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# Analysis of the temperature-frequency effect on dielectric losses in a grain medium

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***Abstract.*** The aim of the study is to determine the influence of the thermal effect on dielectric losses in grain mass subject to bruising during drying and storage on the example of wheat across a wide external electric field frequency range. The study of the electrophysical characteristics of a dispersed medium comprising mechanically activated wheat grains takes into account the effect of the degree of breakage on the dielectric parameters of the studied medium. The studies were carried out on experimental samples having different degrees of mechanical activation of particles, which ranged in size from from 50 to 1000 µm. Variations in the dielectric loss tangent were studied using the dielectric method across a wide temperature-frequency range. Studies of variations in dielectric properties were carried out for wheat samples subjected to grinding according to the mechanical activation method at temperatures varying from 20°C to 255°C with a constant heating rate of 0.7 deg / min. During the course of the experiment, the frequency of the external electric field was varied from 25 Hz to $1{\cdot}10^6$ Hz. Dielectric constant and dielectric loss tangent calculations were carried out using data on electrical capacity and conductivity obtained using an E7-20 immittance meter and a measuring cell in the form of a flat capacitor. An analysis of variations in these dielectric characteristics was also performed. The obtained stable correlation of the dielectric loss tangent with the frequency of external electric impact and the degree of heating of the samples was most pronounced for finely dispersed samples (particle size 50 µm). Variations in dielectric characteristics are most significant when the frequency decreases to 100 Hz and below. The study of variations in the main dielectric parameters can be used to prevent self-heating and ignition of the grain mass during storage, as well as for selecting the most efficient energy-saving drying mode.

***Keywords:*** dispersed medium, mechanical activation, dielcometry, wheat, dielectric losses, dielectric constant
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ЭНЕРГЕТИКА

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# Анализ температурно-частотного воздействия на диэлектрические потери в зерновой среде

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***Резюме.*** Цель – изучение влияния термического воздействия на диэлектрические потери в зерновой массе, подверженной травмированию при сушке и хранении на примере пшеницы в широком диапазоне частот внешнего электрического поля; изучение электрофизических характеристик дисперсной среды, состоящей из подверженных механоактивации зерен пшеницы, с учетом влияния степени измельчения на диэлектрические показатели исследуемой среды. Исследования проведены для экспериментальных образцов с разной степенью механоактивации частиц – от 50 до 1000 µm. Диэлектрический метод, применяемый в широком температурно-частотном диапазоне, позволил изучить вариации тангенса угла диэлектрических потерь для различных условий. Исследования вариаций диэлектрических свойств проведены для образцов пшеницы, подверженных измельчению методом механоактивации при вариации температуры от 20ºС до 255ºС с постоянной скоростью нагрева, составляющей 0,7 град/мин. Частота внешнего электрического поля при проведении эксперимента варьировалась от 25 Гц до $1 \cdot 10^6$ Гц. При помощи измерителя иммитанса Е7-20 и измерительной ячейки в виде плоского конденсатора получены данные по электрической емкости, проводимости; сделаны расчеты диэлектрической проницаемости и тангенса угла диэлектрических потерь. Проведен анализ вариаций данных диэлектрических характеристик. Отмечено наличие устойчивой корреляции тангенса угла диэлектрических потерь с частотой внешнего электрического воздействия и степенью нагрева образцов, наиболее ярко выраженной для мелкодисперсных образцов (размер частиц 50 мкм). Вариации диэлектрических характеристик наиболее значимы при уменьшении частоты до 100 Гц и ниже. Изучение вариаций основных диэлектрических параметров дает возможность предупредить самосогревание и возгорание зерновой массы в процессе хранения и выбрать наиболее эффективный энергосберегающий режим сушки.

***Ключевые слова:*** дисперсная среда, механоактивация, диэлькометрия, пшеница, диэлектрические потери, диэлектрическая проницаемость

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## INTRODUCTION

Issues associated with finding an effective solution for Russia's food supply program that takes into account current issues of energy conservation are currently under focused consideration. At the same time, basic aspects of food security involving the introduction and optimization of state-of-the-art methods in processes such as grain drying remain relevant. Due to the energy-intensive nature of such production processes, it becomes important to obtain solutions that optimize electricity consumption at the same time as ensuring compliance with the necessary conditions for grain storage and drying [1–3].

