ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 12 , December 2020

Measurements of Humidity Using Dielectric Method of Building Materials by Their Electrical Conductivity

Asadulla Turgunboyev, Umid Uralovich Xudaykulov

Candidate of Technical Sciences, Associate Professor,
Department of Electronic and Automatic, Tashkent State Technical University, Tashkent, Uzbekistan
Doctoral student of the Department of Metrology, Department of Electronic and Automatic, Tashkent State Technical University, Tashkent, Uzbekistan

ABSTRACT: This article discusses the physical-mechanical and mechanical properties of building materials, their electrical conductivity, the effect of moisture on these properties. The study of the international market for the production of moisture meters was carried out. Provided, the electric method of moisture measurement, advantages of the method, illustrates the electric circuit of the hygrometer. Also, speaking about dielcometric moisture meters, one should note their ease of manufacture and use, as well as their relative cheapness in comparison with other moisture meters.

KEY WORDS: humidity, thermal conductivity, heat capacity, temperature expansion, dielkometric method, electric dipole, dielko-moisture dependences, complex dielectric constant (CDC), dielectric constant (DC).

I.INTRODUCTION

The source of production of building materials is the country's natural resources, which can be used as building materials in their natural state (stone, sand, wood) or in the form of raw materials processed in the construction materials industry (polystyrene, expanded clay).
The group of physical-mechanical and mechanical properties of building materials consists, first, of the parameters of the physical state of materials and, second, of the properties that determine the relationship of materials to various physical processes. The first include the density and porosity of the material, the degree of powder grinding, the second — hydrophysical properties (water absorption, humidity, water permeability, water resistance, frost resistance), thermophysical (thermal conductivity, heat capacity, temperature expansion) and some others [1,2,3]. Since the humidity of building materials plays one of the main influencing factors on the quality of the product, it is necessary to constantly receive information about humidity. Humidity of materials is an indicator of the quality of construction products, which has a great influence on the technological, consumer, operational, and other properties of products and structures made from these materials. In many normative and technical documents (standards, technical conditions, process maps, etc.) of the construction industry, the humidity of materials and products made from them is normalized at a certain level and should be measured quite often. The method of measuring humidity regulated by these documents has traditionally provided for sampling /making samples, weighing them, drying them at a certain temperature, re-weighing them until a constant mass is reached, and calculating humidity using a standard formula.

II. FORMULATION OF THE PROBLEM

This method was called "thermo-gravimetric" and could only be used in laboratory conditions.

$$W \equiv \frac{m_1 - m_c}{m_c} \times 100\%$$

where: m_1 – weight before material drying; m_c - weight after drying the material.
Since the quality of the parameters and characteristics of building materials is strongly influenced by humidity, humidity must be constantly monitored and measured. The drying method is more accurate but time consuming. This requires static (laboratory) conditions. Without grafts, often repeated and dynamic measurements, the drying method

loses its relevance. Based on the above, there are several methods that are quickly measured. One of them is the dielcometric method for measuring humidity[4,5].

Dielkometric method - based on measuring the dielectric constant of the material. It is possible to obtain reliable information about its percentage content in the material, since the permittivity of water is higher than that of other materials [6,7,8].

The ability of a substance to conduct an electric current is called electrical conductivity. According to electrical conductivity, all substances are divided into three groups:

- conductors;
- dielectrics;
- semiconductors.

The conductors have high electrical conductivity. There are conductors of the first and second kind. Conductors of the first kind include all metals, some alloys, and coal. They have electronic conductivity. The second kind of conductors are electrolytes. They have ionic conductivity. There is no electrostatic field in the conductors (Fig.1).

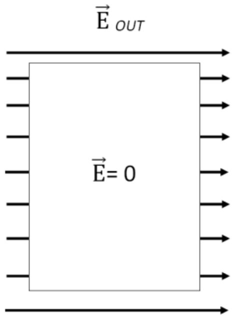

Fig. 1. Electrostatic field of conductors.

