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Study on Dielcometric Moisture Control Method Based on Capacitive Transducers

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Abstract. This article investigates the concept and definition of moisture and its function in regulation and control, where the role of moisture at all stages of the technical process is an important part. Approximation of the actual physical entity by its electrical model in the form of replacement schemes is evaluated by the primary transducers of moisture translated into electrical value, the basis of which is a capacitive sensor-capacitor in the electrical field of which is a certain volume of the studied content. Indirect methods based on the calculation of the dielectric permeability of moisture content of the studied substance are evaluated in order to choose the process, evaluate the dielectric method, consider the design and installation of bulk material moisture management devices based on this method, and draw conclusions on the advantages and disadvantages of the dielectric method.

INTRODUCTION

Moisture is one of the most important indicators of any material or product, e.g., grain is regulated by GOST [1]. Food moisture content (FMC) measurements are susceptible to human variables during agricultural production, although the government has stringent requirements for grain processing, storage, and purchasing. As a result, it is critical to precisely measure FMC.

Water in food has a strong influence on its quality. When the food is wet, germs develop more quickly and the number of mites, insects and other changes occur, which lead to the deterioration of the food. The moisture content of any product must be within the established norm, which is why in all cases products and materials have an optimum moisture content that guarantees the best flavor, appearance and retention period [2].

The direct drying method, neutron method, nuclear magnetic resonance method, and microwave method are now accurate FMC measurement methods. Despite their great measurement precision, these technologies have a number of drawbacks, including inefficient measurement, a complicated procedure, a high price, and a big instrument size. The capacitive approach, on the other hand, may measure FMC indirectly through a change in dielectric constant and has several advantages such as high-speed measurement, high reliability, economy and portability, online detection, and maintainability [3-6].

Generally, FMC is measured by opening the drying oven and picking a food sample at random to test the moisture content with a portable moisture meter [7, 8]. Thereby, heat energy and electric power are lost. Because of technological limitations of the device used to inspect the factor and the status of many essential factors in the oven management process, this is also one of the primary reasons for an increase in baking time, which in turn reduces the amount of baking [9]. As a result, developing a device to detect the moisture content of food during the drying process will boost growth potential and competitiveness [5, 10, 11, 12]. The device should provide benefits in terms

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of energy savings, increased capacity for energy utilization in the drying process, and reduced labor costs associated with data recording. Furthermore, such a gadget can help decrease the number of defective food pounded during the traditional moisture-content-measuring meter's procedure of moisture-content measurement.

For the regulation and control of various automated systems, moisture knowledge is important. In this respect, information on humidity, where humidity is an important component at all stages of the production process, must be known: during preparation, distribution - acceptance and transport of raw materials and finished goods.

MATERIALS AND METHODS

Let us consider what the concept of moisture is made up of.

It is known from [13] that the moisture content of any material is commonly operated by two concepts: moisture on a dry basis and moisture on a wet basis.

$$W = \frac{\rho_w}{\rho_d} \quad (1)$$

$$W = \frac{\rho_w}{\rho} \quad (2)$$

Where (1) dry, (2) wet, ρ_w - density of water distributed in the material, ρ_d -density of dry material.

The density of a wet material is defined as

$$\rho = \rho_w + \rho_d$$

The moisture of any material can be unevenly distributed over the entire volume or surface. Basically, the moisture content can be changed either by adding moisture or by drying. Two variants for determination of moisture content of substances by thermogravimetric method are possible: thermal drying and absorption of moisture by dehumidifiers [14].

Thermal drying is defined as

$$W = \frac{(P_1 - P_2)\cdot 100}{P}. \quad (3)$$

Where P_1- is the weight of the bunk before drying, P_2 - is the weight of the bunk after drying, P - is the weight of the actual charge.

