COMPARATIVE ANALYSIS OF MOISTURE MEASUREMENT OF BULK GRANULAR MATERIALS

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Abstract

The methods that have become most widely used in measuring the moisture content of bulk materials of grain and grain products, as well as moisture meters implementing these methods, currently offered on the markets by leading manufacturers, are considered. The main directions of further development of modern moisture measurement of grain and products of their industrial processing are determined. The estimation and comparison of the error in determining the moisture content of granular materials by various methods is considered. It is revealed that with the variability of the mass of the controlled material, the error of the dielkometric method is less than that of the other methods considered. As a result of the study of the discrete and technological flow, a dielkometric measurement method is recommended to control the humidity of the materials in question.

Keywords: humidity, measurement methods, grain, grain products, error, moisture meter, dielectric constant.

Introduction. In all technological processes, quality control of raw materials and final products is of great importance. Indeed, the suitability of various types of raw materials (grain-wheat, corn, barley, rapeseed, rice, etc.) strongly depends on the moisture content in them. Humidity, an important factor affecting seed growth, should be taken into account not only when predicting the shelf life of seeds, but also during their storage [1].

Climatic conditions are very important for the preservation of grain and seeds, especially their hygroscopicity. Grains and seeds of all crops can absorb (adsorb) vapors and gases from the environment. Under certain conditions, a partial or complete reverse process of isolation (desorption) is possible the same substances are released into the environment. As a result of the adsorption process, grains emit an unpleasant odor. The sorption and desorption of water vapor characterize the hygroscopic properties of the grain. These studies are a necessary condition in the technological process and grain processing and storage.

The humidity indicator is a reliable tool that requires adjustment of the vital activity of the grain mass. An increase in grain moisture leads to an activation of metabolism, and dry grain practically does not breathe, when the culture reaches a humidity of 15%-16% (for most species), the intensity of its respiration increases sharply. Therefore, the task of measuring the moisture content of loose granular substances of crops is very common and relevant.

Material and method.

Humidity (mass) is understood as the percentage ratio of the mass of moisture M contained in a given volume of material to the mass of wet material M_1 or its volume (volume humidity) [2].

$$W = \frac{M}{M_1} = \frac{M}{M_1+M}. \quad (1)$$

Moisture content (mass) u refers to the ratio of the mass of moisture M contained in the material to the mass of wet material M_0:

$$u = \frac{M}{M_0}. \quad (2)$$

They can be expressed in weights or percentages. In this case, the expressions (1) and (2) take the form

$$W = \frac{P-P_0}{P} \cdot 100, \% \quad (3)$$

$$u = \frac{P-P_0}{P_0} \cdot 100, \%.$$

In some cases, for example, when measuring grain moisture, values are used that characterize the water content per unit volume of the material. Then the volume humidity will be expressed as

$$W_{об} = \frac{M}{V} = \frac{V_в}{V}\rho_в = W\rho. \quad (4)$$

Volumetric moisture content

$$u_0 = \frac{M}{V_0} = \frac{V_в}{V_o}\rho_в = u\rho_o.$$

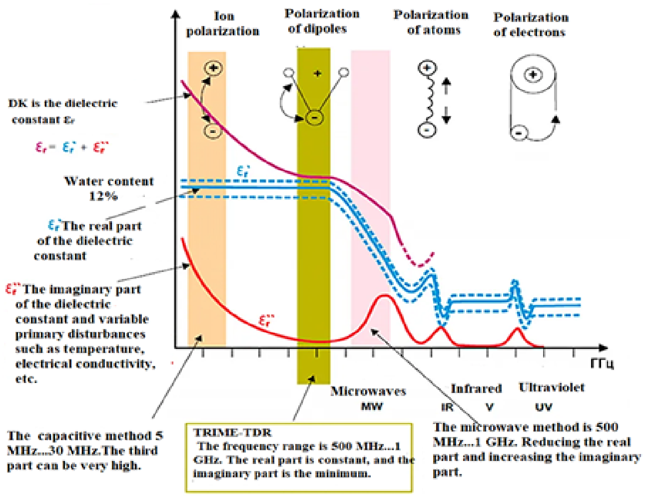
Where: $V, V_o, V_в, \rho, \rho_o, \rho_в$ - is the volume and density of wet, absolutely dry material and water. Volumetric humidity and moisture content have a density dimension.

