Fifty Applications of dielectric spectroscopy in microwave moisture control. Metrology and practice.

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Introduction

A number of some new microchip technologies for manufacture of microwave component has appeared during the last 10 years. It has greatly changed the positions of conductormetric and capacitor moisturemeters in the world. The development of exact technologies has caused the interest to technological, on-line moisturemeters and microwave moisturemeters as they are the most adequate for industrial application .

The properties of wet materials may be expressed explicitly in term of the relative permittivity e = e '- je " , where e ' is the dielectric constant of the material and e " is the loss factor.. The permittivity is a measure of the polarization which the material is undergone in an applied electromagnetic field. The dispersion and absorption observed for the water are caused by the frequency dependence of the polarisation of water molecules .

The principle of microwave moisture content measuring method is based on the fact that the permittivity of water is much higher than that of most dry substances. A small amount of water causes the significant changes of permittivity of wet material which can be detected using even a conventional microwave measuring equipment. It is known that the characteristics of dielectric materials containing water vary with frequency and temperature. However, in practice the frequency dependence may be neglected, while any changes of the material temperature should be monitored and compensated.

The propagation constant of electromagnetic wave in a dielectric medium may be expressed as

$$\gamma = \alpha + j\beta = j\frac{2\pi}{\lambda}\left(\varepsilon' - \rho - j\varepsilon''\right)^{1/2}$$

In free space, where *p* = 0, the following formulae may be used to relate the electromagnetic wave propagation parameters to those of wet materials (e " / e ' < 0.1):

$$\alpha \cong \frac{\pi}{\lambda}\cdot\frac{\varepsilon''}{\sqrt{\varepsilon'}} \qquad \beta \cong \frac{2\pi}{\lambda}\sqrt{\varepsilon'} \qquad r \cong \frac{\sqrt{\varepsilon'}-1}{\sqrt{\varepsilon'}+1}$$

where α is the attenuation constant, b is the phase constant, *r* is the voltage reflection coefficient at the surface of the wet material. The method of direct propagation and the resonator method get the widest spread among microwave methods of moisture control.

The method of direct attenuation

Despite of the complexity of the physical structure of wet materials, usually a simple linear relationship between the moisture content and the attenuation exists for electromagnetic waves passing through the sample, at least in a limited range of moisture content.
Because of the dielectric losses in wet material are determined by the moisture itself, the relationship between the attenuation and the water content may be written in a simple form:

$N = 8{,}7a\, W\rho L$

where

N - microwaves attenuation:

W - material moisture studied;

ρ - material density;

L - material thickness;

a - water absorption coefficient.

As the microwave absorption of dry material practically equals to zero, theoretically, there are no limits to increase of the accuracy of microwave moisture measurements by absorption method. In the practice, for the accuracy limit determination it is necessary to take into account: the influence of material temperature on the value of absorption coefficient , material density instability and inaccuracy of material thickness specification between transmission and reception antennas. These problems can be easily overcome. As the temperature dependence of absorption coefficient is known, or may be determined for chosen range of the electro-magnetic radiation, this dependence is easily compensated by putting additional material temperature correction channel in moisture meter . The stability of parameter L can be provided in a simple way by antenna placement on a large distance, at which its relative fluctuations (vibrations, various deformations, etc.) are insignificant.. In laboratory conditions "L" and "p" can be easily specified by experimental conditions.

Meteorological characteristics and opportunities of the described method were studied during the moisture control of different types of grain , mineral matters ,foodstuffs , other organic and inorganic materials. The thermogravimetric method in terms of ISO 712 standard was used as an example.
All the measurements were carried out in a rectangular wave guide 23*10 mm at 10,5 GHz frequency , sample mass is 10 g., temperature is 20 C°. Other conditions of measurement are in the text.

There are dependencies of microwave attenuation of grain ,wheat ,rye and wheat flour moisture in fig. 1 .

