ŻYWNOŚĆ. Nauka. Technologia. Jakość, 2022, 29, 1 (130), 78 – 87

DOI: 10.15193/zntj/2022/130/409

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NUMERICAL METHODS IN LOSS TANGENT OF HONEY - PROPERTIES ANALYSIS

Summary

Background. The quality assessments of food products often involve evaluating their electrical properties, including impedance, permittivity and dielectric loss factor. The measurements of food electrical characteristics provide an interesting alternative to time-consuming and expensive methods based on chemical parameter measurements. This report describes investigations into the effects of frequency on the electrical properties of honey. Specifically, honey electrical properties were tested under an electromagnetic field with frequency ranging from 1 kHz to 1 MHz.

Results and conclusion. Both experimental and numerical methods were used in this study. Double verification yielded identical results, which confirmed that the numerical method applied and the computational conditions were selected appropriately. The most important feature and the most significant advantage of the numerical approach is the possibility to predict the behavior of the actual object based on its mathematical model. It is much easier and faster to perform computer simulations than to perform the corresponding measurements under real-life conditions. Numerical simulations are also extremely useful when experiments are too dangerous to perform, i.e. when the electromagnetic field being studied can pose a threat to the health or life of a tested subject. The main drawbacks of computer simulations are the restraints of computing resources and the long duration of calculations.

Key words: food quality, dielectric properties measurements, intermediate method, calorimetric method, numerical methods

Introduction

The increasing use of electronic equipment and wireless telecommunication systems in almost all aspects of our lives has aroused the interest of society in electromagnetic field (EMF). The whole environment is intentionally or unintentionally exposed to EMFs. This exposure creates a risk which is currently the subject of studies in bioe-

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lectromagnetics experiments. Particularly important issues are biomedical studies exploring the effects of EMFs on humans [3, 5, 18, 23, 30, 37, 41].

EMFs are not neutral for plants and animals. Electromagnetic radiation may have multiple consequences. Animals, such as birds, bats, fish, are dependent on magnetic field, which they use for orientation [30, 34]. Other animals, like sharks and rays, are sensitive to electric fields, because they possess electric sense organs. The effects of field are of paramount importance to plants. It can, for example, cause changes in their metabolism [14]. Magnetic field of relatively low intensity can be effective in stimulating and initiating plant growth responses [22].

Since the effects of field on all objects is observed, its properties can be used in many areas of everyday life. One of them is agriculture, horticulture and the food industry. PEM is used to test the composition of food products, changes in the biological properties of seeds and moisture [20, 25].

The examples of using electrical parameters for the assessment of the properties of agricultural products can be found in state-of-the-art scientific reports. The impedance of frozen chicken meat was recognized as a useful parameter to assess the product quality [39]. An effective microstrip sensor was developed to monitor milk quality based on changes in a dielectric constant [1]. A dielectric constant and dielectric loss were pointed out as parameters applicable to distinguish pork fat from chicken and beef fat in gelatin [32]. An investigation into relationships between fat content and both a dielectric constant and a loss factor in cow's milk revealed that dielectric parameters depend on fat content. However, a dielectric constant is more accurate for fat content determination [33, 42].

It is well known that the primary tool for quantitative research is hands-on experimentation and measurements. Unfortunately, tests are not always possible due to the high complexity of studied objects, the lack of appropriate sensors or their inaccuracy. This is especially important to the measurement of EMF. It is worth mentioning that any physical quantity measurement (i.e. frequency) is performed with 10^{-10}% accuracy, whereas an error in creating a standard EMF equals 5% ÷ 10% [9, 15]. This affects the accuracy of test instruments, whose error may not exceeds the one of creating EMF. Furthermore, there is a question of whether such tests are ethical. Even though experiments examining the EMF effect on human body are acceptable when a person consents to them, they are still controversial. The same applies to the use of animals for this type of research. The above arguments show that bioelectromagnetic testing is a challenge and is often impossible to perform. In this case, mathematical models and computer programs based on numerical methods may be useful. These tools give us some insight on expected results. Similar results from different numerical methods can be considered exemplary and reliable.

The purpose of this study is to show the possibility of using numerical methods in the assessment of the electrical parameters of honey.

Ever-increasing advances in computer technology enabled many representatives of science and engineering to apply numerical methods to simulate physical phenomena. In electromagnetic studies numerical methods are used very often [10].

The most popular of the include [28]:

- the finite element method (FEM) [7, 12, 27, 31],
- the finite difference method (FDM) [2, 6, 35, 36],
- the moment method (MoM) [13, 16, 17].

The FDM and the MoM are simpler and easier to program than the FEM, but FEM is a more powerful and versatile numerical technique for handling problems involving complex geometries and inhomogeneous media [10].