Humidity can also be characterized by moisture content, or absolute humidity — the amount of water attributed to the unit mass of the dry part of the material.

This value cannot always be accurately measured, since in some cases it is impossible to remove all non-condensed water and weigh the object before and after this operation.

Relative humidity is the ratio of the mass of moisture contained in a material to its mass when wet.

Let's consider the existing methods for measuring the moisture content of bulk granular materials. In practice, there are direct and indirect methods for determining the moisture content of grain crops. When grain arrives at grain processing enterprises after harvesting, it is of particular importance to send each batch to its place: for drying in a grain drying unit, to an active ventilation warehouse, for storage in an elevator.



In most cases, in many grain processing enterprises, direct measurement is used to analyze grain moisture, or it is called the standard thermogravimetric method, i.e. drying grain samples to a constant mass at a temperature of 105 °C. To speed up the process of harvesting and analysis, the express method is used, which uses moisture measurement devices based on an indirect measurement method [3].

In this article, the objects of research are methods for measuring the moisture content of granular materials. The subject of study is direct and indirect methods of measuring humidity. Humidity control devices (moisture meters) are analyzed on the basis of indirect measurement methods. Humidity control devices (moisture meters) are an electronic device that is used to establish the absolute moisture content as a percentage of the mass of granular material [4].

In fact, the permittivity constant of a particular material consists of a real and an imaginary one. In the picture, the real one is highlighted in blue, and the imaginary one is highlighted in red. The total, consisting of real and imaginary, is depicted in purple.

Methods for determining humidity

To obtain the most accurate data when measuring the moisture content of a material, it is necessary to understand: what is the dielectric constant of a material, what are its constant components and which measurement technique is most suitable for a specific task of measuring humidity.

A direct method for measuring humidity. When harvesting, accurate data on the moisture content of the grain mixture obtained using the standard method is transmitted. Its essence is the dehydration of the suspension of the crushed product.

There are various methods for determining the humidity of the standard method: drying method, distillation method, extraction method, chemical method. The most common method is the drying method (thermogravimetric). Let's analyze this method in more detail. The process is carried out in an air-thermal cabinet of a material sample until equilibrium with the environment is reached at a given temperature and drying time, this equilibrium is conditionally considered equivalent to complete removal of moisture. In moisture measurement, this process is also called drying to a constant weight. However, in practice, the so-called accelerated drying methods take place. In the first case, drying is completed if two consecutive weighings of the test sample give the same or very similar results. The duration of determination by the standard thermogravimetric method is usually from several hours or more. When using an accelerated method for determining the humidity of the material under study (for example, grains of ground suspension), the drying temperature is carried out on the order of + 130 °C., the drying duration is limited to 40 minutes. Then the weight loss of the ground grain is calculated.

Indirect methods for measuring humidity. Any moisture meter is based on one or another method of determining humidity. All existing measurements used to determine humidity are divided into two groups: direct and indirect.

Indirect methods are based on the transformation of the concept of humidity into a physical quantity convenient for accounting. The methods used are divided into electrical and non-electrical. In grain processing production conditions, indirect measurements are preferred for grain intake, whereas direct research options are in demand in laboratory conditions.

When using the indirect method, the determination of humidity is carried out in a non-contact way using various humidity meters or moisture meters. The resulting result on the moisture content of the material will be slightly less accurate, but much faster (data processing takes several seconds). Of the indirect methods, the most common are physical methods based on the measurement of physical quantities. Let's consider some electrical and non-electrical methods.