We use the concepts of dry material weight, wet material weight and evaporated water weight when calculating moisture using the thermogravimetric process. Under laboratory conditions, both direct and indirect methods may assess moisture. Direct methods include the thermogravimetric approach alluded to above (3) and indirect methods include physical (dielcometric) methods [15].

There are currently a large number of methods of moisture determination, but there is no consensus on the superiority of one method over the others. In this regard, almost all internationally renowned moisture meter manufacturers try to cover several measurement methods in their production during development. This is due to an extremely large number of heterogeneous materials whose moisture content needs to be controlled in different measurement ranges, with the required accuracy, speed and design.

This approach includes the most accurate moisture meter method, which is regarded to be the most accurate and is used as a reference method for the calibration of moisture monitoring instruments (moisture meters), new measuring instrument condition tests, expert feedback, etc. [16].

Moisture has a strong influence on viscosity, density, hardness and many other parameters. Uniformly distributed moisture in the material is of great importance for many technological processes. The rate of change of humidity under the action of external forces is an important controllable parameter. In this connection let us consider the tasks of indirect method of moisture measurement by electrical methods.

In indirect techniques, a material's moisture content is determined from the alteration in its different properties. The foundation of the electrical (conductometric and dielcometric) moisture measuring methods is that the parameters that describe the action of moist materials in electric fields are dependent on moisture. The main task of the theory of these methods is to create sufficiently accurate mathematical models of a moist material, describing the dependences of the electrical properties of the material on its moisture content and other parameters, i.e. dependences of the form $e=f(W,\xi)$ of the primary transmitter of the moisture meter [17].

RESULTS AND DISCUSSIONS

First of all, when developing and choosing a measuring process, the shape of its coupling to the material, which depends on several factors determined by the form and structure of the materials under analysis, often needs to be

taken into account. Such a dynamic multicomponent and heterogeneous arrangement of several materials belongs to the class of heterogeneous structures, and the characteristics of heterogeneous mixtures have to be taken into consideration when defining their electrical properties along with current dielectric physics methods [18].
On example of dielcometric method let's consider cases, where optimum choice of number of measured parameters of object of research providing maximal accuracy of defined value has the basic value. In this case, the main criterion of optimality can be considered minimization of number of parameters, the most sensitive to measured value

$$C=f(W,m,t,x,k,n\ldots\ldots). \quad (4)$$

Where W – is mass ratio of material moisture, m – is mass, t – is temperature, x – is moisture distribution, k – is electrolyte concentration, n – is electrochemical criterion of the electrode-material interface.
For this circuit, let us consider a generalized structural diagram (Figure 1) reflecting a measuring device based on any electrophysical, including dielcometric method of moisture measurement, consisting of three links connected in series [19].

