EFFECTS OF TIME AND TEMPERATURE ON PROCESS AND CRUDE PALM OIL QUALITY WITH MICROWAVE IRRADIATION STERILIZATION

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To my beloved husband, parents and daughters

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ABSTRACT

Microwave sterilization of oil palm fruits aims to protect palm oil quality and facilitates stripping of oil palm fruit bunches. Microwave irradiation may reduce time and temperature for sterilization process. The purposes of this study were to determine the time and temperature to inactivate 90% lipase (*D*-value) and process sensitivity on temperature (*z*-value) for microwave sterilization. Lipase inactivation as first order reaction rate was used to determine the *D*-value by using *D*-*z* model, while thermal death time (TDT) method was used to determine the *z*-value. The *D*-value resulted from this study ranged from 8 to 17 min, at temperature 82 and 70^{o}C respectively, while *z*-value ranged between 21 to 27^{o}C. Kinetic constant (*k*) for lipase inactivation process ranged from 0.136 to 0.276 min^{-1}. Optimum time and temperature to inactivate 90% lipase in this study were 9.7 min at temperatures of 80.5^{o}C (12 min time of exposure and power density of 854.58 W kg^{-1}) or 12.3 min at a temperature of 80°C (16 min exposure time and power density of 718.53 W kg^{-1}). This study concluded microwave sterilization reduced time and temperature to inactivate lipase as compared to conventional oil palm sterilization. Process performances were indicated by high efficiency of stripping (74 and 81% respectively), and quality of palm oil (levels of free fatty acid (FFA), carotene, vitamin E and fatty acid composition) met the standards of Malaysian Palm Oil Board (MPOB) for crude palm oil (CPO).

ABSTRAK

Pensterilan kelapa sawit dengan menggunakan ketuhar gelombang mikro bertujuan untuk melindungi kualiti minyak sawit dan memudahkan pelucutan kelapa sawit dari tandannya. Penyinaran gelombang mikro boleh mengurangkan masa dan suhu bagi proses pensterilan. Kajian ini bertujuan untuk menentukan masa dan suhu untuk inaktivasi 90% lipase (*D*-value) dan kepekaan proses ke atas suhu (*z*-value) pada proses pensterilan menggunakan ketuhar gelombang mikro. Inaktivasi lipase dalam bentuk kadar tindak balas tertib pertama telah digunakan untuk menentukan *D*-value dengan menggunakan model *D-z*, manakala kaedah *thermal death time* (TDT) digunakan untuk menentukan *z*-value. *D*-value yang diperoleh daripada kajian ini adalah di antara 8 hingga 17 minit, masing-masing pada suhu 82 dan 70^{o}C, manakala *z*-value adalah di antara 21 hingga suhu 27^{o}C. Nilai pemalar kinetik (*k*) untuk proses inaktivasi lipase adalah di antara 0.136 - 0.276 minit^{-1}. Masa dan suhu yang optimum untuk pensterilan kelapa sawit dalam kajian ini ialah 9.7 minit pada suhu 80.5^{o}C (masa pendedahan 12 minit dan ketumpatan kuasa 854.58 W kg^{-1}) atau 12.3 minit pada suhu 80°C (masa pendedahan 16 minit dan ketumpatan kuasa 718.53 W kg^{-1}). Kajian ini menyimpulkan bahawa pensterilan dengan menggunakan ketuhar gelombang mikro boleh mengurangkan masa dan suhu dari segi inaktivasi lipase berbanding pensterilan kelapa sawit menggunakan ketuhar konvensional. Prestasi pensterilan ini ditunjukkan oleh kecekapan pelucutan yang tinggi (masing-masing 74 dan 81%), dan kualiti minyak sawit yang merangkumi peringkat asid lemak bebas (FFA), karotena, vitamin E dan asid lemak komposisi memenuhi standard Lembaga Kelapa Sawit Malaysia (MPOB) bagi minyak sawit mentah (CPO).

