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MULTIFREQUENCY DIELECTRIC SENSING OF MOISTURE AND SLUDGE CONTAMINATION IN CRUDE PALM OIL

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By

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MULTIFREQUENCY DIELECTRIC SENSING OF MOISTURE AND SLUDGE CONTAMINATION IN CRUDE PALM OIL

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Chairman : Samsuzana Abd. Aziz, PhD

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Deterioration of Crude Palm Oil (CPO) quality caused by contamination during and after milling stages is a serious problem in palm oil processing. These include contamination pick-up during milling such as sterilizer condensate introduced during sterilizing stage and badly oxidized sludge oil during purification stage. Meanwhile, contamination after milling stages occured due to illegal activities such as siphoning off CPO while being transported from mill to refineries. The amount that was siphoned off was then replaced by liquid such as water, sludge, diesel or used oil which resulted in deterioration of the CPO being processed at the refineries.

The conventional testing methods to measure CPO quality mostly depending on the determination of parameters such as iodine value (IV), peroxide value (PV), Deterioration of Bleacheability Index (DOBI), free fatty acid (FFA) and moisture content. The procedures to obtain these parameters are laborious, time consuming

and require skilled operators. In-situ monitoring and early detection of CPO contamination could lessen oil degradation, thus enhance the value of the final palm oil products. Therefore, an efficient technique for CPO quality monitoring is needed to enhance the CPO quality and production process.

This study used dielectric spectroscopy technique to detect possible contamination in homogeneous mixture of CPO. Initially, dielectric properties of pure CPO were determined. After that, the dielectric properties of CPO which were artificially contaminated with water and sludge were measured at different temperatures and contamination levels. For water contamination test, dielectric properties of CPO was measured using a 16452A Agilent liquid dielectric test fixture which was connected to a 4263B Agilent LCR meter over six frequencies, ranged from 100 Hz to 100 kHz. For sludge contamination test, the liquid dielectric test fixture was connected to a 4294A Agilent precision impedance analyzer ranging from 3 MHz to 30 MHz. Both tests were replicated three times with a randomized order of temperature and contaminant levels.

The variations of dielectric properties of pure and homogeneous mixture of contaminated CPO at different temperature levels were observed and analyzed using ANOVA and Duncan's multiple range test (DMRT). The principal component regression (PCR) and partial least squares (PLS) analysis were used to develop model for contamination prediction. The results showed that, there was generally significant different in the value of the mean measured dielectric constant as the temperature increased from 28°C to 55°C ($p<0.0001$). This study also found that when water was introduced into the CPO, the value of dielectric constant (measured at frequency ranged from 100Hz to 100 kHz) increased from 3.01 to 4.73 with increasing contamination levels. When sludge was introduced into the CPO, the value of dielectric constant (measured at frequency ranged from 3MHz to 30MHz) increased from 3.01 to 63.53 with increasing contamination levels. Generally for both test, there were significant differences between the dielectric constant of pure and contaminated CPO ($p<0.0001$).

The PCR and PLS calibration models showed a good prediction capability for different temperature with sludge and water contamination levels. The classification of water contamination yielded very substantial correlation with r^2 value ranged from 0.96 to 0.99. The best result was obtained at 55ºC with the lowest value of SECV of 0.58%. The classification of sludge contamination yielded very substantial correlation with r^2 value ranged from 0.91 to 0.98. The best result was obtained at 28ºC with the lowest value of SECV of 1.04%.

The result from this study could provide the foundation for studies on probing the physiochemical properties of CPO for in-situ monitoring of CPO quality. This study found that the frequency range substantial for contamination detection is generally low (<12 MHz). This is very attractive for industrial application because instrumentation required for such measurements is relatively inexpensive and does not have signal integrity issues associated with high frequency instrumentation.

