UNIVERSITI PUTRA MALAYSIA

A MICROWAVE DIPOLE TECHNIQUE FOR DETERMINATION OF MOISTURE CONTENT OF HEVEA RUBBER LATEX (Hevea brasiliensis Müll. Arg.)

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IPM 2015 5

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By

MARDIAH HAFIZAH BINTI MUHAMMAD HAFIZI

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

August 2015

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

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Chairman : Associate Professor Zulkifly Abbas, PhD.
Faculty : Institute for Mathematical Research.

This thesis describes a microwave reflection technique utilising a dipole sensor for determination of moisture content (*MC)* in hevea rubber latex (*Hevea Brasiliensis*). In this study the dipole sensor is used to predict the MC in hevea rubber latex by constructing a calibration equation and validating by comparing with standard method which is the over drying method. A simulation study was done using Finite Element Method (FEM) and was analyzed with measured data.

The design and simulation of the dipole were carried out using Finite Element Method (FEM) in conjunction with a COMSOL Multiphysics version 3.5 software. The measurement setup for reflection measurement consists of a dipole sensor connected to a Professional Network Analyzer N5230A (PNA). All calibrations and measurements were done in the frequency range between 0.1 GHz and 4 GHz. The comparisons between measured and calculated results were carried out for unloaded sensor as well as the sensor loaded in water and hevea rubber latex sample. Complex permittivity values required as inputs to FEM modelling were obtained using an open ended coaxial probe.

Relationships between dielectric constant (ε′), loss factor (ε″), loss tangent (tan δ) percentages of *MC* were obtained from the study. Calibration equations relating *MC* to the ε′, ε″, tan δ and magnitude of reflection coefficient (|Γ|) at various frequencies were analysed. The calibration equation based on (ε′) at 3.6 GHz was found to be the most accurate in the determination of *MC* with mean relative error 0.02 when compared to actual *MC* obtained from standard oven drying method.

Calibration equations have also been obtained to predict the amount of *MC* from the measured |Γ|. The accuracy of the equations was determined by comparing the predicted and actual *MC* obtained using the calibration equation and oven drying method, respectively. The lowest mean relative error of the calibration equation for |Γ| was found to be 0.048 at 1.5 GHz. The calibration equation for

reflection measurement at 1.5 GHz was established to be most accurate with mean relative error 0.048.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Sarjana Sains

TEKNIK MIKROGELOMBANG MENGGUNAKAN SENSOR DWIKUTUB UNTUK PENENTUAN REFLEKSI PEKALI DALAM SUSU GETAH (*Hevea brasiliensis* Müll. Arg.)

Oleh

MARDIAH HAFIZAH BINTI MUHAMMAD HAFIZI

Ogos 2015

Pengerusi : Prof. Madya Zulkifly Abbas, PhD.
Fakulti : Institut Penyelidikan Matematik.

Tesis ini menerangkan teknik gelombang mikro refleksi menggunakan sensor dwikutub untuk penentuan kandungan lembapan dalam susu getah Hevea (Hevea Brasiliensis). Dalam kajian ini sensor dwikutub digunakan untuk meramalkan kandungan lembapan dalam susu getah Hevea dengan membina persamaan penentukuran dan mengesahkan dengan membandingkan dengan kaedah standard yang merupakan kaedah pengeringan menggunakan ketuhar. Satu kajian simulasi telah dilakukan dengan menggunakan Kaedah Unsur Terhingga (FEM) dan dianalisis dengan data yang diukur.

Reka bentuk dan simulasi sensor dwikutub yang dilaksanakan dengan menggunakan Kaedah Unsur Terhingga (FEM) bersama dengan versi perisian COMSOL Multiphysics 3.5. Persediaan pengukuran untuk mengukur pantulan terdiri daripada sensor dwikutub disambungkan kepada Profesional Network Analyzer N5230A (PNA). Semua penentukuran dan pengukuran telah dibuat pada julat frekuensi antara 0.1 GHz dan 4 GHz. Perbandingan antara keputusan diukur dan dikira telah dijalankan bagi sensor tanpa sampel serta sensor dimasukkan dalam sampel air dan susu getah Hevea getah. Nilai-nilai ketelusan kompleks diperlukan sebagai input kepada FEM pemodelan diperolehi menggunakan berakhir kuar sepaksi terbuka.

Hubungan antara pemalar dielektrik, faktor kehilangan, kerugian tangen dan peratusan kandungan lembapan telah diperolehi daripada kajian. Persamaan penentukuran berkaitan kandungan kelembapan kepada pemalar dielektrik, faktor kehilangan, kerugian tangen dan magnitud pekali pantulan pada pelbagai frekuensi telah dianalisis. Persamaan penentukuran pada 3.6 GHz adalah yang paling tepat dalam penentuan kandungan lembapan dengan min ralat relatif 0.02 berbanding

kandungan lembapan sebenar yang diperolehi daripada kaedah pengeringan ketuhar standard.