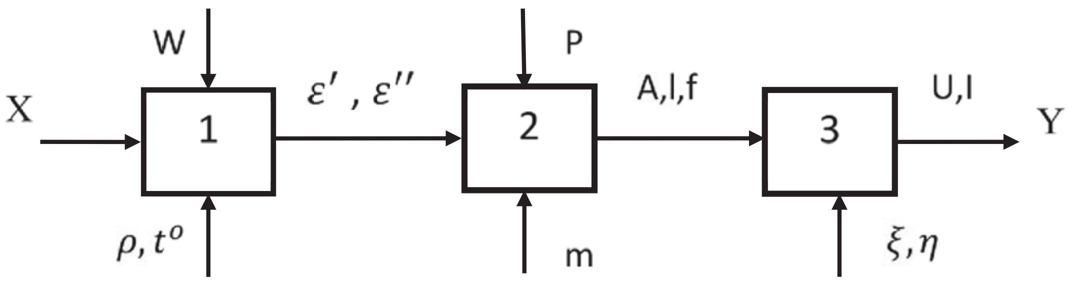

FIGURE 1. Generalized moisture hygrometer schematic diagram

It is known from [20] that link 1 refers to the conversion of the measured quantity, humidity (W), to physical (in our case electrical) quantity ε, i.e., it defines the dependency on the humidity content of the electrical properties of the material used in this process. Link 1 is affected by temperature, density, chemical composition and other quantities affecting the dielectric characteristics of the material under investigation. Link 2 is the primary transducer of the measuring device (sensor), which converts the value ε into the output signal X (capacitance, complex resistance or one of its components), convenient for further processing. Link 2 is affected by the shape, weight of the material, frequency of the electric current, etc., affecting the characteristics of the measuring device. Link 3 describes a measuring transducer (measuring device), the output of which produces an analogue or digital Y signal.
High-frequency (HF) methods are widespread in a number of industries [21]. This is due to the fact that the dielectric permittivity of a material, the moisture contained in it has a greater influence than the whole family of characteristics. However, no product can be regarded as a perfect dielectric and therefore the electrical energy applied to a capacitor transducer filled with material is spent not only on recharging the capacitor but also on dissipation in the form of heat losses in the dielectric. The measurement practically measures not the true but the fictitious apparent capacitance of the capacitor, which depends considerably on the losses.
The basic electro-physical characteristics of any substance are the specific conductivity (γ) and the relative permittivity (ε). In capillary-porous bodies, to which the vast majority of structural building materials belong, γ and ε depend in general on many physical and chemical properties. Modern dielectric physics relates these dependencies to the basic processes that occur in any real dielectric under the influence of an electric field, the polarization of molecules and molecular groups, and dielectric losses [22]. However, due to the different physical nature of γ and ε, the relationship between the influence of individual material properties on each of these electrophysical characteristics is also different.
The specific conductivity γ and the dielectric constant ε enter by proportionality coefficients into the known field theory equations [23]:

$$\bar{I} = \overline{\gamma}\overline{E}\cdot\overline{D} = \varepsilon\overline{E} \quad (5)$$

Where: $\overline{E}$, and $\overline{D}$, $\overline{I}$ - are the vectors of electric field strength, electric induction and electric current density, ε is the dielectric constant respectively.

$$\delta = \gamma \overline{E} \tag{6}$$

Here: δ - is the current density; γ - is the specific conductivity.
Then for (1.8), and (1.9)

$$\overline{E} = grad\varphi \,, \quad Q = \int_s QdS = g(\varphi_2 - \varphi_1) \tag{7}$$

where Q - is the amount of electricity; S - is the *equipotential surface*.

$$\overline{I} = \int_S \delta dS = g(\varphi_2 - \varphi_1) \tag{8}$$

where g - is the conductivity.
Using (7) and (8) we obtain

$$\int_s \varepsilon EdS = C(\varphi_2 - \varphi_1) \; and \; \int_i \gamma EdS = g(\varphi_2 - \varphi_1) \; or \; \frac{\varepsilon \int_s EdS}{C} = \frac{\gamma \int_s EdS}{g} \tag{9}$$

It follows from (9) that the numerical values of conductivity and capacitance should be connected by the relationship $g = C\frac{\gamma}{\varepsilon}$ with the same transducer shapes and sizes. An orderly flow of charges (conduction current) as well as a space-limited displacement of charges (displacement currents) exist concurrently under the action of an external alternating electric mole in the material [24].
In the moisture meter system, the electrical moisture transducer is a capacitive capacitor of one or another type in which a certain amount of the test material is placed in the electrical sector. To analyses the relations between input and output quantities of such a transducer, we pass from the notions of field theory to the notions of circuit theory [25], which is based on approximation of the real physical object by its electrical model - the substitution scheme of this object by idealized elements of an electrical circuit (resistors, capacitors, etc.).
The substitution scheme for a capacitive sensor with moisture-containing material, which has been most widely used to date, is the parallel connection of capacitance C_x with resistance R_x [26] (Figure 2).

