Solid State Science and Technology, Vol. 19, No2 (2011) 99-106
ISSN 0128-7389

EFFECT OF DRYING TIME AND EVAPORATED MOISTURE ON THE DIELECTRIC BEHAVIOR OF GINGER AT 0.2 TO 20 GHz

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ABSTRACT

Dielectric properties of ginger (Zingerber officinale Ross) were measured at 0.2 to 20 GHz and at temperature 26°C, using the HP-85070B open-ended coaxial line probe (OECP) coupled with a computer controlled software automated network analyzer (ANA). The dielectric constant for all samples was found to decrease with frequency. However, the dielectric loss factor decreased initially and started to increase at 2.45 GHz until 20 GHz following the trend of the dielectric properties of deionized water. The penetration depth was affected by evaporated moisture at the lower frequency region.

Keywords: ginger; lower frequency; dielectric properties;

INTRODUCTION

Ginger which is one of the members of Zingiberaceae is a rhizome of Zingiber officinale Roscoe plant. It is a native plant of Asia but widely cultivated in numerous parts of the world including the West Indies, Jamaica and Africa [1]. It has many uses especially in Chinese medicine; it is used to treat rheumatism, nervous diseases, toothache and many more [2]. However, in Asia, especially in Thailand and Malaysia, it is used as a spice or flavouring agent in drinks or dishes [1].

Ginger has many uses including in medicine, thus the demand for it become greater. The technique to extract the essential oil of ginger with shortened extraction time, low cost, enabling automation and reduction in organic solvent consumption was required and the microwave extraction technique fulfills this characterization [3-4]. It is able to overcome the disadvantages using conventional technique because microwave has the ability to penetrate into food materials and cause volumetric heating. The dipole-dipole interaction (friction among polar molecules) and ionic conduction are two mechanisms that are involved in producing this heat [5]. Besides, microwave has many uses such as in dehydration, blanching, thawing, pasteurizing and sterilizing of food [6].

The dielectric properties of food materials are very important as it is the key governing factors in microwave processes such as the microwave penetration into the food, local power absorption rates and heating performance. Interaction between the food products and the microwave applied depends on the frequency used and it is clearly determined by the dielectric properties of the food (dielectric constant, ε', and dielectric loss factor, ε'', with $\varepsilon^* = \varepsilon' - j\varepsilon''$) [5]. The dielectric constant (ε') is a measure of the ability of a material to couple with microwave energy and the dielectric loss factor (ε'') is a measure of the ability of the material to heat by absorbing energy [7]. The power absorption of food is proportional to the loss factor ($P_v = 2\pi f \varepsilon'' \varepsilon_0 E^2$, where f is the frequency, ε_o is the permittivity of free space, E is the electric field) [8], and the penetration depth of microwave energy into foodstuff reduces if the loss factor is higher [9].

Dielectric properties of several foods have been measured in previous works as a function of frequency, temperature and moisture content. For example, dielectric properties of garlic at 2450 MHz as function of temperature and moisture content [9], dielectric behavior of apple at different moisture contents [5], 10-1800 MHz dielectric properties of fresh apples during storage [10], effect of osmotic dehydration on the dielectric properties of carrots and strawberries [11], dielectric properties of fruits and insect pests as related to radio frequency and microwave treatments [12], dielectric spectroscopy of osmotic solutions and osmotically dehydrated tomato products [13] and others.

The objective of this study is to measure the dielectric constant and dielectric loss factor of ginger at various levels of moisture content when dried at different times. The combination of open-ended coaxial line probe with computer controlled software automated network analyzer was used as it were a fast and precise measurement where no sample preparation is needed and the same sample can be used since it is a non-destructive measurement technique [14].