Persamaan penentukuran juga telah diperolehi untuk meramalkan jumlah kandungan lembapan daripada pekali pantulan yang diukur. Ketepatan persamaan ditentukan dengan membandingkan kandungan kelembapan yang diramalkan dan sebenar diperolehi dengan menggunakan persamaan penentukuran dan kaedah pengeringan oven. Persamaan penentukuran untuk mengukur pantulan pada 1.5 GHz telah dibentuk untuk menjadi yang paling tepat dengan min ralat relatif 0,048.

ACKNOWLEDGEMENTS

"In the name of Allah. The most beneficent and the most merciful"

Alhamdulillah, all praise is due to Allah for the blessing and guidance through the completion of the study. There are many people who have lent a hand in completing this research. I would like to express my highest gratitude to my research supervisor, Associate Professor Dr. Zulkifly Abbas for all the teachings, guidance, supports, ideas, encouragements, and suggestions. I am also deeply indebted to my co-supervisor, Dr. Nurul Huda Othman for her guidance and support during this research.

My special thanks go to, Nursakinah Mohamad Ibrahim who always gave me a lot of supports and assistances during the completion of this project. I would like to thank all my colleagues and friends, especially my senior, Dr. Mohamad Faiz Zainuddin and Dr. Nor Zakiah Yahaya who have given me a lot of teachings, knowledge and guidance. Not forgotten, to all my lab mates, Ahmad Fahad, Abu Bakar, Parnia, Izzat and Amizadillah who helped me a lot with my research work.

Last but not least, it would not be possible to finish this thesis without the help and support from the people around me especially to my husband, Ahmad Fahmi Mohd Zin for his personal support, patience and sacrifice at all times. My family and family in-laws have given me their endless support and pray throughout this journey. May God bless all of you in this world and hereafter. Amen.

I certify that a Thesis Examination Committee has met on 13th August 2015 to conduct the final examination of Mardiah Hafizah Binti Muhammad Hafizi on her thesis entitled "A Microwave Dipole Technique for Determination of Moisture Content of Hevea Rubber Latex (*Hevea Brasiliensis* Müll. Arg.)" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVATIONS

DRC	Dry Rubber Content
TSC	Total Solid Content
NR	Natural Rubber
MIDA	Malaysian Investment Development Authority
RF	Radio Frequency
PC	Personal Computer
MC	Moisture Content
FEM	Finite Element Method
PNA	Professional Network Analyzer
MHz	Megahertz
GHz	Gigahertz
FDM	Finite Difference Method
BEM	Boundary Element Method
FDTD	Finite Difference Time Domain
PDE	Partial Difference Method
MoM	Method of Moment
TM	Transverse mode
TEM	Transverse
PTFE	Polytetrafluoroethylene
PEC	Perfect Electric Conductor
RMSE	Root Mean Square Error
S11	Reflection coefficient
ε	Dielectric Constant
ε'	Dielectric Constant
ε"	Loss Factor
m_w	Initial mass
m_d	Final mass
λ	Wavelength
ω	Angular frequency
$\vec{E}$	Electric field
$\vec{H}$	Magnetic field
$\vec{D}$	Electric displacement
$\vec{B}$	Magnetic displacement
$\vec{J}$	Current density
ρ_q	Charge density
μ	Permeability
mm	milimetre
Ω	Ohm
Γ	Reflection coefficient
Γ_m	Reflection coefficient of the sample
Z_s	Characteristics impedance of unloaded
Z_m	Characteristics impedance of loaded sensor
N	Number of elements
V_e	Element potential typically approximated with polynomial equation
n	Number of nodes

α_i	Element shape function
V_{ei}	Potential at node *i*
W_e	Energy per unit length of each element
$C_{ij}^{(e)}$	Element coefficient matrix
f	Node with free potentials
p	Node with predetermined potentials
$[K]$	Sparse matrix
$[b]$	Excitation matrix
E^{inc}	Incident electric field
E^{ref}	Reflected electric field
$U_j^{(k)}$	Unknown complex constants
ℓ	Path of integration
$[S]$	coefficient matrix of global system
$[U]$	solution vector matrix of undetermined coefficients at the nodes
$[f]$	Solution vector matrix of contour integrals
η	Complex intrinsic impedance of the medium
R^2	regression coefficient
f_c	critical frequency

CHAPTER 1

INTRODUCTION

1.1 An Overview of *Hevea* Rubber Latex

Malaysia is one of the largest producing countries for natural rubber other than Thailand and Indonesia. Malaysian rubber industry has developed and renovated itself into a more integrated industry. As a well-known agricultural country, the determination of total solid content (TSC) and dry rubber content (DRC) of *hevea* rubber latex is importance to define the quality and process controls.

