Temperature condition influence analysis on the mechanoactivated wheat dielectric constant

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Abstract. The biochemical properties of the grain depend significantly on the effects of heat and moisture. By regulating the external conditions, it is possible to influence the biochemical processes in grain, to change its biochemical characteristics. The analysis of temperature dependence of electrophysical properties in fine-dispersed non-equilibrium heterogeneous medium has been carried out on the example of mechanically activated wheat. It is shown that the disordering of fine-dispersed grain structure and change of temperature condition have a significant influence on its dielectric properties. The value of the real component of the dielectric constant depends on the degree of samples dispersity, temperature and humidity conditions and the frequency of the external electric field. The study of the dielectric constant spectra showed that the maximum growth of the dielectric parameters corresponds to a temperature close to 100°C and its value increases for wheat samples with lower particles dispersity. The frequency of the external electric field has a significant influence on the dielectric parameters of wheat samples with different degrees of dispersity, which is associated with changes in the structure of the non-equilibrium system as a result of mechanical activation.

1. Introduction
The main factors determining the condition of cereals are humidity and temperature, the variation of which significantly affects its properties. Grain is a living organism, and humidity and temperature are the main factors that determine the grain respiration process and affect the duration of its storage.

Therefore, the moisture contained in the grain and the temperature condition are of paramount importance in the field of grain technology. Temperature changes affect the activity of enzyme activity and have a direct effect on grain proteins. Thus, if the raise of temperature to 30-45°C causes increased activity of enzymes, improved elasticity and gluten, then a partial denaturation of proteins occurs at the temperature raise above 60°C. The temperature condition change is transmitted to the cereallan layer and affect the biochemical properties of the grain. Thus, when heating the grain mass from 45-50°C and above changes occur in the cells of the cereallan layer and the number of water-soluble proteins significantly decreases. Temperature variations are also associated with grain moisture, the higher it is, the stronger the temperature effect. By adjusting the parameters of the ambient environment, it is possible to carry out certain biochemical processes in the grain, to change its biochemical properties. Therefore, it is impossible to study the behavior of grain and grain products during storage without taking into account the temperature and humidity condition. The process of heat and moisture transfer in the grain mass occurs constantly, it exchanges moisture and heat with the atmosphere and is a labile system that is sensitive to the slightest changes in the parameters of the atmosphere through the response
change of its integrated properties [1-2]. The dielectric properties of food products, including cereals, and methods of processing and drying them using various sources of temperature exposure have been studied in [3,4]. The main method for dielectric properties study is the diecometer method, based on the study of the molecular structure of a substance by measuring the dielectric constant and the loss tangent of a dielectric [5,6]. If the grain is damaged: has cracks, chips, is broken or has a certain degree of shredding, then it should be stored at a specially selected temperature and lower relative humidity.

The objective of this paper is to study the characteristics of shredded wheat samples with different degrees of dispersity from 50 to 1000 µm, which is an example of a fine-dispersed mechanoactivated non-equilibrium heterogeneous medium. In addition, wheat is undoubtedly one of the main foodstuff. Therefore, the study of electrophysical properties, temperature and frequency dependence of mechanoactivated wheat is of particular interest.

2. Materials and techniques

The real component of dielectric constant of mechanically activated wheat samples with different degree of particles dispersity depending on temperature in wide frequency range of frequencies of external electric field from 25 Hz to 10^6 Hz has been studied in the paper.