The quality and duration of grain storage is determined by the unique features of the medium, including its physical properties. The primary electrophysical properties of grain are expressed in terms of its moisture content during drying [4], along with temperature and the frequency of its external electric field. Changes in moisture quantity during grain storage leads to changes in its physical characteristics. In the present paper, such variations are considered on the example of mechanically activated wheat, which represents a model of grain mass which has been bruised during drying and storage. In a mechanically damaged grain medium, increased air exchange releases heat leading to possible combustion or otherwise unusable grain mass [5]. During grain storage, the presence of an active ventilation system helps to resolve fire safety issues [6, 7]. Such electrophysical indicators as electrical conductivity, permittivity and the tangent of the dielectric loss angle depend on the moisture content of grain [8].

Dielectric parameters of grain crops, such as permittivity, are used to calculate the humidity of the medium. In [9], a description of the variations in the dielectric properties of the grain medium is presented along with the observation that an increase in the dielectric constant is associated with an increase in moisture content and a decrease in frequency and that the tangent of the loss angle increases or decreases with changes in humidity and frequency. A mathematical model is presented for determining the dielectric characteristics of wheat in order to calculate the dielectric losses when with changes in frequency from 5 MHz to 12 GHz for different wheat moisture levels from 3% to 24% by measuring the dielectric properties. Temperature variations, explained in terms of changes in the state and amount of moisture absorbed by the grain mass, also lead to a serious change in the electrophysical properties.

The dependence of the dielectric parameters of the mechanically activated grain medium on the level of dispersion of samples, as well as the frequency of external electrical and temperature effects, is presented in [10–12]. The results of the described experiment demonstrate that the dependence of inhomogeneous physical properties determined by the size of the specific surface area of the fine-dispersed system is obtained as a result of mechanical activation on temperature and frequency [12, 13]. A failure to maintain the storage conditions of grain in terms of required temperature and humidity may result in the release a large amount of heat leading to its spontaneous combustion; this can be explained in terms of of micro-stimulated currents occuring in such an inhomogeneous environment even in the absence of external voltage [10].

***The purpose of the present work*** is to study the variation of the main electrophysical characteristics of a mechanically activated dispersed heterogeneous medium on the example of samples of grain crops (wheat) having particle fractions ranging from 50 to 1000 µm. Experimental studies were carried out with changes in the frequency of the external electric field from 25 Hz to $1 \cdot 10^6$ Hz and temperature changes from 20°C to 250°C at a constant heating rate of 0.7 degrees / min in order to determine the degree of variation of the studied electrophysical characteristics of wheat from the level of particle grinding and the nature of the frequency-temperature effect.

## MATERIALS AND METHODS OF RESEARCH AND THEIR DISCUSSION

The study of variations in electrical energy losses (the tangent of the dielectric loss angle tgδ) is determined by the magnitude of the electric current flowing in a dielectric medium. This comprises a polar dielectric whose molecules absorb moisture such as to actively affect its electrophysical properties. It is well known that dielectric systems characterized by nonpolar molecules and negligible impurities are characterized by a low level of dielectric losses. However, solid dielectrics, which in most cases are polar mainly represented by organic compounds and substances, differ in significant dielectric losses as a result of their characteristic dipole-relaxation polarization, especially at radio frequencies.

The dependence of the dielectric losses of the dispersed medium of mechanically activated wheat can be understood as a part of the electrical energy converted into heat at an alternating voltage. Dielectric losses occurring during heat treatment of grain mass are caused by electrical conductivity and polarization, which is established gradually under the influence of an electric field to cause heating of the substance under study. For the experiment, samples of bruised grain with different particle sizes in a wide temperature-frequency range were used.

As the main research method, we selected the method of dielectometry, which is widely used in practice in determining electrophysical characteristics, such as dielectric losses, electrical capacitance, conductivity, dielectric permittivity, etc., to investigate the molecular structure of the substance under study [14]. We referred to the model of the influence of various physical conditions through their dielectric parameters on the electrical properties of agricultural materials of the dielectric properties of agricultural crops in addition to calculations was presented in [15]. Taking into account the fact that the moisture level in agricultural products affects its safety and the vital activity of microorganisms, its effect on dielectric properties should also be taken into account. Comprising an example of a polar dielectric, the water forming part of the mechanoactivated grain is the main component affecting its dielectric properties. When modeling technological conditions for processing agricultural products, it is important to take into account the dependence of electrophysical properties on environmental parameters: temperature and frequency of the electric field [15].

