Complex Permittivity of Biological Materials Measurement at Microwave Frequencies

D. Faktorová

Department of Electromagnetic and Biomedical Engineering, Faculty of Electrical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic
Email: faktor@fel.uniza.sk

Abstract. *The paper deals with complex permittivity measurement of biological materials. The used methods are presented and their appropriateness for particular materials is given. The achieved results are given in graphs and also similarities in courses of particular materials as well as anomalies are discussed.*

Keywords: dielectric constant, microwave measurement, Hippel´s method, Poley´s method

1. Introduction

Penetration of electromagnetic energy into various bodies is given by their properties, and also by frequency and other characteristics of the incident wave. Such regulated penetration is core essential for using VHF in biology and medicine. The phenomena observed at VHF effect have essentially temperature character and basically depend on dielectric constant and conductivity.

The methods used at the study of dielectric properties of living tissue as well as attained results are in many relations the same as at ordinary usual matters. E. g. the dielectric constant of blood at great content of water is characterized by water properties. From this point of view dielectric properties of various biological materials are find increasing application namely in research laboratories. In the last 10 – 15 years the concept of permittivity measurement has been extended and applied to various bioresourses problems. The results showed a wide variation in dielectric behaviour due to differences in chemical composition, physical state, and temperature. In our paper we will describe the used methods, measurement equipments, and measurement results.

2. Measurement Methods

There is a great variety of experimental techniques by which dielectric measurement can be carried out. The particular method used depends on the frequency range of interest, the type of target material, amount and form of the available material. For our present needs we differed the methods in three categories based on dielectric losses: method for low-loss materials, method for medium-loss materials, method for high-loss materials.

For low-loss and medium-loss materials we used classic Hippel´s method in the same arrangement. The formulae for dielectric permittivity ε´ and loss tangent tgδ were derived from transmission line theory based on measurement the phase and amplitude of a reflected microwave signal from a sample of material placed against the end of the short-circuited waveguide.

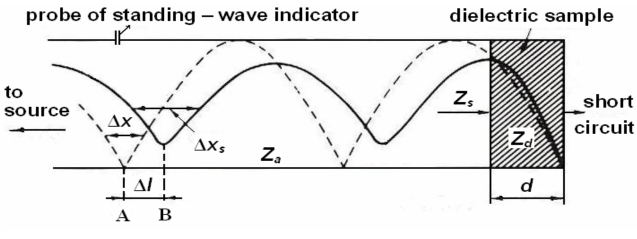

Fig. 1.Hippel´s method and “minimum shift method”

For the complex impedance $\dot{Z}_S$ we have, Fig. 1, [1]

$$\dot{Z}_s = \dot{Z}_d \,\mathrm{tgh}\dot{\gamma}_d \,, \tag{1}$$

where γ_d ($\gamma_d = \alpha_d + \mathrm{j}\beta_d$) is the propagation constant in sample, α_d is the loss factor and β_d is the phase constant. Since air is effectively loss free, $\alpha_{air} = 0$, we can write

$$\frac{1}{\mathrm{j}\beta_{air} l} \frac{\dot{Z}_s}{Z_{air}} = \frac{\mathrm{tgh}\dot{\gamma}_d\, l}{\dot{\gamma}_d\, l} \,. \tag{2}$$

The values of the left side this equation can be obtained from measurement. For solution (2) a chart for the $\frac{\mathrm{tgh}T\mathrm{e}^{\mathrm{j}\tau}}{T\mathrm{e}^{\mathrm{j}\tau}}$ was prepared. From this chart T and τ can be obtained. After finding them the propagation constant γ_d, is determined. Having it, ε′ and tgδ for the material may be derived from the following relations π

$$\varepsilon' = \frac{\left(\frac{2\pi}{\lambda_c}\right)^2 + \beta_d^2 - \alpha_d^2}{\left(\frac{2\pi}{\lambda}\right)}, \qquad \mathrm{tg}\delta = \frac{2\alpha_d \beta_d}{\left(\frac{2\pi}{\lambda_c}\right)^2 + \beta_d^2 - \alpha_d^2}, \tag{3}$$

where λ_c is the critical wavelength for the used waveguide and λ is the wavelength in free space. At this method it is difficult precise measurement of the length of the high-loss liquid. For this purpose we have adapted the short-circuit in the shape of a shallow small bowl. This enabled us to define the length more precisely.

