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Dielectric characterization of alcoholic beverages and solutions of ethanol in water under microwave radiation in the 1–20 GHz range

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ABSTRACT

We measured the dielectric permittivity of several solutions of ethyl alcohol in water and observed that their spectra follow the Debye model. The parameters used to adjust the Debye model according to the alcohol concentration in a solution follow a linear law. We tested the resulting model with various alcoholic beverages and found that we can obtain the concentration of alcoholic solutions using our model.

1. Introduction

In recent years, there has been increasing interest in the properties of food when it is subjected to electromagnetic radiation in the microwave range. This is due to the increasing use of microwave radiation for preparing, cooking, thawing and packaging food. In addition, microwave spectroscopy is an interesting and powerful technique for characterizing food and some of its components in a non-destructive way. There is extensive literature on both areas. Many papers describe studies of microwave use in characterizing the quality of various foods (Herve, Tang, Luedecke, & Feng, 1998; Martinsen, Grimmes, & Mirtaheri, 2000; Nunes, Bohigas, & Tejada, 2006), including measurements of salt content (Kent & Anderson, 1996; Shiinoki, Motouri, & Ito, 1998), and the added water content of processed meat (Kent, Knöckel, Daschner, & Berger, 2001). Microwave spectroscopy has also been reported to be a useful technique for determining the sugar content of yogurt (Bohigas, Amigó, & Tejada, 2008), water activity (Clerjon, Daudin, & Damez, 2003), moisture and salt content of butter (Shiinoki et al., 1998) and the concentration of acetic acid in vinegar (Bohigas & Tejada, 2009).

The aim of our work was to study the dielectric properties of solutions of ethyl alcohol in water and to develop a model of the parameters that determine the behaviour of dielectric permittivity according to the ethyl alcohol content in the solution. To test our model, we analysed various alcoholic beverages. We found that our model could be used to determine the alcohol content of drinks.

2. Experimental

2.1. Experimental equipment

We measured the electrical permittivity of various alcoholic solutions and alcoholic beverages with a coaxial probe Agilent 85070C and a Hewlett Packard 8510C analyzer controlled by a computer.

First, the samples were placed in a 100 ml beaker, into which the coaxial probe was introduced. Special care was taken to fix all of the equipment to avoid any vibrations that could affect the quality of measurements.

For each sample, the spectrum was measured within a frequency range of 1–20 GHz in 121 steps. Before each measurement, the equipment was calibrated with the probe in air, deionised water and the short circuit mode. Special care was taken to eliminate bubbles from the probe's surface, as these could alter the experimental data. All measurements were performed in a temperature range of 22–24 °C.

2.2. Samples studied

We prepared solutions of ethyl alcohol in water using varying concentrations of ethanol of up to 40%. The ethyl alcohol was from a commercial laboratory.

The alcoholic beverages were commercial products purchased from a local supermarket. The drinks were not manipulated before the experimental analysis was performed under microwave radiation. The products that we studied are listed in Table 1. They

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Table 1
List of products.

Brand	Type of product	Alcoholic degree (%)
EROSKI	White	11
EROSKI	Rose	11
EROSKI	Red	11
Valdespino	Sweet sherry	15
Liquorino	Peach liqueur	17
Coronita	Beer	4.6
Yzaguirre	Vermouth	15
Nelson	Brandy	36
Voll DAMM	Beer	7.2
Free DAMM	Beer	0
Xibeca DAMM	Beer	4.6
Bock DAMM	Beer	5.4

included various beers, different types of wine (white, rose and red), sherry, vermouth, brandy and peach liqueur.

Three of the wines were cheap Eroski own-brand products, which could be considered low quality. We wanted to start our study by analyzing products as similar to pure solutions of ethyl alcohol and water as possible. Hence, we chose low-quality wines as we considered that higher-quality wines were likely to have a more complex composition. This is also the reason for our choice of a low-quality brandy that is normally used for cooking.

We prepared solutions that contained alcoholic beverages of more than 10% in water. Valdespino and Yzaguirre Liquorino solutions were prepared from 50% in water. We prepared two solutions of Nelson brandy with 50% and 25% of brandy in water. The aim of preparing these solutions was to find out whether the behaviour of the fitting parameters was a law that was similar to our model, regardless of whether the results for each product were consistent with our model.