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A	-	enzyme activity
a	-	flange diameter (m)
b	-	aperture diameter (m)
Cp	-	specific heat capacity (J kg^{-1} K^{-1})
D-value	-	time to eliminate 90% population of microorganism or activity of enzyme (s)
D	-	thermal death time at temperature T (s)
D_p	-	depth of penetration (m)
E_a	-	the activation energy (cal mol^{-1})
E_ρ	-	tangential electric field intensity (V m-^{1})
E_z	-	axial electric field intensity (V m^{-1})
ϵ^*	-	complex relative permittivity
ϵ'	-	dielectric constant
ϵ''	-	dielectric loss factor
ε_o	-	vacuum permitivity = 8.8542 x 10^{-12} (F m^{-1})
f	-	frequency (Hz)
h_c	-	convection heat transfer coefficient over a surface
j	-	imaginary number $= \sqrt{-1}$
k	-	the first-order reaction rate constant (s^{-1} or min^{-1})

K	-	the thermal conductivity ($Wm^{-1}K^{-1}$)
λ_o	-	wavelength in free space (m)
N	-	number of population
P_v	-	energy developed per unit volume ($W\ m^{-3}$)
φ	-	cycloidal angle of transmitted signal
φ'	-	cycloidal angle of reflected signal
R	-	the gas constant (1.987 cal K^{-1} mol^{-1})
ρ	-	density ($kg\ m^{-3}$)
ρ	-	tangential distance of transmitted signal (m), $\rho \cong a$
ρ'	-	tangential distance of reflected signal (m), $\rho' \cong b$
S	-	a constant, the frequency factor (min^{-1})
T	-	temperature (^{o}C)
T_a	-	temperature of air inside the microwave oven
$tan\ \delta$	-	loss tangent (loss factor or dissipation constant)
t	-	time (s)
ω	-	angular frequency, $\omega = 2\pi f$
z-value	-	the temperature change required to change the *D* by factor of 10 (^{o}C)
z	-	axial distance of transmitted signal (m)
z'	-	axial distance of reflected signal (m)

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CHAPTER 1

INTRODUCTION

The purpose of this study is to investigate potential of microwave heating for sterilization of oil palm fruit. Microwave sterilization of oil palm fruit aims to protect the quality of palm oil and at the same time preserve nutrient in palm oil such as fatty acids and vitamin E. Furthermore, microwave sterilization is also expected to facilitate bunch detachment and soften the palm fruit prior of extraction process.

In this chapter, sterilization process of oil palm fruit such as steam batch sterilization and steam continuous sterilization are described, include weakness and problems of this two methods. Meanwhile, to overcome problems facing by current sterilization process, this study proposes microwave sterilization as an alternative to sterilize oil palm fruit. Furthermore, to conduct this study, objectives of the research are formulated in this chapter. A lay out of thesis also included in this chapter to help reader understand content of whole thesis.

1.1 Introduction to Oil Palm Sterilization

Sterilization is basically a term referring to any process that eliminates or kills all forms of microorganism such as fungi, bacteria, virus, enzyme, etc. One application on sterilization process was sterilization of oil palm fruit (*Elaeis guineensis*). First sterilization of oil palm fruit in history was reported by Henderson and Osborne (2000) as traditional activity in Africa.

Today, palm oil sterilization is an important process in palm oil mill to protect the quality of palm oil. Palm oil is very susceptible to deterioration and spoilage due to lipase activity during harvesting and storage of oil palm fruit bunches. Lipase leads to hydrolysis of the oil and enhance the formation of free fatty acid (FFA) that causes the rancid flavor in palm oil (Odunfa, 1989). The FFA concentration is the key of quality in palm oil. The palm oil is normally traded on 5% basis of FFA. Most exported palm oil is RBD (refined, bleach and deodorized) with maximum FFA of 0.1% to protect palm oil deterioration during transportation.