The materials for the experiment comprised mechanically activated wheat samples with a variation in particle size from 50 to 1000 µm, forming a typical example of a finely dispersed heterogeneous heterogeneous system. Experimental data were obtained using a precision instrument of the E7-20 immitance meter of accuracy class 0.1 with a wide range of operating frequencies from 25 Hz to $1 \cdot 10^6$ Hz. After using this meter to obtain measurements of electrical capacitance and electrical conductivity, the calculation of the real part of the dielectric constant and the tangent of the dielectric loss angle was carried out. In addition to the E7-20 immitance meter, a specially measuring cell having a diameter of 21 mm comprising a flat capacitor with round aluminum electrodes was used. The samples of bruised grain were subjected to uniform heating in the temperature range from 20°C to 255°C at a fixed rate of 0.7 deg/min. To measure the temperature of the samples, a chromel-alumel thermocouple is used. The relative permittivity of the samples was calculated as the ratio of the capacitance of a capacitor with a substance to the capacitance of a capacitor without a substance.

The tangent of the dielectric loss angle was calculated in terms of frequency v, electrical capacitance C and electrical conductivity G:

$$tg\delta = \frac{1}{\omega RC} = \frac{G}{2\pi\nu C}. \qquad (1)$$

The dielectric method for studying the electronic structure of a substance and the nature of its molecular interactions is based on measuring the electrical capacitance and studying the polarization process in a polar dielectric on the example of mechanically activated wheat under the influence of an external electric field. The most important parameters determining the properties of the dielectric are: permittivity, whose variations are considered for the grain medium in [11–13], and the angle of dielectric losses d, defined as complementary to the angle j (up to 90°) of the phase shift between current and voltage.

Experimental data for the electrical capacitance and conductivity of the bruised grain were obtained for the frequency range from 25 to $1\cdot10^6$ Hz by the digital meter E7-20 with a measurement accuracy of 0.2 pF for electrical capacity and 1 pS for electrical conductivity. The scheme of the experimental setup used to study the temperature and frequency variations of electrophysical parameters is given in [16]. After sending the data obtained using an analog-to-digital converter to a personal computer for further processing, the necessary tables and diagrams were compiled, and the electrophysical parameters were calculated.

Calculations of dielectric losses of fine grain samples were carried out in a temperature range from 20°C to 255°C along with changes in the frequency of the electric field from 25 Hz to $10^6$ Hz. The spatially inhomogeneous charge distribution acquired by the studied grain samples as a result of mechanical activation when heated comprising an additional energy reserve that affects the value of electrophysical parameters.

Fig. 1 shows variations in the dielectric loss tangent for wheat samples with different degrees of grinding at a frequency of 1000 Hz depending on the temperature. The average increase in dielectric losses in the range from 65°C to 120°C can be explained in terms of the weakening of intermolecular forces, which in turn facilitates the rotation of dipoles in the electric field. The bruised grain mass can be taken as a polar dielectric having an appropriate permittivity maximum whose dielectric loss angle tangent is explained by the temperature rise. The increase in dielectric losses with an increase in temperature in the studied samples is associated with the phenomenon of desorption of water molecules from damaged chipped grains as a result of their drying. This can also be explained in terms of an increase in the mobility of dipoles when heated, making it easier for them to unfold under the influence of an electric field, which leads to an increase in tgδ. With further heating, the kinetic energy of the thermal motion of the dipoles actively increases, the intensity of Brownian motion increases, followed by disorientation of the dipoles. The resulting decrease in dielectric losses and permittivity with a further increase in temperature above 120°C m corresponds to the literature data [11, 16].

Fig. 1 shows that, for the largest sample with a particle size from 500 to 1000 μm in the temperature range up to 150°C, the maximum value of tgδ = 0.45 corresponds to T = 96.1°C: for sample 2 having a particle size of 251–500 μm, tgδ = 0.97 at T = 96°C, while, for sample 3, which has the lowest degree of particle dispersion, tgδ = 1.6 at T = 100.5°C

In the temperature range of 185.4–188.3°C, there is a second additional maximum, whose presence can be explained by the gradual destruction of the structure of the substance under study during grain combustion. Undoubtedly, the values of the electrophysical parameters depend on many factors including the moisture level in the substance [17]. Analysis of the measurement results showed that the most finely dispersed sample (particle size 50 μm) in the temperature-frequency range under study is characterized by a more significant dielectric permeation and dielectric losses. This  an be explained in terms of the cumulative increase in the total area of the specific surface of the substance of smaller samples during grain grinding. For larger samples, variations in electrophysical parameters are noticeably smoother. In the range from

129.3°C to 166.3°C, variations in dielectric losses of samples with particle sizes of 251–500 µm and 500–1000 µm are less noticeable. In the smallest sample having a grain size of 50 µm, the maximum value increases when approaching the boiling point of water, increasing the polarization of the substance and resulting in more active orientation of the domains when placed in an electric field [18–20]. The experimental data obtained clearly characterize the behavior of relaxation structures characteristic of polar dielectrics when placed in an electric field.