Experimental samples of wheat were prepared by mechanical activation method, which resulted in dispersed systems with particle sizes in the range from 50 to 1000 µm. The sample adsorption value φ=8% was used. To study the dielectric constant ε' and the temperature dependence, the dielectric method [7,8] was used in a wide frequency range. Measurements of electrophysical parameters were carried out using the E7-20 immitance meter, as well as measurement cell, which is a flat capacitor with aluminum electrodes and a cell diameter of 2.1 cm. The samples were heated in the temperature range from 20ºC to 250ºC. The dependence on temperature was studied in the continuous mode of quasi-stationary heating of the wheat samples under study. The heating rate was 0.7 deg / min, and the sample temperature was measured using a chromel-alumel thermocouple. The diameter of the round electrodes in the cell is 2.1 cm. The relative dielectric constant was calculated using the ratio of the capacitor capacitance with a substance to the capacitance without a substance using a formula.

\[
\varepsilon' = \frac{C_{\text{substance}}}{C_0},
\]

where: \(C_0 = 0.0695 \frac{d^2}{h} \); d – diameter of the capacitor, h – distance between the capacitor plates in centimeters [9].

Measurements of dielectric parameters of wheat were made in the frequency range from 25 to 10^6 Hz using a digital voltage immitance meter E7-20. The measurement error of the electrical capacity is 0.2 pF, and the electric conduction is 1pS. The scheme of the pilot unit for studying the frequency and temperature dependence of the capacitance and full electric conduction is performed in accordance with the utility model [10] and is presented in figure 1.

![Image](image_url)

**Figure 1.** Device for diagnostics of electrophysical properties.
The data obtained as a result of the experiment were stored in the memory of a personal computer, then processed and presented in the form of diagrams.

3. Results and discussions

Studies of the electrophysical properties of mechanoactivated wheat samples were carried out by the method of dielcometer [5-8, 9] in a wide temperature and frequency range. The heterogeneous fine-dispersed system of wheat grains under study has a spatially inhomogeneous distribution of electret charges that acquire additional energy when heated and affect the value of electrophysical parameters [9].

Figure 2 shows the temperature dependence of the real component of the dielectric constant for wheat samples with different dispersity at a frequency of 500 Hz. Maxima of dielectric conduct in figure 2 correspond to the temperature range of 92.5°C and 106.2°C and corresponds to the typical behavior of relaxation structures. Thus, for sample 1 with a particle size of 501-1000 µm, the maximum value of ε′=9.68 at T=95.7°C, for sample 2 with a particle size of 251-500 µm ε′=16.6 at T=92.5°C, and for sample 3 with the lowest degree of particle dispersity of ε′=23.8 at T=106.2°C.

One of the main reasons for the variation of electrical parameters is the nature of the distribution of water within the grain mass. The "bound" water is firmly connected in the molecular structure of grain components and is a part of the physical but not chemical structure of molecules. The dielectric constant of bound water, which is not able to dissolve mineral salts, has the same value as that of a grain molecule. Bound water, which is a part of the molecular structure of the medium under study, is a dielectric material. "Free" water is water that can act as a solvent, it is located in the gaps between large molecules. "Free" water contains dissolved salts, conducts an electric current, and its dielectric constant is close to the value 81 for pure water. Increase and sharp decrease of dielectric constant before and after phase transfer in the heterogeneous system under study indicates the presence of different concentration in samples and ionization of local centers, as well as their relaxation during heating [11,12].

In the range of low temperatures growth of ε′ promotes weakening of intermolecular forces and assistance in turn of dipoles under the influence of electric field. In this case, the grain mass can be considered as a polar dielectric material whose temperature dependence ε has a typical maximum.

![Figure 2. Temperature dependence of the permittivity of wheat samples: graph 1 - dispersion 501-1000 µm; graph 2 - dispersion 251-500 µm; graph 3 - dispersion of less than 50 µm.](image)

At low temperatures, water molecules decay into ions that are sources of free electret charges. As temperature increases, the mobility of dipole molecules also increases, and they are more easily oriented by the influence of the external electric field, which contributes to the growth of the dielectric constant
of the medium. During thermal expansion, ion polarizability increases due to the weakening of elastic linkage between them. As the temperature increases, the interatomic spacing also increases and the ionic bonding within the substance weakens, which facilitates the displacement of ions under the influence of an external electric field. A further increase in temperature contributes to a significant increase in the kinetic energy of the thermal motion of the dipoles and the Brownian motion of the molecules contributes to the destruction of the orientation created by the external electric field, the dielectric constant falls [11,12,15].