EXPERIMENTAL METHODS

Sample preparation

Fresh ginger which was bought from the wet market was stored at 4°C in a refrigerator to maintain the freshness. Their skin was removed and cut into 7 slices (30 mm thickness) where each slice was about 20 ± 0.001 g. To obtain different moisture content, all slices of ginger was put into the oven at different drying times (1 h to 7 h) where the temperature of the oven was fixed at 70°C. The ginger was placed in a desiccator containing silica gels for 10 minutes to cool down the temperature to 26°C and to ensure uniform moisture content before weighing its dry weight using an electronic balance (± 0.001 g).

Dielectric properties measurement

After drying at a selected time (1 h to 7 h), the ginger was cooled down in a desiccator and the evaporated moisture was calculated. The dielectric properties of ginger were measured using the HP 85070B open-ended coaxial line probe (OECP) coupled with a computer controlled software automated network analyzer (ANA) at frequencies 0.2 to 20 GHz. The instrument was firstly calibrated using three different loads: (i) air, (ii) metallic short block and (iii) distilled water at room temperature (26°C). After calibration, the measurement of the dielectric properties of ginger was taken. All the measurements were conducted by placing the flat face of the open-ended probe on the surface of the sample.

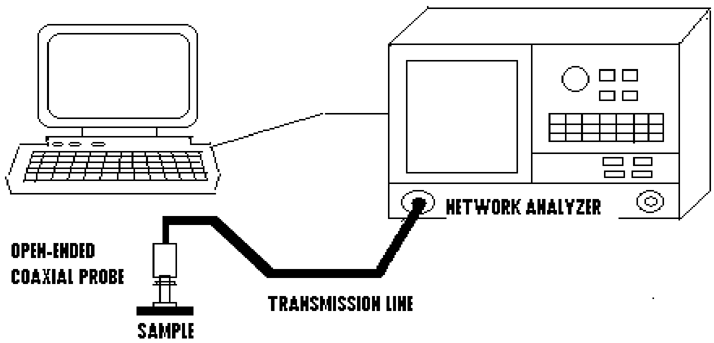

Figure 1: Schematic diagram of the dielectric measurement equipment

Measurements were taken at least three times for each sample in order to avoid erroneous values caused by the presence of air gaps. The probe and sample should have good contact during the measurements.

RESULTS AND DISCUSSION

The evaporated moisture (EM) of ginger as a function of drying time is shown in Figure 2. The change in the evaporated moisture was found to be linear with drying time and is represented by the following equation:

$$EM = A_1 T + B_1 \tag{1}$$

where A is 0.0833 and B is 0.021. The value of R^2 is 0.99 which implies that the evaporated moisture increases linearly with drying time.