If the conductor is placed in an electrostatic field, then under the influence of this field, charges move in the conductor: positive – in the direction of the external field, negative – in the opposite direction (Fig.2). This separation of charges in a conductor under the action of an external field is called electrostatic induction. The charges separated inside the conductor create their own electric field directed from positive to negative charges, i.e. against the external field (Fig.2).

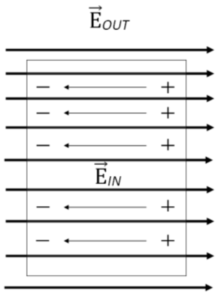

Fig.2 Electrostatic induction

Obviously, the separation of charges in the conductor will stop when the field strength of the separated charges $\vec{E}_{IN}$ becomes equal to the external field strength in the conductor $\vec{E}_{IN}$, т.е. $\vec{E}_{IN} = \vec{E}_{OUT}$, and the resulting field

$$\vec{E} = \vec{E}_{IN} - \vec{E}_{OUT} = 0 \qquad (1)$$

Thus, the resulting field inside the conductor will be zero (Figure 1). An electrostatic screen works on this principle, protecting part of the space from external electric fields (Fig. 3). To prevent external electric fields from affecting the accuracy of electrical measurements, the measuring device is placed inside a closed conductive shell (screen), in which there is no electrostatic field.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 12 , December 2020

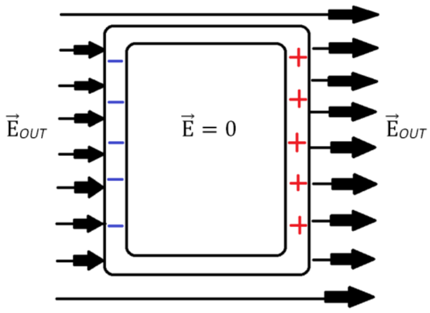

Fig.3. Electrostatic shield

The electrical conductivity of dielectrics is practically zero due to a very strong bond between the electrons and the atomic nucleus of the dielectric [9,10,11].

If a dielectric is placed in an electrostatic field, then polarization of atoms will occur in it, i.e. displacement of opposite charges in the atom itself, but not their separation (Fig. 4). A polarized atom can be viewed as an electric dipole (Fig. 5), in which the "centers of gravity" of positive and negative charges are shifted.

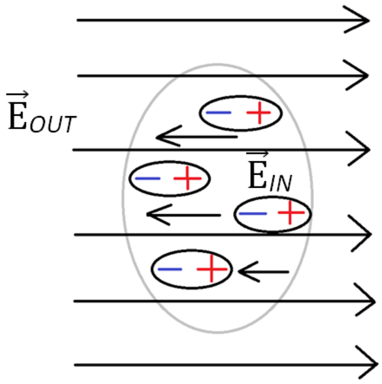

Fig.4. Redistribution of charges.

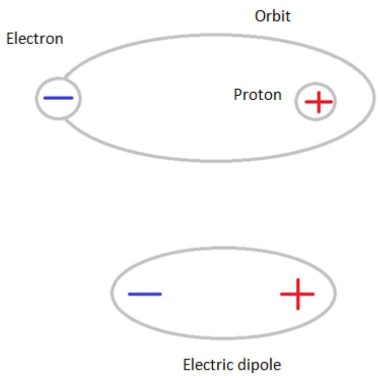

Fig.5. Redistribution of charges.

Dielectric constant, the value of ε, characterizing the polarization of dielectrics under the action of an electric field of strength E. The dielectric constant is included in Coulomb's law as a value that shows how many times the force of interaction of two free charges in a dielectric is less than in a vacuum. The weakening of the interaction occurs due to the screening of free charges by bound ones, formed as a result of polarization of the medium. Bound charges arise as a result of microscopic spatial redistribution of charges (electrons, ions) in an electrically neutral medium in general [12,13,14,15].

