[AMN07] RDWG Technique for Determination of Complex Permittivity and Moisture Content of Oil Palm Fruits

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Introduction

Close relationship between oil content and moisture content [Ariffin et al., 1990, Khalid & Abbas, 1992] suggests the possibility of using moisture content as a parameter to gauge fruit ripeness. It is found [Khalid & Abbas, 1992] that the amount of moisture content is higher at early stage of fruit development. Excess water is reduced in the ripe fruit as the oil accumulates in the mesocarp.

A complex permittivity [Hippel, 1954] is an important parameter to describe the relationship between biological materials and applied electromagnetic fields. A relatively large change in the permittivity of the wet material based on the water content can be detected using the microwave measurement technique. The measurement of moisture content using microwave techniques is widely known to be fast and accurate. Several microwave techniques [Khalid & Abbas, 1992, Yeow et al., 2002] have been applied for the determination of moisture content in oil palm fruits but none have been applied using free space techniques. This paper reports the extension of the rectangular dielectric waveguide (RDWG) technique [Abbas et al., 2001] for the determination of complex permittivity of oil palm fruits of different moisture content from 8 GHz to 12 GHz frequency range.

Materials and Methods

The effective permittivity model has been proposed to represent the dielectric waveguides and sample with their surrounding (air) as homogenous media.

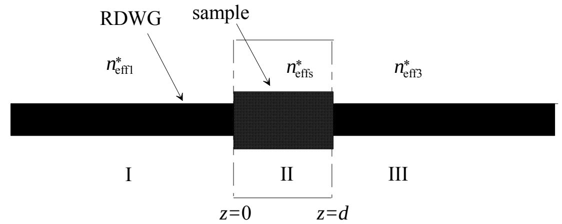

FIGURE 1 The Complex Permittivity Model

The complex transmission coefficient T and reflection coefficient R is due to the RDWG/sample/RDWG interfaces and multiple reflections are considered as effective values. For samples of sufficiently large cross-section the calculation of both T and R takes the form of the familiar plane wave calculation for unbounded homogeneous media

$$R = \frac{(1-P^2)\Gamma}{1-\Gamma^2 P^2} \qquad (1)$$

$$T = \frac{(1-\Gamma^2)P}{1-\Gamma^2 P^2} \qquad (2)$$

where Γ is the reflection coefficient due to the sample at the boundaries $z = 0$ and $z = d$ and the propagation factor P of the sample of thickness d due to propagation constant γ_s is $P = \exp(-\gamma_S d)$. The propagation constant can be determined once the complex permittivity ε^* of the sample is known using $\gamma_s = k_0\sqrt{\varepsilon^*}$ where k_0 is the free space number.

In this work, the dielectric mixture model is used to calculate the permittivity for given moisture content values based on the relationship

$$\sqrt{\varepsilon^*} = v_w\sqrt{\varepsilon^*_w} + v_f\sqrt{\varepsilon^*_f} + v_o\sqrt{\varepsilon^*_o} \qquad (3)$$

where v_w, v_f and v_o are the volume fractions of water, fiber and oil, respectively and ε^*_w, ε^*_f and ε^*_o are the corresponding complex permittivities. The values of ε^*_w are obtained from the Cole-Cole model. Details on the dielectric mixture model of the oil palm fruits can be found in [Abbas et al., 2001].

The measurement system consists of a HP8720B Vector Network Analyzer (VNA), RDWG, WR-90 standard waveguides and horn antennas. All microwave measurements are carried out using the VNA which is controlled using the Agilent Visual Engineering Environment Software.

Results and Discussion

There are two methods that can be used to determine the complex permittivity and moisture content of oil palm fruits. They are empirical method and optimization method. The empirical method is determined by using relationship between return loss and moisture. The relationship between the measured moisture content and return loss varies linearly. At midband frequency, 10 GHz, the sensitivity of the RDWG is given as 0.0464±0.0024 dB/%.

The optimization method is determined by using the error function

$$\xi = \sum_{i=1}^{201}\left\{(|\Gamma_{meas}| - |\Gamma_{theory}|)^2 - \left(|P_{meas}| - |P_{theory}|\right)^2\right\} \qquad (4)$$

where $|\Gamma_{meas}|$ and $|\Gamma_{theory}|$ are the measured and calculated reflection coefficient and $|P_{meas}|$ and $|P_{theory}|$ are the measured and calculated transmission coefficient respectively. Equation (4) is solved using a modified Levenberg-Marquardt algorithm.

It is found that the mean relative error percentages between the predicted moisture content and the actual moisture content using empirical method is ±4.32% at 10 GHz while for optimization method, the mean relative error percentage is less than ±1.14%.

For complex permittivity measurements, it is found that $\varepsilon'_{optimization}$ values are in good agreement with $\varepsilon'_{HP85070B}$ whilst $\varepsilon'_{emprical}$ overestimates the values of the permittivity for all frequencies. In contrast, $\varepsilon''_{empirical}$ values are closer to the $\varepsilon''_{HP85070B}$ whilst the $\varepsilon''_{optimization}$ underestimates the loss factor values for all frequencies. However the true performance of the RDWG technique should not be assessed in terms of permittivity comparison results with the HP85070B probe kit alone. The $\varepsilon'_{optimization}$ and $\varepsilon''_{optimization}$ are calculated based on a more accurate dielectric mixture model where the fruit sample is modeled as a mixture of three components: water, oil and fibre. In contrast, the HP85070B open ended coaxial probe assumes a homogeneous sample and employs Cole-Cole model to extrapolate the values of the permittivity in conjunction with a quasi-static admittance model. However, the Cole-Cole model is only suitable for permittivity predictions of homogeneous liquid sample.

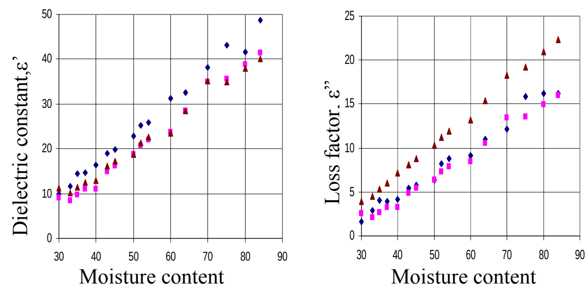

FIGURE 2 Variation in Complex Permittivity with Moisture Content
(■ optimization method ◆ empirical method ▲ HP85070B)

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References

A.Ariffin, S.R. Mat, M. Banjari and Wan, O.W.E. (1990). Morphological changes of the cellular component of the developing palm fruit (Tenera*: Elaeis guineensis*). *PORIM Bulletin* 21:30-34

K.Khalid and Z.Abbas (1992). A microstrip sensor for determination of harvesting time for oil palm fruits (Tenera: *Elaeis guineensis*). *Journal of Microwave Power and Electromagnetic Energy* 27(1):3-10.

V. Hippel (1954). Dielectric Materials and Applications, New York: Wiley.

Yeow, Y.K., Abbas, Z., Khalid, K. and Hassan, J. (2002). Complex permittivity measurements of oil palm fruits using an open ended coaxial sensor. *Proc. 2002 Postgraduate Seminar, Department of Physics, Universiti Putra Malaysia.*

Abbas, Z., Pollard, R.D. and Kelsall, R.W. (2001). Complex permittivity measurements at Ka-Band using rectangular dielectric waveguide. *IEEE Trans. Instrum. Meas.* vol. 50.: pp. 1334-1342.