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DIELECTRIC MEASUREMENTS APPLICATIONS IN FOOD INDUSTRY
NITRATES AND NITRITES CONTENT DETERMINATION

BY

ADRIAN-GABRIEL FERARU[*] and ALEXANDRU-MIHNEA SPIRIDONICĂ

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Electrical Engineering, Energetics
and Applied Informatics

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Abstract. The relative complex permittivity, consisting of the dielectric constant and loss factor, were measured in the frequency range from 1 Hz to 1 GHz at temperatures ranging from 20° to 60°C. Experiments were conducted with a round plate capacitive sample holder. Values for the dielectric constant of carrot samples with different amounts of nitrates and nitrites are presented graphically. The potential for using the dielectric properties to sense quality factors – nitrates and nitrites content, is considered. Both the dielectric constant and loss factor show monotonic decreases in value as frequency increases. The dielectric constant increased with temperature at lower frequencies but decreased with temperature at higher frequencies. Loss factor generally increased with increasing temperature.

Key words: dielectric properties; agricultural products; conductivity; permittivity.

1. Introduction

Dielectrometry is widely used for non-invasive determination of material properties. Applications include agricultural products (Nelson, 2008),

[*] Corresponding author: *e-mail*: adyferaru@tuiasi.ro

food products (Mamishev *et al.*, 2002), paper, transformer board (Mamishev *et al.*, 2002), hydrophilic polymers, etc.

Dielectric properties (electrical characteristics) of Foods have been of interest for many years (Ciobanu *et al.*, 2010). One of the earliest applications of such electrical properties was the study of dc electrical resistance of grain for rapidly determining its moisture content. In later work with radio-frequency (RF) measurements, changes in the capacitance of sample-holding capacitors, when grain samples were introduced between the capacitor plates, were correlated with grain moisture content and used for grain moisture measurement. The subsequent development of electrical grain moisture meters has been described in earlier reviews (Nelson, 2008).

The principles governing the interaction between materials and RF and microwave electric fields, as influenced by the dielectric properties, have been detailed in a recent paper (Nelson, 2006). The same paper included a review of principles and techniques for dielectric properties measurements at frequencies ranging from audio frequencies through radio frequencies well into the microwave region.

The dielectric properties, or permittivity, of a material determine the interaction of that material with electric fields. Dielectric properties have been previously defined and discussed in detail from an electrical circuit viewpoint and in terms of electromagnetic field concepts (Nelson, 1973). For practical use, the dielectric properties of usual interest are the dielectric constant and the dielectric loss factor, the real and imaginary parts, respectively, of the relative complex permittivity, $e = e' - \mathrm{j}e'' = |e|\mathrm{e}^{-\mathrm{j}d}$ where δ is the loss angle of the dielectric. In what follows, “permittivity” is understood to represent the relative complex permittivity, *i.e.*, the permittivity relative to free space, or the absolute permittivity divided by the permittivity of free space, $e_0 = 8.854 \times 10^{-12}$ F/m. Often, the loss tangent, $\tan d = e''/e'$, or dissipation factor, is also used as a descriptive dielectric parameter, and sometimes the power factor ($\tan d / \sqrt{1+\tan^2 d}$) is used. The ac conductivity of the dielectric is $s = we_0 e'$, [S/m], where $w = 2pf$ is the angular frequency, [Hz]. The dielectric constant of a material is associated with the energy storage capability in the electric field into the material and the loss factor is associated with the energy dissipation, conversion of electric energy to heat energy into the material. In this paper e'' is interpreted to include the energy losses in the dielectric due to all operating dielectric relaxation mechanisms and ionic conduction.

