DRYING CHARACTERISTICS AND ELECTRICAL PROPERTIES

Z. Hlaváčová, T. Regrut, M. Malínek

Department of Physics, Slovak University of Agriculture in Nitra, Slovakia

Abstract
The aim of the contribution was to find a correlation between drying characteristics and electrical properties. We measured electrical properties of some food materials by the bridge method. The frequency and moisture content dependencies of these properties were also determined. We investigated the time dependencies of dried samples mass, moisture ratio, and moisture content. We found out that the moisture ratio of samples decreases with time. During drying, the mass of the samples decreases according to fifth degree polynomic function. The impedance decreases with frequency. The resistivity decreases with increase of the moisture content according to the power function.

Key words: electrical properties, moisture ratio, moisture content, temperature.

INTRODUCTION

In the case of food materials storing, the moisture content and temperature are the most important parameters which influence the various processes in them. Food materials have limited durability in general because they are in instable or metastable states. The decrease of food materials stability during ageing is caused by mechanical deterioration, influence of water, transport of heat and humidity, metabolic processes, respiration, destructive processes caused by microorganism (BLAHOVEC, 2008). Water can be removed from food materials by various processes. On the beginning, we can name the mechanical treatment. The water removal is caused by the material compression or centrifugation. Second is the drying, it is the process of the removal of water (moisture) from hygroscopic materials at low to medium moisture contents (normally < 30 % wb) by means of evaporation. When the moisture content of the food products is high (usually > 50 % wb) the process of removal of moisture is referred as dehydration (JAYAS, SINGH, 2011). Drying and dehydration are high energy consumption process, because of very high latent heat of the water evaporation (BOŽIKOVÁ, HLAVÁČ, 2013). Only if we use aeration, it needs only low energy costs (RAGHAVAN, SOSLE, 2007). The aeration is usually carried out in a storage bin with ventilation. In hot, dry countries, they can use solar drying (MISHA ET AL., 2016). Quality assurance of the dried product, potential risks at convective drying, and quality of dried material protection are described by ŽITŇÁK ET AL. (2015), KUBÍK AND ZEMAN (2014). In the convective drying of food can be used power ultrasound, and the drying rate is affected in this case by both the drying temperature and the applied ultrasonic power. Power ultrasound brings mechanical effects both on the gas-solid interfaces and in the material being dried, which may facilitate water removal without introducing a high given amount of thermal energy. The ultrasound application induces an increase of both the effective diffusion and the mass transfer coefficients, although, this increment is more notorious at low temperatures than higher ones (RODRIGUES ET AL., 2014; CÁRSEL ET AL., 2011). Microwave, chemical, and pulsed electric field can be used as a pre-treatment processes on convective drying of food. In such cases, heat is transferred to the product by a heating medium usually hot air or superheated steam, on other hand heat could be applied through radiation, for example, in infrared dryers or through volumetric heating, for example, in microwave dryers. Depending on the heat source, operating pressure, and operating mechanism, dryers are classified as hot air, infrared, microwave, vacuum, freeze, flash, superheated steam, spouted bed, fluidized bed, and spray (JAYAS, SINGH, 2011). Other processes used at water removal from food materials are osmotic drying, lyophilization, and addition of water absorbing substances (e. g. silica gel).

Electrical properties of food materials have many applications in various branches (JHA ET AL., 2011). The measurement of electrical properties of food can be used to get information about many other characteristics of this material; in addition, there are some food processes which are based on electrical effects. An electric current flowing through a food material causes a temperature rise due to energy dissipation by the electric resistance of the food. Ohmic heating has several advantages. The heat is produced inside the food. On the other hand, high voltage electric pulses can damage cells and cause higher permeability of cell walls (FIGURA, TEIXEIRA, 2007). The dielectric properties of materials dictate, to a large extent, the behaviour of the materials when subjected to radio-frequency (RF) or microwave field for the purposes of heating, drying or processing the materials. The characterisation of dielectric properties is vital for understanding the response of a material to microwaves, since most useful quantities needed in the design of microwave thermal processes can be described in terms of them (JHA ET AL., 2011; VENKATESH, RAGHAVAN, 2004).

Many authors use mathematical models for describing the drying process. The effects of air temperature, air-flow rate and sample thickness on the drying kinetics of carrot cubes were investigated by DOYMAZ (2004). The Page model gave better prediction than the Henderson and Pabis model and satisfactorily described drying characteristics of carrot cubes. KERTÉSZ ET AL. (2015) confirmed this model also for carrot slices.

