Dielectric losses of mechanically activated grain crops during heat treatment

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Abstract. Biochemical and electrophysical characteristics of grain crops vary significantly on changes in temperature and humidity conditions. The choice of the way and method of drying provides a significant role on the consumer properties of grain. A study of the dependence of the dielectric losses of grain crops during heat treatment on the example of mechanically activated wheat on the frequency of the external electric field and temperature was conducted in the paper. It was found that the structural features of fine wheat samples as a result of mechanical activation and temperature changes affect the dielectric properties of grain crops. The value of the dielectric loss tangent correlates with the size of the crushed samples, temperature, humidity, and frequency of external electrical influence. Analysis of the results of calculating the dielectric loss tangent showed that the maximum growth of the dielectric parameters lies in the region of near the temperature range close to 100°C, this value also increases for fine structures. A significant impact on the dielectric losses of mechanically activated grain crops samples with different degrees of grinding is exerted by the frequency of the external electric field, which can be associated with a change in the structure of a finely dispersed nonequilibrium heterogeneous environment as a result of the procedure of mechanical activation.

1. Introduction

The main role nowadays in solving the strategic task of providing the country's population with food is given to grain crops as to the most important social food products. Therefore, issues of increasing productivity, improving processing methods and optimizing grain drying processes today play a significant role. The most important technological operation, which is the most expensive resource-consuming process, is to process the obtained grain yield, taking into account the problem of saving energy resources and selecting optimal conditions for its storage [1].

It is important to understand that grain has a number of unique physical properties that have a significant impact on its quality and storage duration. All thermal characteristics of the grain depend significantly on humidity, temperature and frequency of external electrical influence [2-6]. Changes in humidity entail changes in the properties of cereals and all its electrophysical indicators: electrical conductivity $\sigma$, permittivity $\varepsilon$, and the tangent of the dielectric loss angle $\tan \delta$ [2, 6].

The experimentally established relationship of these parameters with the moisture content in the grain is the basis for the development of methods and operation of electrovlagomers. The dielectric properties of the grain crops used in the measurement of their moisture in [7], the dielectric properties of grain are described and it is found that the dielectric constant increases with increasing moisture content and
decreasing frequency, and the loss angle tangent and loss coefficient can increase or decrease with changes in these two variables, depending on the range of each of them.

There are models for estimating the dielectric constant of grain, which is an important parameter in the calculation of grain moisture, including temperature-dependent model. [8, 9]

The correlation of these parameters with the moisture content in the grain, deduced from experiments, lies at the basis of the development of the method and operation of electric moisture meters. The dielectric properties of grain crops are used to measure their moisture. The dielectric properties of grain were described in the paper [7], and it was established that the permittivity increases with increasing moisture content and decreasing frequency, and the loss tangent and coefficient of losses can increase or decrease with a change in these two variables, depending on the range of each of them.

There are models for assessing the permittivity of grain, which is an important parameter in calculating grain moisture, including temperature-dependent models [8, 9]. So, based on measurements of the dielectric properties of hard red winter wheat, a mathematical model is developed for calculating the permittivity of wheat in a wide frequency range from 5 MHz to 12 GHz with varying degrees of grain moisture from 3% to 24% [8].

Temperature has a significant effect on the electrophysical properties of grain, which is associated with changes in the state of water absorbed by the grain [3]. In addition to the direct effect on enzyme activity, temperature variations seriously change the protein composition of crops and, at temperatures near 60°C, its gradual denaturation begins. Therefore, when studying the behavior of grain during its drying and storage, it is important to consider the temperature and humidity conditions [10].

The dielectric properties of grain crops, depending on the particle dispersion, the frequency of the external electric field and the value of the temperature effect, were studied in [2-4, 6, 11]. It is found, that finely dispersed mechanically activated grain crops have unequal physical characteristics, depending on the size of the specific surface area of the grain, temperature and frequency.

If the temperature regime and storage conditions are not observed, the grain can «burn» and one of the reasons for this phenomenon can be considered the occurrence of micro-stimulated currents in a finely dispersed heterogeneous mechano-activated medium in the absence of external voltage [12, 13].

The method of investigation of dielectric losses during heat treatment of grain in this paper is the method of dielkometry [14, 15], which allows us to study the molecular structure of the medium under study by measuring the permittivity and the tangent of the angle of dielectric losses.

The purpose of this work is to study the electrophysical properties of cereals on the example of fine wheat samples with different particle sizes from 50 to 1000 µm in a wide range of changes in the frequency of the external electric field and temperature. One cannot take into consideration the fact that damaged or crushed grains with cracks and chips should be stored at lower relative humidity and optimally selected temperature conditions.