Problem solution by using FEM involves the following four steps [10]:

- to discretize the solution examined area into a finite number of elements,
- to derive governing equations for a typical element,
- to assemble all elements in the solution region,
- to solve the system of equations obtained.

When using FEM, it is important to choose appropriate element sizes. Elements dividing the selected area must be smaller than the shortest wave that may occur.

Materials and methods

Materials

Honey samples harvested in 2011 between May and September, derived directly from beekeepers located in the Lower Silesia region (Poland), were used for this study. A total of 50 samples were analyzed in an experiment and 2 samples in numerical calculations. For the verification of honey types, a pollen analysis was accomplished in an accredited laboratory (Bee Products Quality Testing Laboratory in Puławy, Poland). Pollen analysis was conducted according to harmonized methods of melissopalynology, particularly according to the Polish Standard PN-A-77626. The honey samples were fresh, did not undergo any thermal treatment and were kept in proper storage conditions.

Methodology

A number of techniques for measuring dielectric properties have been developed in recent years [4, 8, 20, 24, 26, 38, 40]. Many of them is designed to determine a dielectric constant and a loss tangent. In the analyzed case, two methods were used: intermediate and calorimetric ones.

The intermediate method is based on the measurements of capacitance and resistance of a sample placed in a capacitor, followed by calculating the dielectric loss factor, permittivity, on the basis of obtained electromagnetic field frequency and the geometry of the measuring capacitor [20].

In the calorimetric method a tangent loss was calculated as a ratio of active power lost (dissipated) in the form of thermal energy during the flow of current through a loss capacitor and reactive power in electric field in the same time [38].

For the measurements of honey impedance the impedance analyzer ATLAS 0441 HIA was used. The impedance analyzer was connected to a copper cylindrical electrode system. The frequency range was set as 10 – 10^6 Hz, measurement voltage was set as 100 mV. The impedance was represented in a complex form:

$$Z = ReZ + j \cdot ImZ \tag{1}$$

where: Z – complex impedance, ReZ – the real part of impedance, ImZ – the imaginary part of impedance.

Based on impedance values, two dielectric parameters, namely relative permittivity ε (-) and a dielectric loss coefficient tgδ (-) were calculated using the following equations:

$$\mathrm{tg}\delta = \frac{ReZ}{ImZ} \tag{2}$$

The FEM was used for loss tangent calculations by calorimetric method. An analysis was made for cylindrical capacitor (Fig. 1).

The capacitance of the cylindrical capacitor is determined using the following formula:

$$C = \frac{2\pi\varepsilon l}{\ln\left(\frac{R_2}{R_1}\right)} \tag{3}$$

where: ε – permittivity, $\varepsilon = \varepsilon_0\varepsilon_r$; ε_0 – vacuum permittivity, $\varepsilon_0 = 8{,}854 \cdot 10^{-12}$ [F/m]; ε_r – relative permittivity; R_2, R_1, l – geometrical dimensions shown in Fig. 1a.

Resistance of the substrate follows:

$$R = \frac{\rho}{2\pi l} ln\left(\frac{R_2}{R_1}\right) \tag{4}$$

where: ρ – electrical resistivity [Wm]

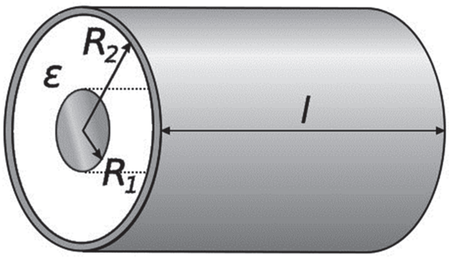
Current flowing through the capacitor has two components: active (I_A) and reactive (I_R) [38, 40]:

$$I_A = \frac{U}{R} \tag{5}$$

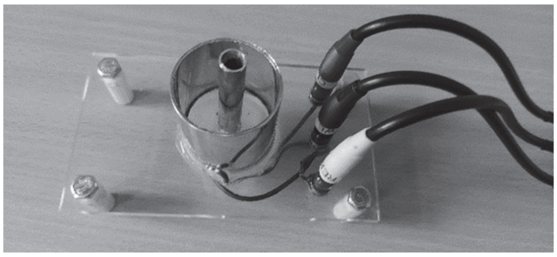
$$I_R = \frac{U}{X_C} \tag{6}$$

where: U – voltage [V]; X_C – capacitive reactance.

a)



b)



c)