The electrometric method is based on measuring the resistance, inductance, capacitance, and dielectric conductivity of a material, depending on its humidity.

When considering indirect methods, we proceed from the fact that the device must be express, automatic, non-contact, provide the required accuracy and be applicable to several types of homogeneous materials. Non-electrical moisture measurement methods are based on the mechanical, acoustic, thermal, and optical properties of the material. This should also include methods using the interaction of various types of electromagnetic vibrations and nuclear radiation with the substance under study.

Gravimetric (thermogravimetric) methods. The principle of operation of gravimetric moisture meters is based on the measurement of humidity by drying canopies. Devices of this type are universal, do not require additional calibration depending on the grain grade and have the highest measurement accuracy. Gravimetric humidity meters are used in self-accounting operations and for calibration of devices that measure humidity by an indirect method. The measurement error is 0.005...0.5%. Since the time required for measurement can reach several hours due to the need for grain grinding, drying and weighing, devices of this type are not suitable for operation as part of automated control systems of grain dryers.

The acoustic method. The search for properties that are most rigidly related to humidity is ongoing. Interesting in this regard is the study of G.S. Zorb [5], who studied the dependence of all the above properties on wheat, as well as the sound level when hitting grain on humidity. Acoustic methods are based on the dependence of the propagation velocity of sound vibrations on the moisture content of the material. Justification of the operating sound frequency range (20...50 Khz), the type and design of acoustic transducers.

The mechanical method. The magnitude of grain destruction on impact has a more unambiguous dependence on humidity. This dependence is the basis for the mechanical moisture meter described in [6]. Tests of the device in the humidity range from 9.8 to 17.4% showed that the relationship between the number of destroyed grains (N) and their humidity (W) is linear. For one series of experiments, this dependence had the form:

$$N = -5{,}03W + 105{,}03. \qquad (17)$$

On average, a 1% change in humidity corresponds to 5.37% of crushed grain. The standard error of the device was ± 0.37%. There was no difference in the readings of the device between the two varieties of wheat.

Radiometric methods use the interactions of various types of radiation and neutron scattering in wet material. Gamma and neutron methods have been used to determine the moisture and density of soils, soils, and peat. The advantages of these moisture meters include non-destructive testing, temperature independence of measurements, high sensitivity and high performance [7,8]. The need to protect personnel from the harmful effects of radiation is a significant disadvantage of the method.

The nuclear magnetic resonance method is one of the most effective methods of studying solid and liquid substances. It is based on the use of the magnetism of the atomic nuclei of the analyzed sample, therefore, the information obtained comes from the very depths of matter and allows us to judge the structure of matter. The determination of the water content by this method is associated with the registration of proton resonance.

Thermophysical methods for determining moisture content have not yet been widely used in practice. Their main disadvantages for a long time were low accuracy and low speed. However, theoretical and experimental studies carried out in recent years have shown that the disadvantages can be largely eliminated, and for a number of materials (for example, complex chemical fertilizers), the thermophysical method of measuring humidity is considered more promising. Its essence is as follows. A thin, uniform layer of material is placed in a sealed volume and subjected to vacuuming. Intensive evaporation of moisture from the sample occurs, which causes a decrease in temperature. As the amount of water in the sample decreases, the evaporation rate decreases, and the temperature of the material begins to rise as a result of heat exchange with the environment. The combined effect of these factors leads to the fact that the temperature change has an extremum, the value of which is proportional to the initial humidity of the sample. The measured parameter is the value of the maximum temperature change.

The optical method. The effect of optical moisture meters is based on the selective absorption by moisture of IR (infrared) radiation of a certain wavelength reflected from the surface of the controlled object or passed through this material [9,10]. In most cases, moisture meters are built according to a two-wave scheme and are based on the dependence of the optical density of the material under study on the moisture content. However, grain products are dispersed, scattering systems and the possibility of using analyzers based on an unambiguous dependence of optical density on moisture content requires experimental verification.

