delta_2 \rightarrow 0}} U_2(t) = \frac{\omega_{20}^2 \cdot U_{1m}}{(\omega_{20}^2 - \omega_1^2)} \cdot \sin(\omega_1 t) \Big|_{\omega_1 \rightarrow \omega_{20}} = U_2(t) \rightarrow \infty. \quad (3)$$

The resulting expression (3) is a well-known dependence, the transition to which indicates the validity of formula (2)

Satisfying the zero initial conditions in expression (2), we find the voltage on the capacitance of the secondary circuit of the Tesla transformer

$$U_2(t) = \frac{(\omega_{20}^2 \cdot k_1) U_{1m}}{(\omega_{20}^2 - \omega_1^2)^2} \cdot \left[e^{-\delta_2 t} \frac{\omega_1}{\omega_2} \left((2\delta_2 \omega_2) \cos(\omega_2 t) + (2\delta_2^2 - (\omega_{20}^2 - \omega_1^2)) \cdot \sin(\omega_2 t) + (\omega_{20}^2 - \omega_1^2) \sin(\omega_1 t) - (2\delta_2 \omega_1) \cos(\omega_1 t) \right) \right]. \quad (4)$$

In accordance with the problem statement, it is necessary to fulfill N. Tesla's recommendation: $Q_2 \gg 1$. This means that $Q_2 = \left(\frac{\omega_{20} \cdot L_2}{R_2} \right) = 0,5 \cdot \left(\frac{\omega_{20}}{\delta_2} \right) \gg 1$. Therefore, $\left(\frac{\delta_2}{\omega_{20}} \right) \sim \frac{1}{Q_2} \ll 1$ is an infinitesimal quantity.

In expression (4), we will neglect infinitesimal quantities of the second order and higher relative to $\frac{\delta_2}{\omega_{20}}$. In this case, we can assume that $\omega_2 \approx \omega_{20}$. In addition, we introduce the resonance condition and assume that the resonant frequency and the excitation frequency of the system are equal to each other $\omega_1 \approx \omega_{20}$. After performing the necessary identical transformations, we obtain the time dependence for the resonant voltage on the capacitance of the secondary circuit of the Tesla transformer.

$$U_2(t) \approx \left(\frac{k_1}{2} \right) \cdot U_{1m} \cdot [2Q_2 \cdot \cos(\omega_1 t) \cdot (1 - e^{-\delta_2 t})] \quad (5)$$

In steady state, when $e \gg \frac{1}{\delta_2} = \frac{2A_2}{K_2}$, neglecting quantities of order $\left(\frac{1}{Q_2} \right)^2$ and higher, from expression (5) we find that

$$U_2(t) \rightarrow -(k_1 \cdot Q_2) \cdot U_{1m} \cdot \cos(\omega_1 t). \quad (6)$$

From (6) we obtain the voltage transformation ratio in the Tesla transformer

$$k_{Tesla} \rightarrow k_1 \cdot Q_2 \gg 1. \quad (7)$$

The obtained result shows that the voltage transformation when fulfilling the resonant excitation conditions and the requirement of a sufficiently large Q factor of the secondary circuit occurs with an efficiency that is much higher than the transformation due to the

inductive coupling between the primary and secondary circuits, since $N_{\text{Tesla}} \ll k_1 \rightarrow Q_2 \gg 1$, and actually $Q_2 \gg 1$.

The depth of penetration of the electromagnetic field into the medium (skin effect) is determined by the formula [12]:

$$h = \frac{1}{a}. \quad (8)$$

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

$$a = \left[\frac{4\pi^2 f^2 \epsilon_0 \mu_0}{2} \left(-1 + \sqrt{1 + \left(\frac{\sigma}{2\pi f \epsilon_0} \right)^2} \right) \right]^{\frac{1}{2}}. \quad (9)$$

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

The electromagnetic power density associated with electromagnetic waves (measured in watts per square meter) is obtained by the cross product between the electric and magnetic field vectors (namely the Poynting vector) for each point in space.