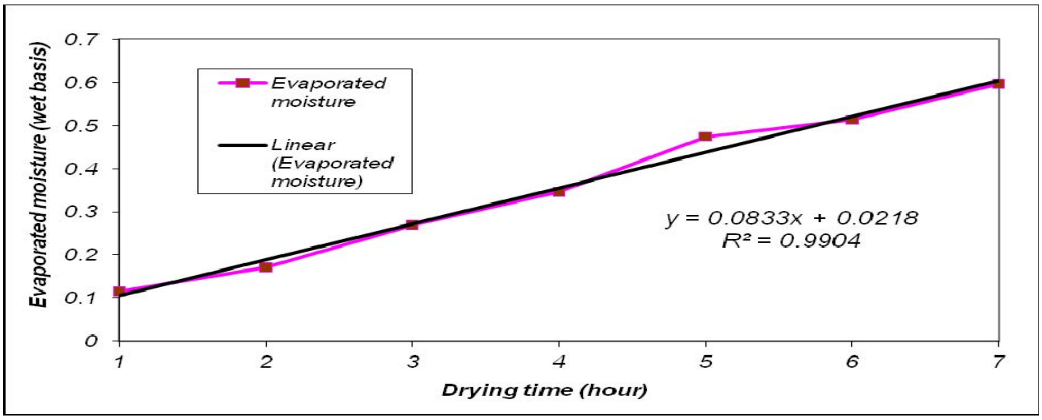

Figure 2: Evaporated moisture of ginger at various drying times

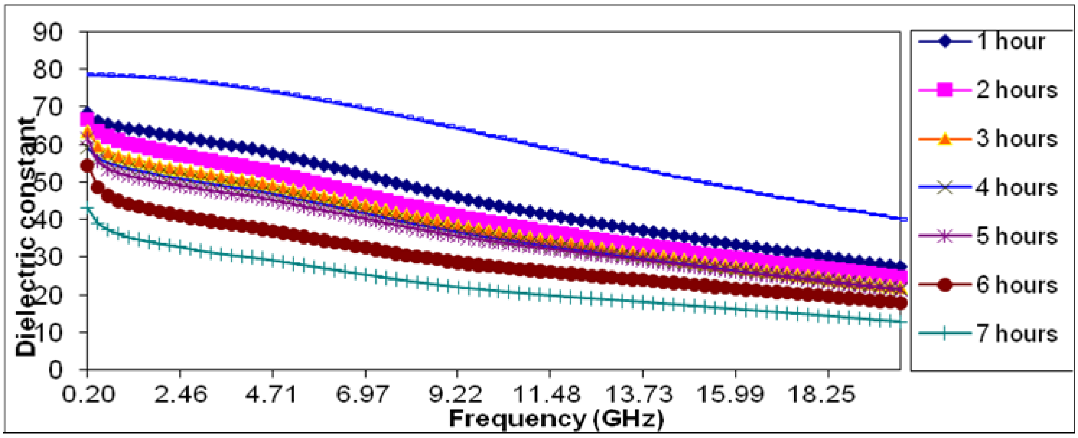

Figure 3: Dielectric constant of ginger as a function of frequency with respect to the drying times

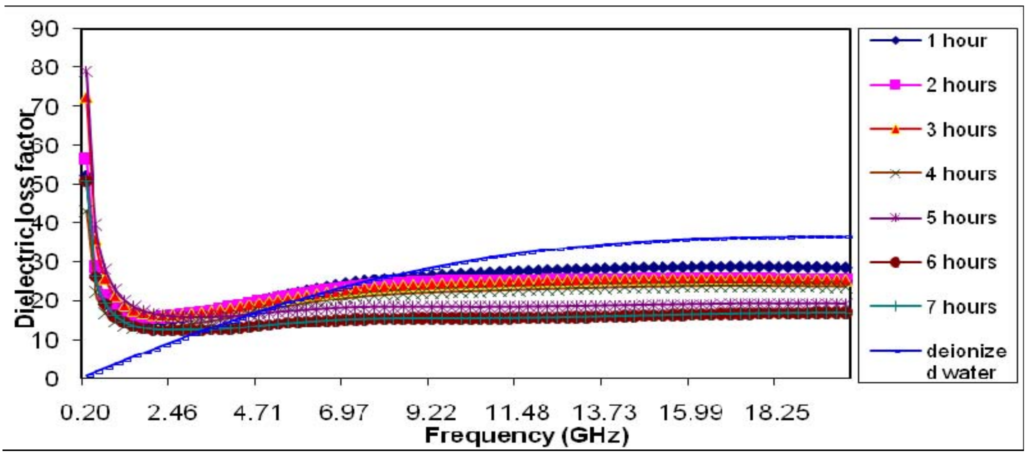

Figure 4: Dielectric loss factor of ginger as a function of frequency with respect to the drying times

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The dielectric constant (ε') of ginger as a function of frequency at various drying times is shown in Figure 3. The values of ε' decreases for all samples. As the water is the main contributor to the dielectric constant in ginger and other food materials [12], the value of ε' for water is higher than other samples followed by the ginger with one hour drying time and so on. As expected, ε' of ginger which was dried for 7 hours has the lowest value because it has the lowest moisture content.