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

PENGESAN DIELEKTRIK PELBAGAI FREKUENSI UNTUK KELEMBAPAN DAN ENAPCEMAR DALAM MINYAK SAWIT MENTAH

Oleh

KHAIRUNNISA HAMDAN

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Kemerosotan kualiti minyak sawit mentah (CPO) yang disebabkan oleh pencemaran semasa dan selepas peringkat pengilangan adalah satu masalah serius dalam pemprosesan minyak sawit. Ini termasuk pencemaran yang terjadi semasa pengilangan seperti kondensasi pensteril di peringkat pensterilan dan enapcemar yang teroksida teruk semasa peringkat penulenan. Sementara itu, pencemaran selepas peringkat pengilangan berlaku disebabkan oleh aktiviti yang menyalahi undang-undang seperti penyaluran keluar CPO ketika sedang diangkut dari kilang ke kilang penapis. Jumlah yang telah disalur keluar kemudian digantikan dengan cecair seperti air, enapcemar, diesel atau minyak yang telah digunakan mengakibatkan kemerosotan kualiti CPO yang akan diproses di kilang penapisan.

Kaedah konvensional untuk mengukur kualiti CPO kebanyakannya bergantung kepada penentuan parameter seperti nilai iodin (IV), nilai peroksida (PV), kemerosotan indeks pelunturan (DOBI), asid lemak bebas (FFA) dan kandungan kelembapan. Prosedur bagi mendapatkan parameter ini agak merumitkan, memakan masa dan memerlukan operator yang mahir. Pemantauan terus dan pengesanan awal pencemaran CPO boleh mengurangkan degradasi minyak, dengan itu meningkatkan nilai akhir produk minyak sawit. Oleh itu, teknik yang cekap untuk pemantauan kualiti CPO diperlukan untuk meningkatkan kualiti dan proses penghasilan CPO.

Kajian ini menggunakan teknik spektroskopi dielektrik untuk mengesan pencemaran yang mungkin terdapat dalam campuran homogen CPO. Pada mulanya, sifat dielektrik CPO tulen ditentukan. Selepas itu, sifat-sifat dielektrik CPO yang tercemar dengan air dan enapcemar secara buatan diukur pada suhu dan tahap pencemaran yang berbeza. Untuk ujian pencemaran air, sifat dielektrik CPO telah diukur menggunakan alat pengujian dielektrik bendalir Agilent 16452A yang disambungkan kepada alat pengukur LCR Agilent 4263B terhadap enam frekuensi, berjulat dari 100 Hz hingga 100kHz. Untuk ujian pencemaran enapcemar, alat pengujian dielektrik bendalir tersebut disambungkan kepada alat penganalisa impedance Agilent 4294A yang berjulat antara 3 MHz hingga 30 MHz. Kedua-dua ujian telah diulang tiga kali dengan susunan suhu dan tahap pencemaran secara rawak.

Variasi sifat dielektrik CPO tulen dan campuran homogen tercemar di peringkat suhu yang berbeza telah dikaji dan dianalisis menggunakan ANOVA dan DMRT. Regresi komponen utama (PCR) dan analisis permbahagian persegi terkurang (PLS)

telah digunakan untuk membangunkan model ramalan pencemaran. Hasil kajian menunjukkan bahawa, secara umumnya terdapat perbezaan yang signifikan dalam nilai purata pemalar dielektrik apabila suhu meningkat daripada 28°C hingga 55°C ($p < 0.0001$). Kajian ini juga mendapati bahawa apabila air telah dimasukkan ke dalam CPO, nilai dielektrik malar (diukur pada frekuensi antara 100Hz hingga 100 kHz) meningkat dari 3.01 kepada 4.73 dengan pertambahan tahap pencemaran. Apabila enapcemar dimasukkan ke dalam CPO, nilai dielektrik malar (diukur pada frekuensi antara 3MHz hingga 30MHz) meningkat dari 3.01 kepada 63.53 apabila tahap pencemaran semakin meningkat. Amnya bagi kedua-dua ujian, terdapat perbezaan yang signifikan antara pemalar dielektrik CPO tulen dengan CPO tercemar ($p<0.0001$).

Model PCR dan penentukuran PLS menunjukkan keupayaan ramalan yang baik untuk suhu yang berbeza dengan tahap pencemaran enapcemar dan air. Klasifikasi pencemaran air menghasilkan korelasi yang sangat signifikan dengan nilai r^2 yang berjulat dari 0.96 hingga 0.99. Hasil yang terbaik telah diperolehi pada suhu 55ºC dengan nilai SECV yang paling rendah iaitu sebanyak 0.58%. Klasifikasi pencemaran enapcemar menghasilkan korelasi yang sangat signifikan dengan nilai r^2 yang berjulat dari 0.91 hingga 0.98. Hasil yang terbaik telah diperolehi pada 28ºC dengan nilai SECV yang paling rendah iaitu sebanyak 1.04%.

