UNIVERSITI PUTRA MALAYSIA

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By

ZAHARIAH ZAKARIA

Thesis Submitted in Fulfilment of the Requirements for the Degree of Master of Science in the Faculty of Science and Environmental Studies, Universiti Putra Malaysia

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To my beloved mother and my late father:

LOSING MAKES WINNING WORTHWHILE

Thank you so much

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LIST OF SYMBOLS AND ABBREVIATIONS

ε^*	Complex permittivity
ε'	Dielectric constant
ε''	Dielectric loss
M_p	Maturity index
Na^+	sodium ion
Cl^-	chlorine ion
ε_f	Permittivity of fibre
ε_l	Permittivity of oil
ε_w	Permittivity of water
V_f	Volume fraction of fibre
V_l	Volume fraction of oil
V_w	Volume fraction of water
ρ_f	Relative density of fibre
ρ_l	Relative density of oil
ρ_w	Relative density of water
W_f	Mass of fibre
W_l	Mass of oil
W_w	Mass of water
$m.c$	Moisture content
C	Capacitance
dQ	Small change in charge
dV	Small change in voltage
E	Electric field
A	Area
d	Distance
$\tan\delta$	Tangent of loss angle
Y	Admittance
I	Current
V	Voltage
G	Conductance
Z	Impedance
i	$\sqrt{-1}$
ε_s	Static permittivity
ε_∞	Infinite permittivity

ω	Angular frequency
τ	Relaxation period
χ	Dielectric susceptibility
κ	Geometrical factor
Z_0	Characteristic impedance
M_w	Mass of wet sample
M_d	Mass of dry sample

Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

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August 1998

Chairman: Associate Professor Hj. Kaida Khalid, Ph.D

Faculty : Science and Environment Studies

Dielectric properties at frequencies from 10^{-2} to 10^{6} Hz and 0.2 to 20 GHz of mashed mesocarp of oil palm fruits at various stages of maturity are presented. The study includes the variation of dielectric constant, ε' and dielectric loss, ε'' with moisture content ranging from 40 to 100% (wet basis). Measurement of the dielectric properties was done by using open-ended coaxial line probe and automated network analyzer for high frequency and spectrum analyzer for low frequency. The accuracy of the measurement is about 5% for dielectric constant, ε' and 3% for dielectric loss, ε''. Results of measurements demonstrate a good relationship between dielectric properties of the mesocarp and moisture content or maturity of the fruit and also close to the values predicted by dielectric mixture models especially at frequencies above 3 GHz. At 10 GHz the difference between predicted and measured values are within 5%.

Results of measurement also show that the ac ionic conductivity dominated in the region less than 3 GHz while above 3 GHz the dipole orientation of water molecules

becomes dominant. Such a crossover in the form of dielectric loss from conductive loss to the dipole orientation about 2 GHz was observed. The effect of ac ionic conductivity is higher in young fruit and decreasing as a degree of maturity increases.

Permittivity of oil palm mesocarp over the frequency range was found to increase with moisture content. A significant variation of ε' and ε'' with maturity at 0.2 GHz and 10 GHz respectively make it suitable to form a maturity index as suggested by Nelson et al.. With moisture content ranging from 25% to 85%, the ε' at 2 GHz varies from 11 to 61 and the ε'' varies from 2.1 to 24.6 at 10 GHz. Based on the above values the permittivity-based maturity index for young and fully ripe fruits are 1 and 0.3 respectively.

In low frequency the results show that almost the same type of dielectric dispersion mechanisms are observed at different range of moisture content. It may be possible to explain all these dispersion processes by means of dielectric mechanism for quasi-dc and diffusive.

This study gives valuable information for the analysis and design of microwave sensor for assessment of quality of the oil palm fruits and could also be used for estimating microwave absorption during fruit sterilization and fruit loosening.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi syarat-syarat untuk penganugerahan ijazah Master Sains.

