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Utilization of electric properties of granular and powdery materials[1,2]

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A b s t r a c t. Determination of electrical properties is utilized in a wide range of disciplines and industries. A brief compendium of electrical properties utilization of granular and powdery agricultural and food materials is presented in this paper. Electrical properties of granular and powdery materials are influenced by various factors. The most important are moisture content and its distribution in materials, temperature, density, volume or bulk density. The relationships between the resistivity, conductivity, capacitance, relative permittivity and various influencing factors are described.

The electrical conductivity measurements are utilized in the determination of the salinity of soils and irrigation water. Biological material properties are determined from their leachates, too. The conductivity measurements are applied for the determination of various characteristics of agricultural materials and foods (frost sensitivity, chilling and freezing tolerance, moisture content, seed germination, mechanical stress). Investigated materials are very various, for example grains, seeds, meat, sugar, milk, wood, soil, fruit and vegetable, infected food. The utilization of dielectric properties is also described; for example in agricultural materials and food quality sensing (moisture content, maturity of fruit, potential insect control in seeds, radio frequency heating). The classification of permittivity measurement techniques is mentioned.

K e y w o r d s: electrical properties, resistivity, relative permittivity

INTRODUCTION

Granular and powdery materials are very complex in their composition and behaviour, including electrical properties. Biological materials are non-homogeneous on the microscopic level, because the inside of cells is conductive and cell membranes are not conductors. The alternate arrangement of the different parts creates biological capacitors. Non-homogeneity on the macroscopic level and influence on the electrical properties of materials are caused by the properties of each type of tissue, by the density and structural arrangement of cells, by the presence of water and by its uneven deployment in the material, by different binding energy in each bound water, by sorption properties, by temperature. For porous materials there are the bulk density, porosity, size and distribution of pores. For loose materials we can name the gappiness, contact surface between the parts, properties of air trapped between the parts or in the pores, its relative humidity and temperature, deployment of the parts in the pack, size of parts (Hlaváčová, 2003).

Measurement of electrical properties is quick and relatively simple and that is why it is exploited in the determination of other characteristics of materials. Electrical properties of materials are utilized in many areas of human activities and most frequently are applied for moisture content measurements.

CONDUCTIVITY MEASUREMENT

Grain and seed properties are determined from their leachates, too. For example, Couto *et al*. (1998) measured electrical conductivity of leachates from cut soybean seeds drowned in distilled water. The response of electrical conductivity to variations in the percentage of damage was linear or quadratic and this method can be utilized for quantitative evaluation of mechanical damage. Verma *et al*. (2001) determined that the increase in conductivity values of seed leachates was related to the initial degree of deterioration of seed lots. Other authors utilized electrical conductivity measurement for determination of pepper seed

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development, for determination of various seeds vigour or, for estimation of seed germination. Panobianco *et al*. (1999) used the same method for determination of the correlation between the electrical conductivity of soybean seed and seed coat lignin content.

Prasad and Singh (1999) used the conductivities of different sugar crystals to assess the quality of sugars, since conductivity decreased with increasing level of the sugar purity. De Andrade *et al*. (1999) evaluated the mechanical damage to bean seeds using measurement of electrical resistivity.

Malicki and Walczak (1999) used bulk electrical conductivity and permittivity measurement for evaluation of soil salinity by means of time domain reflectometry. They determined the salinity index x_s which can be calculated from bulk electric conductivity, σ, and permittivity, ε, and which appeared to be independent of the moisture content and directly proportional to soil salinity. Conductivity measurements of soil have been used to identify contrasting soil properties in the geological and environmental fields by Lund *et al.* (1999). Friedman (1998) simulated potential error in determining soil salinity from measured apparent electrical conductivity.

Our measurements were made with variously treated seeds (filed, coated and encrusted) of 9 sugar beet (*Beta vulgaris convarieta altissima*) cultivars (Hlaváčová *et al*., 2001). All the seeds had natural moisture content. The current passing through the pack of seed was measured. The method of measurement is described in (Hlaváčová, 2001). The current increased linearly with the voltage according to the relation:

$$I = kU + I_o, \tag{1}$$

where: k is constant, I_o is current at the reference voltage, U is reference voltage. The relation had high values of the coefficient of determination. The highest current passed through the sample of filed seeds and the lowest through encrusted seeds (Fig. 1). It was found that the electrical conductivity of seeds is affected by their surface treatment. Average conductivity at the moisture content of 9.39% for cultivar Remona was 1.741 10^{-10} S m^{-1}, for cultivar Polina 2.285 10^{-10} S m^{-1} and for Intera 3.006 10^{-10} S m^{-1}.

