EFFECT OF THE FORM OF BINDING OF THE MOISTURE ON THE DIELECTRIC PROPERTIES OF DAMP CELLULOSE

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The results of an experimental investigation into the dependence of the dielectric constant and the tangent of the loss angle of cellulose on the moisture content and the wavelength of the electromagnetic field are presented, due allowance being made for the different forms of binding of the moisture.

The relationship between the dielectric properties of damp cellulose and its moisture content (due allowance being made for differences in the form of binding of the absorbed moisture) is of particular interest in connection with optimizing the technological processes involved in the hydrothermal processing of cellulose in electromagnetic fields, in studying the mechanisms of damping and drying, and also in the field of electrical humidity measurement.

We studied the dielectric parameters of bleached cellulose sulfite in the form of decalcified filter paper (All-Union State Standard 7246-54, Trade Standard TU MMP RSFSR No. 304-64) as functions of the moisture content over the wavelength range 60,000-30 m, using the IDN-1 and KV-1 types of Q meter.

For this purpose we made a measuring condenser so designed as to ensure a uniform distribution of moisture in the sample while preserving its macroscopically porous structure. In this condenser (Fig. 1) we used the positive sides of a three-electrode condenser [1, 2].

The electrodes 2 of the condenser were made of sheet nickel 0.6 mm thick with apertures 0.3 mm in diameter at a distance of 2.5 mm from one another. The diameter of the electrodes and the distance between them respectively equalled 70 and 3 mm.

The rigid silvered leads 1 of the electrodes were made so as to minimize the dimensions of the feeding conductors. In this way the parasitic parameters of the measuring condenser (which may be taken into account in calculating the electrical parameters of the dispersed, dampened sample materials [3]) were kept constant.

The electrodes were placed in a thin-walled, airtight Teflon cylinder 3 with small taps 4 mounted in the base. The electrodes were kept in a plane-parallel state by machining the ends of the threaded joints of the cylinder very accurately.

A condenser of this kind may be used for both loose and solid dispersed materials. In order to ensure good and stable contact between the electrodes and the sample in the case of loose materials, mechanical agitation is essential in order to maximize the density of the material within the condenser. Solid samples are made in the form of two plane parallel disks fitted to the condenser dimensions.

In order to achieve moisture contents up to the maximum hygroscopic value, moist air is slowly pumped through the sample; the air is derived from three series-connected Tishchenko bottles filled with twice distilled water. Moisture contents greater than the hygroscopic value may be attained by passing the vapor of twice distilled water through the sample in the presence of a steam dome. The condenser is kept in a drying cabinet at 80°C. In order to dry the sample, dry air is passed through it, this having been previously dried by passing through Tishchenko bottles full of P_2O_5.

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TABLE 1. Moisture-Holding Properties of Cellulose

Moisture content of monomolecular adsorption, %		Combined moisture, %		Maximum hygroscopic moisture content, %	
from the BET equation	from drying thermograms	from heats of wetting	from drying thermograms	from sorption isotherms	from drying thermograms
3,4	4,8	14,4	15,8	24,7	24,9

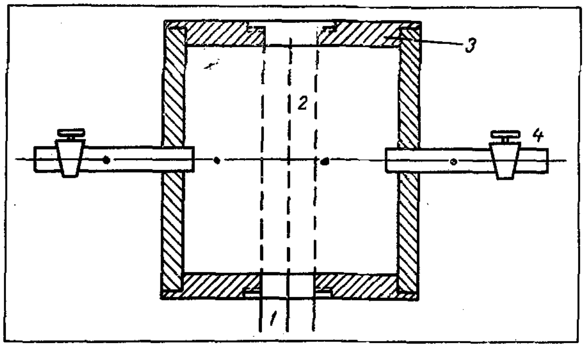

Fig. 1. Arrangement of the measuring condenser.

The moisture content of the sample is determined gravimetrically.

In order to achieve a uniform moisture distribution, the samples are held in the condensers for 2-3 days with the taps closed. The uniformity of the moisture distribution may be judged from the constancy of the input capacity of the condenser, determined by periodically connecting to the Q meter.

We correlated the electrical properties of the damp cellulose with its water-holding properties by studying the differential water-holding properties, these being determined by several mutually independent methods, such as sorption isotherms, isothermal drying thermograms [4], and heats of wetting, using the Dumanskii rule [5]. All the experiments were carried out at 25°C. The differential water-holding properties of cellulose are presented in Table 1.

The experimental results are shown in Fig. 2 in the form of the dependence of the dielectric constant and the tangent of the loss angle ($\tan\delta$) on the moisture content of cellulose for wavelengths of 60,000, 6000, 400, and 40 m.