CIRI-CIRI DIELEKTRIK MESOKARP BUAH KELAPA SAWIT PADA PELBAGAI PERINGKAT KEMATANGAN

Oleh

ZAHARIAH ZAKARIA

Ogos 1998

Pengerusi: **Professor Madya Hj. Kaida Khalid, Ph.D**

Fakulti: **Sains dan Pengajian Alam Sekitar**

Ciri-ciri dielektrik bagi mesokarp buah kelapa sawit yang lumat di antara 10^{-2} ke 10^{6} Hz dan 0.2 ke 20 GHz dikaji pada pelbagai peringkat kematangannya. Kajian ini meliputi perubahan pemalar dielektrik, ε' dan kehilangan dielektrik, ε'' dengan kandungan kelembapan di antara 40% ke 100%. Pengukuran ciri-ciri dielektrik dibuat menggunakan penduga talian sepaksi terbuka hujung dan 'automated network analyzer' dengan frekuensi tinggi dan penganalisa spektrum dengan frekuensi rendah. Ketepatan pengukuran adalah lebih kurang 5% bagi pemalar dielektrik dan 3% bagi kehilangan dielektrik. Keputusan pengukuran ini menunjukkan perhubungan di antara ciri-ciri dielektrik mesokarp dan kandungan lembapan atau kematangan buah dan hampir kepada nilai yang dijangkakan oleh model campuran dielektrik terutama pada frekuensi yang melebihi 3 GHz. Keputusan pengukuran ini juga menunjukkan kekonduksian ionik dominan di kawasan kurang daripada 3 GHz sementara orientasi dwikutub molekul air menjadi dominan di kawasan melebihi 3 GHz. Peralihan dalam bentuk kehilangan

dielektrik kepada kehilangan konduksi ke orientasi dwikutub dapat diperhatikan pada 2 GHz. Kesan daripada kekonduksian ionik adalah tinggi pada buah muda dan menurun apabila kematangan meningkat.

Ketelusan mesokarp pada julat frekuensi meningkat mengikut kandungan lembapan. Perubahan ketara ε' dengan kematangan pada 0.2 GHz dan ε'' dengan kematangan pada 10 GHz adalah sesuai untuk membentuk indeks kematangan seperti yang dicadangkan oleh Nelson et al.. Dengan kandungan lembapan daripada 35% ke 85%, ε' pada 2 GHz berubah dari 11 ke 61 dan ε'' berubah dari 2.1 ke 24.6 pada 10 GHz. Berdasarkan nilai-nilai di atas, ketelusan berdasarkan indeks kematangan bagi buah muda ialah 1 dan buah masak ialah 0.3.

Keputusan pada frekuensi rendah menunjukkan bahawa hampir kesemua mekanisma penyebaran dielektrik adalah kelihatan pada kadar yang berbeza mengikut kandungan lembapan. Kajian ini dapat memberikan penerangan yang penting untuk analisis dan rekaan pengesan gelombang mikro bagi penilaian kualiti buah kelapa sawit dan boleh juga digunakan bagi menganggarkan penyerapan mikrogelombang semasa pensterilan dan peleraian buah.

CHAPTER I

INTRODUCTION

Palm oil is now the leading vegetable oil in international trade. Malaysia is the world's leading producer of palm oil where it accounted for about 51% of total global palm oil production as reported in 1996 (FAO,1996). There are some major features determining the future demand and market opportunities for palm oil. Some of them are (PORIM Occasional Paper No. 30):

- The impact of the EC agriculture policy:

  Latest changes are going to have a double-positive effect on palm oil: They are firstly, the effect on EC domestic production and supplies of oilseeds and, secondly the effects on oilmeal demand (and thus oilseed crushings and seed oil output)
- The population factor in demand.
- The nutritional advantages of palm oil should also have a beneficial effect on both the demand for and price of palm oil.
- The prospective trend on the production of animal fats up to the year 2000.

