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Dielectric Properties of Spices using Microwaves

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Abstract

Moisture measurement is an important factor affecting the physical and chemical properties related to storage, processing and quality control in respect of food products. Pepper (Pepper nigrum) is one of the most valued spices in the world. Moisture content in pepper is one of the most important characteristics for determining quality of pepper. It is also important in determining the proper time for harvest and the potential for safe storage. It also decides the market price, because the dry matter of spice has more value than the water it contains and the cost of drying for safe storage has also comes in to account. Microwave techniques have been considered for a long time for moisture sensing in many food processing and agriculture related industries. They are suitable for on-line real time monitoring and control. In this paper an approach is presented in which moisture content of spice such as pepper are determined directly from microwave dielectric properties. It is based on the method of analysing dielectric properties of wet samples. When exposed to the microwave radiation dielectric materials present in the food items are polarized under the action of an external electric field. The magnitude of polarisation is proportional to the permittivity or the dielectric constant of the material. Also, when microwave radiation is made to interact with a wet material, the dielectric loss or the attenuation of the microwave energy is pre-dominantly due to the total amount of water in the wet material. From the attenuation measured the percentage moisture is computed.

In the proposed method the dielectric properties of moist pepper is calculated from the measured attenuation and phase shift, using two horn antennas and a detector. The dielectric constant and loss factor is functions of measured attenuation and phase shift. The attenuation depends only on the dielectric properties of spice samples when the wavelength and sample thickness are constant, it is possible to measure the moisture content of moist spice by detecting the peak voltage of the microwave signal from the receiving antenna. The dielectric properties of pepper with various moisture contents were determined by computed the attenuation and phase shift of the microwave signal through the cardamom (spice) samples at X- band frequency range. Dielectric constant and loss factor of different moist pepper samples at X-band increased with moisture content. The details of the instrumentation and the results are discussed in the paper.

Key Words: Dielectric constant, phase shift, loss factor, pepper, Permittivity, and moisture measurement.

Introduction

Moisture content of spice is one of the most important characteristics for determining quality. It is important in determining the proper time for harvest and the potential for safe storage. It is also an important factor in determining market price, because the dry matter of spice has more value than the water it contains and because costs of drying for safe storage must be taken in to account. Several methods are proposed in the literature to measure moisture content. Resistance type and RF capacitance type moisture meters are commonly used. The resistant type moisture meters have the advantage of low cost, but spice samples are crushed and wasted. Moisture meters measure the capacitance of the sample between two electrodes, thus sensing the dielectric constant of the pepper. This method can be used with a wide range of moisture contents and it is nondestructive, but is subject to measurement errors caused by changes in bulk density. In the microwave frequency measurement, transmission line using wave guides or coaxial lines and resonant cavity are employed. The disadvantages of these methods are the requirement for precise fabrication of sample holder and confinement of the samples.[3]

A free- space microwave measurement method is very useful for nondestructive and non-contact measurement of the moisture content of spice. Dielectric properties of materials are usually derived from measurement of reflection or transmission coefficients and in some instances from both [2,4]. The transmission coefficient is determined by computing the attenuation and phase shift introduced by a sample placed between two antennas. The dielectric properties of moist spice are calculated from the above two parameters, with two horn antennas and a detector.

The dielectric properties of spices are of interest mainly because of their correlation with grain moisture content and their consequent usefulness for rapid moisture content determination. These electrical properties of grain have been utilized by electrical and electronic grain moisture meters, which sense the electrical conductivity or the dielectric constant of grain, and are calibrated to read moisture content. The essence of microwave dielectric methods for moisture sensing is based on coupling between the electromagnetic energy of the incident wave and the material under consideration. Dielectric properties of material depend on the concentration and activity of permanent electric dipole molecules and ionic conduction and on the degree of dipole alignment with the time varying electric field applied. Therefore, when the sample holder is filled with moist spice, the dielectric properties of the spice are highly affected by water concentration in mass per unit volume and temperature which affects molecular movement. When the electromagnetic field is applied to a dielectric material, electromagnetic energy is dissipated in the dielectric material as a result of dielectric relaxation process. The interaction of the applied electromagnetic field with moist spice depends upon the complex dielectric permittivity, relative to free space