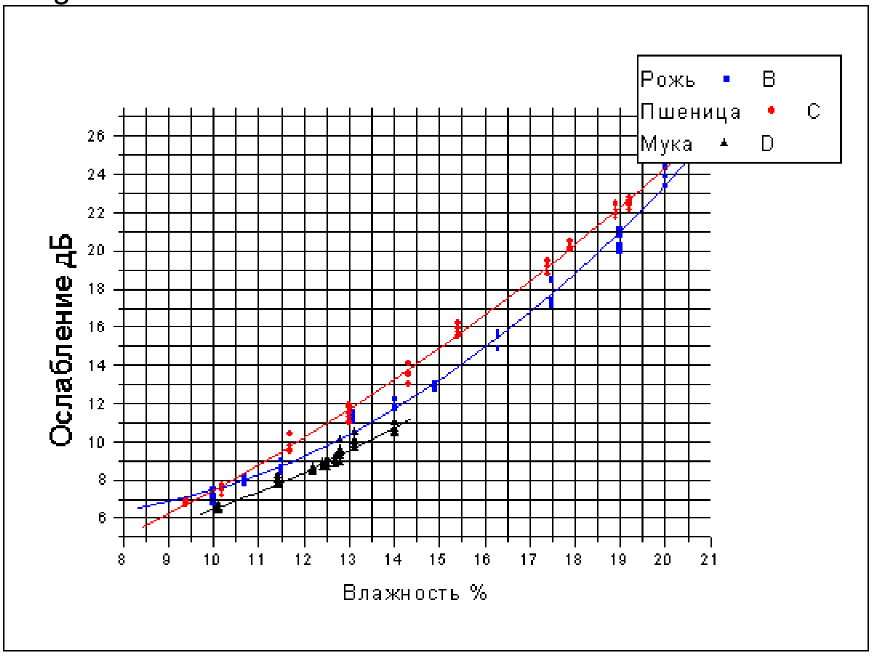


Fig.1. Dependences of microwave attenuation on grain wheat ,rye and wheat flour moisture at 10 GHz frequency.

There are attenuation dependences on moisture for seeds of buckeheat, rice , millet , wheat and rye in fig.2.
The different content of proteins, carbohidrates and starch in these materials does not influence significantly on attenuation of different materials with the same moisture.

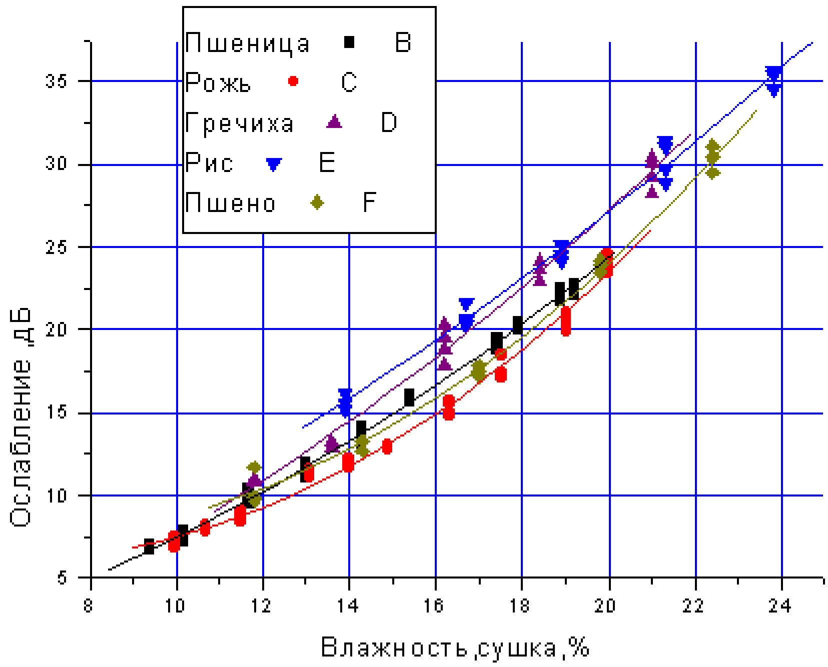
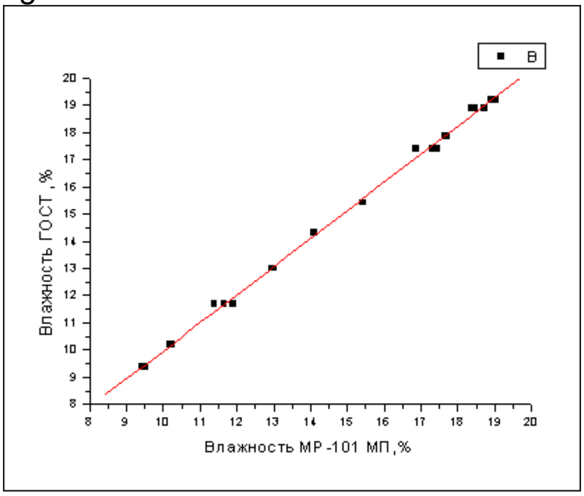


Fig.2.Dependences of attenuation on moisture for seeds of buckwheat, rice , millet , wheat and rye.