MATERIALS AND METHODS

The samples of carrots (*Daucus carota* L.) were procured from the local market. We used 50 slices for the measurement. Other samples: corn (*Zea mays* L.) grains hybrid, of CTF-8C, wheat (*Triticum aestivum* L.) grains variety, of Magister, Amaranth (*Amaranthus hypochondriacus* L. and *Amaranthus caudatus*L.) seeds we had from various departments of the Slovak University of Agriculture in Nitra. Samples were dried in cabinet dryer Venticell 111 (MMM group). Moisture analyser MAC 50NP (RADWAG) was also used for the drying of samples. The mass of samples was measured with a Sartorius Basic electronic analytical and precision balance (Sartorius AG). The moisture content of samples was determined according to standard by drying to constant mass. The moisture content wet basis was calculated from mass losses. Moisture ratio is defined as:

$$M_R = \frac{u - u_e}{u_0 - u_e} \qquad (1)$$

where: M_R is moisture ratio, u, u_0 and u_e are local, initial and equilibrium moisture contents, respectively. The values of equilibrium moisture content, u_e, are relatively low compared to u or u_0. Thus Eq. 1 is simplified (DOYMAZ, 2004) to:

$$M_R = \frac{u}{u_0} \qquad (2)$$

The electrical properties of samples were measured with precision LCR meter GoodWill 821(Good Will Instrument Co.) in frequency range from 100 Hz till 200 kHz, and also with precision LRC meters HP 4284A and 4285A (Keysight Technologies) at frequencies from 30 Hz to 30 MHz, at voltage of 1 V. Each electric property was measured at all frequencies three times. Average value and standard deviation has been computed from these ones. The measured values were loaded by PC.

RESULTS AND DISCUSSION

The moisture ratio versus time of drying curves for the carrot samples No 2, and 5 as influenced by temperature 50 °C are shown in Fig. 1.

Moisture ratio decreases with drying time, and after drying, moisture content (wb) ranged from about 7 % to 8 %. As we can see, the change in moisture ratio at the beginning of the drying period is significant, compared to the final stage of drying where very small changes in moisture ratio were reported. For approximation we used the exponential function:

$$M_R = M_{R0}\, e^{-c\tau} \qquad (3)$$

where: M_{R0} - reference value of moisture ratio, c - constant (s^{-1}).

In Tab. 1, the coefficients of regression equation Eq. (3) and coefficient of determination are presented. The values of the coefficient of determination also for other slices range from 0.9865 to 0.9983. Eq. 3 is in good agreement with Henderson and Pabis model. We can also use the Page's model which has been widely advocated for the thin-layer drying of solids under constant drying conditions. This model has produced good fits in predicting the drying of sweet potato, garlic, apricot, seedless grapes, and mint leaves (DOYMAZ, 2004). The samples of corn and wheat were dried in Moisture analyzer MAC to constant mass. For corn grains the drying time 120 min and for wheat grains 150 min was appropriate. The drying curves can be approximated by polynomial function:

$$m = a_0 + a_1\tau + a_2\tau^2 + a_3\tau^3 + a_4\tau^4 + a_5\tau^5 \qquad (4)$$

where: m – mass, a_i – coefficients of regression equation, τ – time.

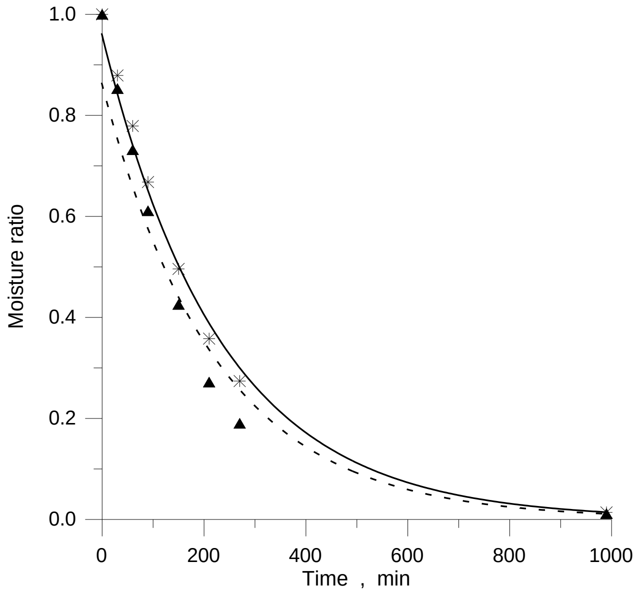

Fig. 1. – Drying time dependence of moisture ratio for carrot slices No 2 (△), 5 (∗)

Tab. 1. – Coefficients of regression equation Eq. (3) and coefficient of determination

Sample	M_{R0}	c (s^{-1})	R^2
Slice 2	0.8637	- 0.0045	0.9865
Slice 5	0.9611	- 0.0043	0.9983

The coefficient of regression equation Eq. (4) and coefficient of determination, which has high value, are in Tab. 2.