Figure 2 shows a second insignificant maximum in the temperature range close to 180°C (for sample 1 with a particle size of 501-1000µm, the maximum value of ε'=9.37 at T=179.8°C, for sample 2 with a particle size of 251-500µm ε'=9.71 at T=174.8°C, and for sample 3 with a particle size of less than 50 µm ε'=19.9 at T=180.6°C. In this temperature range, the structure of the substance under study is destroyed, and the grain "burns". In addition, an increase in temperature leads to a weakening of the forces that prevent the domain orientation. From the analysis of the temperature dependence ε' = f(T) (figure 2), it follows that the sample under study with a dispersity of less than 50 microns in the spectrum of all studied frequencies is characterized by greater dielectric constant throughout the whole temperature range, in comparison with other larger-sized samples under study, which is also associated with an increase in the BET surface area when the sample is shredded [9,13,14]. When the temperature increases above 150°C, differences in the dielectric characteristics of samples 1 and 2 are smoothed out. The strongest dependence on temperature is observed in the sample 3 with the smallest particle size, obviously, the increase in temperature contributes to the weakening of the forces that prevent the domain orientation.

Figure 3 shows the temperature dependence of the dielectric constant for a wide frequency range from 25 to 10000 Hz.

![Figure 3](image_url)

**Figure 3.** Dependence of the dielectric constant of the sample with dispersion 251-500µm temperature at different values of the frequency of the electric field.

Analysis of the results allows us to conclude that the frequency of the external electric field has a significant effect on the dielectric characteristics of grain, especially significant in the low frequency
range from 25 to 100 Hz. At high frequencies, the intensity of dipole polarization decreases and dipoles do not have time to follow changes in the electric field, so the dielectric constant is significantly diminished. As the frequency increases, the maximum dielectric constant of the samples under study not only decreases, but also shifts somewhat towards higher temperatures, that is, to the area of lower viscosity of the substance. Thus, for a sample at a frequency of 25 Hz, the maximum $\varepsilon'=27.6$ at $T=91.5^\circ C$, and at 10,000 Hz, the maximum $\varepsilon'=5.75$ at $T=93.5^\circ C$. It should be noted that a second less significant maximum in the temperature range of 176.2-179.8$^\circ C$ shown in figure 3, obviously associated with the destruction of the structure of the solid component. The real component of the dielectric constant maximum in the specified temperature range varies from 4.13 to 17.42. The maximum value of $\varepsilon'$ is in the range of the lowest frequency of 25 Hz ($\varepsilon'=17.42$), the minimum at a frequency of 10000 Hz ($\varepsilon'=4.13$). Analysis of the maxima of dielectric constant in the graph confirms the complex order in the arrangement of atoms of the dispersed medium and the presence of charges in its defects and traps. When placing the samples under study in an electric field, the processes of electric conduction and polarization occur, accompanied by loss of energy of the electric field. The loss of electric conduction decreases with frequency increasing. However, it is obvious that resonant polarization increases at certain frequencies, which leads to an increase in dielectric losses [13,14]. The accumulation of free electret charges in small-sized electrically active systems also affects the processes under consideration [15]. The decrease in the real component of the dielectric constant with an increase in the frequency of the external electric field can be associated with the degeneration of dipole-orientation polarization in the studied fine-dispersed non-equilibrium medium of mechanoactivated wheat.

4. Conclusion

The paper provides an integrated analysis of the results of the study of the actual component of the dielectric constant in a non-equilibrium heterogeneous fine-dispersed medium consisting of mechanoactivated fine-dispersed wheat with different degrees of fractions. As a result of the study, the presence of a pronounced relationship between the dielectric constant of the medium under study and the amount of structural disordering, the temperature condition and the frequency of the external electric field was established.

