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DETERMINATION OF THE RELATIONSHIP BETWEEN THE MOISTURE CONTENT AND MICROWAVE DIELECTRIC PROPERTIES IN KENAF STEM

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ABSTRACT

A brief history of kenaf stem moisture content measurement by sensing the dielectric properties of kenaf stem is presented. The basic principles are also described for using microwave dielectric properties of kenaf stem for sensing moisture through their correlation with moisture content. Development of these techniques will provide useful instruments for on-line monitoring of moisture content in kenaf stem processing to separate between bast and core of kenaf stem and thus increase the quality of natural fibre, prevent spoilage in storage and transport, improve processing, and provide information important for yield determinations in precision agriculture applications.

***Keywords**: Kenaf, microwave, dielectric properties, natural fibre, moisture content.*

INTRODUCTION

Kenaf has been used as a cordage crop to produce twine, rope, and sackcloth for over six millennia [1]. Kenaf (*Hibiscus cannabinus* L.), is potentially a new industrial fibre crop for Malaysia. It is environmentally friendly and is a step nearer commercialization with various new applications as its long fibres are suitable in the processes for making a number of products such as pulp and paper, fibre and particle board, as well as fibre reinforced plastic components and chemical absorbents [2]. Kenaf fibre is produced from the separation of whole-plant Kenaf into bast and core. Bast has numerous high-value fibre applications; conversely core fibre has relatively low-value uses [3]. Figure 1 shows the cross section of a Kenaf stem showing the bast and core in the inner part [4].

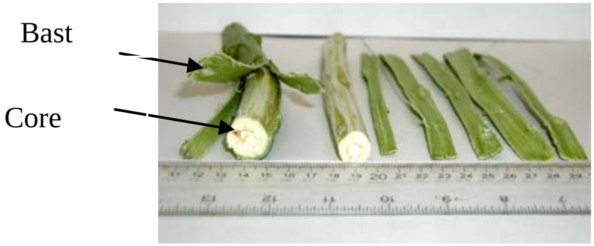


Fig. 1: Cross Section of a Kenaf stem

The electrical properties of agricultural products have been of interest for at least 100 years. One of the earliest applications for the purposeful use of the electrical properties was a study of the direct current (DC) electrical resistance of grain for rapidly determining its moisture content [5]. Electrical properties play an important role to increase the efficiency, quality and quantity of processing for agricultural products so that they can meet the demand from food and agricultural based industries such as bio-composite, textiles and others to provide agricultural products for the needy countries around the world.

Standard methods for determining moisture content (MC) in agricultural material require oven drying for specific time periods at specified temperatures by prescribed methods. Such methods are tedious and time-consuming and the MC is only determined after the oven drying procedure. A researcher in this field needs to know the MC of a stem before it goes into the mechanical process of separation [6]. It has been mentioned in much of the literature that the microwave dielectric properties can be used to measure the physical characteristics of such agricultural material.

Each type of material has different characteristic in terms of dielectric properties determined by using a microwave signal. Theoretically, the dielectric properties of a material depend on the concentration and activity of permanent electric dipole molecules, ionic conduction and on the degree of dipole alignment when at time-varying electric field is applied. Many researchers have striven to determine the relation between agricultural materials MC with dielectric properties. However Jyh Sheen et. al (2009) found that the cavity perturbation method is the preferred method as compared to other methods such as the free space technique, transmission or reflection techniques, and distributed impedance techniques. This is because the cavity perturbation method is fast, non-destructive, non-contacting and suitable with kenaf stem cylindrical shape. When a rectangular waveguide is filled with Kenaf stem at the centre of the rectangular waveguide resonator, the dielectric properties of the Kenaf stem is highly affected by the water concentration in mass per unit volume which affects molecular movement [7] inside the Kenaf stem. The rectangular waveguide cavity dielectric resonance technique as based on the simple field model presented here indicates accurate measurements for both the dielectric constant and the loss tangent based on comparison with other measurement methods [8].The researchers have found that this method is good for limited size of samples.

The theory of cavity perturbation says that the microwave moisture content measurement uses the absorption of microwave energy corresponding to the rotational energy of the water molecules. When an electromagnetic field is applied to a dielectric material, electromagnetic energy is dissipated in the dielectric material as a result of the dielectric relaxation process. It is a fast and efficient technique for measuring a wide range of dielectrics of various thicknesses and cross sections [9]. The dielectric properties can be determined by first measuring the resonant frequency of an empty cavity.