Hasil daripada kajian ini menjadi asas bagi kajian ke atas sifat physiochemical CPO untuk pemantauan terus CPO yang berkualiti. Kajian ini mendapati bahawa julat frekuensi yang sesuai untuk mengesan pencemaran amnya adalah rendah (<12 MHz). Ini amat menarik untuk kegunaan industri kerana peralatan yang diperlukan untuk pengukuran tersebut adalah murah dan tidak mempunyai isu-isu integriti isyarat yang berkaitan dengan instrumentasi berfrekuensi tinggi.

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I certify that a Thesis Examination Committee has met on 10 July 2012 to conduct the final examination of Khairunnisa Hamdan on her thesis entitled "Multifrequency Dielectric Sensing Of Moisture And Sludge Contamination In Crude Palm Oil" 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 Degree of Master Science.

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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 Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

KHAIRUNNISA HAMDAN

Date: 10 July 2012

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LIST OF ABBREVIATIONS

NKEA	National Key Economic Areas
GNI	Gross National Income
PORIM	Palm Oil Research Institute Malaysia
FFA	Free Fatty Acid
DOBI	Deterioration of Bleacheability Index
FAS	Flame Atomic Absorption Spectroscopy
AAS	Atomic Absorption Spectroscopy
PV	Peroxide Value
FTIR	Fourier Transform Infrared
NIR	Near infrared
IR	Infrared
ANOVA	Analysis of variance
DMRT	Duncan's multiple range test
RBD	Refined, bleached and deodorized

LIST OF NOMENCLATURES

ε'	dielectric constant
ε''	dielectric loss
ω	angular frequency
α	correction coefficient
C_p	parallel capacitance
C_o	air capacitance
f	frequency
R_p	parallel resistance

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The oil palm industry plays an important role in contributing to Malaysia's economic growth. In 2010, exports earnings from oil palm products reached RM 59.77 billion with an increase of 20.4% from RM49.66 billion in 2009 (Choo, 2011). Under the National Key Economic Areas (NKEA), palm oil industry is targeted to raise a total Gross National Income (GNI) contribution of RM125 billion to reach RM128 billion by 2020 (Anon, 2010). In order to achieve this target, only the highest quality of Crude Palm Oil (CPO) that has passed through stringent quality procedures is to be produced. This strict standard operating procedure would prevent any possible contamination introduced during or after milling stages.

The conventional testing methods to measure CPO quality mostly depending on determination of parameters such as iodine value (IV), peroxide value (PV), Deterioration of Bleacheability Index (DOBI), free fatty acid (FFA) and moisture content. The procedures to obtain these parameters are laborious, time consuming and require skilled operators. In order to solve this problem, (Moh *et al.,* 1999) have developed a near infrared (NIR) spectroscopy method to measure PV in CPO. Besides, Man and Moh (1998) had also developed this technique in the determination of FFA in CPO. Results from both studies indicated that NIR spectroscopy can reduced the time taken for sample analysis when compared to the conventional wet chemical analysis. Besides, the amount of hazardous solvents can be reduced as well as the cost of labor. More recently, Fourier Transform Infrared (FTIR) spectroscopy has been introduced in the determination of FFA, moisture, peroxide and IV of CPO as well as in the analysis of the extra virgin olive oil adulterated with palm oil (Che Man *et al.* 1999a; Che Man and Mirghani, 2000; Moh *et al.,* 1999; Rohman and Man, 2010). Those studies showed very promising results in rapid determination of oil quality. Hence, the development of rapid and non-destructive measuring techniques for CPO quality monitoring has potential to enhance the efficiency of palm oil quality monitoring.