At the drying beginning, the change in mass is more notable as the end of drying. This fact is right also at lower moisture content as has carrot. We had used the fifth degree polynomial function as regression equation. For thin layer drying, Wang and Sing model can be used (KILIC, 2016), which is second degree polynomial function (quadratic function). But Eq. 4 for our samples has higher coefficient of determination. This may be due to the fact that the sample had a loose character.

Fig. 3 represents drying time dependency of the apparent moisture content for amaranth seeds. The drying temperature was (103 – 105) °C. Each hour after conditioning, samples were weighed and the moisture content was calculated.

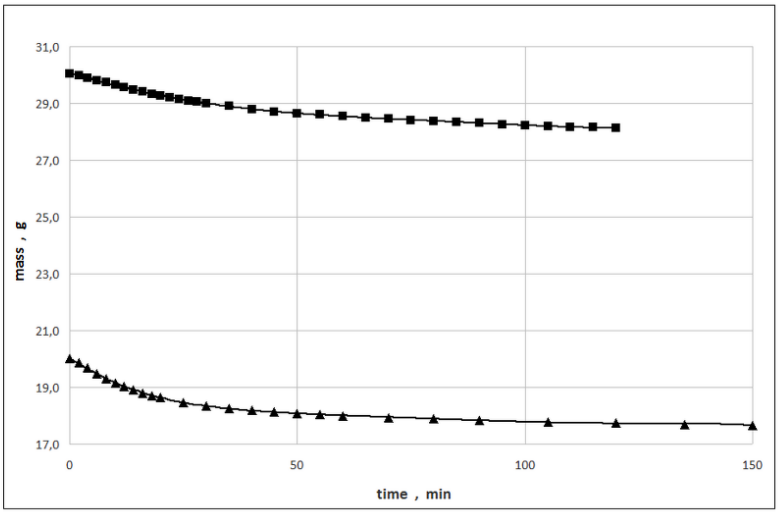

Fig. 2. – Time dependence of the sample mass, maize (CTF-8C) grains (■) and wheat (Magister) grains (▲)

Tab. 2. – Coefficients of regression equation Eq. (4) and coefficient of determination

Coef.	a_0 (g)	a_1 (g/min)	a_2 (g/min^2)	a_3 (g/min^3)	a_4 (g/min^4)	a_5 (g/min^5)	R^2
corn	30.067	- 0.0465	0.0003	4E-06	- 6E-08	2E-10	0.9996
wheat	20,043	- 0.11	0.0025	- 3E-05	2E-07	-4E-10	Higher

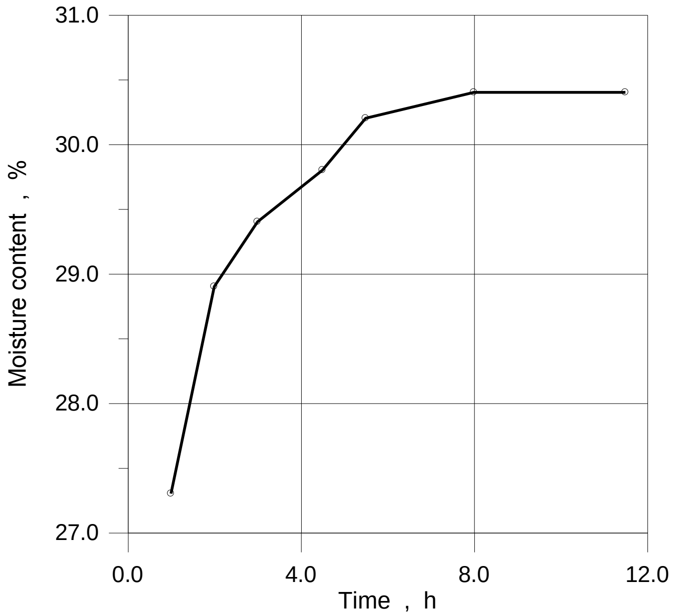

Fig. 3. – Drying time dependence of apparent moisture content (wb) for Amaranthushypochondriacus seeds (mass 10 g)

We can observe the changes in slope of the curve caused by different types of bound water evaporation. The stable (and thus correct) value of moisture content was reached after 8 hours. The standard for the amaranth seeds moisture content determination currently not exist, and according our measurement, we can recommend the required drying time, 8 hours.

Fig. 4 illustrates the frequency dependence of impedance for the sample of dried carrot slice No 16 after drying for 660 min, and 780 min.