Natural rubber (NR) is the basic element of many products used in the industrial, transportation, hygienic, medical sectors and consumer because of its resilience, elasticity, and toughness. According to Malaysian Investment Development Authority (MIDA), there are more than 500 manufacturers products in Malaysia such as tires and tire-related products, industrial and general rubber products. Rubber is sold in the form of dry rubber blocks or concentrated rubber latex. The rubber content determines the price of the rubber. Hence, it is need to determine the dry rubber content before trade-off.

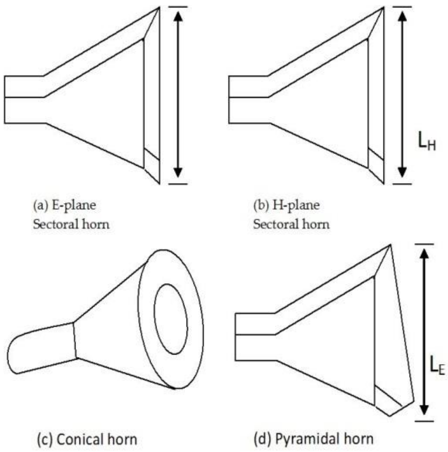
The investigation of the dielectric properties of *hevea* latex has not been in-depth. Thus, it is not fully understood. For this reason and at the same time to increase the quality and usage of natural rubber latex in industrial application in order to compete with its synthetic counterpart, *heve*a rubber latex is chosen as the sample in this study.

1.2 An Overview of Microwave Technique

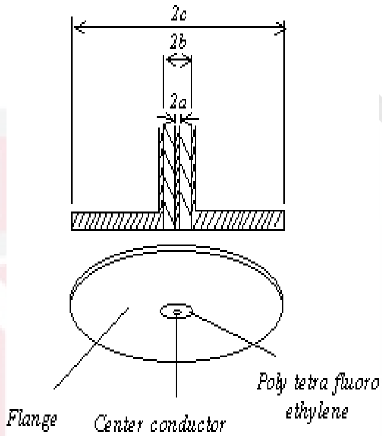
Nowadays, microwaves are widely used in modern technology. Television industry is one of the major fields. Microwaves are also used in national and local security application, such as early warning radar, missile guidance systems, and Doppler's radar, to detect and control the speed of vehicles. Furthermore, microwave oven is becoming more common on consumer level. Even though the field is relatively new, microwaves application is progressive and growing rapidly. Microwave technique takes advantages of the high correlation between dielectric properties of the materials under test and their moisture content.

1.3 Microwave Sensors

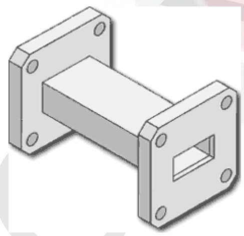
The development of microwave sensor has begun since 1960s. In the past, microwave technology is not suitable for industrial application. The lack of understanding of the material causes difficulties in sample characterization. The sensors are also big, unreliable and very expensive. But nowadays, all these problems have been studied and overcome by expertise who designed a better microwaves sensor for industrial uses. Microwave sensors utilize electromagnetic field and devices internally operating at frequency from 300 MHz up to terahertz range (Polivka, 2007).There are many types of microwave sensor that have been developed and created. The most common microwave sensors are based on coaxial type, waveguide, horn antenna and microstrip as shown in Figure 1.1. Microwave sensors produce an electromagnetic (RF) field between transmitter and receiver. The interaction of microwave sensors consist of reflection, refraction, scattering, emission, absorption, or change in speed or phase.



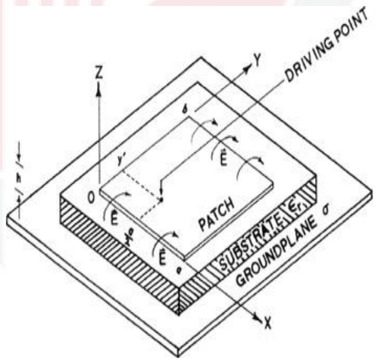
(a) Horn antenna



(b) Open-ended coaxial line



(c) Rectangular waveguide



(d) Microstrip patch antenna

Figure 1.1: Examples of Microwave Sensors.

1.4 Numerical Methods in Electromagnetics

The computation of electromagnetic problems has developed exponentially due to the advancement and availability of computer resources. The main reasons of numerical methods become popular are the advent of personal computer (PC) and the available software in used today. There is various problems in electromagnetics require a numerical solution because it cannot be solved analytically. The governing equations can take the form of either a differential equation or an integral equation in these problems (Maxwell's equations or related equations). The methods below are some of the most commonly used in electromagnetics. The details will be discussed in the next chapter.