In this study, dielectric spectroscopy technique was introduced as an effort to improve the palm oil quality sensing system in Malaysia. Dielectric spectroscopy, also known as impedance spectroscopy, has been used for process analysis for some time, as it offers the ability to measure bulk physical properties of materials. The advantage of dielectric spectroscopy techniques over existing methods of monitoring materials quality is it offers flexibility in term of design where a custom-bulit system (which lower the cost) can be developed once analytical model of sensory attributes is identified. The penetration depth of dielectric spectroscopy can be adjusted by changing the separation between the sensor electrodes, enabling measurement through other materials to reach the substrate of interest. Because it measures the dielectric properties of materials, it can provide information not attainable from other spectroscopy (Bakeev, 2010).

In agricultural studies, dielectric spectroscopy is one of the established techniques which has been well recognized and developed for automatic monitoring of various agricultural products and food materials such as fruits (Nelson and Trabelsi, 2008; Nelson, 2004; Nelson *et al.,* 2005; Nelson *et al.,* 2007; Canchun and Zichen, 2008) vegetables, meat (Nelson, 2009; Nelson and Trabelsi, 2008; Nelson *et al.,* 2007; Bodakian and Hart, 2002) and cereal products (Nelson and Trabelsi, 2008). It has been used for process monitoring as a substitute method to existing technologies that may not detect all the additives or contaminants in formulating food products (Bakeev, 2010).

Since dielectric spectroscopy is a rapid, non destructive and less expensive method, the dielectric properties of agricultural products become area of interest for several reasons (Nelson, 1991). These include the sensing of moisture content through its correlation with the dielectric properties of cereal grain and oilseed crops (Nelson et. al., 2000), the influence of permittivity on the dielectric heating of products at microwave or lower radio frequencies(Nelson, 1996), and the potential use of permittivities for sensing quality factors other than moisture content (Nelson *et al.,* 1995).

1.2 Problem of Statements

There are several factors that cause CPO contamination as well as deteriorate its fully processed product quality. Gee (2005) reported that the deterioration of CPO in a palm oil mill in Johor, Malaysia was mostly caused by conditions and contamination pick-up during milling. These include contamination with sterilizer condensate introduced during sterilizing stage, contamination with badly oxidized sludge oil during purification stage, and overheating of CPO in storage tank after the extraction process.

Contamination of CPO could also occur with the presence of heavy metal like copper and iron. According to Chooi (1981), these heavy metals promote deterioration by accelerating the process of oxidation of CPO which is shown by the change of color, taste, and flavour. A survey studied by Palm Oil Research Institute Malaysia (PORIM) on the quality of CPO produces by the mills in Malaysia indicated that about 25% of the surveyed mills produced consistently high copper content with average of 0.15 ppm. The copper content level was significantly higher than the maximum level of 0.08 ppm in CPO recommended by the refineries (Rohaya et al., 2003).

Perumal (2009) reported that the CPO contamination also occurred after the milling stages due to the siphoning off CPO while being transported from mill to refineries. The amount that was siphoned off by syndicates was then replaced by liquid such as water, sludge or used oil which result in contamination of the transported CPO being processed at refineries. A total of 39 cases of siphoning activity were reported in 2010 which involved 252.73 tonne of CPO that worth RM 674000 (Dompok, 2011). This illegal activity causes the industry losses million of ringgit annually and damage Malaysia's image as one of the largest producers of palm oil in the world as well. CPO contamination also occurred in Indonesia. In 1999, Deli Tama Indonesia storage tanks was asked to be cleaned because of diesel-oil contamination of 19 000 metric tons of CPO exported to Rotterdam Port, Netherlands which caused Netherlands to suspend some import contract with them as well as tarnished the image of Indonesian importers in Netherlands (Anon, 1999).

1.3 Objectives

The overall goal of this study is to develop a sensing system for detecting possible contamination in CPO. In order to accomplish this goal, the following specific objectives were set:

i. to investigate the variation of dielectric properties of homogeneous mixture of CPO across electrical spectrum,
ii. to investigate the dielectric properties of homogeneous mixture of CPO contaminated with water and sludge contamination at different temperature levels, and
iii. to develop analytical model for predicting levels of water and sludge contamination in homogeneous mixture of CPO.