Resonant measurements are the most accurate methods of obtaining dielectric properties. However, there are limitations in the frequencies and loss characteristics of the materials that can be measured with the technique. A rectangular waveguide resonator is one of the perturbation methods used by many researchers for example Zulkifly Abbas et. al and Georges Roussy et. Al. The method uses cavity perturbation techniques by use of a rectangular waveguide resonator and is suitable to apply to Kenaf stem. Before this, no research had been undertaken to determine the online moisture content of Kenaf stems by using their microwave dielectric properties characteristic in the kenaf stem. Thus this current work aims to study Kenaf moisture content using the microwave cavity perturbation method.

MATERIALS AND METHOD

Materials

Kenaf stem was collected from Taman Pertanian Universiti (TPU), Universiti Putra Malaysia (UPM). In this study, five different stems were used and labelled as stem 1, 2, 3, 4 and 5. The diameters of the stems were in the range of 2-4 mm and the length was 20 mm. The limitation of the stem diameter was due to the rectangular waveguide cross sectional area which was restricted at 229 mm^2. The selected stems were divided into two portions of bottom parts (B) and top parts (T) and named as sample B and T respectively. Figure 2 shows Kenaf samples ready to testing in the rectangular waveguide resonator.

Fig. 2: Samples of Kenaf stems

Each sample diameter was measured by using an Electronic Digital Calliper. The diameter of each Kenaf sample was taken at the different points, i.e. the bottom, middle and top to ensure the accuracy of the Kenaf diameter.

The setup for the measurement of the dielectric properties was as shown in Figure 3, consisting of a Vector Network Analyzer (VNA), rectangular waveguide resonator and cable. The dielectric properties measurements were carried out using the VNA in the frequency range of 8 GHz to 12 GHz. The rectangular waveguide cavity was constructed from a length waveguide of nearly 140 mm length. The cross section dimensions were 22.9 mm in width and 10 mm in height. Two thin conducting sheets were used to form the cavity and to close the two ends of the waveguide. The inductive coupling was provided with two symmetric holes of diameter 4mm on these end sheets. In order to insert a sample material into the centre of rectangular waveguide, a circular hole is constructed in the centre of the waveguide. The VNA was used to determine the phase shift changes from the magnitude (dB) versus frequency (GHz) graph before and after insertion of the sample into the rectangular waveguide resonator.

Fig. 3: The Vector Network Analyzer with Kenaf sample inside the Rectangular

Waveguide Resonator

The dielectric properties were determined by measuring the resonant frequency of an empty cavity and a Kenaf sample. The sample was put into the rectangular waveguide resonator as in Figure 3. The frequency and volume data of the empty cavity and the Kenaf sample were applied in the equation 1 [10] to calculate the dielectric properties.

Equation 1:

$$\varepsilon' = \frac{Vc(fc - fs)}{2Vsfs} + 1$$

Where

ε' = Dielectric Constant
Vc = Volume of Cavity
Vs = Volume of Sample
fc = Frequency of Cavity
fs = Frequency of Sample

The fresh weight of the samples was recorded to three decimal places before and after being placed in the oven for the determination of MC. The oven temperature was set at 150 °C for about 15 minutes and the MC was calculated using equation 2. The MC determination was carried out two times successfully after the dielectric constant determination. The MC was calculated and the data were tabulated in a graph of dielectric constant versus MC.

Equation 2:

$$MC = \frac{(Fresh\ Weight - Dry\ Weight)}{Dry\ Weight} \times 100\%$$

The resonant frequency was determined and recorded after drying each Kenaf sample. The result was analyzed by plotting a magnitude (dB) versus frequency (GHz) graph and the microwave dielectric properties versus the MC of samples graph. The dielectric constant and MC values were analysed by using the linear regression technique to obtain the relationship between both of the parameter measured. The linear equation and R^2 were derived from the analysis

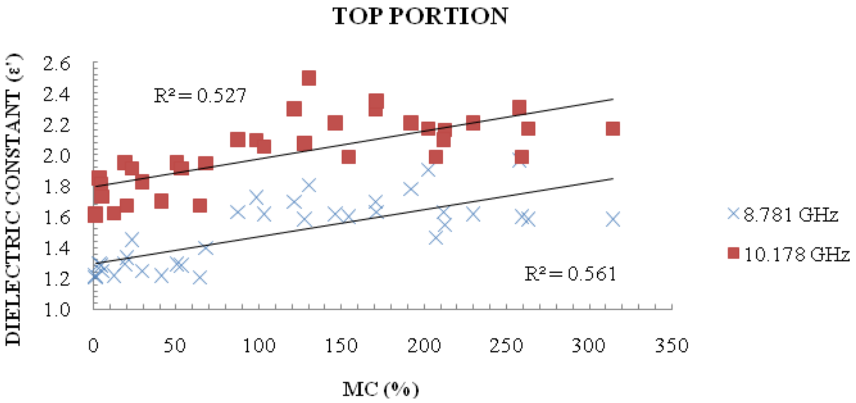
RESULTS AND DISCUSSION

The diameter of the samples was shown in Table 1. It was revealed that the portion 2 (Bottom) of each sample had a larger diameter compared to portion 1(Top). This was due to the position of the sample which was obtained from the bottom (B) portion of the plant which contains more water than the top (T) portion.

