A LABORATORY APPARATUS FOR DETERMINING THE MOISTURE CONTENT IN CAPILLARY-POROUS MATERIALS BY THE METHOD OF SUPER-HIGH-FREQUENCY ABSORPTION

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A test apparatus and procedure are described for determining the moisture content in capillary-porous materials by the absorption of super-high-frequency radio waves. Results are shown which have been obtained for clay and ceramics at temperatures from 300 to 373°K.

The physical principle of the SHF absorption method is based on the fact that in the centimeter range of wavelengths the absorption coefficient of free water is by almost two orders of magnitude greater than of a dry dielectric. The theoretical principles of the SHF absorption method have been explained in [1, 2], according to which the attenuation of SHF electromagnetic energy transmitted through a moist material is proportional to the total water concentration in the material. An analysis of the theoretical expression for the moisture content derived in [1] shows that the dielectric properties of water are functions of its temperature, its chemical content, and the kind of moisture bond, affecting the magnitude of electromagnetic energy losses in the wet material.

A test apparatus for the study of these effects has been designed and built with standard SHF instrument components. It is shown schematically in Fig. 1.

As the clay container one uses a pan of refractive glass transparent to radio waves and with a capacity of 4 liters.

When the moisture content in red brick and in floor tile is measured, the specimens are placed directly on the transmitter horn 2 and the thermocouple is installed in a special hole leading from a lateral

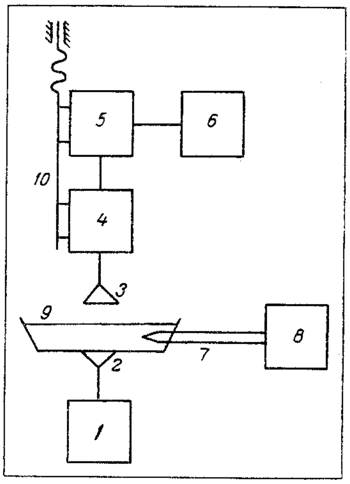

Fig. 1. Schematic block diagram of the apparatus for measuring the moisture content in clay and ceramics by the SHF absorption method: 1) model G_3-14A SHF oscillator; 2 and 3) transmitting and receiving horn antenna respectively (cross section area of the horn opening 90 × 135 mm^2); 4) model D5-5 precision attenuator for the instrument; 5) detector stage; 6) model U2-6 narrow-band amplifier; 7) thermocouple (KhK calibration); 8) model KP-54 potentiometer; 9) test material; 10) movable platform.

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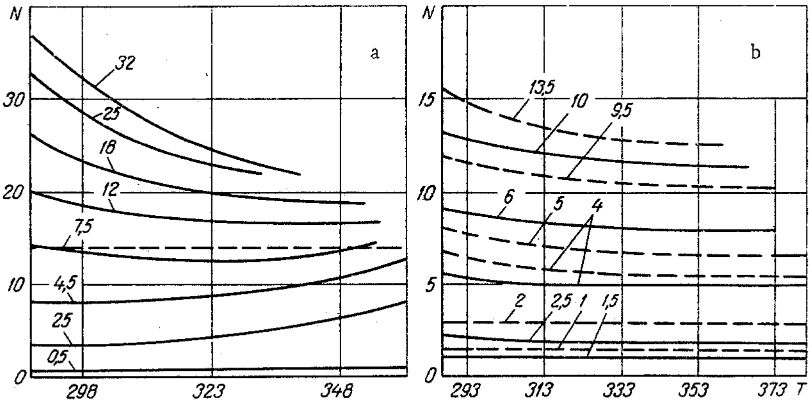

Fig. 2. Attenuation of SHF radio waves (dB) as a function of the temperature, in inorganic capillary-porous materials with various moisture contents: a) clay from the Vitebsk claybed; b) red brick (solid lines) and floor tile (dashed lines). Numbers at the curves indicate the moisture content (%). Attenuation N (dB), temperature T (°K).

surface to the center of the specimen. Specimens are wetted and control measurements are made according to the appropriate GOST (Government Standard).

The measuring procedure is as follows. The container is filled with material, which is then properly leveled and compacted. The proper thickness of a specimen is governed by the condition of maximum sensitivity, according to the formula

$$X = X_1 \frac{N_{\max}}{N_1}.$$

The container with material ready for test is weighed and then placed on the transmitter antenna with the flat bottom surface perpendicular to the optical axis of the horn antennas. The free cold ends of the thermocouple are connected to a potentiometer for temperature measurements. At the same time, the ambient temperature at the cold ends is read with a mercury thermometer. The needle of the indicating instrument connected to a narrow-band amplifier is first adjusted to the middle of the scale by turning the knob of the attenuator, whereupon the platform carrying the receiver antenna is displaced as much as is necessary to obtain the maximum needle deflection, and then the needle is reset back to its original middle position by another turning of the attenuator knob. The difference between the attenuator readings before and after the measurement with a specimen represents the amount, in decibels, by which the SHF radio waves have been attenuated in the wet specimen. Following the measurement, the container is removed from the test stand and placed in a drying oven at a prescribed temperature. After a time t, the container is removed from the oven, weighed, and placed again in the SHF test stand for another measurement of attenuation and temperature in the same sequence as before. Such measurements are repeated until the specimen has lost all the moisture, which is ascertained when its weight remains the same after several drying cycles.