1.3 Thesis Organization

This thesis describes a study of application of dielectric spectroscopy concept in detecting possible contamination in palm oil. The research perform in this thesis is hoped will give a fundamental input for further development of sensing system in palm oil processing industry. A review of previous studies regarding the uses of dielectric spectroscopy in monitoring food quality is discussed in Chapter 2. The concept of dielectric spectroscopy is first explained. Conventional and new techniques other than dielectric spectroscopy to determine the oil palm quality are described. Factors influencing dielectric properties of food material such as frequency, temperature, composition and storage time are reviewed. A brief introduction of statistical analysis techniques used in this study for contamination prediction in palm oil were also discussed.

Chapter 3 provides the material, setup and experimental procedures in performing this research. Sample preparations according to the type of contamination as well as its contamination levels are described. The instrumentation setup for dielectric measurements is described and illustrated by photos. The statistical analyses used are explained in the last section.

Chapter 4 described the dielectric properties of pure and contaminated CPO obtained from the experiment. The effects of temperature and contamination levels on dielectric properties of CPO are also described. The classification of the CPO according to temperature and types of contamination (sludge and water) using PCA and PLS are explained.

Finally, Chapter 5 which is the final chapter in this thesis outlines the findings of this research and ends with some suggestion and recommendation for future work in order to improve the results obtained in this study.

REFERENCES

Abdi, H. (2003). Partial least squares regression (PLS-regression). Thousand Oaks, CA: Sage.

Ahmed, J., Ramaswamy, H.S., Raghavan, G.S.V. (2007). Dielectric properties of butter in the MW frequency range as affected by salt and temperature, *Journal of Food Engineering* 351–358.

Anon (1999). Govt. act to prevent CPO contamination. The Jakarta Post, 11_{th} September 1999.

Anon (2009). Hammering Out IEDs-Detecting Explosives With Biologically Inspired Research. http://www.mitre.org/news/digest/pdf/MITRE_Digest_09_2120.pdf (Retrived on 13 August 2012).

Anon. (2010). National Key Economic Area: National Biogas Implementation.

Ahmed, J., Ramaswamy, H.S., Raghavan, G.S.V. (2007). Dielectric properties of butter in the MW frequency range as affected by salt and temperature, *Journal of Food Engineering* 351–358.

Abd Aziz, S., B. L. Steward, and S. J. Birrell. (2007). Dielectric Spectroscopy of Hydraulic Fluid Contamination Detection. *Proceedings of ISFP' 2007.* Beidaihe, China.

Bakeev. K., A. (2010). Process Analytical Technology: Spectroscopic Tools and Implementation Strategies for the Chemical and Pharmaceutical Industries, John Wiley and Sons.

Barry M. W., Neal B. G., Rasmus B., and Jeremy M. S. (2003). PLS Toolbox 3.0 for use with MATLAB. Eigenvector Research Incorporated 50.

Bouaïcha A., Fofana I., Farzaneh M., Setayeshmehr A., Borsi H., Gockenbach E., Beroual A. and Ngnui Thomas Aka. (2009). Dielectric Spectroscopy Techniques as Quality Control Tool: A Feasibility Study. *IEEE Electrical Insulation Magazine* 25(1): 6-14.

Bodakian B. and Hart, F. X. (2002). The dielectric properties of meat. *Dielectrics and Electrical Insulation, IEEE Transactions on* 1(2):181–187.

Brinley, T., Truong, V. D., Coronel, P., Simunovic, J., and Sandeep, K. (2008). Dielectric Properties of Sweet Potato Purees at 915 MHz as Affected by Temperature and Chemical Composition. *International Journal of Food Properties* 11(1): 158–172.

Cataldo, A., E. Piuzzi, G. Cannaza, E. De Benedetto and L. Tarricane. (2009). The Use of Dielectric Spectroscopy For Quality Control Of Vegetables Oils. XIX IMEKO World Congress Fundamental and Applied Metrology. Lisbon, Portugal.

Cen, H., and He, Y. (2007). Theory and application of near infrared reflectance spectroscopy in determination of food quality. *Trends in Food Science and Technology* 18(2): 72–83.

Canchun Z. L. and Zichen C. (2008). Nondestructive Measurement of Internal Quality of Apples by Dielectric Properties," *Transactions Of The Chinese Society Of Agricultural Engineering*, pg.03.