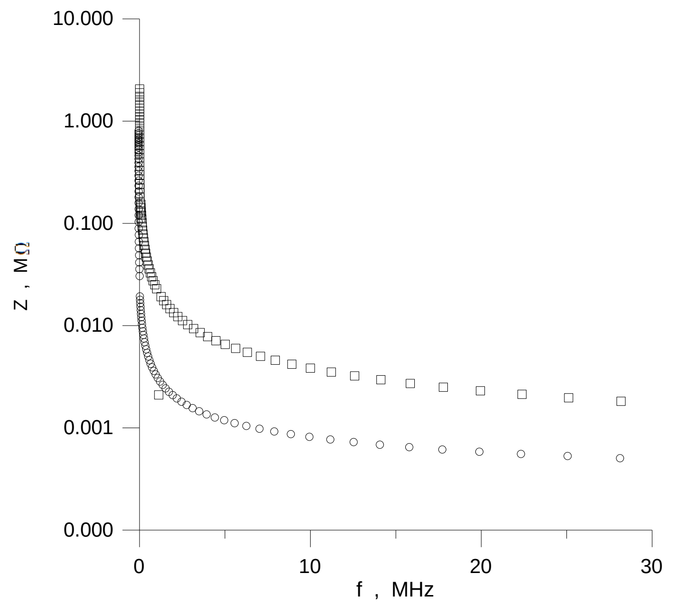

Fig. 4. – Frequency dependence of impedance for the sample of dried carrot slice No 16 (660 min - o, 780 min - □)

The following charts are described by power function

$$Z = Z_o \left(\frac{f}{f_o} \right)^{-k} \quad (5)$$

where: Z - impedance, Z_0 - reference value of impedance, f - frequency, f_o = 1 Hz, k – constant. Tab. 3 contains the coefficients of regression equation Eq. (7) and coefficients of determination.

Tab. 3. – Coefficients of regression equation Eq. (5) and coefficient of determination for slice No 16

Time of drying	Z_0 (MΩ)	k	R^2
660 min	300 000	- 0.926	0.9931
780 min	200 000	- 0.9056	0.9893

The impedance of the sample 16 is increasing with drying time because the moisture content of the sample decreases with drying time. In the final stage of drying, there can be recorded a very little change in the values of moisture content of samples (KERTÉSZ ET AL., 2015). The impedance of these samples at this stage does not differ greatly from each other, as shown on Fig. 4.

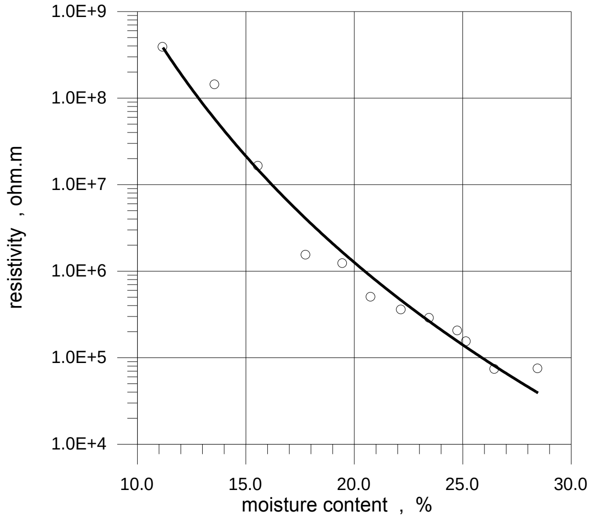

Fig. 5. – Moisture content dependency of resistivity for the sample of Amaranthuscaudatus at an average bulk density of 760.4 kg.m^{-3}

The resistivity decreases with moisture content, as is shown on Fig. 5. We can use once again the decreasing power function as the mathematical model to describe this dependence:

$$\rho = \rho_o \, \omega^{-d} \quad (6)$$

where: ρ - resistivity, ρ_o = 8.00329 .10^{18} Ω.m – resistivity at the reference moisture content, ω - moisture content wet basis, and d = 9.8411 – constant. Regression equation (6) has high coefficient of determinations R^2 = 0.969244. This regression equation was used also by VERMA ET AL. (2001) for the conductivity of Brassica species.

CONCLUSIONS

We found out the connection between drying characteristics (as are change in mass, moisture ratio, moisture content) and electrical properties. Most significant factor influencing electrical properties is the moisture content, and this is the reason why correlation between drying characteristic and electrical properties exists.

The results of the measurements are time dependencies of sample mass, moisture ratio, apparent moisture content. First two characteristics decrease with drying time, apparent moisture content increasing with the time. We found out that the impedance of the measured samples decreases with frequency according to power function in measured frequency range. The impedance of the samples is increasing with drying time because the moisture content of the samples decreases with drying time. The resistivity decreases with moisture content according to power function. The regression equations coefficients of determination reached high values for all measured quantities and materials.

Drying characteristics of various agricultural and food materials are different and are also influenced by growing region, growing season, and weather conditions; therefore, it becomes necessary to study drying characteristics of the specific product for design of proper and efficient drying conditions. We can conclude that the measured electrical properties are investigated to reveal the quality of food materials and quality of drying as well.

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Corresponding author:

Zuzana Hlaváčová, Department of Physics, Slovak University of Agriculture in Nitra, Slovakia