Study of the dielectric parameters of biological liquids

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Abstract. Study of the dielectric parameters of different materials attracts great attention of researchers as these parameters allow knowing various characteristics of different materials and chemical substances. This article presents studies of dielectric loss tangent of albumin protein water solution. Measurements of the frequency dependence of dielectric loss tangent in the range $10^{-1}$–$10^6$ Hz were performed. The experimental results showed non-linear frequency dependences of the dielectric loss tangent.

1. Introduction
Presently, study of the dielectric parameters of various materials and systems attracts the attention of researchers all over the world. [1-10]. Research into the dielectric parameters of various biological systems, in particular solutions of biological fluids, is of particular interest [2, 4-14]. Radio spectroscopic studies of the dielectric properties of molecular solutions and films allow to investigate the molecular structure, intermolecular interactions, kinetics, aggregation mechanisms, and other molecular processes. [1, 5, 11-18]. However, solutions of biological fluids are extremely complex biological and chemical systems. To measure the dielectric parameters of such solutions is a quite difficult task. This work is devoted to the study of the dielectric loss tangent of an albumin protein aqueous solution using dielectric impedance spectroscopy.

2. Experiments
In this part of paper the dielectric losses tangent definition is discussed. The experimental samples are considered. The experimental setup is shown.

2.1. Dielectric loss tangent
Dielectric loss is the energy dissipated in the electrical insulating material under the influence of electrical field. The ability of a dielectric to dissipate energy in the electrical field is usually characterized by the dielectric loss angle and dielectric loss tangent.

We consider insulator to be a capacitor and measure capacity and an angle $\delta$. In our consideration, the angle $\delta$ is a dielectric loss angle, which means that this angle is the phase angle between current and voltage in the capacitive circuit equal to $90^\circ$. When we apply the alternating voltage $U$, a current $I$ flows in the insulator. This current is ahead of the applied voltage in phase by angle $\varphi$ (figure 1) due to the presence of active resistance.
Figure 1. Vector diagram of currents which flow through a dielectric with losses. Here \( I_a \) and \( I_c \) are active and capacitive components of the total current, respectively.

The ratio of the active part of the current \( I_a \) to the capacity part \( I_c \) multiplied by one hundred percent is called dielectric loss tangent. This value is expressed as a percentage:

\[
\tan \delta = \frac{I_a}{I_c} \times 100\%. \tag{1}
\]

For measuring the capacity and dielectric loss angle, the equivalent capacitor circuit is represented as an ideal capacitor with a series-connected resistance or as an ideal capacitor with a parallel resistance. In this work the ideal capacitor with a parallel resistance scheme is used (figure 2).

![Parallel resistance scheme](image)

**Figure 2.** Parallel resistance scheme.

In our study we use bridge measurement.

2.2 **Experimental samples**

The reason we chose human albumin to be a test protein was determined by the importance for human blood plasma, as it regulates the pH of blood together with other plasma proteins, provides the osmotic pressure of blood necessary for the proper functioning of the body [8]. This protein is able to bind a large amount of organic and inorganic substances having different properties, provides transport of physiological metabolites and drugs, as well as providing a mechanism for regulating their level in the blood [9] and performs other equally important functions of the body. Albumin is a negatively charged, amphiphilic and amphoteric protein with a complex molecular structure [6-7, 19-22]. In turn, its aqueous solution is an electrically active system. Therefore, to study it, we chose the dielectric impedance spectroscopy method, based on measuring the dielectric losses of solutions and liquids [6-7, 10, 13], since this method allows a detailed study of the effect of acidity of the medium on the electrical properties of the protein [23-25].

We also chose a saline solution for NaCl studies. Sodium chloride is found in blood plasma and body tissue fluids (concentration of about 0.9%), being the most important inorganic component supporting the corresponding osmotic pressure of blood plasma and extracellular fluid. We assume that studies of the dielectric loss tangent will give a result that differs from the results in the study of albumin.
2.3 Experimental setup
For studying dielectric losses, we developed a setup with cylindrical electrodes, shown on figure 2.

![Figure 3. Experimental measuring set: 1 - a cuvette with a sample, 2 - electrodes, 3 - immitance meter "MNIPI E7-20".](image)

A 15 ml glass cuvette with four cylindrical electrodes placed in it was used for measurements. The electrodes were installed in such a way that the distances between them were d = 10 mm. We used human albumin solutions mixed with water 1:1 with a volume of 6 ml and physiological solution. Each solution had its own pH value. The samples studied had the following values of hydrogen indexes: sample 1: pH=6.9, sample 2: pH=5.1, sample 3: pH=4.8 (isoelectric point) for albumin solutions and pH=4.8, 5.1, 5.7 and 6.1 for physiological solutions. Acetic acid was added to the solution to obtain a solution with the required pH. The impedance $Z$ and phase angle $\phi$ between current and voltage were measured by the immitance meter. The dielectric loss tangent was determined by the formula:

$$D = \tan \delta = \frac{1}{\omega R C}$$

In formula (2) $\omega$, $C$ and $R$ were determined by the parameters measured during the study:

$$R = \frac{|Z|}{\cos(\phi)}$$

$$C = \frac{\sin(\phi)}{\omega |Z|}$$

$$\omega = 2\pi \cdot f$$

where $f$ – is experimental frequency.

3. Results
Solutions of albumin and physiological solution were investigated in the experimental part of this work. The frequency dependences of capacity in albumin and physiological solutions with various pH were obtained (figures 4 and 5).
Figure 4. The capacity of albumin solution with various volumes of pH is shown as a function of frequency by the three lines.

Figure 5. The capacity of physiological solution with various volumes of pH is shown as a function of frequency by the four lines.

From the graphics it can be seen that with increasing frequency the capacity of albumin solution and physiological solution decreases smoothly. At a frequency higher than 500 Hz, the capacitance tends to zero. These dependences are quite logical.

The dependences of peak frequencies and amplitude of $\tan \delta$ on pH for albumin and physiological solutions were obtained. Experimental results are presented in figures 6 and 7.

As we can see in the figures, the frequency of the peaks and their amplitudes also increase with pH.
Figure 6. The volume of dielectric loss tangent of albumin solution with various volumes of pH is shown as a function of frequency by the three lines.

Figure 7. The volume of dielectric loss tangent of physiological solution with various volumes of pH is shown as a function of frequency by the four lines.

4. Conclusions
In this work, we studied the dielectric properties of albumin solution in the frequency range from 100 Hz to 1 MHz by the method of dielectric impedance spectroscopy.

Experiments show that albumin demonstrates non-linear dielectric behavior and has a peak of dielectric loss tangent in this frequency range. The value of hydrogen index has an influence on the albumin solution dielectric parameters. The data obtained allow us to analyze the behavior of biological complexes in the studied frequency range. Thus, according to the results of the research, it is possible to speak about the applicability of this method for obtaining information about the composition and properties of liquid media and protein solutions. Further studies will be aimed to studying the blood serum by this method in order to explore the possibility of diagnosing the human health condition and comparison with dynamic light scattering method [26, 27].
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