Che Man, Y. B., and Moh, M. (1998). Determination of free fatty acids in palm oil by near-infrared reflectance spectroscopy. *Journal of the American Oil Chemists' Society* 75(5): 557–562.

Che Man, Y. B., Moh, M., and Van de Voort, F. (1999a). Determination of Free Fatty Acids in Crude Palm Oil and Refined-Bleached Deodorized Palm Olein Using Fourier Transform Infrared Spectroscopy . *Journal of the American Oil Chemists' Society* 76(4): 485–490.

Che Man, Y. B., Setiowaty G., and Van de Voort, F. (1999b).Determination of Iodine Value of Palm Oil by Fourier Transform Infrared Spectroscopy. *Journal of the American Oil Chemists' Society* 76: 693–699.

Che Man, Y. B., and Mirghani, M. E. S. (2000). Rapid method for determining moisture content in crude palm oil by Fourier transform infrared spectroscopy. *Journal of the American Oil Chemists' Society* 77(6): 631–637.

Choo Y. M. (2011). Overview of The Malaysian Oil Palm Industry 2010. Available online at www. mpob.gov.my.

Chooi,S.Y, Koh, H. F. (1981). A Study of Some Quality Aspects of Crude Palm Oil.II- The Stabilization of Crude Palm Oil at the Mill. In International

Conference on Palm Oil Product Technology in the Eighties, Kuala Lumpur, p23-29

Chow M.C. and Ho C.C. (2000). Surface Active Properties of Palm Oil With Respect to the Processing of Palm Oil. *Journal of Oil Palm Research* 12(1): 107-116.

Dautant, F.J., Simancas K., Sandoval A.J., Muller A.J (2007) Effect of temperature, moisture and lipid content on the rheological properties of rice flour, *Journal of Food Engineering* (pp.1159-1166).

Dompok B. G. (2011). Teks ucapan Menteri Perladangan dan Komoditi, Majlis Pelancaran Keselamatan Pengangkutan Minyak Sawit FELDA Transport Services Sdn. Bhd. 18 April 2011.

Farag, K.W., Lyng, J.G., Morgan, D.J and Cronin, D.A (2008) Dielectric and thermophysical properties of different beef meat blends over a temperature range of -18°C to +10°C, *Meat Science* 740–747.

Folgero K. 1998. Broad-band dielectric spectroscopy of low-permittivity fluids using one measurement cell. *Instrumentation and Measurement* 47(4):881-885

Gan, H., Man, Y., Tan, C., NorAini, I., and Nazimah, S. (2005). Characterisation of vegetable oils by surface acoustic wave sensing electronic nose. *Food Chemistry*, 89(4): 507–518.

Gee, P. T. (2005). Use of the Deterioration Of Bleachability Index (DOBI) to Characterise the Quality of Crude Palm Oil. Crude palm oil and the DOBI , http://www.britanniafood.com/english/invite_04.htm. (Retrieved on: 21 January 2010).

Geoff, S. 2001. Dielectric Spectroscopy. Retrieved on 13 August 2012. http://hlsweb.dmu.ac.uk/research/gsmith/smithg/smith_ds1.htm.

Guo, W., Trabelsi, S., Nelson, S., and Jones, D. (2007). Storage effects on dielectric properties of eggs from 10 to 1800 MHz. *Journal of food science* 72(5): E335-E340.

Haseeb, A.S.M.A., Sia, S.Y., Fazal, M.A. and Masjuki H.H (2010) Effect of temperature on tribological properties of palm biodiesel, *Energy* 1460-1464.

Huang, H., Haiyan Y., Huirong X., Yibin Y. (2008). Near infrared spectroscopy for on/in-line monitoring of quality in foods and beverages: A review. *Journal of Food Engineering* 87:303–313.

Homes C.C. (2011). Fourier Transform Infrared (FTIR) Spectroscopy. Condensed Matter Physics and Materials Science Department Brookhaven National Laboratory

Jaswir, I., Mirghani, M. E. S., Hassan, T. H., and Said, M. Z. M. (2003). Determination of Lard in Mixture of Body Fats of Mutton and Cow by Fourier Transform Infrared Spectroscopy. *Journal of oleo science 52*(12): 633–638.

