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Electromagnetic characterization of cola drinks

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ABSTRACT

The electromagnetic characterization of liquids could be of great interest to manufacturing companies, as it could provide information about the quality of beverages. They could use this knowledge to optimize production processes. Using the probe reflection system, dielectric properties of different varieties of Coca-Cola and Pepsi products in cans have been examined. Measurements have been performed at several temperatures between 0 and 60 degrees Celsius and at periods after opening of 0, 6, 24 and 48 h. The applied frequency range goes from 0 to 20 GHz in steps of 200 Hz. Both experimental and theoretical approaches have been used to model the results. Although all varieties follow the same trend, the results clearly show that differences exist in the electromagnetic behavior of the two brands and of the different varieties.

1. Introduction

In our more and more globalized societies, several beverage brands act as world market producers. Coca-Cola and Pepsi exemplify such a kind of companies, which extend their competence from a local market to all around the world. Part of their market strategies focus on their specific features that make the difference: for example habitual consumers are able to detect various flavors, and so they decide their preferences. This paper shows that these differences also appear at electromagnetic level. Developing a large and precise measurement campaign provides a set of values for dielectric properties characterizing various types of cola sodas. The obtained results allow the identification of cola beverages, but they could also lead to detecting faults along the processing stage.

This work aims to gain insight in the electromagnetic characterization of colas. This knowledge can be useful for a lot of companies to support their production process. Thus, they can detect flaws before the liquids leave the company and thereby reducing the loss of revenue. The main focus in this work is colas from the Coca-Cola and Pepsi brands, where different varieties of each one are compared. A theoretical and experimental approach is used, based on the measurements of the complex permittivity of the above mentioned beverages between 200 MHz and 20 GHz.

As there already exist several ways to measure the dielectric properties of liquids, depending on the required information and the available equipment [1], the first task was to decide which method to apply. This work uses the probe reflection system because of its broad spectrum coverage and its simplicity when taking a large number of samples, as explained along the second section.

Working with liquids imposes some difficulties, especially in the case of colas, or carbonated drinks in general. A key step for such samples is the cleaning of the probe. It should be perfectly cleaned after every measurement to avoid interference. Also a small period of time is required after pouring a drink to mitigate the effect of the foam caused by the gas bubbles, which could affect the actual electromagnetic characteristics of the liquid.

This work focuses on cola beverages from Coca-Cola and Pepsi brands. These have been chosen because they are widely known. We included a wide variety of types (regular, light, zero, caffeine free and lemon) so that we can get a clear image about the properties of certain ingredients (like sugar and caffeine). All liquids have been measured at several temperatures in the range from 0 to 60 degrees Celsius. They were measured at opening and after 6, 24 and 48 h, in a frequency range between 200 MHz and 20 GHz. Results will be discussed at first instance with a graphical representation of ϵ', where we observe a monotonically decreasing trend as frequency increases, in all considered situations. The behaviors of ϵ'' are similar, but monotonically increasing, and are hence not reported in this paper except for showing an example of such a trend.

After this introduction, the paper is organized into five sections. Section 2 in general is about measuring liquids, whereas Section 3 is devoted to the experimental work: the measurements

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performed to gather data. In Section 4, the theoretical approaches are described, i.e. the way the data is analyzed in order to compare the different beverage trends. Results and their analysis occupy Sections 5 and 6 contains the conclusions we have extracted from the work.

2. Measuring the electromagnetic characteristics of liquids: procedures and methods

Measuring electromagnetic characteristics in liquids has been a recurrent topic in research for many years [1]. A good way to get some insight into liquid characteristics is to measure their dielectric properties. This gives us an idea about what happens to the electromagnetic energy (i.e. electromagnetic wave) propagating through the liquid. When a wave reaches a certain liquid, part of its energy is reflected, part is absorbed and a third part is transmitted through the liquid. These three mechanisms can be represented by the permittivity, expressed as a complex value in F/m. In all media (solid, liquid, and gaseous) different from the vacuum, this permittivity reaches values larger than 1, is usually expressed relative to the value of the permittivity of vacuum [2] and is dimensionless. The resulting relative permittivity ϵ^* can be given as the following complex value:

$$\epsilon^* = \epsilon' - j\epsilon'' \quad (1)$$

where ϵ' governs the energy storage and ϵ'' the dielectric loss factor.