The laboratory moisture meter of grain and grain materials was designed by specialists of MICRORADAR company.

The moisture meter has passed State official tests in 1998 . The serial production was started in the end of 1998. The results of tests on wheat of one of moisture meters MR-101 are shown in fig. 3 .



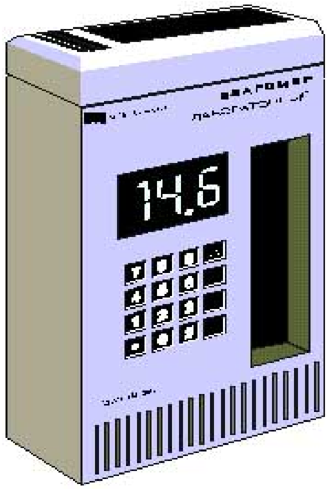


Fig.3.The results of tests on wheat of MICRORADAR-101 moisture meter and outward of MR-101 moisture meter.

The statistical analysis of the obtained results of these tests gives value SD=0,164 % and correlation coefficient R=0,9989. Such high correlation coefficient indicates practically analytical dependence of attenuation of microwaves on moisture of grain. As for measurement the definite mass of material is placed in the sensor of the device , it is possible to expect absence of influence of grain nature on the indications of moisture meter. To take into account, that the dependences of attenuation on moisture for grain of wheat, rye and barley are close enough (Fig. 2), it is possible to consider, that the influence of a mineral structure and percentage ratio of proteins and carbohydrates are insignificant too.

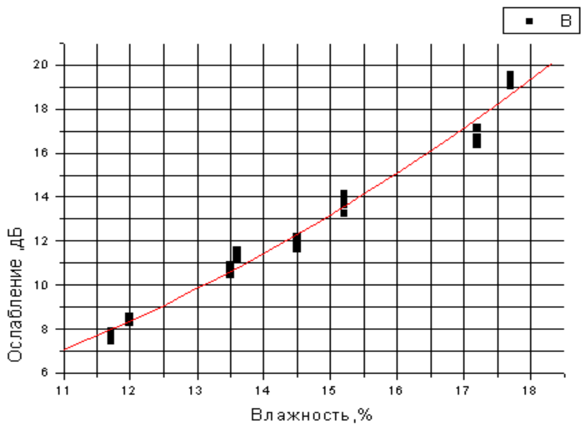
The tests on wheat flour of moisture meter were conducted. The flour for experiment was selected accidentally from the Belorussian and Bryansko-orlovsky regions.

The results of tests for wheat flour have given SD=0,11 % and R=0,986.

It should be noted, that experimentally definited SD of a standard method in our conditions has value 0,05 %, which gives a calculated value SD of moisture meter for flour- 0,10 %.

On-line moisture meters were designed for implementation(on the basis of microwave methods)on- line and portable moisture meters of grain.

The test results of on-line sensor and its outward are shown in fig.4.



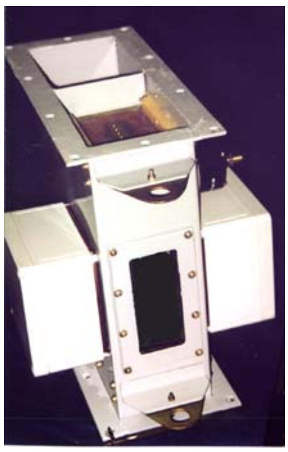


Fig. 4. Dependence of attenuation on moisture in on-line microwave sensor and its outward.