The loss factor (ε") of ginger as a function of frequency at various drying times is shown in Figure 4. Initially, ε" for all samples decreases and started to increase at 2.45 GHz and above following the trend of the dielectric properties of deionized water. The sudden decrease in the loss factor of the entire samples at low frequencies (<2.45 GHz) indicate the existence of ionic species and the increase at frequencies above 2.45 GHz is due to dipolar polarization. Below 2.45 GHz, the losses are mainly by due to the presences of salt and mineral in the sample or ionic losses. However, above 2.45 GHz the losses are dominated by the dipolar losses due to the orientation of the water molecules [7,9].

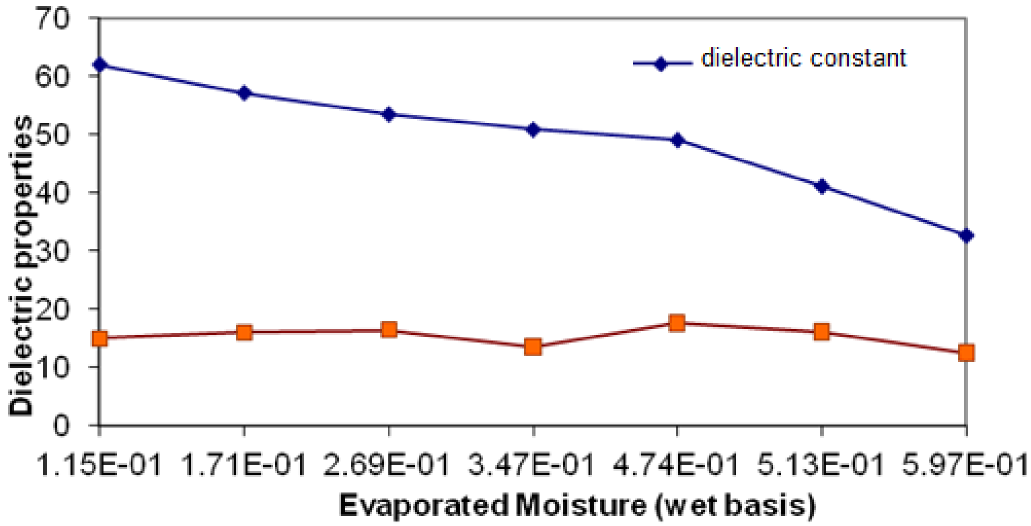

Figure 5: Dielectric properties of ginger as a function of evaporated moisture at 2.45 GHz

The effect of evaporated moisture on the dielectric properties of ginger at 2.45 GHz is shown in Figure 5. The dielectric constant decreases with increasing evaporated moisture and the dielectric loss factor is almost constant. The decrease in the dielectric constant is because there are less free water molecules to be polarized. The almost constant of dielectric loss factor is maybe because the frequency is the transition frequency between ionic polarization and dipole polarization and is not dominated by either one of them [15].

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Penetration depth

The distance where the microwave power decreases to $1/e$ of its surface value is known as the penetration depth, D_p. This is an important parameter in characterizing microwave heating. It can be calculated by the following equation [5]:

$$D_p = \frac{\lambda_o}{2\pi(\varepsilon')^{0.5}}\left[\left\{1+\left(\varepsilon''/\varepsilon'\right)^2\right\}^{0.5}-1\right]^{-0.5} \quad (2)$$

where λ_o is tabulated in Table 1 and it depends on the frequency used [16]:

Table 1: Values of wavelength at 2.45, 10 and 18 GHz.

Frequency (GHz)	Wavelength (cm)
2.45	12.237
10	3.000
18	1.670

The effect of penetration depth on the evaporated moisture of ginger is presented in Figure 6 and the effect of penetration depth with frequency at different drying times is shown in Figure 7.