$$\varepsilon = \varepsilon' - j\varepsilon'' \quad (1)$$

Where ε' = dielectric constant

ε'' = dielectric loss factor

The dielectric constant describes the ability of a material to store electromagnetic energy, while the dielectric loss factor represents the loss of electromagnetic field energy in the material.[7] Improvements in spice moisture measurement are possible use of a combination of the dielectric properties. By measuring both attenuation and phase shift, which are the functions of the loss factor and the dielectric constant, respectively, for microwave energy transmitted through spice, the undesirable effects of bulk density fluctuations can be minimised.

Subject and Methods

Pepper (Pepper nigrum) is one of the most valued spices in the world. Moisture content of pepper is one of the most important characteristics for determining quality. Moisture content is expressed in percentage[5,1,9] as

$$M = m_w / m_{w+} m_d * 100 \quad (2)$$

Where m_w = mass of water

m_d = mass of dry material

Pepper is conditioned to higher moisture levels in environmental chambers in which the temperature and relative humidity could be adjusted in small increments to avoid checking and cracking of the spice. After being conditioned to desired moisture levels, samples were sealed in glass jars and stored at 4^o C for an extended period before they were used for measurements. Different measurement techniques can be used to determine the dielectric constant ε' and the loss factor ε'' of dielectric materials. In this paper we used free space technique and is very useful for nondestructive and non -contact measurement of the moisture content of pepper. It is based on the method of analyzing dielectric properties of wet samples. When a plane wave is incident normally upon a dielectric medium in free space, part of it is transmitted in to the medium and part is reflected at the interface between free space and the dielectric medium. A layer of material of thickness(t), of known bulk density, moisture content, and temperature was placed between two horn antennas and the attenuation (A) and phase shift (ϕ) were measured for each sample. The dielectric constant and loss factor are given as a function of the measured attenuation and phase shift[5,6]. The components of the relative complex permittivity can be obtained as follows:

$$\varepsilon' = (1 + \Phi\lambda o / 360t)^2 \quad (3)$$

$\varepsilon'' = A\lambda_O(\varepsilon')^{1/2}/(8.686\pi t)$ (4)

Where λ_O= free space wavelength

Φ = Phase shift difference with and without spice samples in degrees

A = difference between the attenuation with and without spice samples in decibels

t = thickness of the grain layer in centimeters.

A block diagram of the experimental setup used to measure the attenuation and phase shift of the microwave signal through the spice sample is shown in Figure 1. In this setup a 10.5 GHz microwave signal at 60 mw generated by an oscillator is transmitted through an isolator, attenuator, frequency meter, slotted section and radiated from a transmitting horn antenna in to the sample holder. The microwave signal, attenuated by spice sample is collected by the receiving horn antenna and detected by a detector. The detector converts input RF signal to dc voltage. The sample holder is mounted between the transmitting and receiving antennas. The sample holder is a rectangular container with 1mm wall thickness and its dimensions used in this experiment are 2.5 cm in thickness, 7 cm in width, and 10 cm in height. The output power and the first minimum distance are measured without the spice samples. The sample holder is filled with different moist spice samples, measure the power and the first minimum distances for each samples. From the above observations calculate the attenuation 'A' and phase shift 'Φ'. The phase shift 'Φ' is calculated by measuring the distance D of first minima with the spice sample, the distance D_R without the spice sample and the length L_E of the sample, and then this value is multiplied with twice the phase constant (β) as given below[10]

The phase shift 'Φ' is given by $\Phi = 2\beta (D - D_R - L_E)$ (5)

The experimental results are tabulated in table 1.

Table 1: Experimental Results.

