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Frequency Dependence of Dielectric Properties of Four Cultivars of Apple at Microwave Frequencies

Ravika Vijay[1*], Ritu Jain[2], Krishna Swaroop Sharma[3]

[1*,2,3]Departmeny of physics, The IIS University, Jaipur, Rajasthan, India.

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Abstract

The dielectric constant (ε') and loss factor (ε'') of fresh apple of four cultivars, (i) Red delicious apple (ii) Delicious Apple, (iii) Granny Smith apple and (iv) Fuji apple, are measured at room temperature (28 °C) and at four microwave frequencies 3.43 GHz, 7.31 GHz, 9.30 GHz and 14.70 GHz by two point method using microwave benches at C, J, X and Ku bands. It has been observed that the dielectric constant of all the four cultivars decreases with increase in frequency, whereas the loss factor is observed to first increase and then decrease with a minor qualitative difference for the four cultivars.

Key words: *Apple; Dielectric Constant; Dielectric loss Factor; Frequency.*

1. INTRODUCTION

Dielectric properties directly influence microwave drying characteristics of food products. A knowledge of dielectric properties of different varieties of food is therefore essential in the design and control of microwave drying systems and in determining their efficiency (Feng *et al.* 2002).

The knowledge of dielectric properties has been used for sensing moisture content in agricultural products and food grains so as to determine their safe storage (Nelson, 1977). Radio frequency and microwave dielectric heating has also been used for various applications like, determination of maturity of fruits, pest control in the crops and fruits (Nelson, 1996a; Nelson, 1996b; Ikediala *et al.* 2000), seed treatment (Nelson and Nidhi Bhargava *et al.* 2013), product conditioning (Nelson *et al.* 1981; Pour *et al.* 1981; Senter *et al.* 1984), remote sensing of crop condition (Ulaby and Jedlicka, 1982) and for quality measurement of fruits and crops (Nelson 1980; Nelson *et al.* 1995).

Interaction between a food product and microwave energy is given by the relative complex permittivity (ε* = ε' - jε'') of the product. The real component of the complex permittivity (ε', known as the dielectric constant) is related to energy storage, and the imaginary component (ε'', the loss factor) is related to the energy dissipation in the dielectric medium.

In connection with quality sensing of fruits and vegetables, the dielectric properties of twenty three kinds of common fresh fruits and vegetables were investigated by Nelson over the frequency range from 200 MHz to 20 GHz at 23 ºC by employing a network analyzer and coaxial probe (Nelson, 1983).

Feng *et al.* measured ε' and ε'' of red delicious apple over a moisture content range of 4% to 87.5% at 22 ºC and 60 ºC. At high moisture content (>70%) free water dispersion and ionic conduction account for the dielectric behavior observed in them. At medium

***Ravika Vijay** Tel. . 9314915662
E mail: ravikavijay@gmail.com

moisture content (~23%), ionic conduction plays a major role. At low moisture content (~ 4%), bound water accounts for the major dispersion mechanism. The measurements carried out by them were also based on Network Analyzer and a coaxial probe. At higher frequencies of the order of 10 GHz. and low moisture content, the major interaction is due to dielectric relaxation of bound water.

Though the dielectric properties of fruits and vegetables determined by employing Network analyzer and coaxial probe form a reliable set of data, however the insight of laboratory experiments is missing in such measurements. Moreover, the equipment required for such measurements is costly and beyond the reach of an institutional laboratory. On the other hand laboratory methods employing a microwave bench and based on the measurement of shift in minima on introducing the dielectric sample in the short circuited waveguide are simple to perform and provide insight of the experiment. The objective of the present research was to study the dielectric properties of four varieties of apples at four microwave frequencies 3.43 GHz, 7.31 GHz, 9.30 GHz and 14.70 GHz by using short-circuited waveguide measurement method, which is a laboratory method and has been successfully used for measurement of dielectric properties of liquids and solids.

2. MATERIALS & METHOD

Samples of four varieties of fresh apple as needed for the present research were obtained from the local grocery stores. The four varieties selected for the present study include the red delicious apple, delicious apple, granny smith apple and fuji apple. Two samples of each variety of apple having different lengths but with the same cross sectional area were required for determination of ε' and ε'' by two point method with Ku, X, J and C band waveguides. Samples for each variety were obtained with the help of sharp edge knife.

