UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A NEW TECHNIQUE FOR MEASUREMENT OF DIELECTRIC PROPERTIES OF OIL PALM FRUITS

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DEVELOPMENT OF A NEW TECHNIQUE FOR MEASUREMENT OF DIELECTRIC PROPERTIES OF OIL PALM FRUITS

YOU KOK YEOW

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia
In Fulfilment of the Requirement for the Degree of Master of Science

April 2003

Specially dedicated to:

My beloved

Father, Mother, and Sister,

Niece,

and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

DEVELOPMENT OF A NEW TECHNIQUE FOR MEASUREMENT OF DIELECTRIC PROPERTIES OF OIL PALM FRUITS

By

YOU KOK YEOW

April 2003

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The thesis describes the development of a low cost open-ended coaxial sensor for the determination of both complex permittivity and moisture content of the oil palm fruits of various degree of fruit ripeness. The sensor operating between 2 GHz and 4 GHz was fabricated from an inexpensive 4.1 mm outer diameter SMA coaxial stub contact panel and suitable for single fruit measurement. A theoretical analysis has been carried out to establish the optimum operating frequency based on the relation ship between the admittance and frequency of the sensor. The propagation of electromagnetic wave is assumed to be transverse electromagnetic (TEM) mode. The measurement system consists of the sensor and a PC-controlled vector network analyzer (VNA). A dielectric measurement software has been developed to control and acquire data from the VNA using Agilent VEE. The software is also used to calculate the complex permittivity from the measured reflection coefficient at each 201 frequency points between 2 GHz and 4

GHz. The permittivity values were then fitted to a dielectric mixture model to obtain the values of moisture content of oil palm fruits. The actual moisture content were found by standard oven drying method. A calibration equation relating the measured and predicted moisture content has been established based on more than 80 fruit samples. The equation was found to be accurate within 5.2 ± 0.4 % when tested on 69 different fruit samples. The values of moisture content obtained from the calibration equation were used in the mixture model to improve accuracy in the determination of the complex permittivity of the oil palm fruits. The sensitivities of the sensor in the measurement of the dielectric constant and loss factor of the oil palm fruits with respect to changes in moisture content were typically 0.82 and 0.05, respectively. The sensor can be used to monitor fruit ripeness based on the measurement of the magnitude of reflection coefficient alone. Fruits are considered to reach ripeness stage once the magnitude of the reflection coefficient is greater than 0.85 at optimum operating frequency 2.6 GHz.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan bagi mendapat Ijazah Master Sains

PEMBINAAN TEKNIK BARU UNTUK MENENTUKAN SIFAT-SIFAT DIELEKTRIK BAGI BUAH KELAPA SAWIT

Oleh

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Tesis ini memperihalkan pembinaan peranti deria sepaksi hujung terbuka yang murah untuk menentukan ketelusan kompleks dan kandungan kelengasan bagi buah kelapa sawit yang mempunyai peringkat kematangan yang berlainan. Peranti deria ini beroperasi antara 2GHz hingga 4GHz yang difabrikasi daripada 4.1 mm diameter luaran pucuk panel sentuhan sepaksi SMA yang murah dan sesuai kepada pengukuran buah tunggal. Analsis teori telah dilaksanakan supaya mengetahui optimum frekuensi operasi yang merujuk kepada hubungan antara admitans dan frekuensi bagi peranti deria tersebut. Rambatan gelombang elektromagnet tersebut telah dianggap sebagai ragam elektromagnet melintang (TEM). Sistem pengukuran ini terdiri daripada peranti deria dan penganalisis rangkaian vektor (VNA) kawalan PC. Perisian pengukuran dielektrik telah dibina untuk mengawal dan memperolehi data-data daripada VNA dengan menggunakan Agilent VEE. Perisian ini boleh juga digunakan supaya mengira ketelusan kompleks