Kaatze U. (2008). Perspectives in dielectric measurement techniques for liquids. Journal of Measurement Science Technology 19:1-3.

Koch, M and K. Feser. (2004). Reliability and Influences on Dielectric Diagnostic Methods to Evaluate the Ageing State of Oil-Paper Insulations. Retrieved April 14, 2005 from University of Stuttgart Web site: http://www.uni stuttgart.de/ieh/forschung/veroeffentlichungen/2004_aptadm_koch.pdf.

Kremer, F. and Schonhals, A. (2003). Broadband Dielectric Spectroscopy. ISBN 978-3-540-43407-8 352-352, Springer.

Lachenmeier, D. W. (2007). Rapid quality control of spirit drinks and beer using multivariate data analysis of Fourier transform infrared spectra. *Food Chemistry*, *101*(2):825–832.

Li, X., Zyuzin, A., and Mamishev, A. (2003). Measuring moisture content in cookies using dielectric spectroscopy. *Electrical Insulation and Dielectric Phenomena, 2003. Annual Report Conference on* 459–462.

Lin, W. S., Thin Sue, T., and Yew Ai, T. (Eds.). (1995). *PORIM Test Methods* (Vol. 1). Palm Oil Research Institute of Malaysia.

Lizhi, H., Toyoda, K., and Ihara, I. (2008). Dielectric properties of edible oils and fatty acids as a function of frequency, temperature, moisture and composition. *Journal of Food Engineering*, *88*(2):151–158.

Lizhi, H., Toyoda K., and Ihara I. (2010). Discrimination of olive oil adulterated with vegetable oils using dielectric spectroscopy. *Journal of Food Engineering* 96: 167–171

Manaf, M. A., Man, Y. B. C., Hamid, N. S. A., Ismail, A., and Abidin, S. Z. (2007). Analysis of adulteration of virgin coconut oil by palm kernel olein using Fourier transform infrared spectroscopy. *Journal of Food Lipids*, *14*(2): 111–121.

Mengshi L., Barbara A. R., Anna G. C. and Murad A. (2009). Infrared Spectroscopy for Food Quality Analysis and Control. Elsevier Inc. 119-120

Moh, M., Che Man, Y., Van De Voort, F., and Abdullah, W. J. W. (1999). Determination of peroxide value in thermally oxidized crude palm oil by near infrared spectroscopy. *Journal of the American Oil Chemists' Society*, 76(1):19–23.

Nahm, S. H. 2006. Use of Dielectric Spectroscopy for Real-Time In-situ Reaction Monitoring. JCT Research, .3 No 4.4: 257-265.

Nelson S. O. (2004). Dielectric spectroscopy of fresh fruit and vegetable tissues. Paper presented at ASABE Annual International Meeting. Ontario, Canada. 1- 4 August 2004.

Nelson S. O. (2005). Dielectric Spectroscopy of Fresh Fruits and Vegetables. Instrumentation and Measurement Technology Conference Ottawa, Canada, 17-19 May 2005

Nelson, S. O., Trabelsi, S., and Kays, S. (2006). Dielectric spectroscopy of honeydew melons from 10 MHz to 1.8 GHz for quality sensing. *Transactions of the ASABE* 49(6): 1977–1981.

Nelson S. O., W. Guo, S. Trabelsi, and S. J. Kays, (2007). Dielectric spectroscopy of watermelons for quality sensing. *Measurement Science and Technology*, vol. 18, p. 1887.

Nelson S. O. , S. Trabelsi, and H. Zhuang (2007) Dielectric spectroscopy of fresh chicken breast meat. Paper presented at ASABE Annual International Meeting. Minneapolis Convention Centre, Minnesota. 17-20 June 2007.

Nelson S. O. (2009). Use of Dielectric Spectroscopy for Determining Quality Attributes of Poultry Meat. Paper presented at ASABE Annual International Meeting. Grand Sierra Resort and Casino Reno, Nevada. 21 June-24 June 2009.

Nelson S. O. and Trabelsi S (2008). Dielectric spectroscopy measurements on fruit, meat, and cereal product. Paper presented at ASABE Annual International Meeting. Rhode Island Convention Centre Providence. 29 June-2 July 2008.