Metrology characteristics of the method in application to moisture control of common salt, tile powder, dense sugar syrups, macaroni and others were studied also. The results are shown in fig. 5 - 8

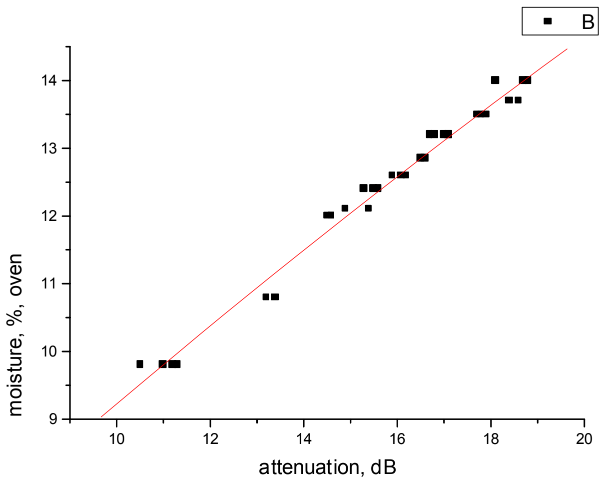


Fig. 6 Dependence of attenuation on moisture of macaroni.

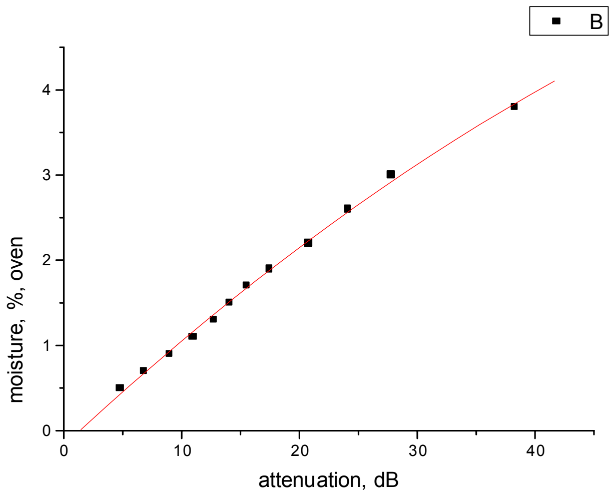


Fig. 7 Dependence of attenuation on moisture for salt NaCl. The measurements were conducted in the rectangular waveguide of 23-10 mms at 10,5 HHz, mass is 25 g.

The study of the metrology characteristics of a method on dense sugar syrups was conducted on the equipment shown in fig. 8.

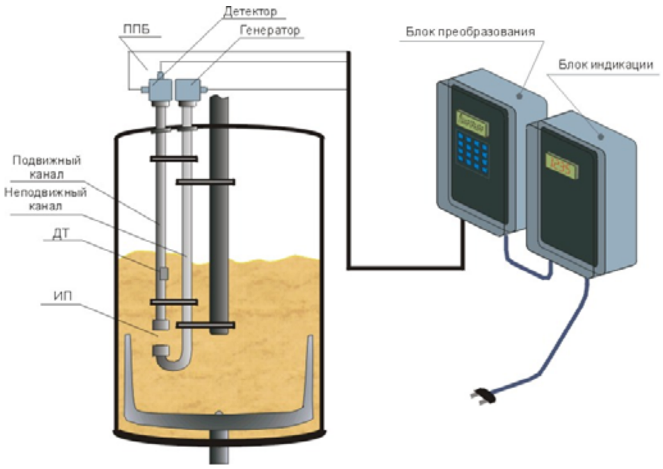


Fig. 8 Measurements of moisture of sugar syrups.

The material temperature at moisture of 4- 12 % was stabilized at 95 C.

It is obtained: root-mean-square deviation SD=0.18%, correlation coefficient R=0.96

2. Resonator two-parameter method.

The study of the metrology characteristics of the resonator method was conducted on the laboratory and industrial conditions (Fig. 9). In all cases the density of each sample was varied over a wide range and there was a correlation relation between moisture and generalised parameter «m» at variable density.

