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DIELECTRIC PERMITTIVITY AND LOSS FACTOR OF TAP WATER AT 915 MHz

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ABSTRACT: *Real and imaginary parts of complex dielectric permittivity of hot tap water are measured at 915 MHz. The obtained results are compared with theoretical and experimental data available in the literature.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 42: 419–420, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20322

Key words: *dielectric constant; experimental measurements; microwave processing*

1. INTRODUCTION

Dielectric properties of various media are among the most important factors that influence the accuracy of mathematical modelling of microwave systems. In computer-aided design (CAD) of microwave applicators, for example, it is necessary to know accurate values of dielectric permittivity (ε') and loss factor (ε'') of materials. These parameters, in general, depend on temperature and frequency. Simultaneous application of high-frequency electromagnetic (EM) fields and hot circulating water is a new technology, which was recently proposed for microwave sterilization of food at 915 MHz [1]. Such a combined approach improves the uniformity of microwave treatment for packaged food. For a more accurate modelling of physical processes in those specially designed microwave applicators, one should know the dielectric properties of hot tap water at 915 MHz.

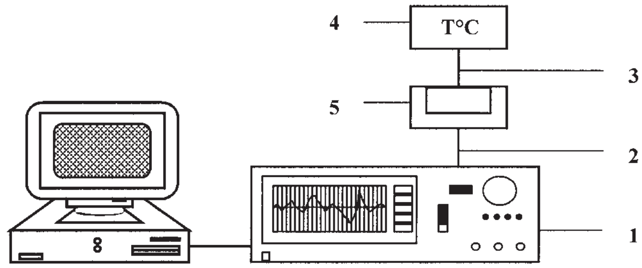

Figure 1 Schematic diagram of the experimental setup: (1) impedance analyzer; (2) coaxial cable; (3) thermocouple; (4) measurement cell; (5) thermometer

Complex dielectric permittivity of distilled water at 3 GHz was measured for the first time in [2] over a temperature range between 1.5°C and 95°C. Subsequently, $\varepsilon'(T)$ and $\varepsilon''(T)$ of pure water have been measured at 1.74 GHz [3] and 2.45 GHz [4, 5]. The presence of salts and other chemical substances in tap water may change both ε' and ε''. A universal mathematical model, which is valid for temperatures between 0°C and 40°C with water salt content between 0% and 3.5%, has been developed and tested in [6] for tap water at industrial scientific medical (ISM) frequencies 2.45 GHz and 915 MHz. Also, in [7] both parameters $\varepsilon'(T)$ and $\varepsilon''(T)$ were measured at 915 MHz for $20 \leq T°C \leq 60$. In microwave sterilization processing, packaged food products are exposed to sterilization temperatures $T = 121°C–125°C$ for several minutes. Data of complex dielectric constant of tap water for temperature range $40 \leq T°C \leq 121$ at 915 MHz are not available in the literature. The objective of this study was to determine dielectric properties of tap water at 915 MHz between 40°C and 121°C.

2. EXPERIMENTAL TECHNIQUE

The measurement system utilized in this work included an Agilent impedance/dielectric properties analyser, a customer-built measurement cell, a thermometer, and a personal computer with corresponding software and coaxial cables (Fig. 1). The measurement technique was based on a well-known open-end coaxial-probe method. A more detailed description of this experimental setup can be found in [8]. Some characteristics of fresh tap-water samples used in this work are given in Table 1.

3. RESULTS OF MEASUREMENTS

Theoretical and experimental data of $\varepsilon'(T)$ and $\varepsilon''(T)$ for tap water at 915 MHz are represented in Figure 2. As can be seen from this figure, $\varepsilon'_m(T)$ of tap water at 915 MHz and 2.45 GHz almost completely coincide when $20 \leq T°C \leq 70$. Also, $\varepsilon'_e(T) < \varepsilon'_m(T) < \varepsilon'_t(T)$, where $\varepsilon'_m(T)$ is the dependence measured in the present work (given that the results are the mean of three replicates, with standard deviation not exceeding 1%); $\varepsilon'_e(T)$ is the experimentally obtained dependence from [7]; $\varepsilon'_t(T)$ is the theoretical model proposed in [6]. For $\varepsilon''_m(T)$, the situation is vice versa: $\varepsilon''_t(T) < \varepsilon''_m(T) < \varepsilon''_e(T)$. Extrapolation of $\varepsilon'_m(T)$ and

TABLE 1 Properties of Tap Water (Pullman, WA)

Conductivity (μS/cm)	Hardness (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Sodium (mg/L)	Iron (mg/L)
304–350	116–268	0.6–2.6	≤28	23.4 ~ 48.7	0.2–1