It follows that coating and encrusting of seeds increase their resistance. The mode of sugar beet seeds surface treatment could be determined by the measurements of their electric properties.

Knowledge of the temperature distributions and electrical properties dependence on temperature of treated material is necessary in the case of thermal treatment (for example ohmic heating). We found out that the conductivity increases and the resistivity decreases with temperature exponentially for all samples at all moisture contents (Hlaváčová, 2001). The method of measurement is described in this paper. For illustration, Fig. 2 shows the resistivity temperature dependencies for 2 hybrids of corn

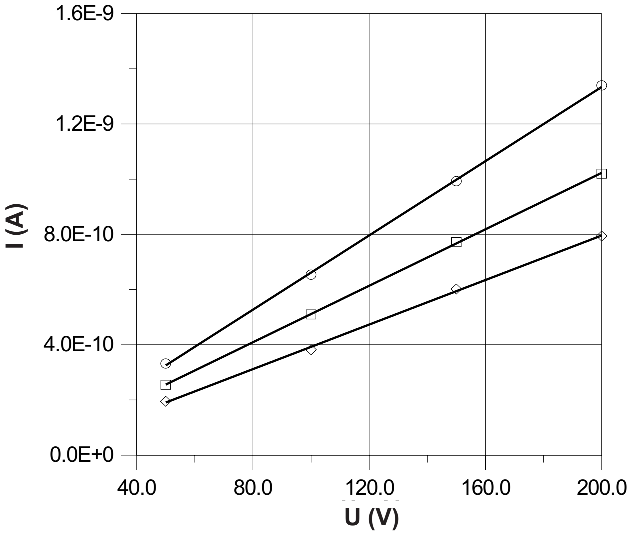

Fig. 1. The dependence of current passing through the sample on voltage, for sugar beet seeds of cultivars: Intera (filed seeds) (○), Polina (coated seeds) (□) and Remona (encrusted seeds) (◇), at average moisture content of 9.39%.

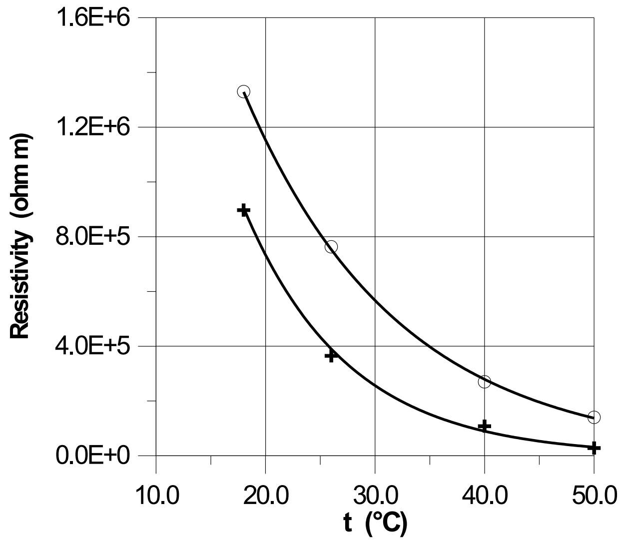

Fig. 2. The resistivity temperature dependencies for corn grains hybrids of Fabullis (○) at the moisture content wet basis of 16.9% and of Raissa (+) at 17.34%.

(*Zea mays*) grains at approximately equal moisture content. Displacement of the curves is caused by various properties of two hybrids. The regression equation for resistivity has the form:

$$\rho = \rho_o e^{-\mathrm{k}\frac{t}{t_o}}, \tag{2}$$

where: ρ_o – resistivity at the reference temperature, t – temperature, k – constant, t_o = 1 °C. The regression equation has high coefficients of determination for all samples.

The moisture content has an important effect on the values of the conductivity and resistivity and the replacement of the temperature dependencies are influenced by this fact.