Sl. No	Moisture Content (%)	Attenuation (A) In db	Phase Shift (Φ) In Degrees	Dielectric Constant (ϵ')	Dielectric Loss Factor (ϵ'')
1.	3.75	15.563	21.83	1.144	0.698
2.	7.20	17.501	22.23	1.146	0.786
3.	10.5	119.305	22.58	1.149	0.868
4.	13.5	21.584	22.98	1.151	0.971
5.	16.3	29.542	23.16	1.153	1.331
6.	18.9	35.563	23.36	1.154	1.602

Results

The dielectric properties of pepper with various moisture contents were determined by measuring the attenuation and phase shift of the microwave signal through using pepper samples at 10.5 GHz. The dielectric constant and loss factor has found to be a function of attenuation and phase shift respectively. Both the dielectric constant and loss factor increased with moisture content as shown in Figures 2 and 3, Figures 4 and 5 shows that the attenuation and phase shift also varies with moisture content. The output power is decreased with increased moisture content is shown in Figure 6.

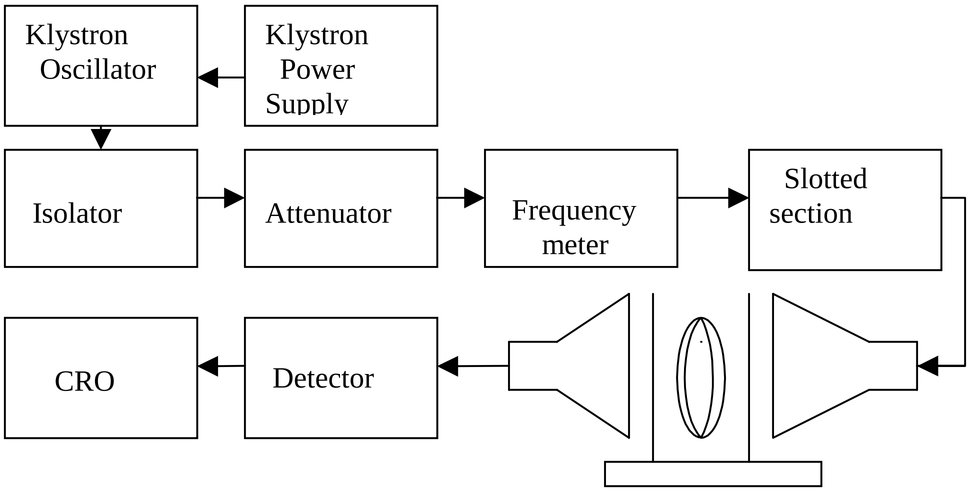

Figure 1: Experimental Set up.

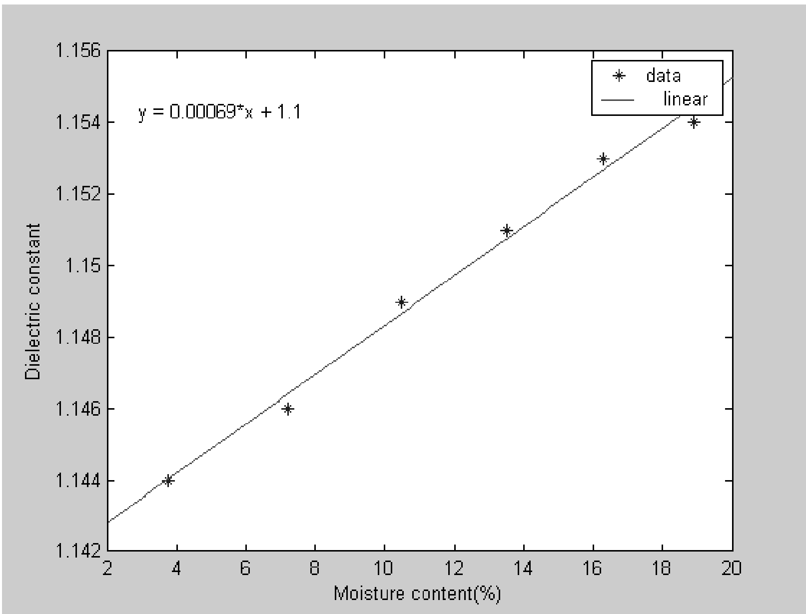

Figure 2: Moisture content Vs Dielectric constant.