Nunes, A., Bohigas, X., and Tejada, J. (2006). Dielectric study of milk for frequencies between 1 and 20 GHz. *Journal of food engineering* 76(2): 250–255.

Ouyang, Y. (2005). Evaluation of river water quality monitoring stations by principal component analysis. *Water Research*, 39(12): 2621–2635.

Perumal E. (2009). Palm Oil Importers Reassured. The Star Online, 13_{th} June 2009

Peter Fr¨ubing. (2004). Dielectric spectroscopy. University of Potsdam, Institute of Physics Advanced lab experiments, December 17, 2004 http://polymerscience.physik.hu-berlin.de/anleitg/dielectric.pdf

Piotr, P.L., and Ewa, J. (2004) Effect of hot air temperature on mechanical properties of dried apples, *Journal of Food Engineering* 307-314.

Prieto, N., Roehe, R., Lavín, P., Batten, G., and Andrés, S. (2009). Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review. *Meat science*, 83(2): 175–186.

Ragni, L., Al-Shami, A., Mikhaylenko, G., and Tang, J. (2007). Dielectric characterization of hen eggs during storage. *Journal of food engineering*, 82(4): 450–459.

Rao, M. A., S.S.S, R., and A.K., D. (2005). *Engineering properties of food* (3rd ed.). Taylor and Francis Group.

Rohaya, M. H., I. Razali, Y. A. Tan. (2003). Variation in Trace Metal Content in Crude Palm Oil During Milling Process. Engineering News, 6-10.

Rohman, A., and Che Man, Y. (2010). Fourier transform infrared (FTIR) spectroscopy for analysis of extra virgin olive oil adulterated with palm oil. *Food Research International*, 43(3): 886–892.

Sipahioglu, O., Barringer, S., Taub, I., and Prakash, A. (2003). Modeling the dielectric properties of ham as a function of temperature and composition. *Journal of Food Science*, 68(3): 904–909.

Scotter, C. N. G. (1997). Non-destructive spectroscopic techniques for the measurement of food quality. *Trends in Food Science and Technology*, 8(9): 285–292.

Sheiretov, Y. and M. Zahn. 1995. Dielectrometry measurements of moisture dynamics in oil-impregnated pressboard. IEEE Trans. On Dielectrics and Electrical Insulation 2(3):329-351.

Smith, L. I. (2002). A tutorial on principal components analysis. *Cornell University, USA*, *51*, 52.

Subramanian A. and Luis R.S. (2009). Fourier Transform Infrared (FTIR) Spectroscopy. Infrared Spectroscopy for Food Quality Analysis and Control. pp 148.

Suwarno, Ilyas, M. and Rubadi (2008) Effects of temperature on Dielectric properties of Rhicinnus Oils as insulating liquid. Proceedings, International Conference on Condition Monitoring and Diagnosis, Beijing, China.

Syahariza, Z., Man, Y., Selamat, J., and Bakar, J. (2005). Detection of lard adulteration in cake formulation by Fourier transform infrared (FTIR) spectroscopy. *Food Chemistry*, 92(2): 365–371.

Tjomsland, T., J. Hilland, A.A. Christy, J. Sjoblom, M. Riis, T. Friiso, and K. Folgero. (1996). Comparison of infrared and impedance spectra of petroleum fractions. Fuel 75(3):322-332

Tobias, R. D., and others. (1995). An introduction to partial least squares regression. *Proceedings of the Twentieth Annual SAS Users Group International Conference* 1250–1257.

Van de Voort, F.(1992). Fourier transform infrared spectroscopy applied to food analysis. *Food Research International,* 25: 397-403

Volkers, K., Wachendorf, M., Loges, R., Jovanovic, N., and Taube, F. (2003). Prediction of the quality of forage maize by near-infrared reflectance spectroscopy. *Animal feed science and technology*, 109(1-4): 183–194.

Zheng, S., Fang, Q., and Cosic, I. (2009). An investigation on dielectric properties of major constituents of grape must using electrochemical impedance spectroscopy. *European Food Research and Technology*, 229(6):887–897.