The $\varepsilon'(w)$ and $\tan\delta(w)$ curves are characterized by regions of dissimilar increments in the dielectric constant and $\tan\delta$. On the first part of these curves, the dielectric constant and $\tan\delta$ increase very slightly (in a linear manner) with increasing moisture content for all wavelengths; this is apparently because successively adsorbed water molecules made similar contributions to the total polarization of the system.

On the second part of these curves, the dielectric constant and $\tan\delta$ increase more sharply, more particularly for long wavelengths. This indicates a dispersion of the dielectric constant and the $\tan\delta$ of the system. This is evidently associated with the fact that, in this range of moisture contents, the molecules of adsorbed moisture are less firmly attached to the sample. Relaxation polarization of the system is characteristic of this range.

The transition from the first part of the curves to the second corresponds approximately to the transition from a monomolecular layer to polymolecular moisture adsorption for all wavelengths studied.

For wavelengths of 60,000 and 6000 m the function $\varepsilon'(w)$ increases still more sharply after reaching a moisture content of 15%, approximately corresponding to the total quantity of combined moisture.

Thus the manner in which the dielectric constant and $\tan\delta$ of cellulose vary with its moisture content is determined both by the wavelength of the electromagnetic field and by the form of binding of the moisture. The part played by the form of binding becomes more evident as the wavelength increases.

Figure 3 presents some experimental data giving the dielectric properties of damp cellulose as functions of the logarithm of the wavelength for moisture contents corresponding to monomolecular moisture adsorption, combined moisture, moisture in the hygroscopic state, and completely wet samples.

Analysis of the $\varepsilon'(\log\lambda)$ and $\tan\delta(\log\lambda)$ curves shows that a dispersion of the dielectric constant and $\tan\delta$ takes place for moisture contents exceeding the value corresponding to monomolecular adsorption. The slight linear rise in the dielectric constant of the system in the region of monomolecular adsorption for the range of wavelengths studied is evidently due to displacement polarizations, the time required to establish these being under 10^{-12} sec [6]. Since the adsorbed molecules of moisture are bound quite firmly to the surface of the body, their mobility is low.

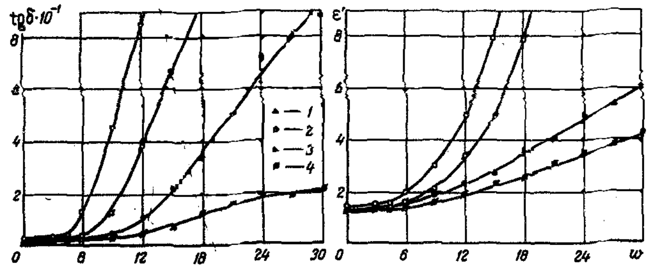

Fig. 2. Dependence of the dielectric properties of cellulose on moisture content for wavelengths: 1) λ = 60,000; 2) 6000; 3) 400; 4) 40 m. w, %.

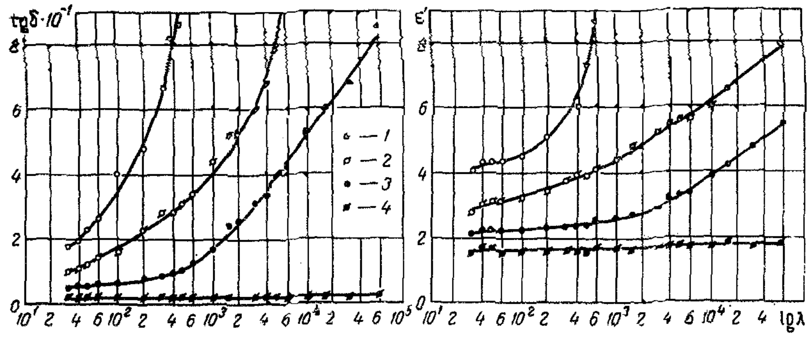

Fig. 3. Dependence of the dielectric properties of cellulose on wavelength for particular moisture contents: 1) 30; 2) 18; 3) 12; 4) 4.5%.

We see from Fig. 3 that the range of dispersion of the dielectric constant and tan δ embraces a very wide frequency range; the greater the moisture content, the stronger is the dispersion. With increasing moisture content the range of dispersion of the dielectric constant and tan δ moves in the short wavelength direction; this is evidently associated with changes in the mobility of successive molecules of absorbed water, oriented in the alternating electric field.

Thus our study of the dielectric properties of damp cellulose shows that the manner in which these properties vary with moisture content is determined, not so much by the total moisture content of the system, as by the manner in which the absorbed moisture is bound; it also depends on the wavelength of the electromagnetic field.

This experimental result must be taken into account when developing and calibrating electrical humidity meters intended for colloidal materials. The foregoing experimental data may be used to calculate the amount of energy dissipated in cellulose on drying the latter in a high-frequency electromagnetic field.

NOTATION

ε' is the real part of the complex dielectric constant of the material;
w is the moisture content of the material;
λ is the wavelength of the electromagnetic field.

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