The relationship between the vectors of polarization P, electric field strength E and electric induction D in an isotropic medium in SI units is:

$$D=\varepsilon_0 E+P=\varepsilon_0 \varepsilon E \qquad (2)$$

where: ε_0 is an electrical constant. The dielectric constant ε depends on the structure and chemical composition of the substance, as well as on pressure, temperature, and other external conditions (Table 1). For gases, its value is close to 1, for liquids and solids it varies from several units to several tens, for ferroelectrics it can reach 10^4. This spread of ε values is due to different mechanisms of polarization that take place in different dielectrics.

Table 1. Dielectric constant of some dielectrics.

Substance	ε
H_2 (normal conditions)	1,00026
CO_2 (normal conditions)	1,0029
H_2O vapor (110 ° C)	1,0126
Polyethylene (20 ° C)	2,3
NaCl	5,62

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 12 , December 2020

Ethyl alcohol (15 ° C)	26,8
Ice (-5 ° C)	73
Water (20 ° C)	81
$CaTiO_3$	130

The dielkometric method uses the dependence of the material's permittivity on its moisture content. For water, the relative permittivity is 81, and for bulk materials, it is on the order of several units. Thus, the permittivity of a material strongly depends on its humidity. This method uses a high-frequency electromagnetic oscillator (f~10^6-10^7 Hz, usually 3-30 MHz), C~10 pF. In modern devices, sensors are pressed with a force of 5-10 H to the surface of wood or concrete and measure. HF currents penetrate the material to a depth of 20-30 mm, the device estimates the amount of current attenuation, which depends on the properties of the material and its humidity. The device's microprocessor unit converts the value of ε to absolute humidity. The moisture meter's memory usually stores data about the density of the materials it is designed for. The user's pre-selection of a wood type or concrete grade before measuring increases the accuracy of the results. The advantages of this method include:

1) high measurement accuracy and a wide range of moisture measurement;
2) high speed of obtaining the measurement result;
3) the moisture meter does not damage the surface.

Based on the above-mentioned advantage of the method, the demand for the production of dielkometric moisture meters is greater than the rest. The study of the international market for the production of moisture meters was analyzed (Fig.6).

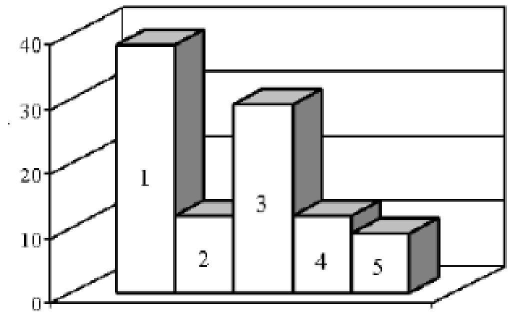

Fig. 6. Market share of manufactured moisture meters: 1 – dielkometric moisture meters; 2 – conductometric moisturemeters; 3 – IR moisture meters-dryers; 4 – IR spectrum analyzers; 5 – microwave moisture meters.

Dielcometric moisture meter (Fig. 7) consists of a capacitor sensor filled with a test material and a measuring device that measures the impedance of the sensor, its capacitive or active components. They use resonant, bridge and differential measurement circuits operating in the HF range. To calibrate the moisture meter, use a set of samples with different humidity values determined by the exemplary method (drying method).

The circuit consists of an HF generator based on a VT1 transistor, a capacitive sensor C5, a rectifier bridge based on VD1-VD4 diodes and a microammeter. With an increase in the moisture content of the material placed in the capacitive sensor, the capacitance of the capacitor C5 increases and its capacitance decreases, which leads to an increase in the current through the microammeter included in the diagonal of the rectifier bridge.