The absorbed electromagnetic power (P_d) in a volume (V) over a period of time is given by [9]:

$$P_d = \iiint_V \frac{\gamma \cdot E^2}{2} dV, \quad (10)$$

where: γ is the conductivity S/m E is the amplitude of the electric component, V .

The distribution of the specific power of the electromagnetic field, determined in the area of the location of the crushed wheat straw samples, is shown in Fig.2.

The specific field power during processing was 200 W/m² at a frequency of 1.51 MHz.

Before and after processing with the electromagnetic field of the Tesla transformer, the structure of the straw was examined under a light microscope.

Fig.3, Fig.4 and Fig.5 show images of the surface of the crushed wheat straw of the control sample, respectively, treated with the electromagnetic field of the Tesla transformer for 15 min and 30 min.

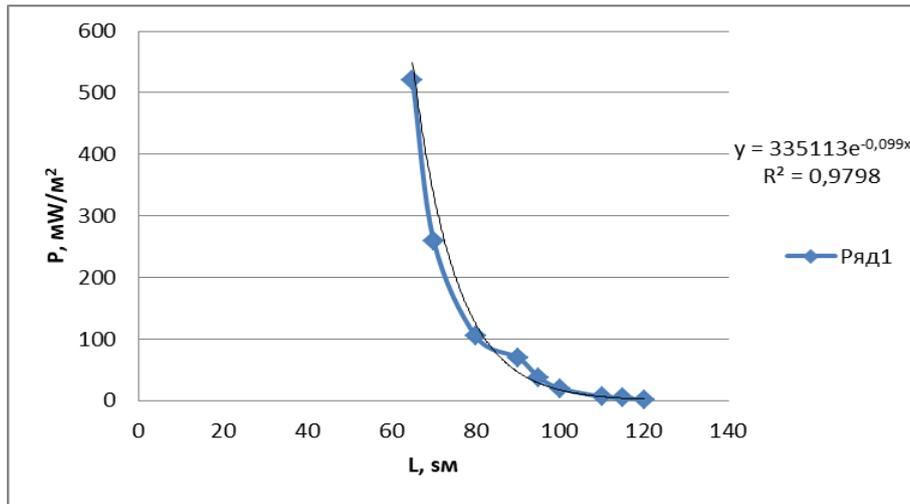


Fig.2. The dependence of the specific power of the electromagnetic field of the Tesla transformer on the distance



Fig. 3 Image of straw untreated with an electromagnetic field

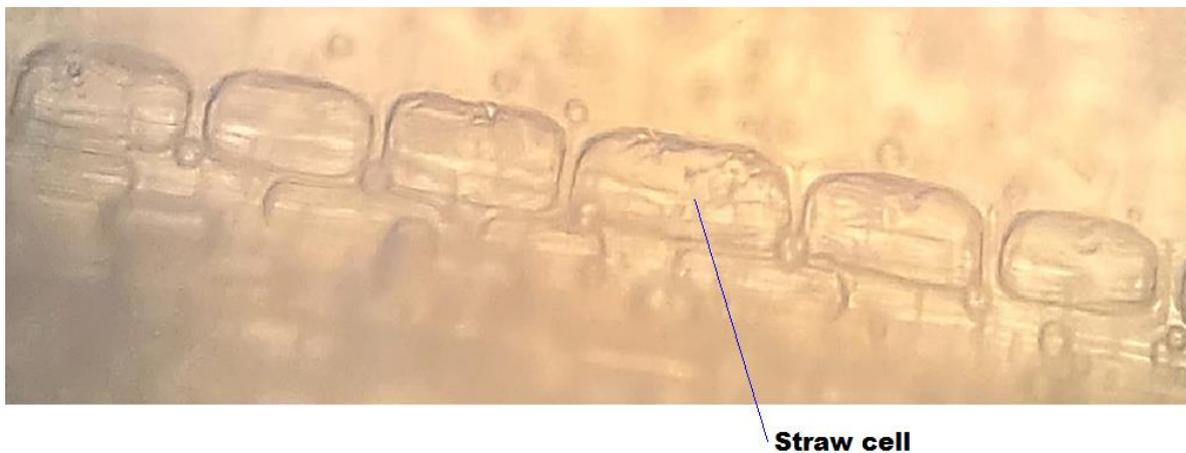


Fig.4. Image of wheat straw after exposure to a high-frequency electromagnetic field of high electric intensity for 15 min