The conductometric method. Moisture is measured indirectly by measuring the electrical conductivity of the grain mass. Devices of this type have a high measurement speed and low cost, but they have insufficient measurement accuracy, a large range of readings depending on the grain variety, its temperature and the quality of contact of the measuring probe with the material under study. They have a narrow humidity measurement range, usually from 5 to 35%. The measurement error is 0.5...2%, and it increases as the moisture content of the grain decreases due to an increase in its electrical resistance and an increase in the influence of various interfering factors on the readings. They are mainly used for manual measurement of grain moisture; they are not applicable in automated control systems of grain dryers.

In the low frequency range (up to DC), the dependence of the resistivity of materials on their humidity is used [11]. This method is used to control the moisture content of wood, concrete mix, grain, etc. Conductometric moisture meters for various materials are produced at instrument-making plants in Russia, Ukraine, Estonia and Latvia, as well as in foreign countries. The main disadvantage of this method is the large influence of interfering factors on the measurement result.

The high-frequency method. Humidity measurement is carried out indirectly by measuring the dielectric constant of the measured medium, which significantly depends on the moisture content in it. Devices of this type have a high measurement speed, have sufficient measurement accuracy, are less critical to the quality of the contact of the measuring probe with the material under study, and have a wide range of humidity measurements. Humidity analyzers of this type are most widely used in automated control systems of grain dryers and have a measurement error of 0.3 ...1%. But due to the dependence of the indications on the grain variety and the conditions of its growth, appropriate calibration is required. In addition, the moisture meter readings depend on the temperature of the grain being measured, so temperature correction of the readings is required.

In the medium- and short-wave (0.3-30 MHz) frequency range, the dependence of the dielectric characteristics on the moisture content of the material is used [12,13]. Using this method, the electrical capacitance of the primary converter filled with the test material is measured, which is a function of the dielectric constant, and, accordingly, the humidity of the controlled material. The dielectric measurement method is the most common due to its high sensitivity in a wide range of humidity, obtaining information about humidity in the form of an electrical signal, and the possibility of implementing the method with compact and inexpensive devices for discrete and continuous measurements. Therefore, high-frequency humidity measurement methods are widely used in industry.

Ultrahigh frequency (UHF) methods for measuring humidity.

These methods are based on the dependence of the dielectric parameters of materials on their humidity when measuring these parameters in the microwave range [14,15]. The principle of measuring humidity in a microwave moisture meter is based on the absorption of electromagnetic field energy by the measured sample, which is greater the higher the humidity of the analyzed medium. Microwave moisture meters have a small measurement error from 0.1 to 0.3% and their readings practically do not depend on the grain variety, therefore they are used, among other things, to check and calibrate moisture meters of other types. Compared with dielkometric moisture meters, they have a higher cost and are more demanding on the installation site and operating conditions. They are widely used in automated control systems of grain dryers.

Electrophysical properties of grain and practical application of the results of their research

The dielectric constant of water at 20 °C is constant and equal to 81, while the dielectric constant of bulk materials requiring humidity control is in the range

of 3... 30. Such a contrast in the value of the dielectric constant makes it possible to use the dielectric constant indicator as an indicator of the amount of water in the material and, accordingly, the moisture content of the material.

Studies of the electrophysical properties of wheat seeds are aimed at determining such electrical characteristics as electrical conductivity,

The dielectric constant and capacitance parameters are also aimed at studying the effects of electric fields on wheat grains and the amplitude-frequency characteristics of electrical signals recorded from seeds under various conditions.

The actual dielectric constant depends on the water content and the intrinsic dielectric constant of the material.

The imaginary dielectric constant will vary depending on temperature, mineral composition, water structure (ice, snow, steam, liquid), granulometric composition of the material and its chemical uniformity. The imaginary part is not constant, but depends on the listed factors, distorting the real values of the dielectric constant, and, accordingly, the results of humidity measurement.