In general, the methods proposed for permittivity measurements are the slotted line reflection system, the guided wave transmission system, the free space transmission, the filled cavity resonance, the partially filled cavity resonance and the probe reflection [3]. Not all of them are suited for measuring liquids, only those listed in Table 1. We have chosen the probe reflection procedure because it works with a broad frequency spectrum being at the same time easy to use.

The coaxial probe method is basically a modification of the transmission line method, where a tip senses the signal reflected by the material. To perform a measurement the tip is brought into contact with the flat surface of a solid or immersed in a liquid. The method is quite easy to use, it is possible to measure the dielectric properties over a wide range of frequencies (500 MHz–110 GHz), and its accuracy is enough for our purpose of observing a trend in soda properties. There has been a number of variations of the basic coaxial-line probe, for example, elliptically ended and with a conical point [1,4–9].

3. Experimental procedure

3.1. Setup

We used a Dielectric Assessment Kit (DAK) [10] connected to a Vector Network Analyzer (VNA) Keysight N5222A [11] and a computer with the required processing software for performing the measurements. Fig. 1 depicts the probe, which immersive length reaches 50 mm. The DAK-3.5 probe presents a 19 mm flange diameter, PC-3.5 coaxial connector and 50 Ω impedance. That probe has been used for all measurements, keeping a stable and common setup along the complete experiment time. It is an open ended coaxial probe with the ability to measure liquids, in a frequency range from 200 MHz to 20 GHz. Its operation temperature goes from 0 to 60 °C. Because the probe is made of stainless steel, it is resistant to corrosive materials, and therefore suitable for measuring carbonated drinks without deterioration.

3.2. Description of the study

As the measurement campaign involved a large number of experiment conditions and cola varieties, a strict protocol was defined to assure that all measurements were made under the same conditions.

The first step in the measurements was the calibration of the equipment, by using regular water at 20 °C as the reference medium. Then, the different liquids under study were measured at different temperatures at the time of opening, beginning near 0 °C and then every 5 °C until 30 °C was reached. After that, two additional measurements were made, namely at 40 °C and 60 °C. Different periods after opening were also considered: the liquids were measured at opening and again after 6, 24 and 48 h, all of them at 10 °C and 20 °C. Between every measurement event, the probe was cleaned to avoid error due to interference of different substances. Although the DAK system could measure additional parameters, the campaign gathered ϵ' and ϵ'' at different frequencies. Different charts throughout this paper represent ϵ' at different frequencies, temperatures and times since opening. A graph showing the differences among some measurements has also been set out, to clearly highlight the frequencies at which the differences are more remarkable. We have also added a plot with the average of all measurements to establish a better comparison among different soda varieties.

3.3. Considered varieties and commercial identification of the brands

From all possible cola brands, Coca-Cola and Pepsi have been chosen for their wide variety of subtypes and also because they are commercialized all over the world. Besides regular varieties also colas with reduced and no sugar were examined, trying to test the influence of the sweetener in the beverage. Also the influences of caffeine and lemon were investigated. Table 2 shows all examined subtypes.

4. Mathematical approach

To gain some insight in the measurements, coefficients of the polynomial regression model are calculated with Matlab software, approaching the evolution of the real part of the permittivity as a function of the frequency. First, both the frequencies and corresponding values are imported into Matlab vectors. Then we have used the Matlab polyfit function to generate the coefficients that are finally exported to an Excel file. The general equation of the regression is given by:

$$\epsilon' = \alpha + \sum_{i=1}^{n} \beta_i * f^i \quad (2)$$

where α is a constant factor, n indicates the order of the polynomial and β_i is the constant that multiplies the i^{th}-power of the frequency

Table 1
Electromagnetic measurement methods on liquids.

Method	Frequency range	Accuracy for low loss material	Accuracy for high loss material	Measured parameter (μ or/and ϵ)
Probe reflection	Broad band	Low	High	Permittivity
Slotted line reflection	Broad band	Very low	Low	Permittivity
Filled cavity resonance	Single	High	Low	Permittivity or permeability