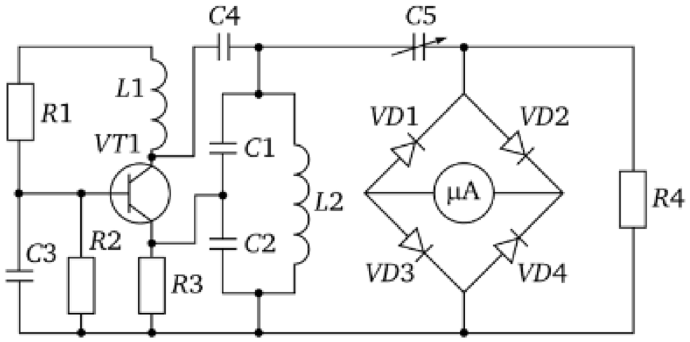

Fig. 7. Scheme of dielcometric moisture meter.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 12 , December 2020

Experiments on the influence of pollution on the dielectric constant of soils have been carried out.

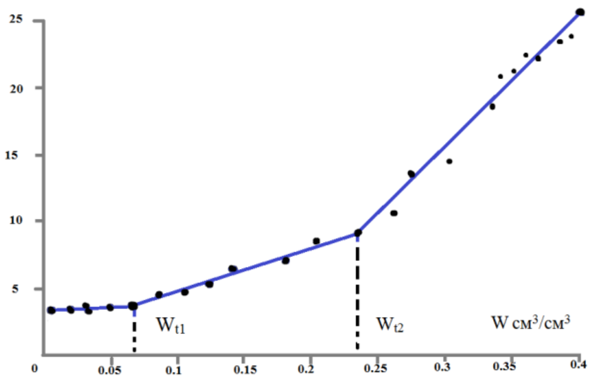

Fig. 8. dependences of the real part of the CDC of sample V1 (humus content 6.6%) on the volume humidity with the release of a section of strongly bound water (humidity $W<W_{t1}$), loosely bound water (humidity $W_{t1}<W<W_{t2}$) and free water ($W>W_{t2}$) at a frequency of 4.5 GHz.

The experiment showed that the addition of ash to soil with a low humus content leads to an increase in the proportion of bound moisture and a decrease in the DC values of the sample as a whole (Fig. 9). From a comparison of the obtained dielko-moisture dependences, it was found that the inflection point in the sample containing ash shifts relative to the control sample towards increasing humidity. With increasing frequency, this dependence is retained, but the difference between the CDC of the measured samples in the free water region decreases. However, the W_t values of the samples under study hardly change with increasing frequency.

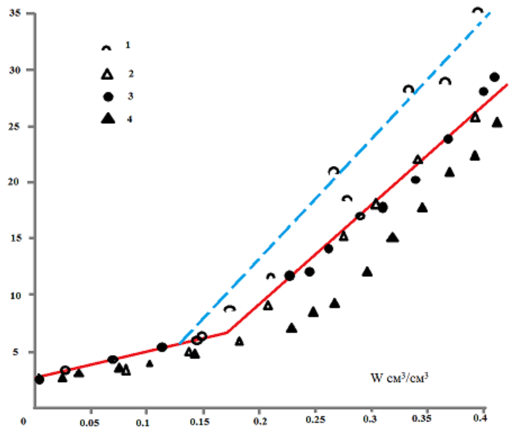

Fig. 9. Dependence of the real part of the CDC on the volumetric moisture: 1.2 - humus content 0.6%; 3.4 - with the addition of 30% ash; 1.3 - frequency 0.25 GHz; 2.4 - frequency 4.5 GHz (the lines show the approximation of the data of both samples at a frequency of 0.25 GHz).

With increasing frequency, this dependence is retained, but the differences between the CDC of the measured samples in the region of free water decreases. However, the Wt values of the samples under study hardly change with increasing frequency.