2. Materials and techniques

In this paper, the dependence of the tangent of the dielectric loss angle $\tan \delta$ of mechanically activated wheat samples with different particle dispersion values in a wide range of temperatures and frequencies of the external electric field from 25 Hz to $10^6$ Hz is studied.

Experimental samples of wheat were prepared by mechanical activation, which resulted in dispersed systems with particle sizes in the range from 50 to 1000 µm. The dielectric method was used to measure the electrical capacitance and calculate the temperature dependence of $\tan \delta$ [3, 15].

All measurements were carried out using an E7-20 LCR meter and a specially designed measuring cell in the form of a flat capacitor with a diameter of 21 mm and aluminum electrodes. Mechanically activated wheat samples were continuously quasi-stationary heated in the range from 20°C to 270°C at a speed of 0.7 deg/min. The temperature of the samples was measured using a chromel-alumel thermocouple. The electrodes in the cell had a circular shape with a diameter of 21 mm. The relative permittivity of the samples was calculated as the ratio of the capacity of a capacitor with a substance to the capacity of a capacitor without a substance. Dielectric losses are calculated by the formula:
\[
\varepsilon'' = \varepsilon' \tan \delta
\]

Loss tangent of a dielectric was determined through frequency \( \nu \) electrical capacity \( C \) and conductivity using \( G \) equation:

\[
tan \delta = \frac{1}{\omega RC} = \frac{G}{2\pi\nu C}
\]

The capacitive method of studying the electronic structure and molecular interactions used in this work is based on the study of the polarization process that occurs in a dielectric under the influence of an external field. The main parameters characterizing the dielectric is the permittivity, studied for grain crops in [2-4, 6, 8, 9, 11] and the dielectric loss angle \( \delta \), supplementing the phase shift \( \phi \) angle between current and voltage up to 90 degrees. Part of the electrical energy that goes into heat under alternating voltage is meant by dielectric losses. These losses are due to electrical conductivity and slow-setting polarization, which cause heating of the test samples. The measurement of electric capacity and full conductivity of wheat samples were measured in the frequency range from 25 to \( 10^6 \) Hz with a E7-20 digital LCR voltage meter with an accuracy of 0.2 pF and 1 pF electrical conductivity. 

Then the experimental data were transferred to a personal computer using an analog-to-digital converter, processed by well-known statistical methods and presented in the form of diagrams. Figure 1 shows a diagram of an experimental setup for obtaining the frequency and temperature dependence of the capacitance and total electrical conductivity of materials.

![Experimental setup diagram](image)

**Figure 1.** Experimental installation for measuring the electrophysical properties of materials.

### 3. Results and discussions

The study of the electrophysical properties of fine dispersed grain samples was carried out by the dielkometrical method [14, 15] in the temperature range from 20ºC to 270ºC and the frequency range from 25 Hz to \( 10^6 \) Hz. When the temperature increases, the studied fine-dispersed medium of mechano-activated wheat with a spatially inhomogeneous charge distribution receives additional energy that affects the electrophysical properties. Figure 2 shows the temperature dependence of the dielectric loss tangent for wheat samples with different degrees of grinding at a frequency of 500 Hz.

In the low temperature region, the growth of \( \varepsilon' \) and \( \tan \delta \) weakens the intermolecular forces, which contributes to easier rotation of the dipoles in the electric field. In this case, the studied grain samples can be considered as a polar dielectric with the corresponding maximum for \( \varepsilon' \) and \( \tan \delta \) when the temperature increases. The increase in conductivity at the beginning of heating, observed in the heterogeneous system under study, is associated with the processes of desorption of water molecules from small-sized wheat grains and their drying. As the temperature increases, the mobility of dipoles increases, it is easier for them to change their orientation in the electric field, which contributes to the growth of the above parameters. With the subsequent increase in temperature, the kinetic energy of the thermal motion of the dipoles increases and as a result of brownian motion, their orientation gradually...
collapses, while the permittivity of the tangent of the dielectric loss angle decreases. A similar nature of the dependence for the tangent of the loss angle and the permittivity is noted in [2,4,6,11].

Figure 2. Temperature dependence of the tangent of the angle of dielectric losses of wheat samples by dispersion: 501-1000\(\mu\)m; 251-500\(\mu\)m and less 50\(\mu\)m.