To overcome the difficulty the phase measurement of high-loss liquid dielectrics, [3] Poley has developed a technique which involves only the measurement of the standing wave ratio s as a function of the length d of the liquid column, Fig. 2.

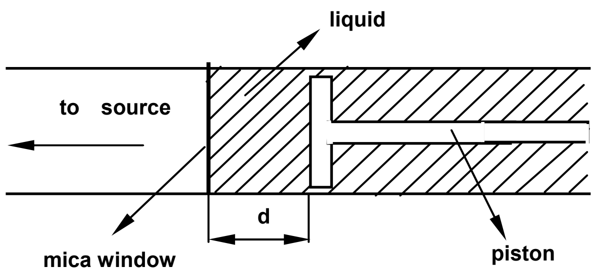

Fig. 2 Poley´s method for liquids

The test specimen is contained in a liquid-tight section of waveguide terminated by a short circuited piston which is driven by a micrometer head. Standing wave ratios is plotted as a function of d. The obtained curve exhibits a series of maxima and minima and tends to a limiting value s_∞. The spacing between the minima of the curve is constant and equal to λ_{gd} (λ_{gd} is the wavelength in the specimen placed in the waveguide). Let s_m and s_n be the values of s for the m-th and n-th maxima respectively; then

$$\frac{s_m}{s_n} = \frac{\operatorname{tgh}\left(m\pi \operatorname{tg}\frac{\Delta}{2} \right)}{\operatorname{tgh}\left(n\pi \operatorname{tg}\frac{\Delta}{2} \right)}, \qquad \frac{s_m}{s_n} = \operatorname{tgh}\left(m\pi \operatorname{tg}\frac{\Delta}{2} \right). \tag{4}$$

By means of $\frac{s_n}{s_\infty}$ (from the curve) we can obtain the value for the $\operatorname{tg}\frac{\Delta}{2}$ (it may be shown that $\operatorname{tg}\frac{\Delta}{2} = \frac{\alpha_d}{\beta_d}$, [2]). $\frac{\lambda_{\mathrm{gd}}}{2}$ and $\operatorname{tg}\frac{\Delta}{2}$ being known, we have for the complex permittivity of the liquid

$$\varepsilon' = \left(\frac{\lambda}{\lambda_{\mathrm{c}}} \right)^2 + \left(\frac{\lambda}{\lambda_{gd}} \right)^2 \left(1 - \operatorname{tg}^2 \frac{\Delta}{2} \right), \qquad \operatorname{tg}\delta = \frac{2\left(\frac{\lambda}{\lambda_{gd}} \right)^2 \operatorname{tg}\frac{\Delta}{2}}{\varepsilon'} \tag{5}$$

3. Experimental Results

The measuring methods were used in the standard laboratory arrangement at frequency 10GHz, Fig. 3 but we modified Hippel´s method by the short circuit as mentioned above and at the Poley´s method the waveguide with the piston was placed in a vertical position without the mica window to avoid the influence of mica on measurement. For other materials was used the “minimum shift method.”

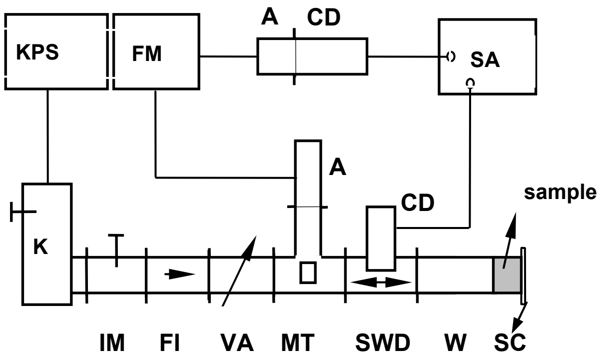

Fig. 3 Experimental set-up for complex dielectric constant measurement. K – klystron, KPS – klystron power supply, FM – frequency meter, SA – selective amplifier, IM – impedance match, FI – ferrite isolator, VA – variable attenuator, MT – magic T, SWD – slotted section, W – waveguide, SC – short circuit, A – adapter, CD – crystal detector

In Fig. 4 and Fig. 5 different dependences of ε´ and tgδ can be seen. The course of cow butter shows a reverse slope around 60ºC for tgδ in similar way as cow butter and pig fat around 40ºC.