Introduction to Sampel Composition

Palm oil is obtained from the mesocarp of the oil palm fruits. The fruit of the oil palm is a drupe. It consists of a pericarp, made up of exocarp (skin), mesocarp (often wrongly called pericarp) and endocarp (shell), surrounding usually one, but sometimes up to four kernels. The kernel has a testa (skin), a solid endosperm and an embryo. The mesocarp contains fibres which run longitudinally through the oil bearing tissue from the base towards the fruit tip. The fibrous material constitutes almost 16% of the mesocarp (Hartley, 1977). Based on the shell thickness, a fruit or palm may be described as being either dura, tenera or psifera variety. The psifera is shell-less; many psifera palms fail to set fruit, so the psifera is not commercially important. The other variety dura has a thick shell, while tenera has a thin shell and high mesocarp content. The tenera variety is the type of fruit preferred for commercial use, because more of the pericarp consists of oil bearing mesocarp than in dura.

The fruit bunch is ovoid and may reach 50 cm in length and 35 cm in breadth. The bunch consists of the outer and inner fruit and the spikelets stalks and spines, as illustrated in Figure 1.1 (Khalid, 1992). Ripening is usually from the apical to the basal of the bunch and from the outer spreading gradually towards the inner fruits of the spikelet. As the fruit in the bunch ripens, the colour changes from black to reddish orange and the oil content increases in the process. When the oil content reaches the maximum, the fruit becomes loose and falls to the ground.