daripada pengukuran pekali pantulan pada setiap 201 titik frekuensi antara 2GHz and 4GHz. Kandungan kelengasan dalam buah kelapa sawit boleh diramalkan dengan memadankan nilai ketelusan tersebut dengan model campuran dielektrik. Kandungan kelengasan yang sebenar telah diperolehi dengan kaedah piawai pengeringan oven. Persamaan penentukuran yang berhubung antara pengukuran dan ramalan kandungan kelengasan telah dibina bergandung kepada lebih daripada 80 buah sample. ketepatannya persamaan tersebut adalah dalam linkungan 5.2 ± 0.4 % apabila diuji atas 69 buah sampel. Nilai-nilai kandungan kelengasan yang diperolehi daripada persamaan penentukuran tersebut telah dimasukkan dalam model campuran supaya memperbaiki kejituan bagi penentuan ketelusan komplek buah kelapa sawit. Kepekaan peranti deria bagi pengukuran pemalar dielektrik dan factor kehilangan untuk buah kelapa sawit akibat perubahan kandungan kelengasan adalah 0.82 dan 0.05, masing-masing. Peranti deria ini boleh digunakanuntuk menentukan kematangan buah hanya berdasarkan pengukuran magnitud pekali pantulan. Buah adalah dianggap mencapai peringkat matang jika magnitudpekalipantulan mencatat bacaan melebihi 0.85 pada frekuensi optima sensor, iaitu 2.6 GHz.

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I certify that an Examination Committee met on 12th April 2003 to conduct the final examination of You Kok Yeow on his Master of Science thesis entitled "Development of a New Technique for Measurement of Dielectric Properties of Oil Palm Fruits" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

YOU KOK YEOW

Date: 6 / 6 / 2003

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LIST OF SYMBOLS

ε^* or ε	-	complex permittivity
ε_o	-	permittivity of vacuum
ε'	-	real part of permittivity or dielectric constant
ε''	-	imaginary part of permittivity or loss factor
ε_∞	-	optical permittivity
ε_s	-	static permittivity
ε_c	-	complex permittivity of coaxial line (PTFE)
ε_w^*	-	complex permittivity of water
ε_f^*	-	complex permittivity of fiber
ε_o^*	-	complex permittivity of oil
ε_{fruit}^*	-	complex permittivity of oil palm fruit
μ_o	-	free space permeability
μ	-	permeability
σ	-	conductivity
$\tan \delta$	-	loss tangent
v_w	-	volume fraction of water
v_f	-	volume fraction of fiber
v_o	-	volume fraction of oil

ρ_w	-	relative density of water
ρ_f	-	relative density of fiber
ρ_o	-	relative density of oil
m_w	-	mass of water
m_f	-	mass of fiber
m_o	-	mass of oil
m.c. or m	-	moisture content
γ	-	propagation constant
f	-	frequency
f_c	-	cutoff frequency
t	-	time
T	-	temperature
ω	-	angular frequency
τ	-	relaxation time
c	-	velocity of light
λ	-	wavelength
λ_o	-	free space wavelength
λ_c	-	cutoff wavelength
a	-	inner radius of coaxial probe
b	-	outer radius of coaxial probe
d	-	sample thickness or sensitivity depth
D	-	physical length of the probe
L	-	effective transmission line length

k_o	-	free space wave number
k_1	-	wave number of internal medium probe
k_2	-	wave number of external medium under test
$\vec{E}$	-	electric field or electric intensity
$\vec{D}$	-	electric flux density
H	-	magnetic field or magnetic intensity
$\vec{B}$	-	magnetic flux density
$\vec{P}$	-	polarization
$\vec{J}$	-	current density
ρ_q	-	charge density
I	-	electric current
$\vec{S}$	-	area
r	-	distance
x, y, z	-	Cartesian coordinates
ρ, ϕ, z	-	cylindrical coordinates
V	-	total potential
Γ	-	reflection coefficient
$\|\Gamma\|$	-	magnitude reflection coefficient
Γ' or $Re(\Gamma)$	-	real part of reflection coefficient
Γ'' or $Im(\Gamma)$	-	imaginary part of reflection coefficient
Γ_1	-	theoretical reflection coefficient of short circuit
Γ_2	-	theoretical reflection coefficient of open circuit