To produce crude palm oil (CPO) with high quality, sterilization of oil palm fruit should be conducted. However temperature and time selection for sterilization process should also retain the nutrients such as vitamin E and fatty acids in palm oil. Meanwhile, the carotene, except for red palm oil, should be removed from palm oil to satisfy consumers. Furthermore, content of water in palm oil should be minimized to prevent oil deterioration in the presence of water during storage and transportation.

The aim of oil palm sterilization is to inactivate lipase. Currently, method of palm oil sterilization are steam batch sterilization and continuous sterilization. The steam batch sterilization is used by conventional palm oil mill in Malaysia and other palm oil producing countries. The process has to supply the fruit in such a way to maintain the subsequent extraction processes in continuous operation. Production capacity of palm oil mill with conventional steam batch sterilization process is varied between 30 to 90 ton/hr. Sterilization is carried out at pressure of 3 kg/cm^2 and temperature of 140^oC (Choon-Hui *et al*., 2009). The sterilization process based on a multiple-peaks cycle operation to remove air trapped inside the sterilizer. The pressure is maintained for 20 to 30 minutes and is released rapidly after third occasion. Complete sterilization requires 80-90 minutes includes loading and unloading process (Berger, 1983).

The disadvantages of steam batch process are the use of a substantial quantity of heavy equipment, and a series of repeated operations from bunch reception process until the sterilized fruit are introduced into the stripper (or thresher). This process also involves the use of substantial quantities of steam, and thus a lot of heat is lost.

Meanwhile, continuous sterilization of oil palm fruit is a new method that aim to improve steam batch sterilization, especially for continuous processing. It also able to reduce high operation and maintenance cost as shown in Table 1.1. Recently, several new installations of palm oil mills in Malaysia are using the continuous sterilization system. Annual capacity of palm oil mill with continuous sterilization process is varied between 60,000 to 360,000 t (Sivasothy *et al*., 2006). Continuous sterilization system ensures continuous and un-interrupt flow of the product, and consistent product retention time with little or no short-circuiting (Sivasothy *et al*., 2005). Comparison on effect of sterilization batch and continuous process on palm oil quality is given in Table 1.2.

However, in some country, palm oil mill still operates in traditional way. In Nigeria for example, about 95% of palm oil mill in some part of Nigeria operates in small scale capacity (0.2-3.0 t/hr). Majority of the mills still utilize the cooking drum or tank for sterilization of oil palm fruit. Capacity of cooking drum is only 100 to 200 kg, while capacity of tank is 3 to 5 drums (Owolarafe and Oni, 2011).

Table 1.1: Comparison of operation cost between steam batch sterilization and continuous sterilization of oil palm fruit

Parameter of improvement	Batch sterilization	Continuous sterilization
Number of process operators (person)	• 20 (mill capacity: 20 t/hr) • 30 (mill capacity: 45 t/hr)	• 10 (mill capacity: 20 t/hr) • 15 (mill capacity: 45 t/hr)
Process labour cost (RM)	450.00 (based on 25 operators per shift)	180.00 (based on 10 operators per shift)

Sources: (Sivasothy *et.al*, 2006, copyright *Journal of Oil Palm Research*, 2006)

Table 1.2: Effect of sterilization process on palm oil quality

Parameter	Batch sterilization	Continuous sterilization
FFA content (%)	2.68	2.10
Peroxide value (meq)	0.30	0.29
DOBI	2.77	3.22
Carotene content (ppm)	598.00	546.00
Iron content (ppm)	4.24	6.18

Source: (Sivasothy, 2005, copyright *The Journal of Oil Palm Research*, 2005)

The facts that during sterilization the fruit become soft and after sterilization the fruit can be detached from the bunches easily, improve the objective of sterilization of oil palm fruit. In other word, sterilization of oil palm fruit facilitates threshing process and palm oil extraction process.