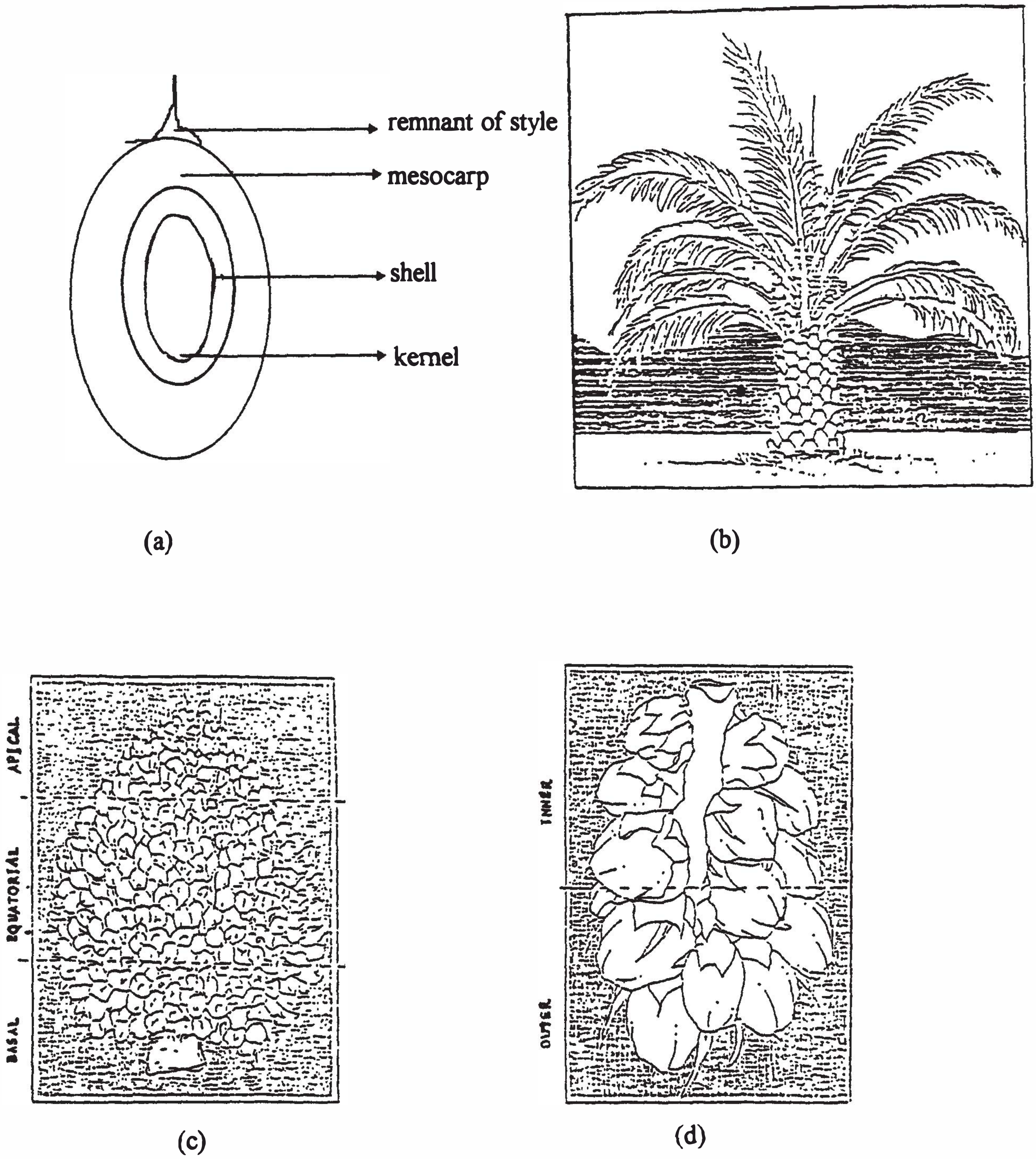

Figure 1.1: Palm oil fruit, tree and bunch
a) cross-section of fruits
b) palm oil tree
c) schematic division of fruit bunch
d) the outer and inner halves of a spikelet

The fruit has at least three important constituents that is water, oil and fibre. It has also been assumed that fibre consists almost 16% of the total constituents throughout. The water and oil contents depend on the stage of ripeness.

Oil from fresh ripe fruit contains as little as 0.1% fatty acid (estimated as palmitic acid), but in bruised and crushed fruit the free fatty acid (FFA) may increase up to 50% in a few hours (Hartley,1977). Fruits which has been kept for several days before processing or which has been allowed to become over-ripe on the palms, may be covered or invaded by a number of moulds. Usually these fungi invaded the base of detached fruits or wounds on the fruit surface.

Fat formation in the mesocarp takes place very late in fruit development. From the 8th. to the 16th. week after pollination fats constitute less than 2% of the dry weight. There is in fact very little addition of any kind to the dry weight of the mesocarp from the 8th. to the 19th. week when, just prior to ripening, dry weight increases by 300-500% and fats rather suddenly come to constitute 70-75% of dry matter (Hartley,1977).

For the production of low FFA in the oil, the major requirements are:

i) minimal bruising of the fruit during harvesting, carriage and movement at mill side.

ii) minimal time between harvesting and sterilisation.

iii) the processing system must be such that the fruit or extracted oil does not cool down and come into contact with apparatus or materials which could cause a recommencement of lipolysis.

Oil and fats are predominantly made up of triglycerides. In palm oil saturated palmitic acid and mono-unsaturadetic oleic each account for about 40% of the fatty acids present since fatty acids contribute about 95% of the total weight of triglyceride molecule and because they comprise the reactive portion of the molecule, they greatly influence the character of the glyceride. Thus the chemistry of oils and fats is to a large extent the chemistry of their constituent fatty acids and their physical characteristics are related to the make-up of the triglycerides.

Free fatty acids (FFA) occur as a result of fat splitting reactions in which the glyceride molecule combines with water to yield FFA and in succession , diglycerides, mono-glycerides, free glycerol (Joncin,1953). Enzymatic hydrolysis, due to a highly active lipase which occurs naturally in palm fruits, is prevented by prompt sterilisation of the freshly cut bunches; subsequent contact of the processed oil with cell debris and dirt should be avoided.

The percentage of FFA is a useful quality criterion for crude palm oil. It is indicative of the total damage suffered, as the increase in FFA is generally paralleled by oxidation spoilage as well.