While effects of individual food components have been investigated, it is not yet possible to predict the effect of the composition of the food on the dielectric properties. Literature reporting the dielectric properties of many foods collected at different temperatures and frequencies, is available (Kent, 1987). Calay *et al.* (1995) developed equations predicting dielectric properties as a function of salt, moisture, fat content, density, temperature, and frequency, for different food groups, including meats. Sun *et al*. created predictive equations for foods and a subset that included meats. For beef, turkey, and meat juice, dielectric properties have been measured from 5° to 65°C (To *et al*., 1974).

The aim of the present study was to explore the determination of nitrates and nitrites content and the frequency and temperature dependence of the dielectric properties of carrot.

2. Material and Method

The dielectric constant and loss factor were measured using a network analyser (Alpha-A, Novocontrol, Germany) interfaced with a computer. The dielectric properties were measured using a round plate capacitive sample holder, which is connected to an oil bath. The sample bored from the sample was cooled to measurement temperature by the jacketed sample holder (20°C). The first measurement was made when the temperature was stable. The oil bath was then increased to 10°C above the next temperature of measurement. When the sample reached the desired temperature the dielectric properties were measured, and the oil temperature was increased with another 10°C. This continued until the final temperature was reached (60°C). All reported measurements are at 1 Hz to 1 GHz and are presented in Figs. 1 and 2.

The response variables, dielectric constant, and loss factor, were fit by using multiple regression from combinations of temperature, moisture content, and wet basis ash. The fitting principle was least squares, which is the most appropriate method to employ when the data are expected to exhibit significant random errors (Calay *et al*., 1995). The models and all predictors included in the models had a significance < 0.001. Quality of fit was assessed from adjusted coefficient of determination (R^2_{adj}) of the equation. The data were analysed using WinDETA software (Novocontrol, Germany).

3. Results and Discussion

Because of the need for rapid nondestructive quality measurements for fresh fruits and vegetables, the dielectric properties of carrot samples were measured at 1 Hz to 1 GHz frequencies and 20° to 60°C. Models for calculating dielectric constants of many fruits and vegetables, moisture content, and bulk density have been reported (ASAE, 2000; Nelson, 1987; Kraszewski *et al*., 1989).

Measurements of the permittivities of samples in the frequency range from 1 Hz to 1 GHz, at temperatures ranging from 20° to 60°C, revealed dielectric constants decreasing. Dielectric loss factor decreased regularly when the frequency increased. The dielectric constant increased with temperature at lower frequencies but decreased with temperature at higher frequencies. Loss factor generally increased with increasing temperature.

Figs. 1 and 2 present the permittivity response of the carrot samples to frequency and temperature variations. As it can be observed, the presence of nitrates and nitrites in vegetables has a strong influence on the value of the dielectric constant and the shape of the graphics – the value of the dielectric constant, increases sharply with the increase of nitrates and nitrites amount from 2.2 mg to 7.4 mg.

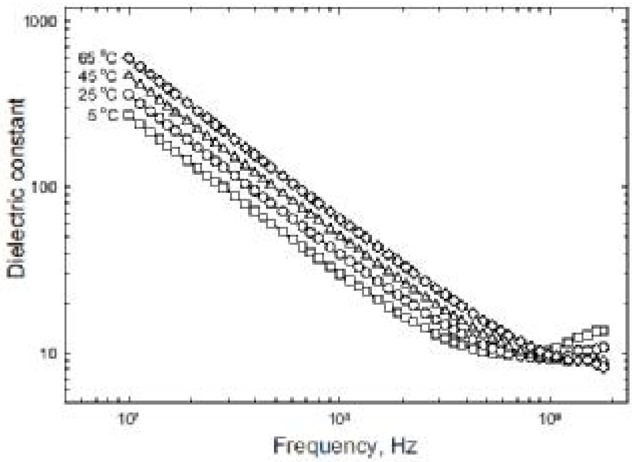

Fig. 1 – Frequency and temperature dependence of carrot permittivity – samples containing 2.2 mg of nitrates and nitrites.