Fig. 2 demonstrates the temperature dependence of the tangent of the dielectric loss angle for a wide range of frequencies for the most finely dispersed sample with a particle size of less than 50 µm.

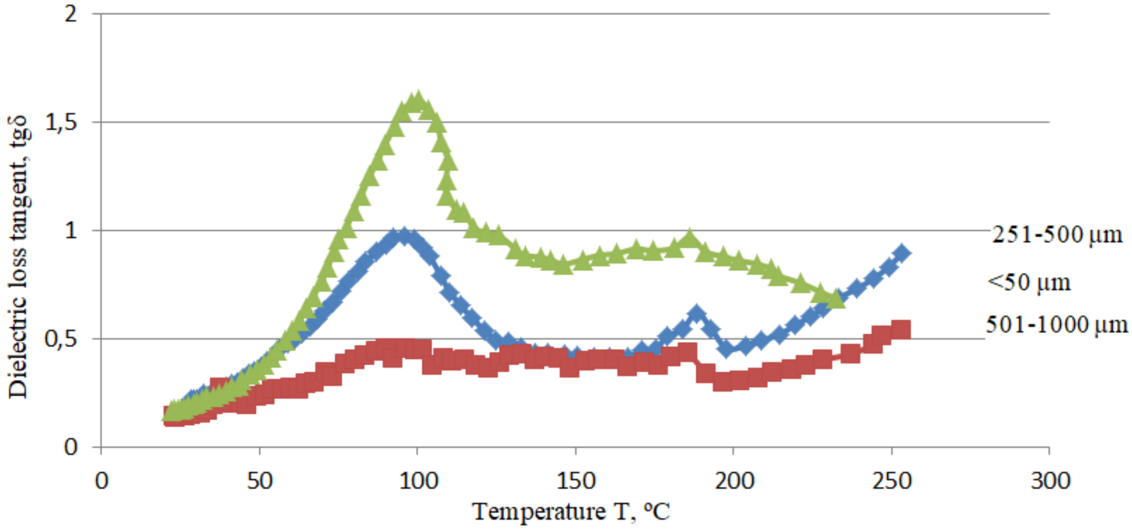


***Fig. 1. Variations of the tangent of the dielectric loss angle on temperature for wheat samples with dispersion: 501–1000 µm; 251–500 µm and less than 50 µm***
***Рис. 1. Вариации тангенса угла диэлектрических потерь от температуры для образцов пшеницы дисперсностью: 501–1000 µm; 251–500 µm и менее 50 µm***