Table 1: The diameters of the samples

Kenaf	Sample	Average Diameter
1	B	2.15
	T	2.17
2	B	2.30
	T	2.35
3	B	2.43
	T	2.02
4	B	2.08
	T	2.05
5	B	2.57
	T	2.38

a)



b)

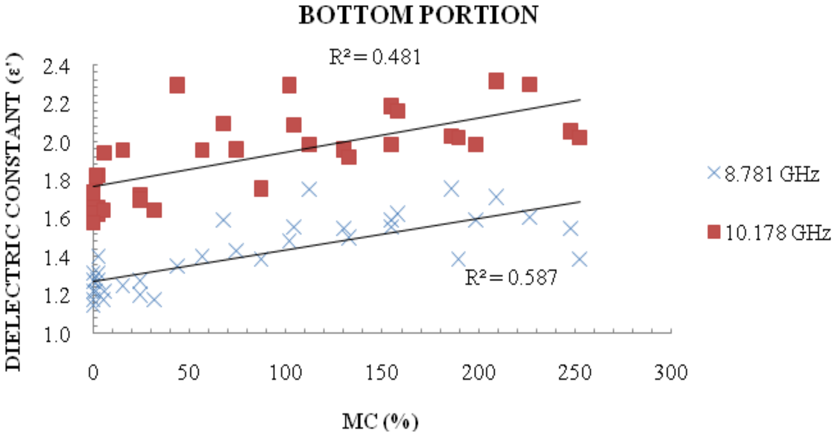


Figure 4: The Dielectric Constant versus MC in Kenaf Stems

In the case of grain, the microwave techniques for moisture evaluation rely on the determination of the dielectric properties of the grain and this can be achieved by measuring either single grains, an aggregation of uncompressed grain samples or bulk grain samples where a block of grain is inserted into a microwave cavity or waveguide. The ε' of the wheat grain increases as the moisture content is increased [11]. In the current study, a similar microwave technique was selected for the perennial crops of the hibiscus family such as Kenaf, and it was assumed that the MC and dielectric constant also have a linear correlation. From the experiment, Figure 4 shows that the samples of different portions indicates a linear relationship between ε' and MC which is in agreement with the grain ε' behavior. For the 8.781 GHz frequency, the B and T shows slight difference in ε' at different MC. However when the MC has been removed almost 0% by drying process, the ε' was almost same. It seems that at high MC, the value of the dielectric constant ε' also increases.

There was a small difference in the MC equations for between B and T. This was because each sample had a different diameter size. A larger diameter was expected to have a higher capacity to hold water inside the kenaf stem, and thus contribute to higher MC. However there was no significant difference in the MC obtained from the different stem portions. The reason for this might be due to the microstructure of the Kenaf stem whereby the xylem, the woody portion of the stem, is a hollow cylinder whose cross-section decreases from the bottom upwards. In general, the chemical compositions of the two types of Kenaf fibres indicated that the Kenaf core fibres were higher in holocellulose and lignin, while the Kenaf bast fibres were higher in α-cellulose, extractive, and ash content [12]. Those chemical compositions inside the Kenaf stem is suggested to give the effect of the dielectric constant value inside the Kenaf stem.

The dependence of the ε'on the Kenaf part MC is shown in Figure 4 In this figures, both graphs show the ε' increased with MC. However, when comparing the R^2 between both graphs, it can be clearly seen that at 10.178 GHz for B and T portion in the both graph in Figure 5 and Figure 6 has an R^2 higher than R^2 at 8.781 GHz. It is clear that the fluctuations in Kenaf parts result in different values of the dielectric constant, depending on the diameter and MC of the Kenaf part. It also shows that at 10.178 GHz is more appropriate to determine the ε' and MC of Kenaf stem with a diameter of less than 4 mm

CONCLUSION

A new online sensor to determine the moisture content of Kenaf stems in the farm can be developed by using a Microwave Rectangular Waveguide Resonator which will increase the efficiency of processing machine based on the MC of Kenaf stem. By this technique, the kenaf sample diameter is only limited to more than 4 mm because this technique utilises a small cross sectional area of 229 mm^2 and it is only appropriate with small diameter size samples.

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