2.1 Two Point Method

Two point method is a technique involving measurement of reflection coefficient of a solid placed in a wave guide, backed by a short circuiting conducting plate. The experimental set-up for this method is shown below in Fig. 1. In order to use this method for fruits and vegetables; a specially designed dielectric cell is

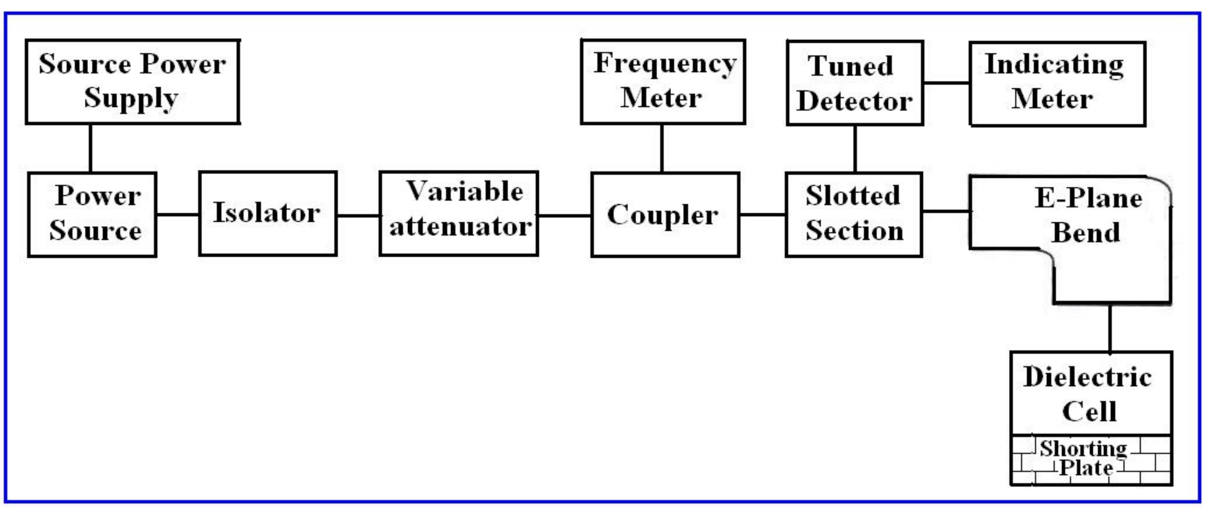

Fig. 1: Experimental set-up for determination of dielectric properties of solids by two point method.

used to hold the samples. The samples are cut in to pieces with cross-sectional area equal to that of the waveguide and length in the range $\lambda/4 < \lambda/2 < 3\lambda/4$. The samples so obtained are inserted inside the dielectric cell which is shorted with the help of a metal plate, such that the sample is in contact of the metal plate. This method is suitable for low and medium loss dielectrics and can be adopted for measurement of dielectric properties in solid form (Susher and Fox, 1963).

In two point method, the complex dielectric constant is given by

$$C\angle -\psi = \frac{1}{j\beta l_{\in}}\frac{1-|r|}{1+|r|}\frac{e^{j\psi}}{e^{j\psi}} = \frac{\tan X\angle\theta}{X\angle\theta} \qquad (1)$$

The transcendental equation provides several solutions for $X \leq \theta$, which can be found by employing graphs and tables provided for solution of such equations by Hippel or alternatively the problem may be solved by mathematical tool like MATLAB. The experiment is repeated with a different length of the sample and the common root is chosen for evaluation of the admittance. Alternatively we may perform the experiment for a given sample at two different frequencies to obtain the correct root $X \leq \theta$.

The admittance Y_{ε} of the material of the sample is given by

$$Y_{\in} = \left(\frac{X}{\beta l_{\in}}\right)^2 \angle 2\left(\theta - 90^0\right) = G_{\in} + jS_{\in} \qquad (2)$$

Where $G\varepsilon$ and $S\varepsilon$ are respectively the conductance and susceptance of the sample.

The values of $G\varepsilon$ and $S\varepsilon$ are obtained by separating eqn (2) into real and imaginary parts, from which the values of $\varepsilon/$ and $\varepsilon//$ can be obtained in the following form:

$$\in^{/} = \frac{G_{\in} + \left(\lambda_g/2a\right)^2}{1 + \left(\lambda_g/2a\right)^2} \qquad (3)$$

$$\in^{//} = \frac{-S_{\in}}{1 + \left(\lambda_g/2a\right)^2} \qquad (4)$$

A computer program in MATLAB may be used to solve the transcendental equation and obtain the values of dielectric constant (ε') and loss factor (ε'').