1.2 Problem Statement

The steam batch sterilization process has several disadvantages such as requires long operation time to complete the sterilization process, energy intensive because the process utilizes a large amount of steam, and as consequence large amount of waste water is also discharged as palm oil mill effluent. There are also a few cases in palm oil mill with steam batch process involves human accident which is mostly relates with human error.

The process modification from batch sterilization into continuous sterilization was reported not fully successful. In fact, continuous sterilization only reduce the labor by process automation and lower operating and maintenance costs because utilization of steam at atmospheric pressure to sterilization of oil palm fruit (Sivasothy *et al*., 2005; Sivasothy *et al*., 2006). However, Sivasothy *et al*. (2006) reported no significant improvement in sterilization process by continuous system compared to batch system. He observed oil palm fruit that leave the continuous sterilization was hard, un-cooked, and difficult to be pressed to extract the oil. Furthermore, stripping efficiency of oil palm fruit bunches was lower compare to steam batch process, because continuous sterilization process utilizes steam at atmospheric pressure that is un-sufficient to penetrate into the fruit and detaches the fruit from bunches (Sivasothy *et al*., 2006).

To achieve best practice on sterilization process of oil palm fruit, the weakness of current sterilizaton processes should be improved. Microwave energy is one of the options that suitable to be used in oil palm fruit sterilization process. Microwave sterilization is application of microwave heating which had been applied extensively to food processing during the last decade (Lau and Tang, 2002; Schneider *et al*., 2005; Sun *et al*., 2007 and Coronel *et al*., 2008). Microwave sterilization offers significant advantages for sterilization process such as reduces sterilization time and consumes less amount of energy. Furthermore, the microwave energy is more easily directed because of the waveguide and controlled by switch on/off button. Advantage of microwave energy is that heat is generated in a distribution manner inside of oil palm fruit, allow heat to be uniform and faster heating (Haji Kamis *et al*., 2005).

Some studies had investigated microwave heating of oil palm fruit (Tan, 1981; Chow and Ma, 2001, 2007; Sukaribin and Khalid, 2009; Cheng *et al*., 2011 and Umudee *et al*., 2013). They reported the potency of oil palm fruit as dielectric material that can be used for microwave heating (Tan, 1981 and Sukaribin and Khalid, 2009). Meanwhile quality of palm oil was investigated and compared with palm oil from commercial palm oil mill (Chow and Ma, 2001, 2007; Cheng *et al*., 2011 and Umudee *et al*., 2013). Stripping efficiency of microwave heating process was also investigated and compared with stripping efficiency in palm oil mill (Chow and Ma, 2001, 2007; Sukaribin and Khalid, 2009). However, none of their study had explained and investigated mechanism of heat generation and heat transfer in oil palm fruit during microwave heating process, and determined critical time and critical temperature for microwave heating of oil palm fruit.

Time and temperature of heating are very crucial due to the main objective of microwave heating of oil palm fruit is to inactivate lipase. Combination of time and temperature in microwave heating process should ensure lipase inactivation occurs in oil palm mesocarp. It should also facilitate bunch stripping, and ensure quality of palm oil meet the Malaysian Palm Oil Board (MPOB) standard for CPO. Based on that, determination of time and temperature for lipase inactivation, that ensure sterility of palm oil, are important. The microwave heating for purpose of sterilization is microwave sterilization. The time that required to inactivate 90% of lipase activity is referred as decimal reduction time (*D*-value), while temperature sensitivity for lipase inactivation process referred as *z*-value. Studies of microwave sterilization has been reported by several authors. The microwave irradiation had proven effectively eliminate and inactivate microorganism and enzyme (Ponne and Bartels, 1995; Woo *et al*., 2000; Valsechi *et al*., 2004). This indicates microwave energy can be used for sterilization of oil palm fruit.

1.3 Justification of Research

This Section describes on the importance of research and research gap in microwave heating of oil palm fruit based on literature review. Detailed literature review discussed in Chapter 2.