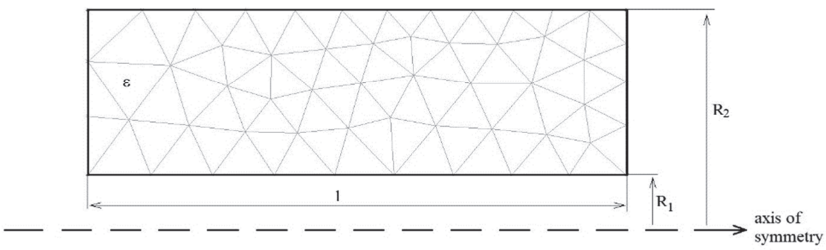


Figure 1. Cylindrical capacitor as exposure system: a) model, b) real object c) model with a mesh made with FEM

Rysunek 1. Układ ekspozycyjny w postaci kondensatora cylindrycznego: a) model, b) rzeczywisty obiekt, c) model z siatką wykonany przy użyciu metody FEM

Capacitive reactance is calculated using the following equation:

$$X_C = \frac{1}{2\pi f C} \tag{7}$$

where: f – frequency [Hz]

When active and reactive currents (5) (6) are known, then active power (P_A) and reactive power (P_R) are determined using the following formulas:

$$P_A = UI_A \tag{8}$$

$$P_R = UI_R \tag{9}$$

Now loss tangent is calculated as follows:

$$tg\delta = \frac{P_A}{P_R} \tag{10}$$

Results and discussion

Dielectric spectroscopy is a technique of measuring the electric and dielectric properties of a material as a function of the frequency domain. The dielectric properties of material are the effect of the interaction of external electric field with electrical dipole moment and the charges of the medium [33]. The behavior of certain material in external electric field is unique due to a unique molecular structure. In external electric field, electrical charges in material are polarized. Each dielectric mechanism (ionic, dipolar, atomic and electronic one) has limited frequency. For lower frequencies ionic relaxation is observed. One of the dielectric parameters used for the quality assessment of food based on dielectric spectroscopy is a relative dielectric loss coefficient [19]. The results of experiments and numerical calculations of tgδ for rape and honeydew honey are shown in Figs. 2 and 3 respectively.

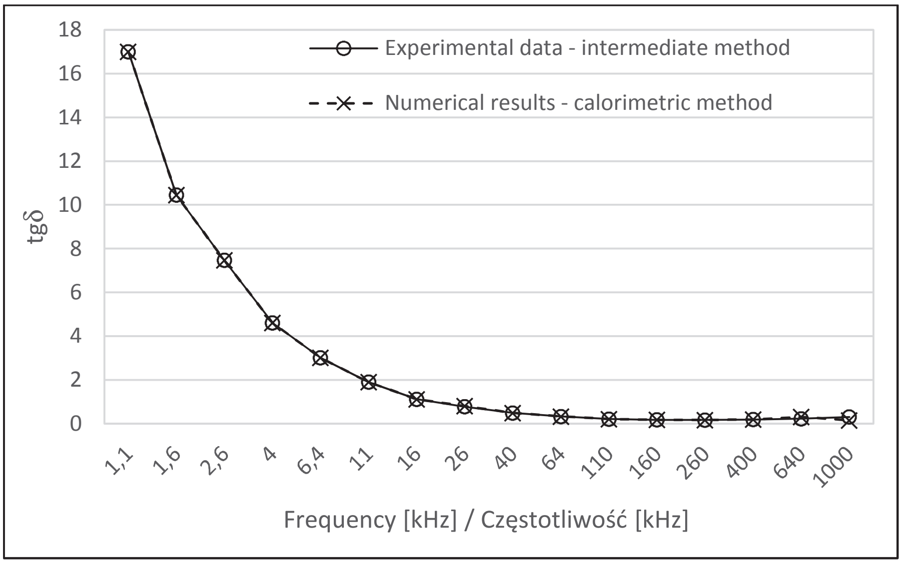


Figure 2. The frequency dependence of the relative dielectric loss coefficient for rape honey at a temperature of 20 °C
Rysunek 2. Zmiany współczynnika strat dielektrycznych dla miodu rzepakowego w funkcji częstotliwości w temperaturze 20 °C