These behaviors can be explained with regard to possible anomal dispersion just in this area. In this connection the existence of the inflection point for ε´ of pig fat in the same temperature region may be of interest. Pig fat was chosen for its similarity to the human fat and the plant oils (olive oil, sunflower oil) were taken for comparison.

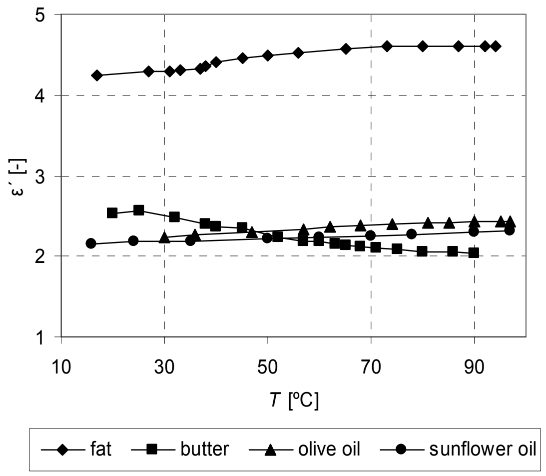

Fig. 4 Thermal dependence of dielectric constant ε´ for fat, butter, olive oil and sunflower oil

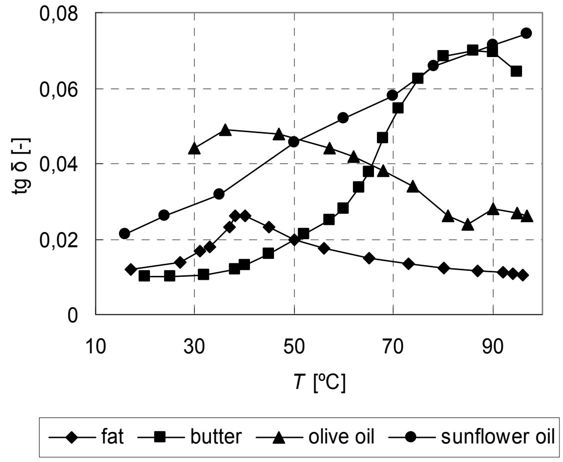

Fig. 5 Thermal dependence of loss tangent tgδ for pig fat cow butter, olive oil and sunflower oil

4. Conclusions

Our measurements were directed either right on biological materials like pig fat, cow butter, olive oil and sunflower. The choice of suitable method for complex permittivity measurement is important and we have given the report about some of them.

In view of the fact that microwave investigation it is mostly a case of interaction with surface layers containing a great percentage of water it will be necessary to pay attention also in future to investigation of mineral solution in water especially in the sphere of anomalous dispersion as we have measured with fat. Because at microwave therapy [3], [4] there always a necessary heating occurs, thermal dependences will create an unavoidable part of information for practical applications.

Acknowledgements

The authors would like to thank MSc. Pavol Žirko director of High School for Agriculture and Fishing in Mošovce for technical help at realization of experiments.

References

[1] Wang Y., Asfar M., N.: Measurement of complex permittivity of liquids using waveguide techniques. *Progress in electromagnetics research, PIER 42,* 2003, 131-142.

[2] Jaspard F., Nadi M.: Dielectric properties of blood an investigation of temperature dependence. *Physiological measurement*. 2002, 23, 547-554.

[3] Vrba J.: Microwave applicators for medical applications, imaging and thermotherapy treatment. *Microwave review*, 2005, 43-46.

[4] Baker/Javis J., Vanzura E., Kissik W.: Improved technique for determining complex permittivity with the transmission/reflection method. *IEEE Transactions on microwave theory and techniques*, 1990, 38, 1096-1103.