Radio Frequency (RF) and Microwave Frequency (MW)

Before we briefly introduce the topics, it is important to define the frequency ranges for which the terms microwave and radio frequency will be subsequently used. At frequency below 100 MHz, where conventional open wire circuits are used, the technique of industrial processing will be referred to as radio frequency heating. However at microwave frequencies (above 500 MHz) wired circuit cannot be used and the power is transferred to the applicator containing the material to be processed in waveguides. This technique will be referred to as microwave heating systems. This definition combining the two frequencies regime is shown in the spectrum in Figure 1.2.

Microwave permittivities or dielectric properties of materials are important because these properties affect the interaction of electromagnetic energy with the materials at microwave frequencies. The complex relative permittivities is represented as $\varepsilon^* = \varepsilon' - i\varepsilon''$, where the real part ε' is the dielectric constant and the imaginary part ε'' is the dielectric loss factor. The dielectric constant ε' influences the electric field distribution and the phase of the waves travelling through the material, where the energy absorption and consequent attenuation is influenced principally by the loss factor, ε'' (Nelson,1994).

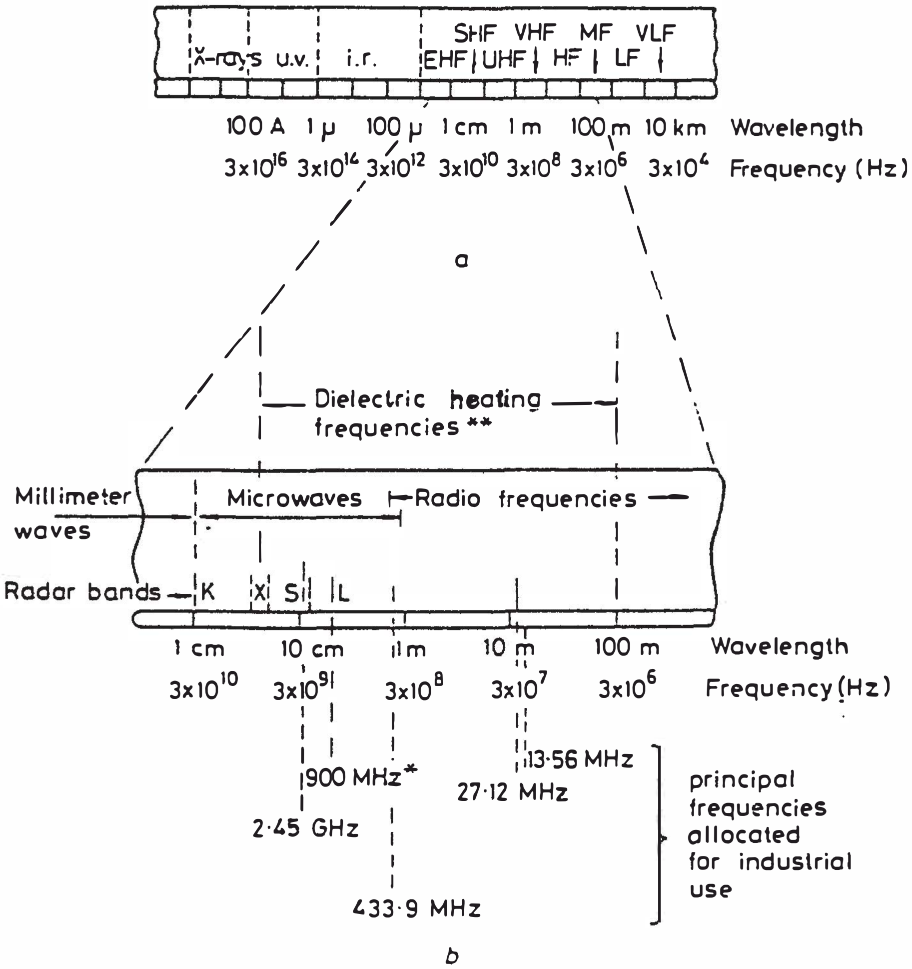

Figure 1.2. (a) The electromagnetic spectrum
(b) Definition of various frequencies.