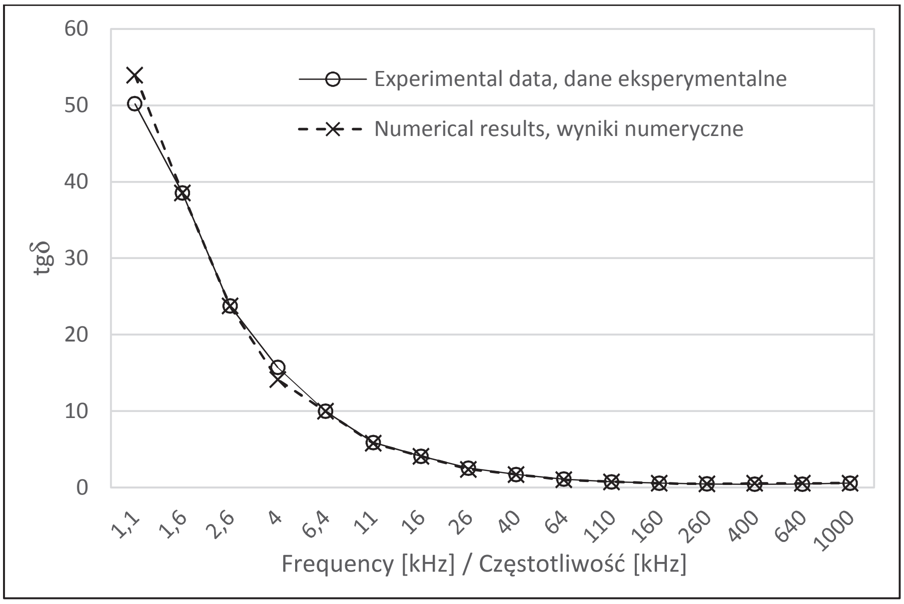


Figure 3. The frequency dependence of the relative dielectric loss coefficient for honeydew honey at a temperature of 20 °C
Rysunek 3. Zmiany współczynnika strat dielektrycznych dla miodu spadziowego iglastego w funkcji częstotliwości w temperaturze 20 °C

As is shown in Figs. 2 and 3, the values of relative dielectric loss coefficient decrease when frequency increases. The relationship between tgδ and frequency depends on the honey type. It is noteworthy that the results obtained by the numerical method and the experiment are convergent. The verification of the numerical method by the experiment enables the use of computer simulations in research and allows the obtained results as reliable. If we additionally notice that the numerical calculations use a different method (the calorimetric method) to calculate dielectric parameters than the experiment (the intermediate method), then we have conviction bordering on certainty that the obtained results are correct. Thus in many places it is possible to replace time-consuming and costly experiments with numeric methods.

Conclusions

1. The most important feature and the biggest advantage of computer simulations is their ability to predict the behavior of the actual object based on its mathematical model[5]. It is much easier and faster to perform computer simulations, rather than perform measurements in real life conditions. Computer simulations are also extremely useful when experiments are too dangerous to perform, i.e.: when the re-

searched EMF can pose a threat to the health or life of tested objects. The major drawbacks of computer simulations are restraints of computing resources and long duration of calculations.

2. Computer simulations are used where analytical techniques cannot provide accurate solutions or experiments cannot be done. But if double verification gives identical results, it means that the numerical method and the conditions for carrying out calculations have been correctly selected - as it is shown in this paper.
3. A certain limitation of the method is the fact that the electrical properties of honey depend significantly on the chemical composition, including the pollen content. These dependencies are not yet well understood. Therefore, their determination requires further research into the different types of honeys obtained in different seasons.
4. The authors want to clearly state that the presented research and results are exploratory.

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METODY NUMERYCZNE W ANALIZIE TANGENSA STRAT DIELEKTRYCZNYCH MIODU – ANALIZA WŁAŚCIWOŚCI

S t r e s z c z e n i e

Wprowadzenie. Właściwości elektryczne żywności, takie jak impedancja, przenikalność elektryczna i współczynnik strat dielektrycznych, są obecnie często wykorzystywane do oceny jej jakości. Pomiar elektrycznych cech żywności może być bardzo ciekawą alternatywą dla czasochłonnych i kosztownych metod opartych na pomiarach parametrów chemicznych. W niniejszej pracy zbadano wpływ częstotliwości na właściwości elektryczne miodu. Przeprowadzono badania cech elektrycznych miodu w polu elektromagnetycznym w zakresie od 1 kHz do 1 MHz. Wykorzystano do tego metody eksperymentalne i numeryczne. Podwójna weryfikacja dała identyczne wyniki, co oznacza, że metody numeryczne i warunki przeprowadzenia obliczeń zostały dobrane poprawnie.

Wyniki i wnioski. Najważniejszą cechą i zaletą metod numerycznych jest przewidywanie zachowania się obiektu rzeczywistego na podstawie jego modelu matematycznego. Znacznie prościej i szybciej można przeprowadzić symulację komputerową, niż wykonać pomiary w warunkach rzeczywistych. Poza tym pomiary takie mogą być niemożliwe do wykonania, ponieważ – m.in. w przypadku wpływu pola elektromagnetycznego na badany obiekt (żywność, obiekt biologiczny) – eksperyment może być niebezpieczny dla zdrowia lub życia badanego obiektu. Jednak poważną wadą symulacji komputerowych są ograniczenia związane z zasobami komputerów i długim czasem trwania obliczeń.

Słowa kluczowe: miód, metody numeryczne, współczynnik start dielektrycznych, metoda pośrednia, metoda kalorymetryczna