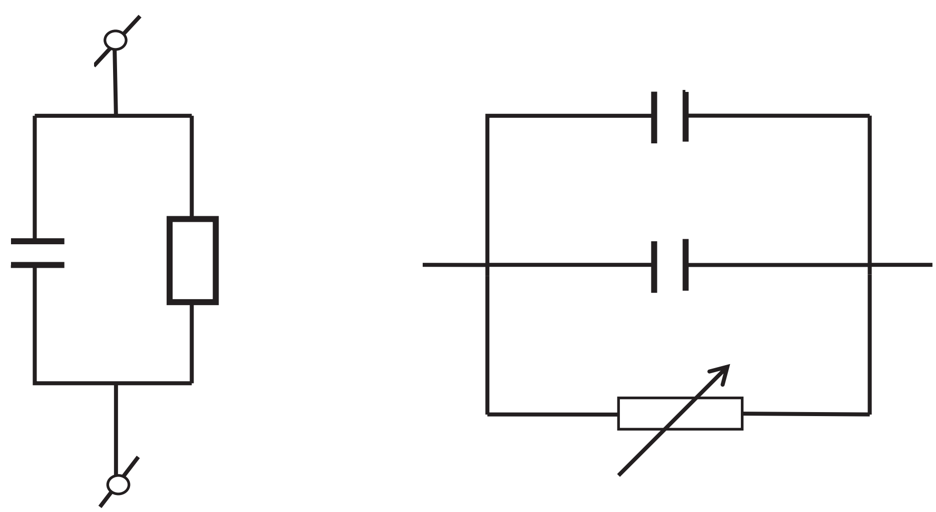

FIGURE 2. Substitution diagrams for the primary moisture transducer: a) for solid, granular disperse materials b) for liquid materials

When an alternating voltage source with a frequency is connected to such a circuit, the total current in the circuit is expressed as

$$\overline{I} = \overline{U}\left(\frac{1}{R_x} + j\omega C_x\right) \tag{10}$$

The expression in brackets describes the total (complex) conductivity of a capacitive sensor with material at frequency ω. The identity of the expressions for the total current through a real capacitor and its electrical model gives a formal basis for a similar approximation. The transition from the specific electrophysical material properties γ and ε to the measured characteristics of the capacitive sensor R_x and C_x is made with the help of the constant k:

$$\gamma = \frac{1}{kR_x} \quad \text{and} \quad \varepsilon = \frac{1}{k} C_x \tag{11}$$

The value of k characterizes only the geometric dimensions and shape of the capacitor and is, for a particular transducer (sensor), a constant of unit length dimensionality.

The task of calculating humidity content using the dielcometric approach is technically to calculate the transducer power (sensor). It should be emphasized that the R_x value does not influence the calculation of the C_x power, i.e., the measurement system must ensure that the "true" capacity value is obtained in order to be able to appreciate the advantages of the dielcometric method. Ignoring this circumstance, along with the arbitrary choice of field frequency ω, leads to an almost complete loss of the advantages of the dielcometric method of moisture measurement over the conductometric method, as well as to misconceptions about the metrological characteristics of the dielcometric method [27].

A generator with a useful power of ±100 V, with a frequency of 40 MHz, produces a high-frequency electric field. It should be remembered that the feature of the calibration is, in effect, a statistical representation of the object of measurement obtained from the results of specially arranged experiments, and questions of metrological precision are questions of model adequacy to the results of the experiments with the confidence-based accuracy of their description [28-31].

It is also important to ensure that the precision of the calculation of moisture is similar to or at least equal to that of the thermogravimetric process. Capacitive sensors with shielded electrodes are used, since foodstuffs are usually media with a high specific conductivity. Figure 3 illustrates an analogous illustration of such a sensor.