Well-known methods for measuring humidity based on the principles of dielectric constant control, such as the capacitive method, microwave method, optical method, etc. they are not able to distinguish between real and imaginary dielectric permittivity.

The indicators of the total dielectric constant, as well as the real and imaginary parts of it, differ depending on the frequency, and these dependences are not identical.

Humidity is the cause of the occurrence and changes in the electrophysical properties of cereals. As a result of moisture, wheat grains become semiconductors. These patterns formed the basis for the development of methods and means of controlling grain moisture by electrical resistance. The research results are widely disclosed in the works of both Russian and foreign authors, which are based on the dependence of the capacitance of the condenser plates on grain moisture. The next group of results of the study of the electrophysical properties of grain includes an assessment of the effect of an electric field on wheat seeds and the transmission of an electric current through the grain.

The most common and arbitrable method for determining the humidity of solid fuels in laboratory conditions is air drying under certain and controlled conditions [16].

In cases where air drying cannot be used, for example, if there are significant amounts of volatile substances in the sample, its decomposability, etc., vacuum drying is used, in a nitrogen atmosphere, either by freezing or by distillation.

The standard method. To measure humidity from an average grain sample, after careful mixing, a suspension weighing (300 ± 10) g is isolated and placed in a container, filling it by two thirds of the volume.

Note - If the grain temperature is below (20 ±5) ° C, it is necessary to place the sample container in the laboratory until it aligns with the specified temperature. Before taking measurements, the buckets are thoroughly washed and dried in a drying cabinet at a temperature of (105 ± 2) °C for 60 minutes. The prepared buckets are stored in a desiccator.

In the isolated grain, humidity is measured using moisture meters to select a method option and establish the duration of drying.

For grain with humidity up to 17.0% (inclusive), measurements are carried out without preliminary drying. For grain with a moisture content above 17.0%, measurements are carried out with preliminary drying to a residual moisture in the range from 9.0% to 17.0%. For oat and corn grains, pre-drying is carried out at a humidity of over 15.5%.

Processing and expression of measurement results

The moisture content of grain and corn kernels X without pre-drying, %, is calculated by the formula

$$X = 20\,(m_1 - m_2), \qquad (1)$$

where m_1 is the weight of the suspension of crushed grain or rods before drying, g; m_2 is the weight of the suspension of crushed grain or rods after drying, g; 20 is the coefficient for calculating humidity, %.

The calculation results are written down to the second decimal place. Grain moisture when measured with pre-drying X1, %, is calculated by the formula

$$X_1 = 100 - m_1 \cdot m_2, \qquad (2)$$

where m_1 is the weight of the whole grain after pre-drying, g; m_2 is the weight of the ground grain after drying, g; 100 is a conversion factor equal to 100%.

Humidity measurement by indirect method

The state system for ensuring the uniformity of measurements, indirect measurements, determination of measurement results and evaluation of their errors MI 2083-90, currently applies to normative and technical documentation containing methods for performing indirect measurements, and establishes the basic provisions for determining measurement results and evaluating their errors, provided that the arguments on which the measured value depends are accepted as constant physical quantities; known systematic errors in the measurement results of the arguments are excluded, and the non-excluded systematic errors are distributed evenly within the specified boundaries ± θ.

The desired value of the physical quantity A is found based on the measurement results of the arguments $a_1, \ldots, a_i, \ldots, a_m$, associated with the desired quantity by the equation

$$A = f(a_1, a_2 \ldots, a_m) \qquad (3)$$

The function f must be known from theoretical premises or established experimentally with an error that can be neglected.

The results of measurements of arguments and estimates of their errors can be obtained from direct, indirect, cumulative, and joint measurements. Information about the arguments can be taken from the reference literature, technical documentation. When estimating the confidence limits of the errors of the indirect measurement result, a probability of 0.95 or 0.99 is usually assumed. The use of other probabilities must be justified.