1) Finite difference method
2) Moment method
3) Finite element method

1.5 Interaction of Microwaves with Material

During the interaction between electromagnetics wave and material, the energy of the wave will be captivated by the water molecules. The amount of energy being captivated depends on the number of water molecules within the material. The behaviour of bulk materials in a microwave field can be characterized easily. One can characterize how bulk materials behave in a microwave field. The energy can be absorbed, reflected, refracted or scattered by the materials. The characteristics, chemical composition, size and shape of the materials will affect how it reacts in microwave field.

The electrical properties of materials can be expressed in terms of complex permittivity or dielectric properties of material, $\varepsilon=\varepsilon'-j\varepsilon''$. The real part, ε' is identified as the dielectric constant which represent the capability of the material to store energy whilst the imaginary part, ε'', known as dielectric loss factor which is a measure of the energy absorbed from the applied field.

1.6 Problem Statement

The quality of *hevea* latex is based on the dry rubber content (DRC). The demand of rubber is very high. The competition between the sellers has caused the immoral practises such as addition of water in the latex which lead to disagreement between buyer and seller. Moisture content can be determined by a variety of methods which will be briefly described in Chapter 2, but the challenge is to get a fast and accurate data, especially if the required method is non-destructive. The advantage of conventional method which is oven drying method is precise but it takes a long time to get the result. Moreover, it is also laborious and unproductive. Hence a rapid testing method such as microwave method needs to be developed.

Microwaves technique has been widely used since 1950s. Different types of sensors have been used in microwave technique. The work done by (Yahaya, 2012) proposed the application of microstrip patch sensor for determination of moisture content in *hevea* rubber latex. The limitation of this study is that limited volume of sample can be tested due to the restricted sensing area.

For this study, the reflection measurement was done using dipole sensor with operating frequency between 0.1 GHz and 4 GHz. The dipole sensor has the advantage of deep sensing as the sensor can be fully immersed in the sample. However, electromagnetic interaction between the sensor and external media are not reported due to unavailability of exact and analytical methods to compute reflection coefficient of this dipole sensor. Thus this study provides the analytical method.

1.7 Objectives

The main objectives of this work are:

1. To determine the variation in the dielectric constant, loss factor and loss tangent of latex of various percentages with frequency.
2. To obtain the relationship between the dielectric constant, loss factor and loss tangent with different percentages of moisture content (*MC*) in *hevea* rubber latex.
3. To establish calibration equations to predict *MC* from measured reflection coefficient.
4. To explore the application of Finite Element Method (FEM) to calculate the reflection coefficient of dipole sensor in latex.

1.8 Scopes and Limitations

The thesis describes a study on a microwave dipole technique for determination of moisture content of *hevea* rubber latex (*hevea brasiliensis*). The standard method used was oven-drying method. The focus of this study is to introduce a new method in determination of *MC* in *hevea* rubber latex. Dielectric constant, loss factor and loss tangent of *hevea* rubber latex were studied in the research as well as the reflection coefficient of the dipole sensor. The study involves Finite Element Method, which is a numerical technique used in exploring the dipole sensor. The comparisons were made between the dipole technique and standard method. However, there are limitations of this study which is time constraint in producing a well-designed sensor. The accuracy of the technique can be increased and improved by extending the works on the sensor design. FEM was done by using COMSOL Multiphysics® version 3.5 software. FEM depends on the number of elements used in order to have a good result. High performance computer is needed to generate a simulation with high number of elements.

1.9 Overview of the Thesis

This thesis is divided into six chapters. Chapter 1 is a general introduction on the technique. This chapter also gives details about objectives and the significant of the research. Chapter 2 reviews and summarizes various experimental techniques in the moisture determination and numerical techniques in microwave application

.Chapter 3 presents the design of dipole sensor based on finite element method (FEM) using COMSOL software. The chapter describes the basics of electromagnetic theory, Maxwell's equation, as well as the calculation procedures of FEM, which is applied on dipole sensor. In this chapter, the processes involves in Finite Element Method (FEM) using COMSOL software were explained.

Chapter 4 describes the practical and measurements of reflectivity using dipole sensor as well as permittivity measurement using HP85070B Coaxial Probe. The measurements techniques were discussed in details in this chapter. In this chapter, the design of this sensor using COMSOL software is described in details. Chapter 5 focuses on the results and discussion of the measurements. It discusses the relationship between moisture content with dielectric constant, loss factor, loss tangent and magnitude of reflection coefficient. In addition, this chapter also discusses the *MC* prediction based on permittivity and reflectivity measurement. Comparison between measured and calculated was also presented in this chapter as well as comparison between actual *MC* and predicted *MC*. Finally, Chapter 6 summarizes the contribution of the research and also provides recommendation for future works.

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