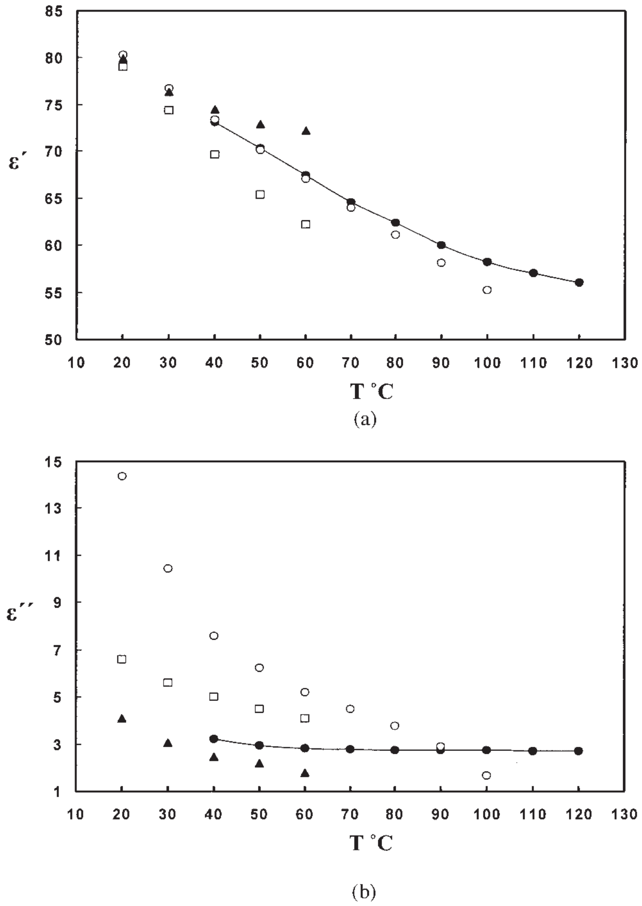

Figure 2 (a) Dielectric permittivity and (b) loss factor of tap water at ISM frequencies: ●–●–●–● experimental data obtained in the present work at 915 MHz; ○○○○○ mathematical model [5] for water at 2.45 GHz; ▲▲▲▲▲ mathematical model [6] for tap water at 915 MHz; □□□□□□ experimental results [7] for tap water at 915 MHz

$\varepsilon''_m(T)$ for $20 \leq T°\mathrm{C} \leq 40$ has shown a good agreement with $\varepsilon'_r(T)$ and $\varepsilon''_r(T)$. The loss factor $\varepsilon''_m(T)$ is very weakly dependent upon temperature when $T > 60°\mathrm{C}$. Both functions $\varepsilon'_m(T)$ and $\varepsilon''_m(T)$ may be approximated by analytical expressions obtained in this work by means of the least-square method and polynomial interpolation, respectively given by

$$\varepsilon'_m(T) = -16.308 \cdot \ln(T) + 133.75, \quad R^2 = 0.996, \tag{1}$$

$$\varepsilon''_m(T) = -3.68 \cdot 10^{-6}\, T^3 + 1.03 \cdot 10^{-3} \cdot T^2 - 0.0947 \cdot T + 5.6, \quad R^2 = 0.989 \tag{2}$$

where R^2 is the regression coefficient. The obtained equations have been employed in the finite-difference time-domain (FDTD) model developed with the help of commercial code QuickWave-3D (www.qwed.com.pl). The FDTD model was intended for simulation of EM fields and S-parameters in a pilot scaled microwave sterilization applicator on a rectangular waveguide with operating frequency 915 MHz. The reflection-coefficient value predicted when using this model, $S_{11} = 0.329$ for the case when the applicator is filled with tap water ($T = 121°\mathrm{C}$) and two food samples (whey protein gel) are used, agrees well with experimental one of $S_{11} = 0.379$.

4. CONCLUSION

An open-end coaxial-probe method has been used for measuring the complex dielectric permittivity of tap water as a function of temperature ($40 \leq T°\mathrm{C} \leq 120$) at 915 MHz. The obtained experimental data have been implemented in the CAD of new microwave technology for high-temperature processing of food.

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IMPROVEMENT OF THE EXTINCTION RATIO OF A MACH–ZEHNDER INTERFEROMETER FILTER

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ABSTRACT: *A novel structure of a Mach–Zehnder interferometer filter is proposed and demonstrated. The interferometer is structured by adding an optical isolator to the two outputs of the conventional Mach–Zehnder interferometer. The characteristic of the transmission spectrum is studied theoretically and experimentally. The extinction ratio of the novel interferometer filter is improved greatly in comparison with that of a conventional Mach–Zehnder interferometer filter with the same parameters.* © 2004 Wiley Periodicals, Inc. Microwave Opt Technol Lett 42: 420–422, 2004; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20323

Key words: *extinction ratio; Mach–Zehnder interferometer; optical isolator; filter; WDM*

1. INTRODUCTION

Since the transmission spectrum of a Mach–Zehnder interferometer filter is characterized by a series of equally spaced transmission peaks in the wavelength domain, it has important applications in optical-fiber WDM systems and optical sensing. These applica-