Γ_3	-	theoretical reflection coefficient of water
Γ_{fruit}	-	measured reflection coefficient of fruits
Γ_c	-	calculated reflection coefficient of fruits
ϕ	-	phase of reflection coefficient
S_{ε}^{Γ}	-	sensitivity of an open ended coaxial probe
$S_{MC}^{\sqrt{\varepsilon^*}}$	-	*sensitivity of mixture model*
Y_o	-	characteristic admittance of coaxial line
G	-	conductance
B	-	susceptance
$\frac{G(0)}{Y_o}$	-	normalized conductance
$\frac{B(0)}{Y_o}$	-	normalized susceptance
$\widetilde{Y}$	-	normalized admittance
Y	-	aperture admittance
Z_o	-	characteristic impedance
Z	-	impedance
R	-	resistance
X	-	reactance
C_o	-	static value of the fringe-field capacitance
C_f	-	fringe-field capacitance of coaxial line
C_T	-	total fringe-field capacitance of coaxial line
A_1, A_2, C_1	-	parameters empirical

A	-	surface of the sample
F	-	flange radius
Si(x)	-	sine integral
$J_o(x)$	-	Bessel function of zero order
α, β, χ	-	optimization coefficients
G_m	-	series terms of normalized conductance, n=0,1,2…
B_m	-	series terms of normalized susceptance, n=0,1,2…
G'	-	modified series terms of normalized conductance
B'	-	modified series terms of normalized susceptance
$e_{11}, e_{22}, e_{12}, e_{21}$	-	[e] matrix
S_1 or ρ_1	-	measured reflection coefficient of short circuit
S_2 or ρ_2	-	measured reflection coefficient of open circuit
S_3 or ρ_3	-	measured reflection coefficient of water
S_d or ρ_m	-	measured reflection coefficient of medium under test
S_{11M}	-	measured values of reflection coefficient
S_{11A}	-	actual values of reflection coefficient
ξ_1, ξ_2, ξ_3	-	criterion error or error function
TEM	-	Transverse Electromagnetic Mode
TE	-	Transverse Electric Mode
TM	-	Transverse Magnetic Mode
EFIE	-	Integral Equation for Aperture Electric Field
MFIE	-	Integral Equation for Aperture Magnetic Field

PTFE	-	Polytetrafluorethylene (Teflon)
SMA	-	Sub-Miniature A
type N	-	Navy type connector
VNA	-	Vector Network Analyzer
GPIB	-	General Purpose Interface Bus
OD	-	Outer Diameter
Agilent VEE	-	Agilent Visual Engineering Environment
MATLAB	-	Matrix Laboratory

CHAPTER 1

INTRODUCTION

The world production of palm oil for 2002 was about 6.819 million metric tons (FAO, 2002). Palm oil is increasingly popular as it provides a rich source of α and β-carotene and vitamin E, which play important roles in blood coagulation, suppression of cholesterol production and cancer inhibition. Nutrition as well as environment protection will figure prominently in consumer's choice of edible oils and fat to consume. Besides its nutritional value it is increasingly popular as raw materials for oleo chemical industry and fuel for automobiles.

Palm oil is obtained from the mesocarp of the oil palm fruits. Normally a palm tree takes about three years to produce its first fruit bunch. The oil accumulation in the mesocarp starts approximately 14-15 weeks after anthesis and increases rapidly during about 20 weeks after anthesis (Ariffin, 1986). After 20 weeks, only a small increase is observed and at the same times the percentage of free fatty acid (FFA) in oil increases as the bunch ages, thus reducing the quality and quantity of the oil. Therefore there will be a time in the life spa of each bunch when oil yield and quantity are in optimal balance. This optimum time is the time to harvest the bunch. Insufficient due to inefficient attention to ripeness standards can therefore results in very substantial oil losses since the oil content of the fruit bunch is a function of its degree of ripeness.