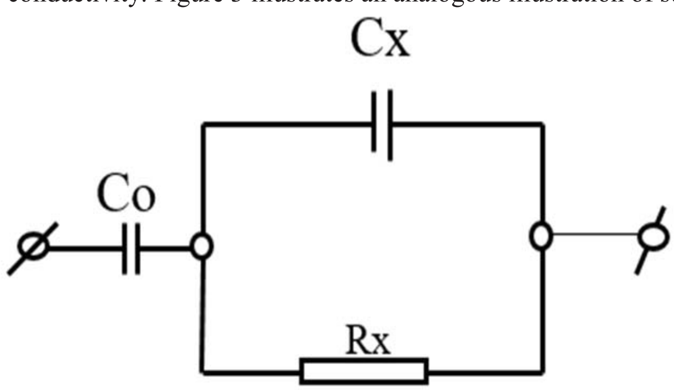

FIGURE 3. Block diagram of capacitive moisture hygrometer sensor: C_0 - isolation pad capacitance; C_x and R_x - capacitance and power attributable to the presence of the material to be analyzed

CONCLUSIONS

When evaluating the process, it can be inferred that dielectric methods are dependent on their dielectric parameters, which depend on the moisture content of the materials under examination, to calculate the moisture content of the materials. Their privileges include [29, 30]:

a) High sensitivity to moisture content in the material.
b) Wide range of moisture content measurement of materials (0÷100%).
c) Dielectric moisture meters have relatively simple construction of moisture transducer and measuring device.

The disadvantages of dielectric moisture measurement methods include:

a) They are only applicable if the material only contains water in the liquid phase.
b) The results of moisture measurement by these methods depend on the density and thickness of the material under investigation.
c) There is no explicit mathematical model linking the change in dielectric constant of the controlled material to its moisture content.

d) Relatively low interference immunity from random dielectric characteristics of the controlled material and the intermediate medium.