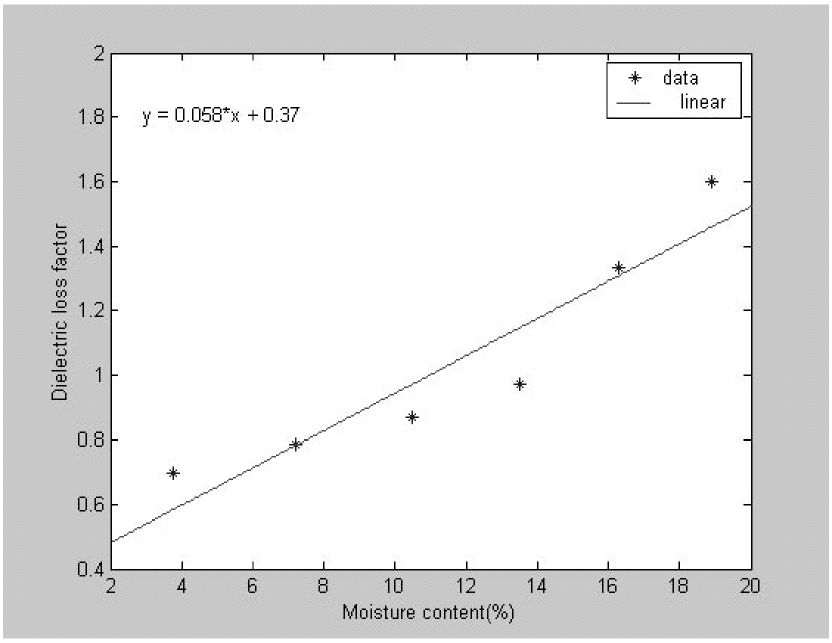

Figure 3: Moisture content Vs Dielectric loss factor.

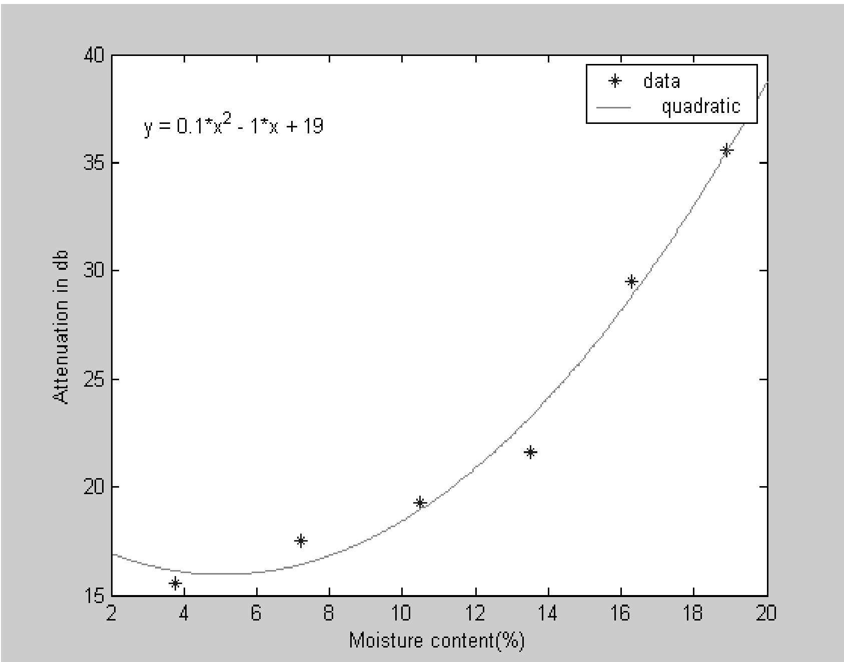

Figure 4: Moisture content Vs Attenuation.