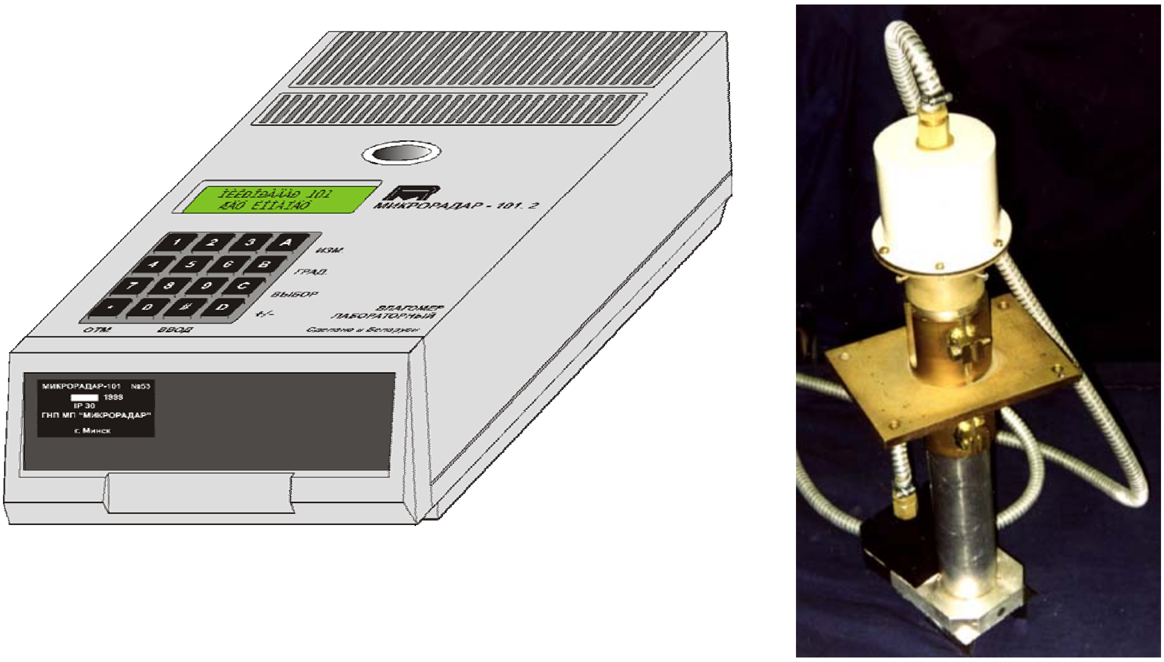


Fig. 9. The equipment for research of metrology parameters of the resonator two-parameter method.

The researches were conducted on organic and inorganic stuffs, thus the moisture of each of them was determined in conditions of the submitted Russian conforming standard.
Usually it was the thermogravimetric method, but the method of the Fisher was applied too.

The results of researches for some stuffs are shown in fig. 10 -11 .