Our other measurements were done on various varieties of amaranth (*Amaranthus*) seeds (Hlaváčová, 2001). For illustration, in Fig. 3 we present the dependence of the resistivity on moisture content wet basis for *Amaranthus hypochondriacus*. The dependence has the decreasing power function character whose regression equation is:

$$\rho = \rho_o \omega^{-\mathrm{d}} \tag{3}$$

where ρ is resistivity, ρ_o is resistivity at the reference moisture content, ω – moisture content wet basis and d – constant. All regression equations have high coefficients of determinations up to 0.969.

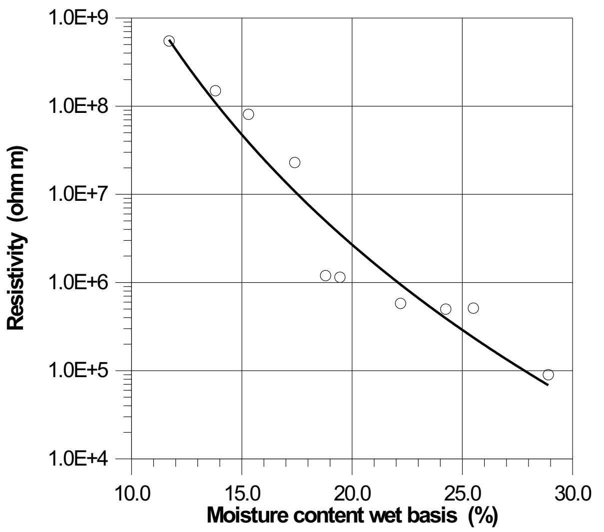

Fig. 3. The dependence of resistivity on moisture content wet basis for *Amaranthus hypochondriacus* at an average bulk density of 760.4 kg m^{-3}.

At the moment, the moisture meters for amaranth seeds are not produced and that is why the described dependencies can be utilized for the calibration of present resistance moisture meters for granular materials.

DIELECTRIC PROPERTIES MEASUREMENT

Various techniques have been developed to study the dielectric properties (bulk relative permittivity and loss factor) of granular and powdery materials. These have the biggest application in moisture content measurements because of the high dielectric permittivity of liquid water relative to that of solids and of air. Measurement methods for granular and powdery materials can be classified as follows: capacitance measurement, measurement of single kernel of grain, wave guide measurements, cavity measurements, open resonator, coaxial probe, non contact scattering measurements.

For measurement of dielectric parameters of powder and granular materials in radio frequencies based on the capacitance principle, the most appropriate arrangement of the electrodes is either as parallel or juxtaposed plates or concentric cylinders. The parallel plates arrangement has the advantage of providing a uniform electric field but, if the cell is not shielded, influence of external objects on the cell capacitance may introduce appreciable errors in the measurement. The main disadvantage of the concentric cylinders arrangement is associated with the non-uniformity of the electric field between the plates and the advantage is electrical self-screening property of the concentric cylinders, which prevents influence from external objects on the cell capacitance. Berbert *et al*. (2001) described the construction of a coaxial capacitor for the measurement of dielectric properties of grains.

We measured the capacitance of a coaxial capacitor with samples by means of a Q-meter in the frequency range from 2 to 50 MHz (Hlaváčová, 2003). We determined the temperature dependencies of relative permittivity for various samples. Figure 4 presents the temperature dependencies of relative permittivity for wheat (*Triticum aestivum*) grains of the Jubilejná variety at 2 MHz for 4 moisture contents. These dependencies are needed for electrical heating of material.

The permittivity of samples increases with temperature linearly in this frequency range and the regression equation is:

$$\varepsilon_r = \varepsilon_{ro} + \mathrm{q}\frac{t}{t_o}, \tag{4}$$

where ε_r is relative permittivity, ε_{ro} is relative permittivity at reference temperature, q is constant, t is temperature of sample and $t_o = 1$°C. The coefficients of determination have high values.

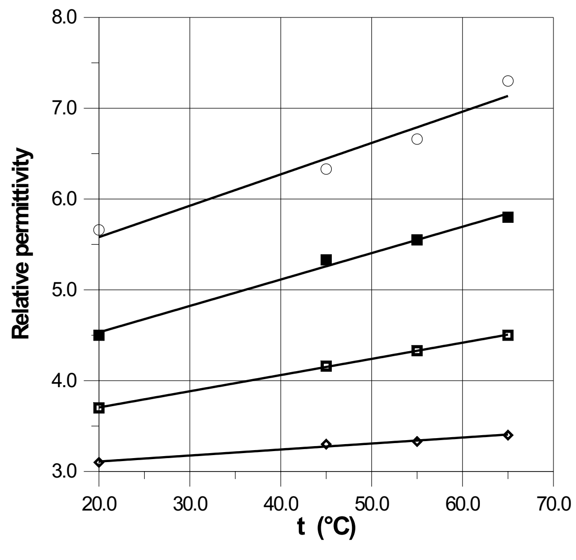

Fig. 4. The temperature dependencies of relative permittivity for wheat grains of Jubilejná variety at 2 MHz for moisture contents wet basis of: 12.5 (◇), 15.2 (□), 22.1 (■) and 26.3% (O).