1.3.1 Importance of Research

Microwave heating of oil palm fruit is a process of heat generation and heat transfer in oil palm fruit. There are several parameters that influence the process of microwave heating during the process of heat generation and heat transfer in the oil palm fruit. The parameters involved in the process of heat generation is the dielectric properties of oil palm fruit, the electric field of the electromagnetic wave, the depth of penetration of electromagnetic waves in the oil palm fruit, and moisture content of oil palm fruit. Meanwhile, the process of heat transfer is indicated by the rise in the temperature of the fruit.

Dielectric properties of oil palm fruit plays an important role in the absorption of electromagnetic waves and converting microwave energy into thermal energy. Water molecules present in the oil palm fruit will move (re-orientation) to follow the direction of the electric field of the electromagnetic wave. Movement between water molecules in turn creates friction that causes heat, which is characterized by an increase in temperature inside the fruit. The heat that is formed during the process of heat generation is highly dependent on the dielectric properties of oil palm fruit, the magnitude of the electric field and the frequency of the microwave heating process. Heat developed per unit volume can be estimated by using Eq. (2.13). This heat is then transferred from the kernel/endocarp (interior) to exocarp (exterior), and oil palm fruit as a whole is heated very quickly. Meanwhile, the penetration depth of electromagnetic waves in the oil palm fruit can be approached in two ways: through measurement or estimated by mathematical equations as has been shown in Eq. (2.21).

Based on literature review, dielectric properties of oil palm fresh fruit had been measured by several authors (Tan, 1981; Abbas *et al*, 2005; Chow and Ma, 2007; Sukaribin and Khalid, 2009 and You *et al*, 2010). However to study effect of microwave heating on dielectric properties of oil palm fruit, measurement of dielectric properties of heated oil palm fruit should be conducted, especially to study relationship between dielectric properties, especially dielectric loss factor, with temperature, and moisture loss. From relationship between moisture loss and dielectric loss factor, critical moisture can be determined. This critical moisture was important to indicate critical time and critical temperature of microwave heating so as to adjust maximum power and time for microwave heating that could avoid excessive heating. Meanwhile, the importance of estimation on heating rate and rate of temperature increment was to study power developed per unit volume and heat transfer process in oil palm fruit. The dielectric properties data could be used to estimate power developed per unit volume, which referred as heating rate, and rate of temperature increment during microwave heating process, after estimated the electric field of electromagnetic waves. Heating rate could indicate number of thermal energy that was dissipated into the oil palm fruit to increase temperature of fruit. However, no studies in literature review reported: (1) the dielectric properties of heated oil palm fruit, (2) the critical moisture in microwave heating of oil palm fruit, (3) penetration depth of microwave energy into the whole bunches of oil palm fruit, (4) heating rate or power developed per unit volume as convertion of microwave energy into thermal energy, and (5) rate of temperature increment during microwave heating of oil palm fruit. Until this study was carried out, no studies reported estimation on the distribution of temperature in oil palm fruit during microwave heating process that based on transient heat equation. The only study on modeling temperature distribution in oil palm fruit was conducted by Tan (1981) using diffusion equation. However, Tan (1981) did not measure temperature changes during heating process but after the heating process at various depths of oil palm fruit.

