Measurement of Electrical Properties of Rapeseed Seeds with LCR Meter Good Will 8211

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Abstract

This article aims to present methods for measuring the electrical properties of sample - a granular material - rapeseed seeds developed in physics research laboratory at the Slovak University of Agriculture in Nitra Electrical properties were measured with LCR meter. Resistance R, impedance Z, capacity C, relative permittivity ε of six samples of rapeseed seeds with different moisture content were measured. The results are represented graphically and analytically. Obtained results are analyzed. The measured values and results obtained allow to conclude that resistance, impedance and capacity of rapeseed seeds functionally dependent on the frequency, as obtained by other authors. Research on electrical properties of biological materials and the results can be used when constructing the apparatus for measuring moisture content based on electrical and dielectric properties of materials. Knowing the dependencies would allow to find the most optimal and accurate method for measuring moisture content in agricultural production.

Keywords: rapeseed seeds, resistance, impedance, capacity, relative permittivity, moisture content, frequency

Introduction

Investigation of electrical properties of materials is done in many areas of science. In agricultural sciences study the electrical properties of biological materials are important both for storage in output to process control and product quality. Measurements of the electrical properties of biological materials are made quickly, the results are used to determine other properties of materials .

The largest application is in measuring the moisture content of agricultural produce (grain, seeds, etc.). or dielectric losses.

Study of electrical properties is important for predicting the behavior of biological materials in the electrical field, as well as its connection to an electric circuit.

Electrical properties of the biological materials are influenced by various factors. The most important of these is water content (moisture content) and its asymmetric distribution in materials, temperature, bulk density, presence of pests, and other mechanical damage [1].

Particularly important are the dielectric properties of materials. They change by placing the material in high-frequency field.

These properties are related (correlate) with the percentage of moisture content in biological materials. Small changes in the water absorbed in the specimen can cause major changes in the electrical and dielectric properties of hygroscopic materials.

Using the relationship between the electrical characteristics of biological materials and variation of their other characteristics (water content, impurities, etc.). allows the development of measuring instruments.

Brief theory

It is known that electrical properties of living cells are passive and active.

From the microscopic point of view inside the cell has ion conductivity. Cell membrane has a large resistance 10^8-10^9 Ω and is not conductive.

For various tissues and biological materials electrical properties are different. In applying an alternating current biological materials have not only resistance R, but capacity C, inductance L and total resistance - impedance Z that is greater than R.

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

Where $\omega = 2\pi f$.

There are studies which found what dependence of R, C and Z on frequency of the alternating current [1]. Dependency is a monotonically decreasing function of the type

$$R = R_0 \left(\frac{f}{f_0}\right)^{-n} \qquad Z = Z_0 \left(\frac{f}{f_0}\right)^{-n} \qquad C = C_0 \left(\frac{f}{f_0}\right)^{-n} \qquad (1)$$

In these formulas R_0, Z_0, C_0 are constants, and n is coefficient.

From the macroscopic point of view in cell membrane there are channels through which can pass physiological ions and anions, and particle charge carriers.

The density of electric current is:

$$i_d = \sigma.E + \frac{d(\varepsilon.E)}{dt}$$

Where E is the electric field intensity and ε is the dielectric permittivity of the material (insulator).

$$\varepsilon = \varepsilon_r.\varepsilon_0,$$

where ε_r is the relative permittivity of the substance ε_0 = 8.85. 10^{-12} $F.m^{-1}$ is the dielectric constant.

There are studies [1,7], showing that $\varepsilon_r = f(f, t^0)$, as well as moisture content in the material $\omega\%$. This dependence is transmitted on $\varepsilon = f(\omega\%)$.

Last dependence is determined by the method of connecting the water with the material, of variability in it and by chemical bonds. For bulk materials the dependence is affected by the mass in bulk, the frequency of the electric field and temperature.

Measurement of moisture content in biological objects (grains, seeds, etc.) is the most important in storage and processing of agricultural produce. The accuracy of these measurements depends on several groups of factors.