Nelson and Bartley (2001) used an open-ended coaxial-line probe with sample temperature control equipment designed for use with the probe to measure permittivities of some liquid, semisolid, and pulverized food materials as a function of frequency and temperature. Graphical data for the dielectric constant and loss factor of homogenized macaroni and cheese, whey protein gel and ground whole-wheat flour illustrated the diverse frequency- and temperature-dependent behaviour of food materials.

Daschner *et al*. (2001) determined foodstuffs composition by using microwave dielectric spectra and artificial neural networks. Etherington *et al*. (1998) used time domain reflectometry to monitor the moisture content of grated coconut in real time and its effect on oil production. The moisture content of grated coconut affected the ease and efficiency of oil extraction. Thakur and Holmes (2001) used a three dimensional vector finite element method (FEM) to model the permittivity of rice grain using the scattered far field radiation.

For in-field use there are five well-developed moisture content measurement techniques operating between 10 MHz and 10 GHz in soil:
- time domain reflectometry (TDR),
- capacitance (C),
- ground penetrating radar (GPR),
- airborne/satellite active radar,
- passive microwave methods.

Time domain reflectometry (TDR) and capacitance approaches use probes which convey signal into the soil and thus can measure principally the upper one-meter depth. Ground penetrating radar (GPR) using non-invasive transmitting and receiving antennae possesses the capability to measure to even greater depths without causing soil disturbance. Remote radar and passive microwave methods, operating generally above 1 GHz, derive their information from within a few cm of the ground surface.

Skierucha (2000) described the accuracy of soil moisture measurement by TDR technique. Ren *et al*. (1999) developed a thermo-time domain reflectometry probe to simultaneously measure soil volumetric water content, bulk electrical conductivity, thermal conductivity, heat capacity and thermal diffusivity. Kaya and Fang (1997) used dielectric constant and electrical conductivity to characterize and identify contaminated fine-grained soils.

CONCLUSIONS

1. Electrical properties of granular and powdery materials are utilized in many areas of human activities and most frequently are applied for moisture content measurements.

2. Electrical properties of materials are influenced by various factors. The most important of these factors are moisture content and its asymmetrical distribution in materials, temperature, density, volume or bulk density.

3. The electrical properties measurement is applied for the determination of various characteristics of granular and powdery materials, for example for the salinity of soils and irrigation water determination, for the evaluation of moisture content, of mechanical damage, for sugar purity determination, for evaluation of seed surface treatment, for the determination of thermal treatment of materials, and for many other purposes.

4. It was found that the electrical conductivity of sugar beet (*Beta vulgaris convarieta altissima*) seeds is affected by their surface treatment. Average conductivity at the moisture content of 9.39% for cultivar Remona was 1.741 10^{-10} S m^{-1}, for cultivar Polina 2.285 10^{-10} S m^{-1} and for Intera 3.006 10^{-10} S m^{-1}. It follows that coating and encrusting of seeds increase their resistance. The mode of sugar beet seed surface treatment could be determined by measurements of the electric properties of the seeds.

5. We found out that the conductivity increases and the resistivity decreases with temperature exponentially for all samples at all moisture contents. The permittivity of all samples increases with temperature linearly in frequency range from 2 to 50 MHz. The electrical properties dependence on temperature of treated material is necessary in the case of its thermal treatment.

6. The dependence of the resistivity on moisture content wet basis has the decreasing power function character for all amaranth seeds and it can be utilized for the calibration of present resistance moisture meters for granular materials. At the moment, moisture meters for amaranth seeds are not produced.

7. Granular and powdery materials are so complex in their composition and in their dielectric behaviour that it is usually necessary to measure the electrical properties under the particular conditions of interest to obtain reliable data.

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