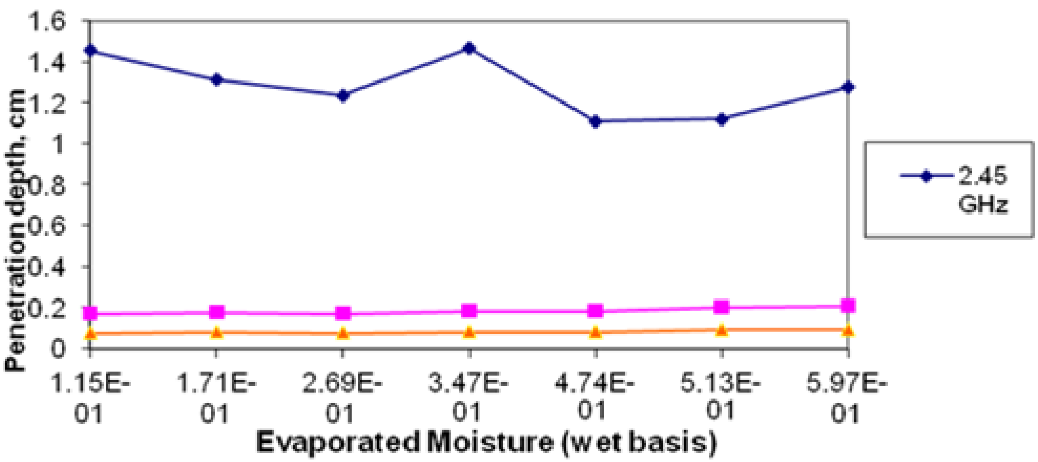

Figure 6: Power penetration depth for ginger as a function of evaporated moisture at 2.45, 10 and 18 GHz

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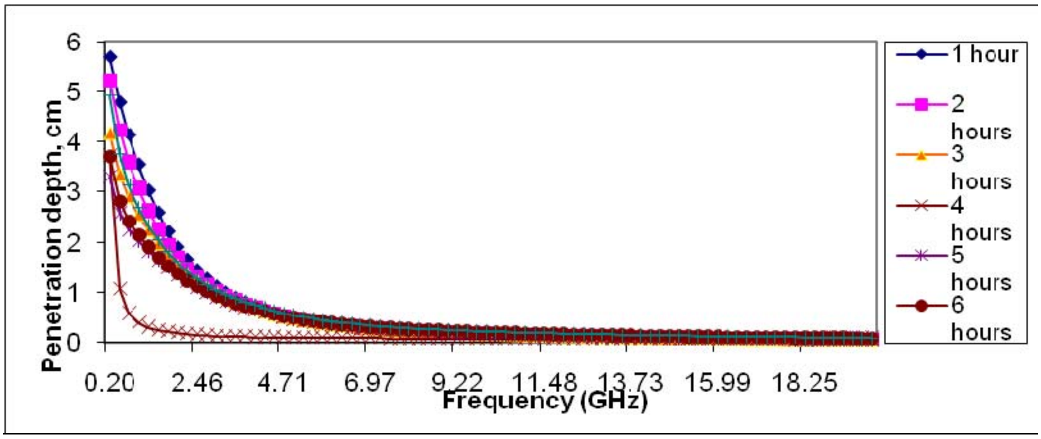

Figure 7: Power penetration depth for ginger as a function of frequency with respect to the drying times

The penetration depth is independent of moisture at 10 GHz and above. However, it is affected by the moisture in the low frequency region (<10 GHz). The penetration depth is larger at low frequency so a suitable frequency in microwave heating should be in the lower frequency region as the increase in penetration depth will increase the uniformity in microwave heating [17].

CONCLUSION

The dielectric constant decreases with increasing frequency following the trend of the dielectric properties of deionized water. Below 2.45 GHz, the dielectric loss factor decreases rapidly due to ionic losses, while above 2.45 GHz, it approaches a constant value due to dipolar losses. The penetration depth is affected by the evaporated moisture in the lower frequency region.

ACKNOWLEDGEMENT

The authors thank Universiti Putra Malaysia for the financial support through the Graduate Research Fellowship.

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