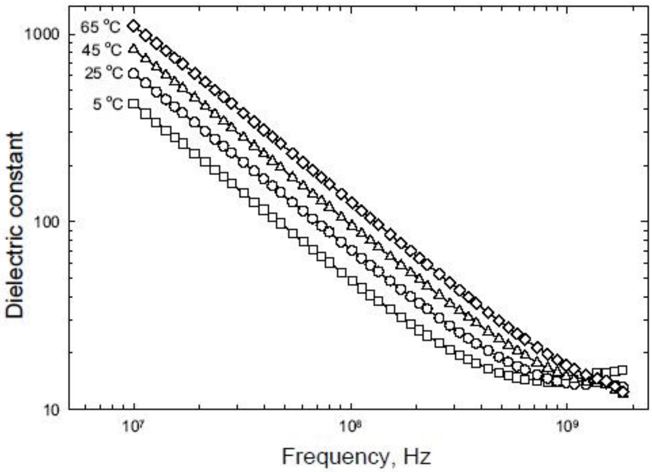

Fig. 2 – Frequency and temperature dependence of carrot permittivity – samples containing 7.4 mg of nitrates and nitrites.

The highest values of the dielectric constant at low frequencies are no doubt assigned to the contribution of the interfacial polarization and ionic conduction, while the behavior of the dielectric constant at high frequencies is assigned to the dipolar relaxation. For a higher amount of ionic compound, *e.g.*

a cumulative value of nitrates and nitrites concentration of 7.4 mg/kg, it was observed a significant influence of the polarization phenomena at low frequencies, and an increase of the permittivity at 10 Hz and 25°C, from 84 to 100; also the critical frequency increases from 0.95 MHz to 1.04 MHz.

4. Conclusions

The temperature and frequency dependence of the dielectric properties of fruits can be efficiently measured with an open-ended coaxial-line probe, network analyser, and suitable sample temperature control equipment. Both the dielectric constant and loss factor show monotonic decreases in value as frequency increases. The dielectric constant increased with temperature at lower frequencies but decreased with temperature at higher frequencies. Loss factor generally increased with increasing temperature.

The importance and usefulness of the dielectric properties of fruits and vegetables, namely carrot, are discussed briefly, pointing out their use in the rapid sensing and measurement of nitrates and nitrites content in fruits and vegetables and in governing the behavior of materials subjected to dielectric analysis. Sources of information concerning the dielectric properties of such products are provided, and values of the dielectric constants and loss factors are presented graphically for carrot samples. These examples provide information not only on typical values of the dielectric properties, but also on their dependence *vs*. such variables as frequency of the alternating fields applied and temperature.

The obtained curves are considered to be standard ones for the analysis of food quality. Other foods were analysed aiming the determination of standard curves. Altered food products were, also, analysed, and the obtained results were compared with the standard curves, for establishing the critical values in quality control for food products.

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APLICAŢIILE MĂSURĂTORILOR DIELECTRICE ÎN INDUSTRIA ALIMENTARĂ

(Rezumat)

Permitivitatea relativă complexă, compusă din constanta dielectrică şi factorul de pierdere, au fost măsurate la frecvenţe cuprinse între 1 Hz şi 1 GHz şi la temperaturi cuprinse între 20° şi 60°C. Măsurătorile au fost efectuate folosind o celulă cu un capacitor plăcuţă rotund. Valorile constantei dielectrice pentru probe de morcov cu diferite adaosuri de nitraţi şi nitriţi sunt prezentate grafic. A fost investigat potenţialul utilizării proprietăţilor dielectrice pentru analiza factorilor de calitate – conţinut de nitraţi şi nitriţi. Atât constanta dielectrică cât şi factorul de pierdere prezintă scăderi monotone odată cu creşterea frecvenţei. Constanta dielectrică a crescut odată cu creşterea temperaturii la frecvenţe scăzute dar a scăzut odată cu creşterea temperaturii la frecvenţe ridicate. Factorul de pierdere a crescut, în general, odată cu creşterea temperaturii.