The potency of microwave energy to generate heat in oil palm fruit and increased temperature above 47^{o}C at which lipase activity halt, enhancing application of microwave heating concept for the purpose of sterilization which called microwave sterilization of oil palm fruit. The inactivation of lipase in oil palm fruit at temperature above 47^{o}C had been reported by Ebongue (2006). In microwave sterilization, temperature is very crucial and should be designed properly to obtain sterile product. Main purpose of microwave sterilization in this study is to inactivate lipase in oil palm fruit at temperature above 47^{o}C. To obtain sterile product, it is important to determine *D*-value for microwave sterilization of oil palm fruit. The *D*-value can be used as benchmarking to adjust time of exposure for microwave sterilization. However, since *D*-value represents not only time to inactivate 90% of lipase activity, but also temperature of inactivation process, then the *D*-value is related to *z*-value. The *z*-value is important because it expresses sterilization process sensitivity to temperature. In order to speed up microwave sterilization process, or to reduce the *D*-value, sterilization should be carried out at temperature greater than initial temperature with respect to *z*-value data. So far, no studies in literature review reported *D*-value for microwave sterilization of oil palm fruit. However from literature review it is known that microwave heating of oil palm fruit carried out between 1 to 18 min depend on microwave power and size of oil palm sample used in their studies (Tan, 1981; Chow and Ma, 2001 and 2007; Sukaribin and Khalid, 2009; and Cheng *et al.*, 2011). According to literature review, steam batch sterilization normally requires 1 to 1.5 h (Berger, 1983) to sterilize oil palm fruit with temperature of 140^{o}C (Choon-Hui *et al.*, 2009). From literature review, the objective of sterilization of oil palm fruit includes also facilitating stripping of bunches of oil palm fruit and soften the oil palm fruit. To meet the objective of sterilization of oil palm fruit, investigation on efficiency of stripping of bunches of sterilized fruit should be conducted. Meanwhile, the quality of palm oil from microwave sterilization was investigated to ensure product of microwave sterilization meet the MPOB standard for CPO which includes contents of FFA, fatty acids composition, carotene content and vitamin E content.

1.3.2 Research Gap in Microwave Heating of Oil Palm Fruit

From literature review, no studies in microwave heating of oil palm fruit discuss about (1) dielectric properties of heated oil palm fruit, (2) critical moisture of oil palm fruit that indicated critical time of exposure and critical temperature, (3) penetration depth of microwave energy into the whole bunches of oil palm fruit, (4) power developed per unit volume that indicates energy from converstion of microwave energy into thermal energy, (5) rate of temperature increment during microwave heating, (6) distribution of interior temperature in oil palm fruit during heating process and (7) kinetic of lipase inactivation (*D*-value, *k* and *z*-value) for microwave sterilization of oil palm fruit. Based on the facts:

1. Dielectric properties of heated oil palm fruit from microwave heating is identified as research gap in microwave heating of oil palm fruit. The purpose of measurement of heated fruit is to study effect of microwave heating to dielectric properties of oil palm fruit, especially dielectric loss factor.
2. Critical moisture of oil palm fruit that indicates critical time of exposure and critical temperature on microwave heating is identified as research gap in this microwave heating. The purpose of determination of critical moisture is to adjust sufficient variable in microwave heating to avoid oil palm fruit become harder.
3. Penetration depth into the whole bunches of oil palm fruit was identified as research gap in microwave heating of oil palm fruit. The purpose of determination of penetration depth is to study penetration of microwave energy into the depth below oil palm fruit surface at which the power density of electromagnetic wave, decay exponentially.
4. Power developed per unit volume or heating rate during microwave heating of oil palm fruit is identified as research gap in microwave heating of oil palm fruit. The purpose of estimation of heating rate is to study effect of dielectric properties on heating rate during heating process.
5. Rate of temperature increment during microwave heating of oil palm fruit is identified as research gap in microwave heating of oil palm fruit. The purpose of estimation of rate of temperature increment is to study effect of power developed per unit volume on heating rate during heating process.

6 Distribution of interior temperature in a single oil palm fruit is identified as research gap in microwave heating of oil palm fruit. The purpose of simulation of interior temperature at various diameters of single oil palm fruit is to study interior temperature distribution during microwave heating process.

7 Decimal reduction time (*D*-value) of lipase, kinetic constant for lipase inactivation (*k*) and temperature sensitivity (*z*-value) for microwave sterilization of oil palm fruit are identified as research gap in microwave heating of oil palm fruit. The purpose of determination of *D*-value and *z*-value for microwave sterilization is to obtain sterile palm oil and facilitates stripping of bunches of oil palm fruit.