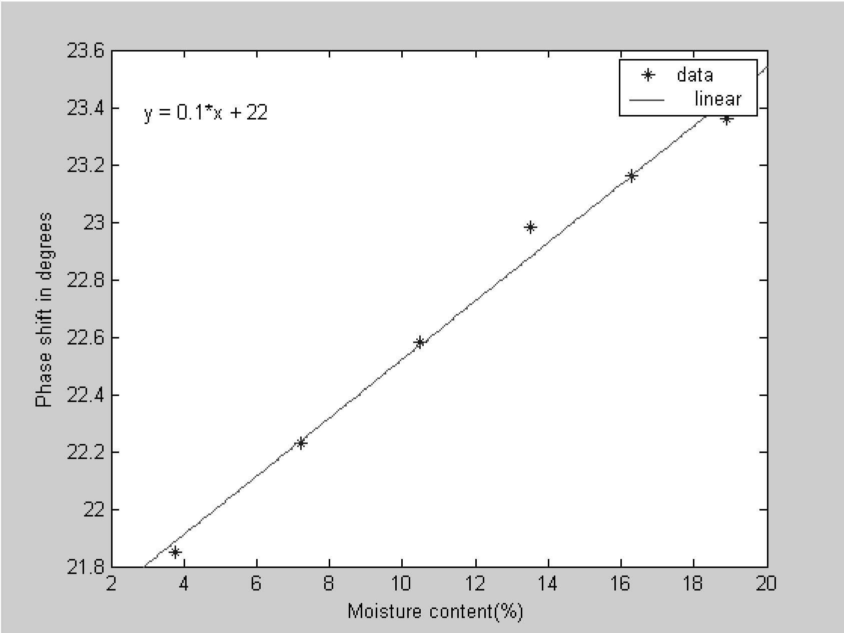

Figure 5: Moisture content Vs Phase Shift.

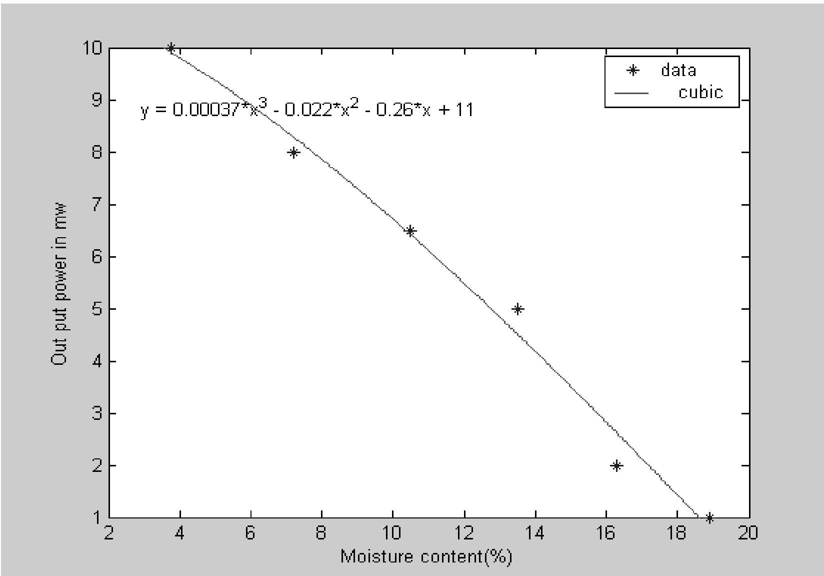

Figure 6: Moisture content Vs Output power.

Conclusion

Permittivity of spice samples at RF's are useful in rapid and nondestructive sensing of moisture content because of high correlation between the dielectric properties of spice and amount of water present in the spice. In this free space technique the dielectric constant and loss factor of pepper is determined by measuring attenuation and phase shift. The dielectric properties of pepper is increased with moisture content. At microwave frequencies the moisture content of pepper spice has been achieved by computing the value of attenuation and phase shift.

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