REFERENCES

1. GOST 13586.5-2015. Interstate standard. Grain. Method for determination of moisture.
2. S. A. Bogatyrev, Technology of storage and transportation of food products (Saratov State Agrarian University, Saratov, 2017).
3. P. Soltani Zarrin, F. I. Jamal, S. Guha, J. Wessel, D. Kissinger, C. Wenger, Design and Fabrication of a BiCMOS Dielectric Sensor for Viscosity Measurements: A Possible Solution for Early Detection of COPD, Biosensors (Basel) **8**(3), 78 (2018).
4. Q. Song, X. Wei, W. Sun, Z. Lu, T. Tao, Design of Capacitive Paddy Moisture Sensor Based on Electrical Impedance Spectroscopy Analysis, Applied Sciences **10**(11), 3968 (2020).
5. M. V. Zambrano, B. Dutta, D. G. Mercer, H. L. MacLean, M. F. Touchie, Assessment of moisture content measurement methods of dried food products in small-scale operations in developing countries: A review, Trends in Food Science and Technology **88**, 484-496 (2019).
6. J. Srikiatden, J. S. Roberts, Moisture Transfer in Solid Food Materials: A Review of Mechanisms, Models, and Measurements, International Journal of Food Properties **10**(4), 739-777 (2007).
7. C. Zhang, Z. Shi, H. Yang, X. Zhou, Z. Wu, D.S. Jayas, A Novel, Portable and Fast Moisture Content Measuring Method for Grains Based on an Ultra-Wideband (UWB) Radar Module and the Mode Matching Method, Sensors (Basel) **19**(19), 4224 (2019).
8. S. O. Nelson, S. Trabelsi, Historical development of grain moisture measurement and other food quality sensing through electrical properties, IEEE Instrumentation and Measurement Magazine **19**(1), 16-23 (2016).
9. A. Miś, A. Nawrocka, D. Dziki, Identification of Baking Expansion Phases of Leavened Dough Using an Experimental Approach, Food Bioprocess Technol **9,** 892–903 (2016).
10. F. Raponi, R. Moscetti, D. Monarca, A. Colantoni, R. Massantini, Monitoring and Optimization of the Process of Drying Fruits and Vegetables Using Computer Vision: A Review, Sustainability **9**, 2009 (2017).
11. S. K. Amit, M. M. Uddin, R. Rahman et al., A review on mechanisms and commercial aspects of food preservation and processing, Agric & Food Secur **6,** 51 (2017).
12. K. K. Patel, A. Kar, Heat pump assisted drying of agricultural produce-an overview, J Food Sci Technol. **49**(2), 142-160 (2012).
13. A. A. Starostin, Technical means of automation and control: textbook, Urals University Press, Yekaterinburg (2015).
14. E. S. Krichevsky et al., Theory and Practice of Express Control of Moisture of Solid and Liquid Materials, Energy, Moscow (1980).
15. V. G. Gulyaev, I. V. Gulyaev, Patent 2565348 of the Russian Federation Measuring instrument of a flow of a two-phase stream of dielectric materials moved by air on the metal pipeline (State Architecture, Nizhegor, 2015).
16. V. G. Gulyaev, I. V. Gulyaev, A method for measuring the amount of pneumatically transportable bulk material in pharmaceutical production, based on the Pockels effect, Drug development & Degistration **2**(23), 52–56 (2018).
17. D. J. Am Ende et al., Production of medicines: Chemical technology from R&D to production (CSC Profession, Saint Petersburg, 2015).
18. B. G. Gulyaev, I. V. Gulyaev, Method of express measurement of humidity of pneumatic transported bulk material in pharmaceutical production, based on the Pockels effect (review), Drug Development and Registration **8**(3), 40-43 (2019).
19. M. Y. Chervyakov, Atmospheric sounding: Applied hydrometeorology (Science, Moscow, 2019).
20. V. V. Buyantuev, V. P. Shiyan, SVC moisture metering of cereal crops, Vestnik Nauki Sibiri **5**(6), 36-40 (2012).
21. Sh. Li, Sh. Cao, W. Meng, Design of Grain Dryers' Control System, IOP Conference Series Materials Science and Engineering **212**(1), 012017 (2017).
22. J. Mukhitdinov, E. Safarov, Reviewing technologies and devices for drying grain and oilseeds, Chemical Technology, Control and Management **2021**(3), 1 (2021)
23. P. I. Kalandrov, Study of technological process of drying and instrumental support of grain moisture control, Bulletin of Tashkent State Technical University **1**, 128-132 (2018).

24. E. Y. Golub, A. V. Zabolotnyy, Compensation of "grade uncertainty" of moisture measurements by dielcometric moisture meters, Part 1: The Comparative Analysis of Methods of Determination of Substance Moisture, Radioelectronic and Computer Systems **2**(72), 28-35 (2015).
25. A. B. Makarenko, Justification of investment attractiveness of oil refining industry of Ukraine on the example of CJSC "Linik", Visnik of National Technical University **50**, 95–98 (2010).
26. P. I. Kalandarov, Z. M. Mukimov, Instrumental support for moisture control during hydrothermal treatment of grain and its products, Instruments **11**, 16-21 (2020).
27. P. I. Kalandarov, B. P. Iskandarov, Automatic control of humidity of solid bulk materials in technological flow. International collection of scientific works, Electrotechnical systems and complexes **20**, 303-308 (2012).
28. P. R. Ismatullaev, P. I. Kalandarov, Ultrahigh-frequency moisture metering and problems of metrological support, Journal of Instrumentation **7**, 40-44 (2011).
29. B. I. Iskandarov, P. I. Kalandarov, Analysis of the influence of factors on the result of measurements of material moisture at high frequencies, Measuring Technique **7**, 64-66 (2013).
30. P. I Kalandarov, Z. M Mukimov, The role of automatic control systems in technological processes in grain processing, Agroilm **5**, 99-101 (2020).
31. P. I. Kalandarov, Z. M. Mukimov, O. S. Logunova, Analysis of hydrothermal features of grain FND instrument desulphurization of moisture control, Technical Science and Innovation **1**, 117-122 (2020).