UNIVERSITI PUTRA MALAYSIA

RELATIONSHIP BETWEEN REFLECTION COEFFICIENT AND MOISTURE CONTENT OF OIL PALM FRUIT USING AN OPEN-ENDED RECTANGULAR WAVEGUIDE TECHNIQUE

ADIB BIN ALI

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~~DETERMINATION OF REFLECTION COEFFICIENT OF OIL PALM FRUITS IN VARIOUS MOISTURE CONTENTS AT X-BAND FREQUENCIES USING A WAVEGUIDE PROBE~~A STUDY ON THE RELATIONSHIP BETWEEN REFLECTION COEFFICIENT AND MOISTURE CONTENT OF OIL PALM FRUIT USING ~~A~~AN OPEN-ENDED RECTANGULAR WAVEGUIDE TECHNIQUE

Comment [Adib1]: DRS

By

ADIB BIN ALI

Thesis Submitted to the School of Graduate Studies, ~~Universiti~~Universiti Putra Malaysia,
~~I~~in ~~Fulfilment~~Fulfil~~l~~ment of the Requirement for the Degree of Master of Science

May 20076

Specially dedicated to:

My ~~Wife and Daughter~~Family,

My beloved

Father, Mother, Brothers and Sisters,

Nieces and Nephews,

and Friends.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

~~DETERMINATION OF REFLECTION COEFFICIENT OF OIL PALM FRUITS IN VARIOUS MOISTURE CONTENTS AT X BAND FREQUENCIES USING A WAVEGUIDE PROBE~~A STUDY ON ~~THE~~ RELATIONSHIP BETWEEN REFLECTION COEFFICIENT AND MOISTURE CONTENT OF OIL PALM FRUIT USING AN OPEN-ENDED RECTANGULAR WAVEGUIDE TECHNIQUE

Comment [Adib2]: DRS

By

ADIB BIN ALI

May 200~~5~~7

Chair~~person~~: Zulkifly Abbas, Ph~~.~~D~~.~~

Faculty~~———~~: Science

The thesis describes the development of an open-ended waveguide technique for the determination ~~of~~of complex permittivity and moisture content of the oil palm fruits of various degree of fruit ripeness. The operating frequency of the waveguide ~~operate between~~was between 8 GHz and 12 GHz. A theoretical analysis has been carried out to determine the relationship between reflection coefficient, frequency and moisture content in the oil palm fruit. The propagation of electromagnetic wave is assumed to be transverse electric (T~~Z~~E) mode. The measurement system consists of ~~the~~a standard waveguide and a PC-controlled vector network analyzer (VNA). ~~Dielectric measurement software~~ A computer program has been developed to control and acquire reflection data from the VNA using Agilent VEE at each 201 frequency points between 8 GHz and 12 GHz. Comparison results between calculated and measured reflection coefficient are presented. A calibration equation relating the

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measured and predicted moisture content has been established based on more than 1500 fruit samples. The actual moisture content ~~were~~was ~~found determined~~determining by standard oven drying method. The calibration equation was found to be accurate within ± 5–% when tested on 50 different fruit samples ~~which each biker have 30 fruits with same moisture content.~~of various moisture contents.

Comment [Adib4]: Drs

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan ~~bagi mendapat~~untuk ~~I~~ijazah Master Sains

KAJIAN KAITAN DI ANTARA KANDUNGAN KELENGASAN DAN PEKALI PANTULAN BUAH KELAPA SAWIT MENGGUNAKLAN TEKNIK PERANTI PANDU GELOMBANG

Oleh

ADIB BIN ALI

Mei 200~~5~~7

Pengerusi~~——~~: Zulkifly Abbas, Ph~~.~~D~~.~~

Fakulti~~———~~: __Sains

Tesis ini memperihalkan pembinaan teknik pandu gelombang hujung terbuka untuk menentukan ketelusan kompleks dan kandungan kelengasan bagi buah kelapa sawit yang mempunyai peringkat kematangan yang berlainan. Peranti pandu gelombang ini beroperasi antara 8GHz hingga 12GHz. Analisis teori telah dilaksanakan untuk menentukan hubungan diantara pekali pantulan, frekuensi dan kandungan kelengasan di_dalam buah kelapa sawit. Rambatan gelombang elektromagnet tersebut telah dianggap sebagai ragam elektrik (T~~Z~~E). Sistem pengukuran ini terdiri daripada peranti pandu gelombang dan penganalisis rangkaian vektor (VNA) kawalan PC.

Perisian pengukuran dielektrik telah dibina untuk mengawal dan memperolehi pantulan data-data daripada VNA dengan menggunakan Agilent VEE pada setiap 201 titik frekuensi antara 8GHz and 12GHz. Perbandingan keputusan diantara pekali pantulan yang diukur dan yang dikira ditunjukkan didalam tesis ini. Persamaan penentukuran kandungan kelengasan yang ~~berhubung~~ mengaitkan antara pengukuran kandungan kelengasan dan ramalan kandungan kelengasan telah dibina ~~bergantung kepada~~menggunakan lebih daripada 1500 ~~–~~buah kelapa sawit ~~sampel.~~ Kandungan kelengasan yang sebenar telah ~~diperolehi dengan~~ditentukan menerusi kaedah piawai pengeringan oven. Ketepatannya penentukuran persamaan tersebut adalah dalam lingkungan ± 5–% apabila diuji atas 50 buah sampel yang mana setiap bikar mengandungi 30 biji buah kelapa sawit.

Comment [Adib5]: drs

ACKNOWLEDGEMENTS

I would like to thank "The man of a thousand and one ideas", my advisor, Dr. Zulkifly Abbas. His patience, encouragement, guidance and financial support were essential to the completion of this thesis.

I would like to thank my other thesis committee members for their suggestions and criticism. I would like to thank all the wonderful supervisory committee, especially for Prof. Abd Halim Shaari and Dr. Jumiah Hassan for always keeping me thinking and for always being willing to answer even the most stupid questions.

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I thank the other members of research group, for their overall help in ~~the~~ completeion~~n~~ of this thesis.

I want to thank the Electromagnetic Research Lab and Graduate ~~s~~School ~~o~~Office for early financial support through the Exploratory and Foundational Research program.

~~I would like to thank all the wonderful supervisory committee, especially for Prof. Abd Halim Shaari and Dr. Jumiah Hassan for always keeping me thinking and for always being willing to answer even the most stupid questions.~~

I certify that an Examination Committee met on ~~12~~11th ~~April~~May 200~~3~~7 to conduct the final examination of ~~You Kok Yeow~~Adib Bin Ali on his Master of Science thesis entitled "~~A Study on the~~ Relationship Between Reflection Coefficient and Moisture Content in Oil Palm Fruit Using An Open-Ended Rectangular Waveguide

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Technique~~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 of Master of Science.

Comment [Adib7]: DRS

Members of the Examination Committee ~~are~~ were as follows:

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Date: 3 AUGUST 2007

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were 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, and is nor~~or~~ concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institutions.

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ADIB BIN ALI

Date: 1st AUGUST 2007

~~T~~TABLE OF CONTENTS

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LIST OF ~~SYMBOLS~~ABBREVIATIONS

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 δ	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
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
$\vec{H}$	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 $\mathrm{Im}(\Gamma)$	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
$\tilde{Y}$	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
Agilent VEE	Agilent Visual Engineering Environment
MATLAB	Matrix Laboratory