Physical properties of agricultural products affect the accuracy of measurement of moisture.

Depending on the measuring method used for the physical characteristics can be separated: measuring the dependence of electrical resistance in hygrometers, specific resistance, conductivity, impedance, permittivity of moisture content [2].

Many methods have been used to measure moisture content especially high-frequency intervals.

There have been studies of the dependence of the dielectric properties of different frequencies from 250 Hz to 12 GHz. [6]

There is available information of results related with dependence of dielectric properties of wheat and seeds at low frequencies [4,6] and microwave frequencies.

Some scientists discuss the possibility of applying dielectric method for measuring moisture in materials [2,5].

Studies were implemented [9] at low frequencies from 435 Hz to 1740 Hz to determine the dielectric constant and lossfactor of rice grains.

They found that $\varepsilon_r = f\left(\omega\%, \rho, t^0, f\right)$.

There have been studies [4] on the application of radio frequency heating of biological materials.

One method for measuring the moisture content is the dielectric method, that is based in dielectric hygrometers. On that with electrical methods follow the behavior of the dielectric (organic material) over time for a change of the electric field.

Under the influence of electric field dielectric is polarized and its dielectric permittivity can be measured by measuring the capacity at different frequencies of alternating current.

The test substance is placed between the plates of a capacitor. One way to measure the capacity of the condenser is bridge method by resonance and after is calculated ε of the substance.

Such measurings are made by Novak [7] at frequencies from 1 MHz to 16 MHz. He found that in this frequency range there is a linear relationship between ε and $\omega\%$.

If the condenser is plane, then by $C = \varepsilon_r . \varepsilon_0 \frac{S}{d}$ for a capacitor with a dielectric (organic matter) and $C_0 = \varepsilon_0 \frac{S}{d}$ for air condenser, then $\varepsilon_r = \frac{C}{C_0}$.

The last formula allows measurement of both the capacity to find the relative permittivity of the material - the biological material.

1. Materials and method of measurement

There was test - studied rapeseed seed harvest in 2007 with approximately equal-sized seeds.

Measurements were made in laboratory conditions at 21^{0}C and humidity $\omega = 54\%$.

1.1 Preparation of samples for testing

Six samples rapeseed seeds were prepared with different moisture content - 4.875%, 7.3056%, 8.768%, 11.639%, 13.022%, 14.263%.

This moisture content is achieved by gravity method, such samples are artificially moisturized by addition of distilled water and then dried. Mass is measured with an electronic balance accurate to 0, 0001 g.

1.2. Sensor

For sensor is used plane capacitor with copper plates, which are circular with a diameter of 37,78 mm and the distance between them is 49,2 mm. The surrounding area is plexiglass with great resistance. On top of the sensor there is a spring so that the model is under constantly mechanical pressure. This provides a minimal presence of air between seeds of the sample.

Then to determine the dielectric permittivity can use the formula $\varepsilon_r = \frac{C_X - C_P}{C_0 - C_P}$, where C_X is the capacity of the condenser filled with seeds, C_0 is the capacity of the empty capacitor - no seeds, C_P is the capacity of the air spaces between the seeds.

Assuming that all samples were under constant mechanical pressure, this may allow disregarding C_P.

1.3. Method of measurement

Measurement of electrical characteristics R, Z, C_X for each model having different moisture content and C_0 becomes with a LCR meter Good Will8211.

The device can measure R, Z, L, C and Q factors with an accuracy of 0.05% and coefficient of dispersion D with an accuracy 0.0005%.

The chain offers six test methods $R/Q, C/D, C/R, L/Q, Z/Q.L/R$.

Frequency can be changed from f = 1 kHz to 200 kHz. The speed of measurement is 60 ms.

For each of the prepared samples are measured three times R, Z and C_X under values of frequency f = 1, 3, 5, 10, 15, 25, 40, 50, 100 and 200 kHz. The empty capacitor C_0 is measured three times for the same frequencies.