3. RESULTS & DISCUSSION

The values of dielectric constant and loss factor of four different varieties of apple, viz. red delicious apple, delicious apple, granny smith apple and fuji apple, as determined from a microwave bench at room temperature and at frequency 3.43 GHz, 7.31 GHz, 9.30 GHz and 1 4.70 GHz, by employing two point method are shown below in Table 1. The present results are at room temperature (23 ^{0}C) and moisture content around 87%. The same may be compared with the values reported by other authors on the basis of measurements taken by them using Network Analyzer and coaxial probe method. Fig. 1 and Fig. 2 show variation in dielectric properties (ε' and ε'') with frequency for four cultivarsof apple. It is observed from Fig. 1 that ε' decreases for all the samples with increase in frequency. Fuji apple has higher values of ε' and granny smith apple has lower values of ε' at all frequencies. It is observed from Fig. 2 that as frequency increase, ε'' increase first, reach its peak value and then decreases suddenly.

A fresh apple contains moisture around 88% on the wet basis. For this moisture content, the values of ε' for apple have been reported by Nelson (1983) to be 57.0 at 915 MHz and 54.0 at 2.45 GHz whereas the values of ε'' reported by him are 8.0 at 915 MHz and 10.0 at 2.45 GHz at 23 ^{0}C. Feng *et al.* (2002), have reported

Table 1. Dielectric properties (ε' and ε'') of four cultivars of apple at four microwave frequencies

Frequency / Sample	ε'				ε''			
	3.43 GHz	7.31 GHz	9.30 GHz	14.70 GHz	3.43 GHz	7.31 GHz	9.30 GHz	14.70 GHz
Red Delicious apple	58.8	52.11	30.35	16.35	1.03	1.44	1.23	0.17
Delicious apple	59.23	55.53	37.90	18.32	1.10	1.26	1.56	0.30
Granny Smith apple	57.06	51.15	29.58	14.61	1.32	1.78	1.44	0.42
Fuji apple	62.28	55.11	37.69	20.47	0.48	0.62	1.55	0.26

dielectric properties for Red delicious apple at moisture content at 87.5% at 22 ^{0}C. The ε' values reported by him are 56.0 at 915 MHz and 54.5 at 2.45 GHz whereas the ε'' values of Red Delicious Apple have been reported to be 8.0 and 11.2 at the two frequencies respectively.

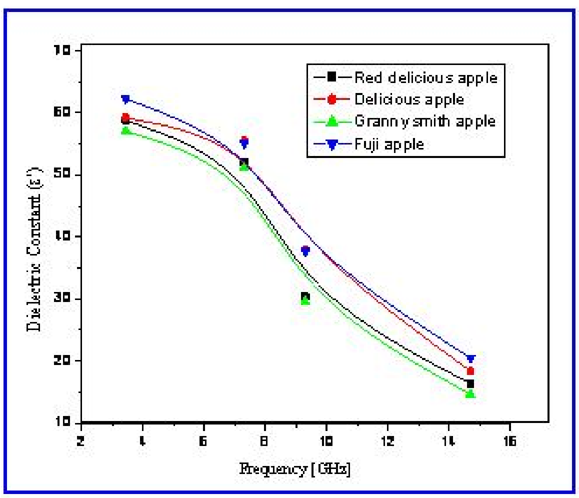

Fig. 2: Variation in Dielectric Constant of four cultivars of apple with frequency

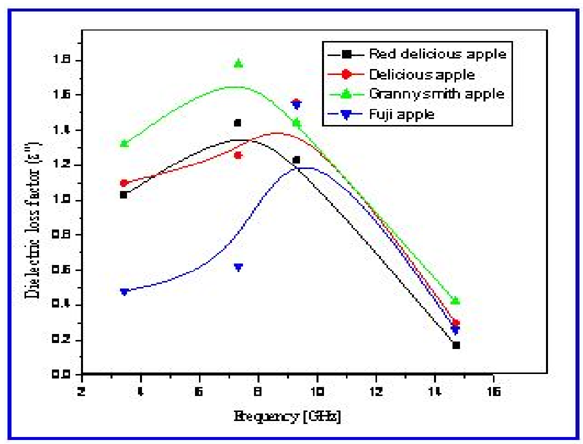

Fig. 3: Variation in Dielectric loss factor of four cultivars of apple with frequency

4. CONCLUSION

The dielectric properties of fruits can be efficiently measured by laboratory technique. The general trend of the variation of ε' in this frequency range show a decrease with .increase in frequency. In this frequency range ε' monotonically decreases whereas

ε'' has been reported to increase first upto 7 GHz for red delicious and granny smith apple, 9 GHz for delicious apple and upto 10 GHz for fuji apple there after decreases. The present values of ε' and ε'' are found to be in good agreement with the values reported by other authors at comparatively lower frequencies, and are also is in agreemet with the trend described by Nelson. These measurements may be useful in dielectric heating applications and as background material in exploring the dielectric properties of fruits for potential new quality sensing applications.

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