2.3. Theoretical background

The response of a material to electromagnetic radiation is related to its dielectric permittivity, which can be written as $\varepsilon = \varepsilon' - j\varepsilon''$, where ε' is the real part, ε'' is the imaginary part and $j = \sqrt{-1}$ is the complex unit. The permittivity generally depends on the frequency at which the sample is radiated. For polar species, it fits the Debye model quite well, which is expressed as:

$$\varepsilon'(\omega) = \varepsilon'_\infty + \frac{\varepsilon'_s - \varepsilon'_\infty}{1 + \omega^2\tau^2} \quad (1)$$

and

$$\varepsilon''(\omega) = \frac{(\varepsilon''_s - \varepsilon'_\infty)\cdot\omega\tau}{1 + \omega^2\tau^2} \quad (2)$$

where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space; $\omega = 2\pi f$ where f is the frequency; $\tau = 1/2\pi f_R$ where f_R is the relaxa-

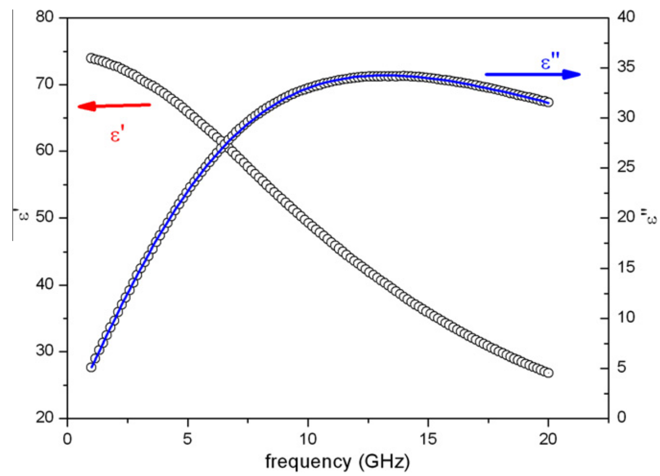

Fig. 2. Dielectric permittivity of a solution of 10% ethyl alcohol in water (dots) and the corresponding fit using the Debye model (line).

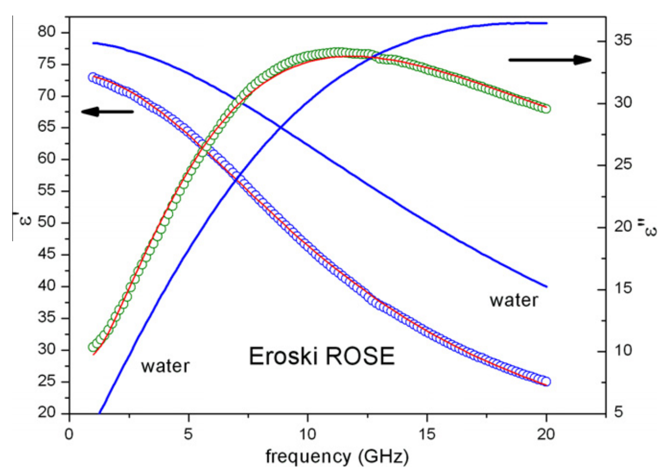

Fig. 3. Experimental data (dots) and fitting (line) corresponding to the permittivity of an Eroski rose wine.

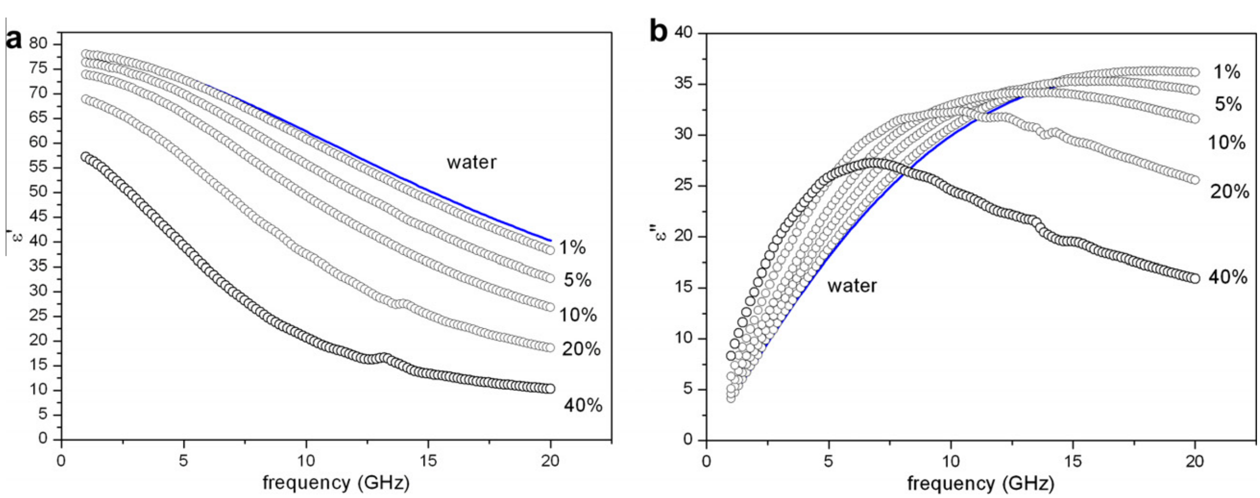

Fig. 1. Electric permittivity spectra: (a) real part and (b) imaginary part of ethyl alcohol solutions in water. The spectrum of water is presented as a reference.