Fig.5. Image of wheat straw after exposure to a high-frequency electromagnetic field of high electric intensity for 30 min

As can be seen from Figure 4, with a treatment duration of 15 min, lignocellulose in the cell began to break down, and Figure 5 shows that they are broken down, so it is necessary to subject the crushed wheat straw to 5 mm for 30 min. At the same time, the specific energy consumption for the preliminary treatment of wheat straw before methanogenesis was 39.7 kWh/t. of which 7.5 kWh/t for mechanical grinding, and 32.2 kWh/t for the influence of the electromagnetic field. Soaking - 100 l/t of water.

The specific energy consumption for mechanical grinding of straw on a hammer crusher to fractions with sieves of 3.2 and 0.8 mm is 11.4 and 51.6 kWh t⁻¹, respectively [13].

Conclusions and prospects.

The results of the research show that under the influence of a high-frequency electromagnetic field, lignin in wheat straw is destroyed with lower specific energy consumption than mechanical grinding, and accordingly, the amount of biogas produced during its fermentation will increase.

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ПІДГОТОВКА ПШЕНИЧНОЇ СОЛОМИ ДО ЗБРОДЖУВАННЯ ВПЛИВОМ ЕЛЕКТРОМАГНІТНОГО ПОЛЯ ТРАНСФОРМАТОРА ТЕСЛА

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Анотація. Найпоширенішим відходом сільськогосподарського виробництва є солома різних культур і, зокрема, солома пшениці. У час енергетичного дефіциту солomu можна використовувати, як енергетичний ресурс двома способами: перший – це пряме спалювання і отримання теплової енергії, а другий – це її збродження. При цьому крім отримання біогазу, ще отримають високо мінералізоване органічне добриво, яке при внесенні в ґрунт буде покращувати його родючість. Як видно, другий спосіб використання соломи більш раціональний, але

вимагає більш складного обладнання та наукового підходу до процесу метаногенезу, оскільки солома містить лігнін, який надає жорстку структуру і робить її стійкою до біологічного розкладання. Тому перед зброджуванням необхідно провести попередню обробку соломи, щоб зруйнувати лігнін і дати доступ мікроорганізмам до полісахаридів целюлози і геміцелюлози.

Для деградації соломи існують різні способи, а саме: механічний, хімічний, біологічний, фізичні, термічні або комбіновані. Використання того або іншого способу вимагає техніко-економічного обґрунтування. Тобто потрібно враховувати питомі витрати енергії, вартість обладнання, хімікатів та екологічність процесу.

Щоб змінити структуру соломи, можна використовувати високочастотні електромагнітні поля, які генеруються трансформатором Тесла.

Перед обробкою солому подрібнюють і замочують у водопровідній воді і після цього піддають впливу електромагнітного поля високої частоти. Під дією високочастотного електромагнітного поля проходить руйнування клітинних органел соломи, що дозволить покращити і пришвидшити процес зброджування, оскільки складні сполуки такі, як полімери розщеплюються та розчиняються на мономерні одиниці через ферментативно каталізовану реакцію з водою. Також під дією високочастотного електромагнітного поля відбуваються зміни не тільки в тканинах, які піддаються безпосередньому впливу, але також системно у віддалених тканинах стебла.

Ключові слова: *високочастотне електромагнітне поле, пшенична солома, трансформатор Тесла, енергетична ефективність*