It was found that fine-dispersed wheat obtained as a result of mechanical activation shows heterogeneous physical properties depending on the size of the BET surface area of the particles, the temperature condition, and the frequency.

Experimental studies conducted using the dielcometer method to study the effect of temperature exposure and changes in the frequency mode of the external electric field on the properties of the fine-dispersed medium of mechanoactivated wheat grains with different degrees of fractions have shown that the effect of temperature exposure is particularly significant for the most fine-dispersed samples.

The dependence of the actual component of the dielectric constant on the frequency and temperature at different degrees of dispersity of the medium is established.

References

[1] Lichko N M 2008 Technology of processing of crop production (Moscow: Koloss (Colossus) p 616
[2] Karpov B A 1987 Technology of host-harvesting processing and storage of grain (Moscow: Agropromizdat (Agriculture and industrial publishing) p 288
[3] Makarchuk N O 2019 Evaluation of extruder thermal conditions under primary grain processing wastes granulation Youth of the XXI century: a step into the future (materials of the XX regional scientific and practical conference vol 3 (Blagoveshchensk: Amur State University) pp 306–7
[4] Frolov V F 1987 Simulation of dispersed materials drying (Leningrad: Chemistry) p 208
[5] Tareev B M 1982 Physics of dielectric materials (Moscow: Energoizdat) p 320
[6] Gorokhovsky Y U A and Borodovsky G A 1991 Thermoactivational current spectroscopy of high-ohmic semiconductors and dielectrics (Moscow: Nauka (Science) p 244
[7] Poplavko Y U M 1980 *Physics of Dielectrics* (Kiev: Vyshcha shkola (High school) p 398
[8] *Chemical Encyclopedia (DAF-Med vol 2)* ed I L Knuniants 1998 (Moscow: The Great Russian encyclopedia) p 671
[9] Buzunova M Y 2019 Study of fine heterogeneous systems dielectric and structural properties on the example of crops *Baikal Letter DAAD* 1 124–9
[10] Ruzhnikov L I, Maksimova N T and Shcherbachenko L A 2014 Pat. of the Russian Federation No 136581 appl. 12.08.2013, publ. 10.01.2014
[11] Shcherbachenko L A, Donskoy V I, Shurigina N A, Barishnikov E A, Ezhova L I, Barishnikov D S, Vasilev S A, Afanasov S V and Lenev D A 2012 Structural and phase transitions in dispersed heterogeneous systems in presence of heterogeneous components electric contact interaction *Vestnik of Burat State University* 3 208–16
[12] Shcherbachenko L A, Maksimova N T, Komarov E S, Ruzhnikov L I, Karnakov V A, Krasnov D A, Troshev A A, Baryshnikov D S, Ezhova L I and Baryshnikov E S 2012 Electret processes in disordered systems based on liquid dispersion media *Technical Physics. The Russian Journal of Applied Physics* 57(10) 1417–23
[13] Buzunova M Y and Bonnet V V 2019 Mechanism of thermally stimulated current occurrence in fine heterogeneous medium on the example of grain crops *IOP Conference Series: Earth and Environmental Science* 421 052032
[14] Tanaev A B, Shcherbachenko L A, Bezrukova Y V, Tsydykov S B, Buzunova M Y, Baryshnikov S S, Ezhova L I and Baryshnikov D S 2017 Peculiarities of the accumulation and transport of electret charges in fine-sized disordered structures due to internal voltage *The Russian Journal of Applied Physics* 62(3) 406–12
[15] Shcherbachenko L A, Tsydykov Sh B, Bezrukova Ia V, Karnakov V A, Arskaiia L I, Marchuk S D, Chernyk D O and Zhovnitskii V A 2017 Accumulation of free electret charges in the small-sized electrically active systems *News of higher educational institutions. Physics* 60(1) 93–7