This procedure yields the integral moisture content in a material layer of thickness X. The effect of moisture gradient on the measurement accuracy may be disregarded, inasmuch as the main effect is due to the total loss of SHF energy [1]. The degree of localization of measurements (or the resolving power with respect to specimen surface) depends on the directivity characteristics of the antennas and can be regulated over a wide range. This problem will not be further discussed here.

The results of such measurements made on clay from the Vitebsk claybed as well as on red brick and floor tile at various temperatures are shown in Figs. 2 and 3. The SHF oscillator operated on the 3 cm wavelength (frequency f = 10 GHz).

According to Fig. 2a, the temperature characteristics of SHF electromagnetic energy losses in clay vary with the moisture content. At a high moisture content (32-18%) the trend of the N = f(T) curve is analogous to that for free water (negative temperature coefficient of absorptivity), which indicates a predominance of free water in the clay–water system.

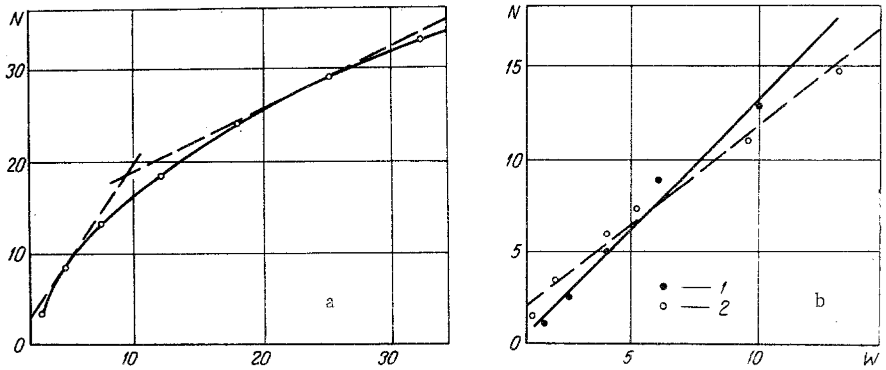

Fig. 3. Attenuation of SHF radio waves (dB) as a function of the moisture content in capillary-porous materials: a) clay from the Vitebsk claybed at T = 298°K; b) red brick (solid line) and floor tile (dashed line) at T = 293°K. Test points (1, 2), moisture content W (%), attenuation N (dB).

As the moisture content is decreased (within the 18-7.5% range), the shape of the N = f(T) curve changes gradually to a straight line (the dashed line in Fig. 2a). At a moisture content within the 8-10% range the temperature coefficient becomes constant, and at still lower moisture contents it becomes positive. The slope of the N = f(T) curve within the W = 7.5-4.5% range increases, and then decreases beginning at W = 2.5% until at W = 0.5% absorption becomes independent of the clay temperature. Thus, the temperature coefficient of attenuation changes three times as the moisture content drops from 32 to 0.5%. It is negative at high moisture contents, becomes zero (W ≈ 10%), then becomes positive, and at W ≤ 0.5% becomes zero again. Such a trend of the N = f(T) curve can be explained by the structural characteristics of the clay–water dispersion system and it is due to a change in the dielectric properties of water. In such a system one observes a steady transition from strongly bonded water to unbonded (free) water with known values of ε' and $\tan\delta$. The measurement data indicate that at low moisture contents the dielectric properties of water change while the SHF energy losses become higher. As W decreases, the concentration of bonded water in the system increases, and at W ≤ 10% the absorption of SHF energy is apparently governed by the presence of bonded water.

While the moisture content in clay decreases from 32 to 0.5%, one notes a parabolic relation between the attenuation of SHF energy and the moisture content (Fig. 3a) which can be approximated by two straight lines (the dashed lines in Fig. 3a) with different slopes and an intersection point at W ≈ 10% corresponding to a constant temperature coefficient.

The attenuation of SHF energy as a function of the temperature is shown in Fig. 2b for red brick and floor tile with various moisture contents. On the basis of the preceding discussion, one can explain the trend of these N = f(T) curves by the presence of free water (negative temperature coefficient) in the ceramic–water system. The dependence of the absorption of SHF energy on the moisture content can be closely approximated by a straight line (correlation coefficient 89%).

NOTATION

X	is the thickness of wet material layer, cm;
X_1	is the thickness of wet material layer corresponding to an attenuation N_1, cm;
N_1	is the attenuation, dB;
N_{max}	is the maximum attenuation recorded on the test stand, dB;
T	is the temperature of the material, °K;
W	is the moisture content in the material, %.

LITERATURE CITED

1. V. K. Benzar', Inzh.-Fiz. Zh., 18, No. 6 (1970).
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