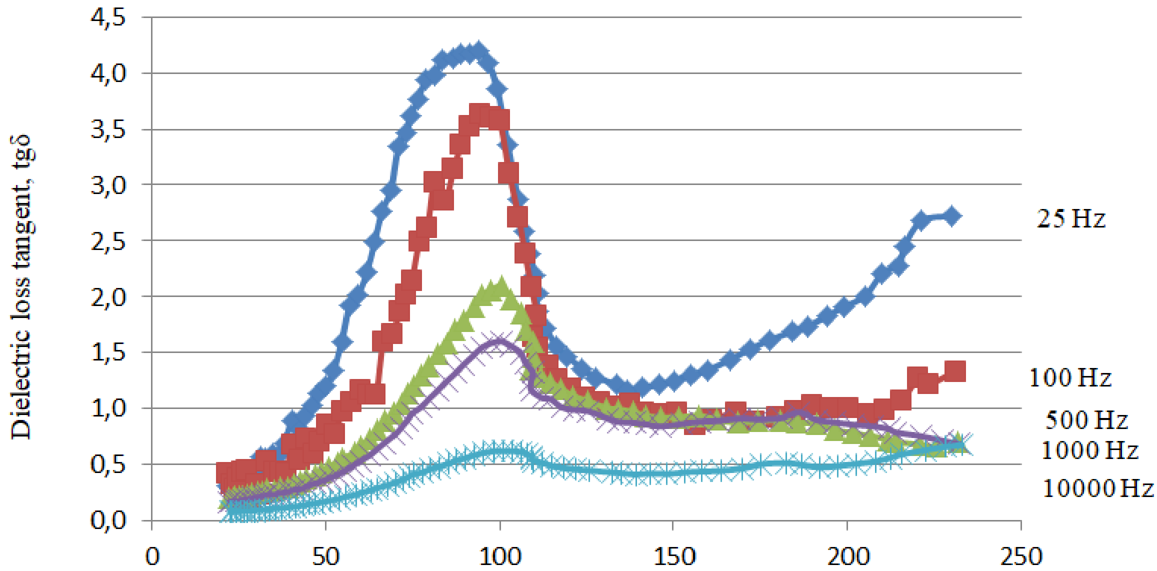


***Fig. 2. Variations of the dielectric loss tangent on temperature for wheat samples with a dispersion 50 µm for various frequencies: 25 Hz, 100 Hz, 500 Hz, 1000 Hz and 10000 Hz***
***Рис. 2. Вариации тангенса угла диэлектрических потерь от температуры для образцов пшеницы дисперсностью 50 µm для различных частот: 25 Гц, 100 Гц, 500 ГЦ, 1000 Гц и 10000 Гц***

Data analysis confirms the significant dependence of dielectric losses in the grain mass on the frequency of the external electric field, which is most significant in the low-frequency range from 25 to 100 Hz. The sharp decreases in tgδ with a further increase in the frequency to 500 Hz and above can be explained by a weakening of the dipole-orientation polarization in the disordered medium under study, the decrease in the kinetic energy and ion path length, as well as the probability of their collision with the structural elements of matter.

Therefore, an increase in the frequency of the electric field leads to a decrease in dielectric losses. The maximum value of dielectric losses, which corresponds to a frequency of 25 Hz, is 4.13 at a temperature of 86.4°C: for a frequency of 100 Hz, it is 3.63 at a temperature of 94.5°C; for a frequency of 500 Hz and above, the maximum value of dielectric losses decreases sharply comprising 2.05 at a temperature of 97.6°C for a frequency of 100 Hz, 1.6 at a temperature of 97.9°C and a frequency of 10000 Hz, and 0.62 at a temperature of 100.2°C.

Fig. 2 depicts distinctive features corresponding to an increase in tgδ with an increase in temperature above 150°C. These occur mainly for the low-frequency region due to the destruction of the structure and combustion of the substance of a polar dielectric having a rather complex composition. With an increase in the frequency of external electrical action, the ion path length and kinetic energy decrease, the possibility of molecular interaction weakens and, accordingly, dielectric losses decrease

As a result of the experiment, it was found that the dielectric losses in the bruised grain medium in a temperature range from 20°C to 250°C have a maximum at a temperature of 86.4–100.2°C. This close to the boiling point of water, which forms part of the studied samples and affects their electrophysical properties. Cracks and chips of bruised grain play the role of electrically charged defects that attract polar water molecules to trigger the interfacial Coulomb interaction mechanism at the interface.

## CONCLUSION

The conducted studies demonstrated the presence of a stable correlation of the dielectric parameters of an inhomogeneous heterogeneous medium on the example of finely dispersed wheat samples having varying fractional components depending on the frequency of the external electric field and temperature. In the studied disordered systems, the significant decrease in the tangent of the dielectric loss angle tgδ is due to the degeneration of dipole-orientation polarization and increase in the frequency of the external electric field,

By analyzing the spectra of the tangent of the dielectric loss angle, we were able to establish the presence of higher electrical activity for experimental samples of a small-sized structure and an increase in the dielectric permittivity and tangent of the dielectric loss angle, which was most pronounced at frequencies below 100 Hz. The established dependence of the tangent of the dielectric loss angle tgδ on the frequency of the external electric field and temperature is especially significant for finely dispersed wheat samples.

The study of the dependence of the electrophysical properties of finely dispersed heterogeneous media on the example of wheat can be important in modeling and optimizing the drying process of grain crops and the selection of an effective energy-saving mode

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The author performed the research, made a generalization on the basis of the results obtained and prepared the copyright for publication.

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Автор выполнила исследовательскую работу, на основании полученных результатов провела обобщение, подготовила рукопись к печати.

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