Figure 2 analysis showed that for sample 1 with a particle size of 501-1000 \(\mu\)m, the maximum value of \(\text{tg}\delta = 0.57\) corresponds to \(T = 92.4^\circ\text{C}\), for sample 2 with a particle size of 251-500 \(\mu\)m, \(\text{tg}\delta = 1.16\) at \(T = 92.5^\circ\text{C}\), and for sample 3 with the lowest particle dispersion, \(\text{tg}\delta = 2.09\) at \(T = 100.4^\circ\text{C}\).

In the temperature range close to 180,6-192,5\(^\circ\text{C}\), a second insignificant maximum is observed, obviously associated with the destruction of the structure of the solid component (for sample 1 with a particle size of 501-1000 \(\mu\)m, the maximum value is \(\text{tg}\delta = 0.48\) at \(T = 185.8^\circ\text{C}\), for sample 2 with a particle size of 251-500 \(\mu\)m, \(\text{tg}\delta = 0.69\) at \(T = 192.5^\circ\text{C}\), and for sample 3 with a particle size of less than 50 \(\mu\)m it is less noticeable and \(\text{tg}\delta = 0.9\) at \(T = 180.6^\circ\text{C}\). The increase in temperature contributes to the weakening of forces that prevent the orientation of domains.

In the specified temperature range, the structure of the studied samples is destroyed and the grain «burns out». Thus, it is established that a sample with a particle size of less than 50 microns in the range of the studied temperatures and frequencies from 25 to \(10^6\) Hz has a greater permittivity and greater dielectric losses in comparison with larger samples. A similar nature of the dependence for the tangent of the loss angle and the permittivity is noted in the works [2, 6, 11]. When the temperature increases above 130\(^\circ\text{C}\), the differences in the dielectric parameters of samples 1 and 2 are smoothed out, and the dependence is most obvious in sample 3 obviously, this is due to an increase in the polarization of the samples and a weakening of the forces that prevent the orientation of the domains [16]. The Measured permittivity and loss angle tangent spectra demonstrate typical behavior of relaxation structures [16, 17].

Figure 3 shows the temperature dependence of the loss angle tangent at different frequencies for a sample with a dispersion of 251-500 microns. The analysis of the results shows a significant influence of the frequency of the external electric field on the dielectric parameters of grain samples, especially noticeable at low frequencies from 25 to 100 Hz. At frequencies above 500 Hz, the permittivity and dielectric losses are reduced. The decrease in the actual component of the permittivity \(\epsilon\) and the tangent of the dielectric loss angle \(\text{tg}\delta\) with an increase in the frequency of the external electric field is associated
with the degeneration of dipole-orientation polarization in the disordered systems under study. When the frequency of the external electric field increases, the length of the ion path over the half-period of vibrations, the kinetic energy, and the probability of an ion colliding with the structural units of the material decreases. Therefore, when the frequency of the electric field increases, the dielectric losses decrease.

Figure 3. Temperature dependence of the tangent of the angle of dielectric losses of wheat samples by dispersion 251 501 µm for the frequency: 25Hz, 100Hz, 500Hz, 1000Hz и 10000Hz.

The curves $\tan \delta = f(T)$ also show anomalies corresponding to an increase in $\tan \delta$ when the temperature rises above 180°C, especially pronounced for the low frequency region. Obviously, in the area of high temperatures for a complex dielectric at a frequency of less than 100 Hz due to the destruction of the structure of the substance and its «combustion». There is a sharp increase in dielectric losses. In general, the analysis showed that when the frequency of the external electric field increases, the length of the ion path over the half-period of vibrations, the kinetic energy and the probability of an ion colliding with the structural units of the material decreases. Therefore, when the frequency of the electric field increases, the dielectric losses decrease.

As a result of the research, it was found that the tangent of the dielectric loss angle of small-sized mechanoactivated wheat in the studied temperature range has a maximum on average at a temperature close to 92°C. Analysis of the experiment results confirms the complex order in the arrangement of atoms of the heterogeneous non-equilibrium fine-dispersed medium under study and the presence of electric charges on its cracks and chips [12-17].

4. Conclusion
As a result of the conducted research, the presence of a pronounced dependence of the dielectric parameters of fine wheat samples with different degrees of fractions on the frequency of the external electric field and temperature was established. Due to the degeneration of dipole-orientation polarization in the disordered systems under study, a pronounced decrease in the tangent of the dielectric loss angle $\tan \delta$ occurs with an increase in the frequency of the external electric field.

Samples with smaller particles are characterized by higher electrical activity, a higher concentration of water films, and an increase in the permittivity and tangent of the dielectric loss angle, most noticeable at frequencies below 100 Hz.
The dependence of the tangent of the dielectric loss angle \( \tan \delta \) on the frequency of the external electric field and temperature is established, especially pronounced for fine wheat samples.

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