With the program Grafer are built graphs $R = f(f), Z = f(f)$ and $C = f(f)$ with average values of three measurements.

It is calculated relative permittivity in the formula $\varepsilon_r = \frac{C_X}{C_0}$ by average capacity for each sample at different frequencies.

There are constructed dependencies $\varepsilon_r = f(f)$ and $\varepsilon_r = f(\omega\%)$ for frequencies 3, 25, 40, 50, 100 and 200 kHz.

Results

There are presented some graphs of results.

Fig.1.Dependence of resistance and impedance on frequency ($\omega = 4{,}875\%$).

Fit 1: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -1.63048 * log(X) + 11.509
Alternate equation:
Y = pow(X,-1.63048) * 99611.2
Coef of determination, R-squared = 0.986712

$$R = R_0\left(\frac{f}{f_0}\right)^{-n}$$

R_0 = 99611.2 k Ω
n = 1.63048
R^2 = 0.986712

Fit 10: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -0.856328 * log(X) + 11.2512
Alternate equation:
Y = pow(X,-0.856328) * 76971.9
Coef of determination, R-squared = 0.990064

$$Z = Z_0\left(\frac{f}{f_0}\right)^{-n}$$

Z_0=76971.9 k Ω
n = 0.8563
R^2 = 0.990064

Fig.2.Dependence of resistance and impedance on frequency ($\omega = 11{,}639\%$).

Fit 1: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -0.545544 * log(X) + 7.64193
Alternate equation:
Y = pow(X,-0.545544) * 2083.77
Coef of determination, R-squared = 0.985002

$$R = R_0\left(\frac{f}{f_0}\right)^{-n}$$

R_0 = 2083.77 k Ω
n = 0.545544
R^2 = 0.985002

Fit 10: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -0.450113 * log(X) + 7.64051
Alternate equation:
Y = pow(X,-0.450113) * 2080.8
Coef of determination, R-squared = 0.987188

$$Z = Z_0\left(\frac{f}{f_0}\right)^{-n}$$

Z_0=2080.8 k Ω
n = 0.450113
R^2 = 0.987188

Fig.3. Dependence of capacity on frequency ($\omega = 11{,}639\%$).

Fit 10: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -0.678415 * log(X) + 5.20944
Alternate equation:
Y = pow(X,-0.678415) * 182.991
Coef of determination, R-squared = 0.995618

$$C = C_0\left(\frac{f}{f_0}\right)^{-n}$$

C_0 = 182.991 pF

n= 0.678415

R^2=0.995618

Fig.4. Dependence of relative permittivity on frequency.

Fit 10: Power, log(Y)=B*log(X)+A
Equation:
log(Y) = -0.249001 * log(X) + 1.25321
Alternate equation:
Y = pow(X,-0.249001) * 3.50158
Coef of determination, R-squared = 0.976216

$$\varepsilon_r = \varepsilon_{r0}\left(\frac{f}{f_0}\right)^{-n}$$

ε_{r0} = 3.50158
n= 0.249001
R^2=0.976216

Fig.5. Dependence of relative permittivity on moisture content ($f = 200kHz$).

Fit 10: Exponential, log(Y)=B*X+A
Equation:
log(Y) = 0.276406 * X + -1.77881
Alternate equation:
Y = exp(0.276406 * X) * 0.168838
Coef of determination, R-squared = 0.927181

Analysis of results

For all values of moisture content $Z > R$. At smaller values of moisture content $Z >> R$.

With increasing frequency R and Z decreased function of the type (1).

The same results are obtained for C.

This shows that the frequency range of 1 kHz to 200 kHz is good for the study of electrical properties R, Z and C of biological materials - rapeseed seed and other granular materials. (Small volume to avoid the presence of air between the particles).

The results for $\varepsilon_r = f(f)$ shows that at low moisture content ε_r decreases with increasing frequency. The results for ε_r are real for low moisture content, but for high moisture content there are unreal results for ε_r.