Of particular interest are studies of pollution of high-humus fertile soils. To study the effect of ash pollution on this type of soil, the DC was measured for a mixture of soil sample V.1 and ash in an amount of 30% by weight (sample V.2). The results of these measurements showed that in the region of bound moisture, the values of the real part of the CDC of the sample with ash (V.2) practically correspond to the values of the initial sample V.1, and only at values $W>W_t$, in the region of free water, they take slightly underestimated values compared to with the original sample (Fig. 10).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 12 , December 2020

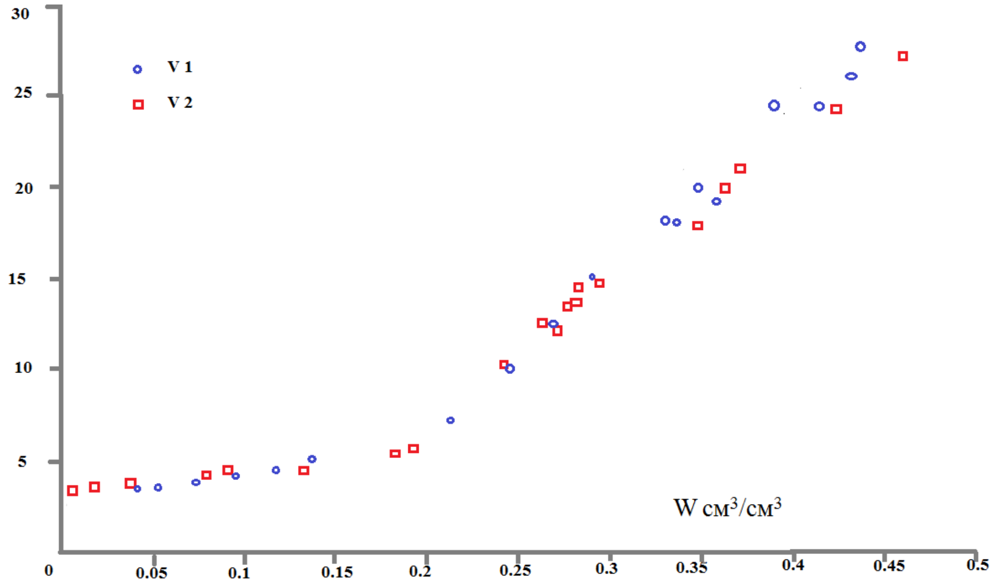

Figure: 10. Dependences of the real part of the CDC on the volumetric moisture content of samples V1 (humus content 6.6%), V2 (with the addition of ash 30% by mass to V1) at a frequency of 4.5 GHz.

In this case, it is likely that the amount of bound moisture for sample V.1 is greater than that for ash, and an increase in the specific surface area due to the finely dispersed ash does not play a significant role in the total CDC of high-humus soil.

IV. CONCLUSION

The results of the studies were applied to a natural soil sample (sample III) containing an unknown amount of ash taken from an area located in the area of pollution by emissions. The granulometric analysis carried out made it possible to establish the percentage of physical clay, sand and humus. From the results of measurements in the frequency range from 0.1 to 16 GHz, the CDC values of this sample and the Wt value were determined. Based on the assumption that the presence of ash in the samples changes the maximum amount of bound moisture in them, by approximating the data for samples 1.2, II. 1, FV.3 and V.2, the following regression relationship was obtained:

$$W_t = C \cdot 0.360 + S \cdot 0.017 + H \cdot 0.790 + A \cdot 0.064 \quad (3)$$

where: C, H, S, and A are the percentage of physical clay, physical sand, humus and ash in the sample, respectively. The observational error in determining the value of W_t by formula (3) was

$$\Delta W_t = 0.03.$$

Thus, in the course of the research carried out, the dielectometric method is one of the most superior and frequently used method for measuring moisture at present. As a result of the research, the article discusses the physical, mechanical and mechanical properties, electrical conductivity of building materials. The analysis of the study of the international market for the production of moisture meters. The dielcometric method for measuring moisture is provided, the advantages of the method and the principle of operation is shown, the diagram of the dielcometric moisture meter. The uncertainty of dielcometric moisture meters is about 0.5%, however, as practice shows, for most cases of moisture measurement such accuracy is quite sufficient. Also, speaking about dielcometric moisture meters, one should note their ease of manufacture and use, as well as their relative cheapness in comparison with other moisture meters. Thus, taking into account all the indicators obtained as a result of the analysis, it can be concluded that the most promising direction for further research should be considered the dielcometric method for determining moisture.