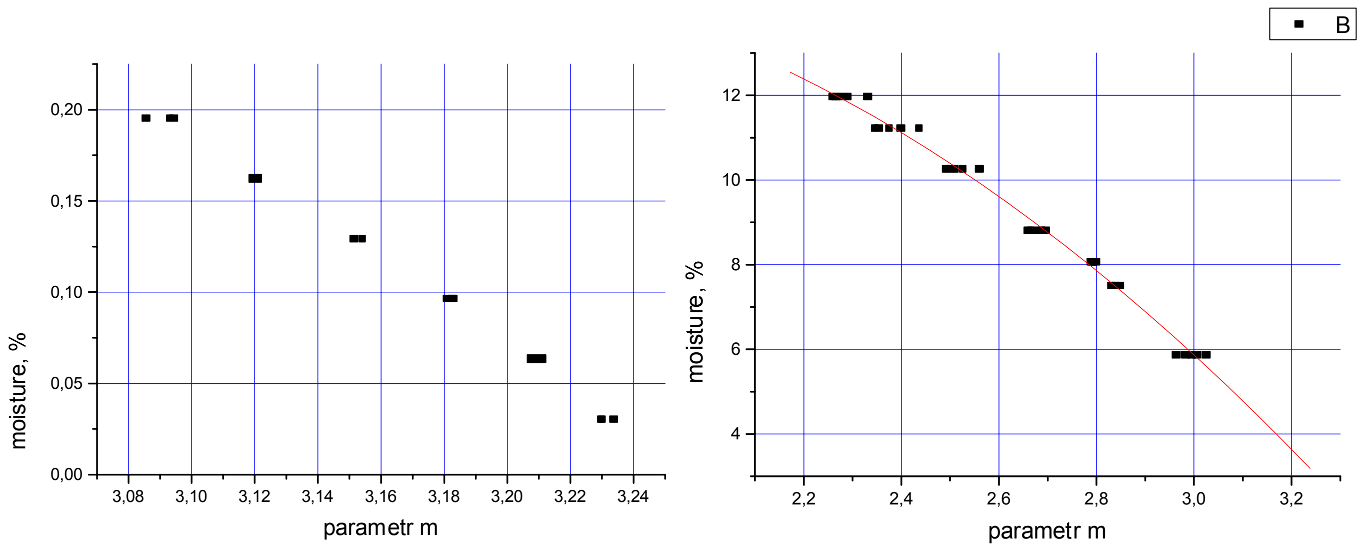


Fig. 10 The results of tests for sugar (on the left) and fish flour (on the right). For sugar SD=0.0031 % abs., R=0.9977; for a fish flour SD=0.19 % abs, R=0.992.

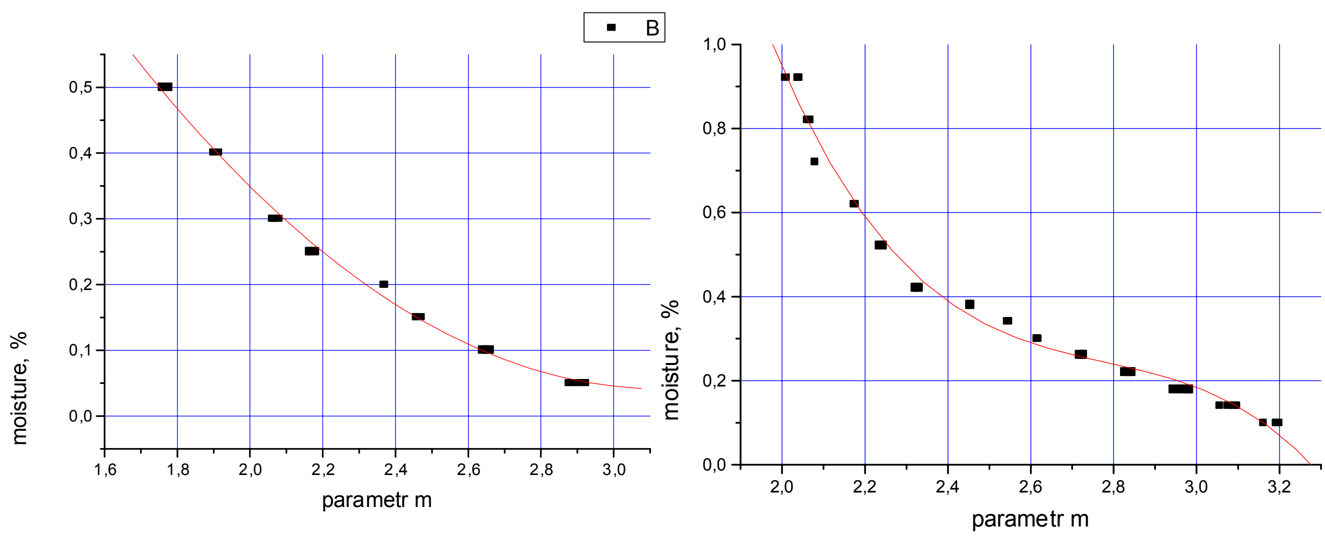


Fig. 11. The results of researches of sulphate of ammonium (on the left) and NaCl (on the right). For sulphate of ammonium SD=0.011 % abs., R = 0.995; for NaCl SD=0.025 % abs., R=0.99.

CONCLUSION

We have systematised the results of researches with 50 dielectrics, which contain water. The microwave method of definition of moisture depending on the technological requirements is offered for several of them. Also the comparative estimation of accounts on general model and experiment was carried out.

In this work the general modelling approach to the task of measurement of moisture by microwave methods is described. The choice of the microwave method depends on dielectric properties of the material, geometry of measurement and required accuracy.

We have determined borders of accuracy of microwave methods for concrete applications. All data are confirmed experimentally at the enterprises of Russia.