The results for $\varepsilon_r = f(\omega\%)$ show that low frequencies are not good for studying the relationship between dielectric permittivity and moisture content. Good and realistic results are obtained at a frequency of 200 kHz.

One reason for these results is the types of using capacitor. We believe that values can be improved if to increase the area S of the plates and to reduce the distance *d* between them, leading to an increase of C_0.

Conclusions

The measured values and results obtained allow to conclude that resistance, impedance and capacity of rapeseed seeds depend on the frequency depending on function on type (1) obtained by other authors. With increasing moisture content of the samples, the values of R and Z decrease. In dry materials R and Z have higher values than materials with higher moisture content.

Capacity values C for samples with higher moisture content are higher than dry materials.

The results for the dependence of relative permittivity on the frequency and on moisture content of the samples show that these tests are suitable for frequencies greater than 200 kHz.

Research on electrical properties of biological materials and the results can be used when constructing the apparatus for measuring moisture content based on electrical and dielectric properties of materials. Knowing the dependencies would allow to find the most optimal and accurate method for measuring moisture content in agricultural production.

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Fig.1.Dependence of resistance and impedance on frequency

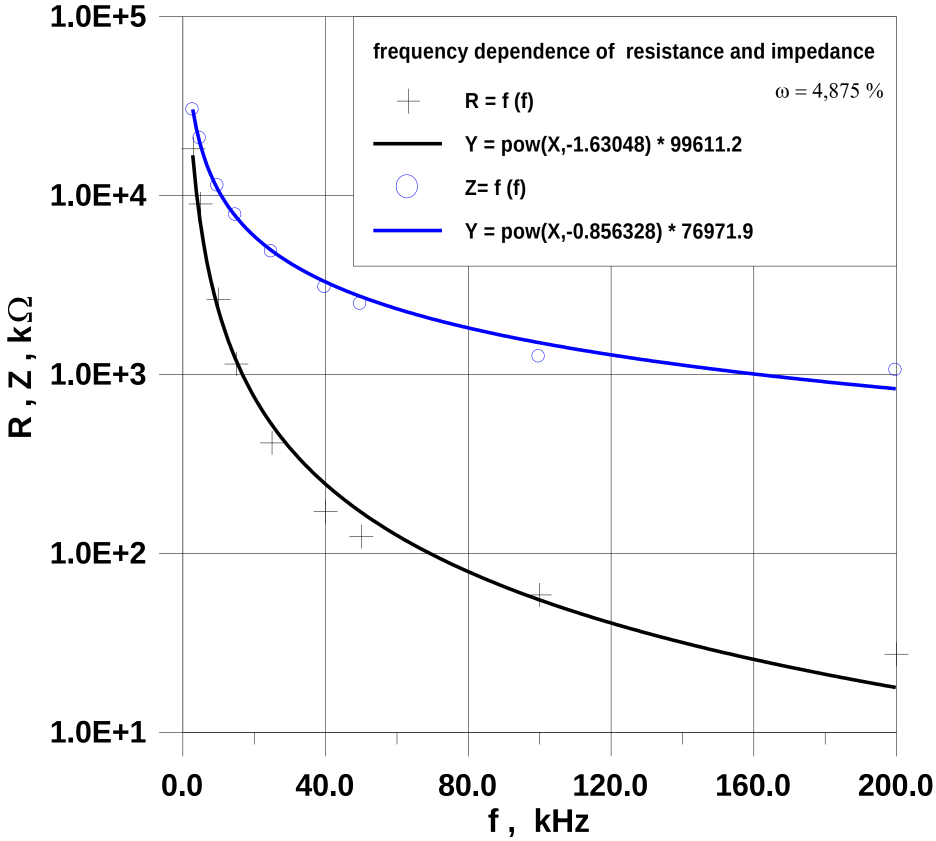

Fig.2. Dependence of resistance and impedance on frequency

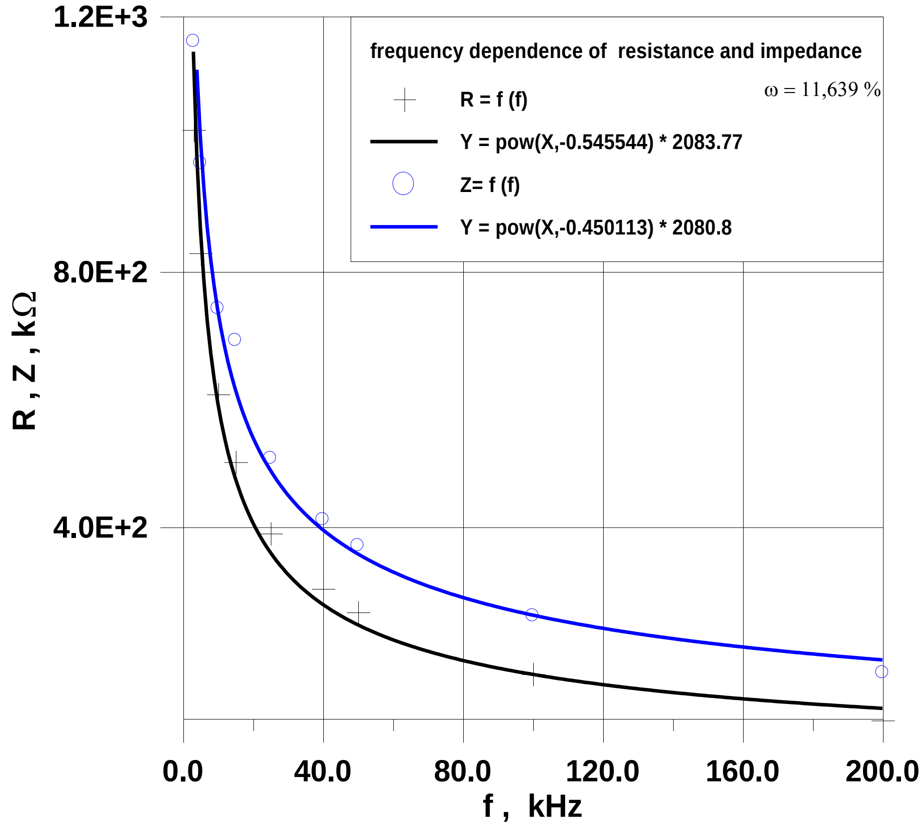

Fig.3. Dependence of capacity on frequency

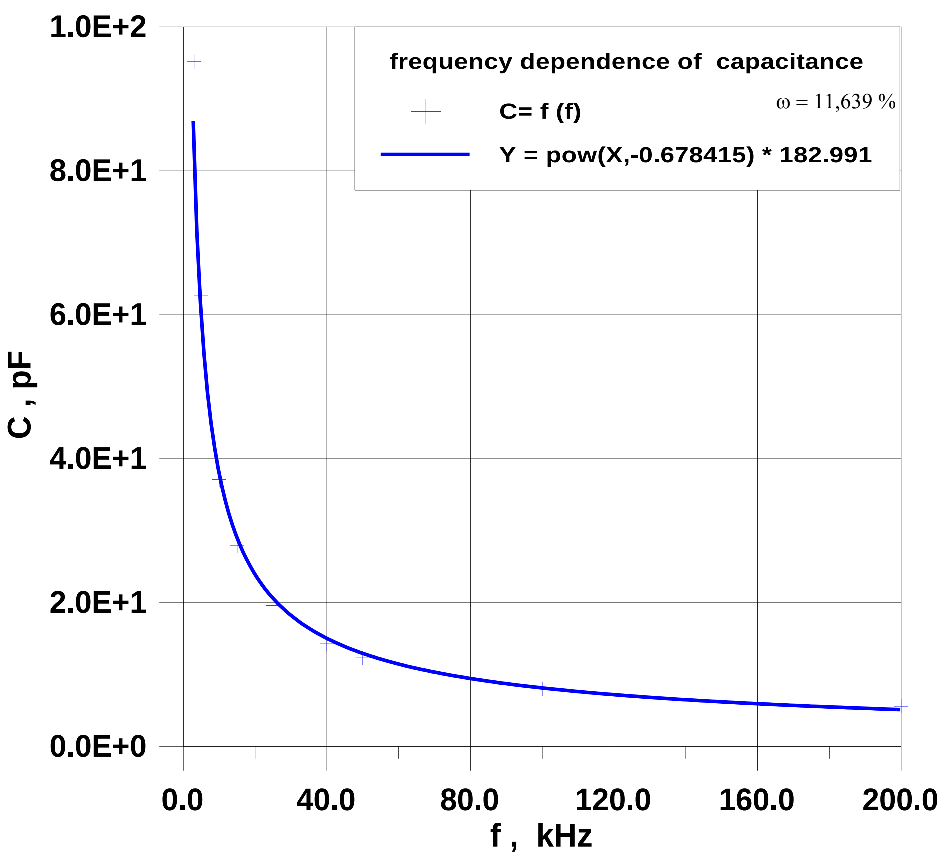

Fig.4. Dependence of relative permittivity on frequency.

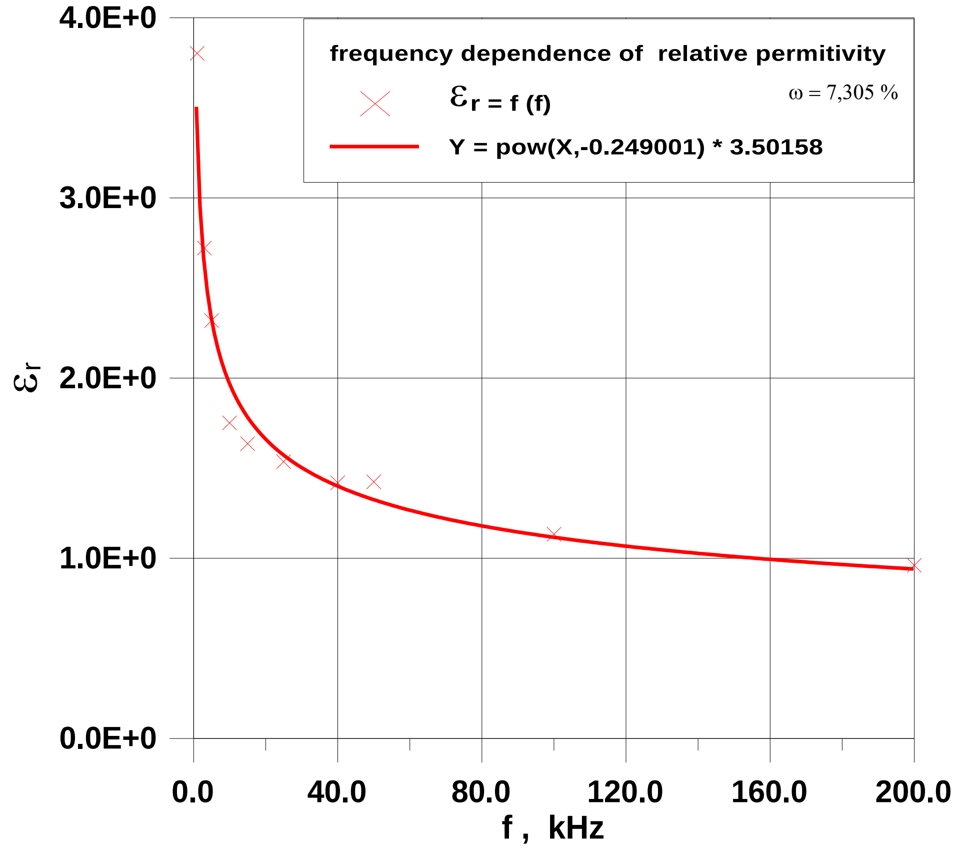

Fig.5. Dependence of relative permittivity on moisture content