REFERENCES

[1]. E.V. Platonov, B.F. Drachenko: Fundamentals of the construction business. GOSSTROYIZDAT Ukrainian SSR, Kiev 1963.
[2] D. Pena, R. Feick, H. D. Hristov, and W. Grote, “Measurement and ˜ modeling of propagation losses in brick and concrete walls for the 900-MHz band,” IEEE Trans. Antennas Propag., vol. 51, no. 1, pp. 31–39, Jan. 2003.
[3] A. Muqaibel, A. Safaai-Jazi, A. Bayram, A. M. Attiya, and S. M. Riad, “Ultrawideband through-the-wall propagation,” IEE Proc.

[4]. Juan Martinez Vega: Dielectric Materials for Electrical Engineering. 1 March 2013. DOI:10.1002/9781118557419. Copyright © 2010 by John Wiley & Sons, Inc.
[5] Zhekov, S. S., Franek, O., & Pedersen, G. F. (2020). Dielectric Properties of Common Building Materials for Ultrawideband Propagation Studies [Measurements Corner]. I E E E Antennas and Propagation Magazine, 62(1), 72-81.
[6] D. Ferreira, I. Cuinas, R. F. S. Caldeirinha, and T. R. Fernandes, "A ˜ review on the electromagnetic characterisation of building materials at micro- and millimetre wave frequencies," in Proc. 8th Eur. Conf. Antennas Propag. (EuCAP), Apr. 2014, pp. 145–149.
[7] F. Sagnard and G. E. Zein, "In situ characterization of building materials for propagation modeling: frequency and time responses," IEEE Trans. Antennas Propag., vol. 53, no. 10, pp. 3166–3173, Oct. 2005.
[8] C. Thajudeen, A. Hoorfar, F. Ahmad, and T. Dogaru, "Measured complex permittivity of walls with different hydration levels and the effect on power estimation of TWRI target returns," Prog. Electromagn. Res. B (PIER B), vol. 30, pp. 177–199, May 2011.
[9] K. Noborio, "Measurement of soil water content and electrical conductivity by time domain reflectometry: a review", in Computers and Electronics in Agriculture, vol. 31, 213–237, 2001
[10] M. Nussberger, "Soil moisture determination with TDR: single-rod probes and profile reconstruction algorithms," Dissertation. Technische Wissenschaften ETH Zürich, 117 pp, 2005.
[11] W. Feng, C.-P. Lin, R. J. Deschamps and V. P. Drnevich, "Theoretical model of a multisection time domain reflectometry measurement system", Water Resources Research, vol. 35 (8), pp. 2321-2331 (1999).
[12]. Muzyleva, I.V. Electrical and structural materials science. Semiconductor materials and their application [Electronic resource]: textbook. allowance / I.V. Muzylev .– Lipetsk: LSTU, 2014. – 85 p.
[13]. Glaudell, A.M.; Cochran, J.E.; Patel, S.N.; Chabinyc, M.L. Impact of the doping method on conductivity and thermopower in semiconducting polythiophenes. Adv. Energy Mater. 2015, 5, 1401072.
[14] G. C. Topp, J. L. Davis and A. P. Annan, "Electromagnetic determination of soil water content: measurements in coaxial transmission lines", Water Resources Research, vol. 16 (3), pp. 574-582 (1980).
[15] C. Salat and A. Junge, "Dielectric permittivity of fine-grained fractions of soil samples from eastern Spain at 200 MHz," Geophysics, vol. 75 (1), pp. 1-9, 2008.