The main provisions of the recommendation are established for evaluating the indirectly measured value and measurement result errors: with linear dependence and no correlation between the measurement errors of the arguments; with nonlinear dependence and no correlation between the measurement errors of the arguments; for correlated measurement errors of the arguments in the presence of a series of individual values of the measured arguments.

The desired value of A is related to the m measurable arguments a1, a2...am by the equation

$$A = b1a1 + b2 \cdot a2, + \ldots + bm \cdot am, \qquad (4)$$

where b1, b2...bm, are constant coefficients for the arguments

a1, a2 . . ., am, respectively. There is no correlation between the measurement errors of the arguments. If the coefficients b1, b2, ..., bm are determined experimentally, then the task of determining the result of measuring a quantity is solved in stages: first, each term bi · ai is evaluated; as an indirectly measured quantity obtained as a result of the product of two measured quantities, and then an estimate of the measured quantity A is found.

The result of the indirect measurement A is calculated using the formula

$$A = \sum_{i=1}^{m} b_1 \cdot a_1, \qquad (5)$$

where a1 is the result of measuring the argument ai; am is the number of arguments.

The mean square deviation of the indirect measurement result S(A) is calculated using the formula

$$S(A) = \sqrt{\sum_{i=1}^{m} b_1^2\, S^2(a_1)} \qquad (6)$$

where S(A) is the mean square deviation of the measurement result of the argument ai.

The linearization method is to find the measurement result and estimate its errors based on the ratio

$$A = f(a_1,...a_m) = f(\tilde{a}_1,...,\tilde{a}_m) - \sum_{i=1}^{m} \frac{\partial f}{\partial a_i} \Delta a_i + R \quad (7)$$

The method of reduction (reduction of the results of indirect measurements to a number of direct measurements) is to obtain a number of individual values of the measured value by substituting individual values of arguments into a formula expressing the dependence of the indirectly measured value on the arguments.

Discussion

The review made it possible to outline promising areas for further development of peat moisture measurement, which will be determined, first of all, by the emergence of new technologies in the field of measuring information processing and the improvement of microprocessor technology.

The nuclear magnetic resonance method is one of the promising methods [17], however, its application in the moisture measurement of grain materials has not found application due to the relatively small volume of controlled material, the complexity and high cost of equipment and, consequently, the need for highly qualified service personnel. The disadvantages of radiation methods are the strong influence of material density on the accuracy of control, as well as the need for biological protection measures during the operation of such moisture meters. However, it is promising to use these methods in conjunction with electrical ones in order to compensate for temperature errors.

The main disadvantage of the thermogravimetric method (standard method) is the duration, as well as the inability to automate the measurement process [18-19]. This method is mainly used for metrological support of indirect moisture meters. Electric moisture meters based on the conductometric principle are simple, but reliably measure humidity only in a small range and the measurement process cannot be automated [20]. It should be noted the strong influence of temperature, density, as well as the quality of the electrical contact of the measuring electrodes with the material under study.

Conclusions

In order to obtain reliable values of the qualitative characteristics of solid bulk granular materials necessary for accounting and quality control of finished products, it is mandatory to develop specialized test methods harmonized with the requirements of European standards.

For simple applications, if the influence of external factors, such as temperature, is absent, the composition and mineralization of the material is always unchanged, the water phase is unchanged and high accuracy of humidity measurement is not required. There are enough moisture meters on the capacitive measurement method.

If there is a high probability of the influence of external and internal factors contributing to an increase in the measured humidity of the "imaginary" part, especially if the ratio of the real and imaginary parts is close to one, and high accuracy of stable measurements is required, microwave methods should be chosen.

The only method that meets all the requirements of the technological process, namely the contactless control process, speed and control of the average humidity value by volume, is satisfied by the dielkometric method, which allows one hundred percent control. In addition, the dielkometric method is the most promising in terms of its improvement, namely the possibility of using different frequencies to increase the reliability of control results.

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