1.4 Hypothesis

Hypothesis of this research study are:

1. Microwave energy can penetrates into the oil palm fruit bunches and heats the bunches to inactivate lipase;
2. Microwave sterilization can be carried out very fast based on thermal death time of lipase and utilizes lower energy, and;
3. Microwave sterilization is able to facilitate stripping of bunches of oil palm fruit.

1.5 Research Objective

The study aimed to determine time and temperature for microwave sterilization of oil palm fruit based on lipase inactivation. The objectives of the research:

1. To determine critical parameter for microwave heating of oil palm fruit bunches such as critical moisture, critical time and critical temperature;

2. To estimate heating rate and interior temperature distribution in fruitlet during microwave heating process;
3. To investigate penetration depth of microwave energy into the oil palm fruit bunches;
4. To determine kinetic parameters such as lipase activity, kinetic constant, *D*-value and *z*-value for microwave sterilization of oil palm fruit bunches;
5. To investigate effect of microwave sterilization on the stripping efficiency, and;
6. To investigate effect of microwave sterilization on quality of palm oil (content of FFA, carotene, vitamin E, water and fatty acids composition).

1.6 Scope of Research

In order to justify research gaps in microwave sterilization of oil palm fruit, investigation on dielectric properties of heated oil palm fruit, critical moisture, penetration depth, heating rate, temperature increment, interior temperature distribution, *D*-value and z-value was conducted using methods and scope as shown in Table 1.3.

Table 1.3: Scope of study and method

Research objectives	Scope of study	Methods
Investigation of microwave heating of oil palm fruit	• Measurement dielectric properties of heated oil palm fruit • Determination of moisture loss • Determination of critical moisture • Determination penetration depth of whole bunches of oil palm fruit • Measurement of temperature • Modeling interior temperature distribution	• Open ended coaxial probe (Abbas *et al.*, 2005) • Gravimetry • Characterization of critical moisture based on the graph of the dielectric loss factor-vs-moisture (Metaxas and Meredith, 1989) • Measurement the depth of penetration of microwave energy • Thermocouple type K • Finite difference method and Matlab R12a software
Determination of kinetic parameters for microwave sterilization	• Determination lipase activity • Determination of *D*-value and *k* • Determination of *z*-value • Measurement of temperature	• Lipase assay (Lindfield *et al*., 1984 and Khor *et al.*, 1986) • *D-z* method • TDT method • Thermocouple type K

Table 1.3: Scope of study and method (continued)

Research objectives	Scope of study	Methods
Investigation of effect microwave sterilization on the stripping efficiency of oil palm fruit bunches	Determination of the stripping efficiency	Chow and Ma method (Chow and Ma, 2001)
Investigation of effect microwave sterilization on quality of palm oil	• Determination of FFA content • Determination of fatty acids composition • Determination of carotene content • Determination of vitamin E content • Determination of water content	• MPOB Test Method p.2.5: 2004 (MPOB, 2005) • MPOB Test Method p.3.4 and p.3.5: 2004 (MPOB, 2005) • MPOB Test Method p.2.6: 2004 (MPOB, 2005) • HPLC, fluroscence detector, ASI- 60 column, mobile phase hexane : tetrahydrofuran: isopropanol (Chandrasekaram *et al*., 2009) • Karl Fisher titration (Cheng *et al*., 2011)

1.7 Layout of the Thesis

This thesis describes the research work to investigate microwave heating of oil palm fruit and determine parameters of lipase inactivation (*D*-value and *z*-value) for microwave sterilization of oil palm fruit and investigate effect of microwave sterilization to bunch stripping process, and quality of palm oil.

Chapter 2 reviewed the related theories of sterilization, sterilization kinetic, microwave heating, microwave heating of oil palm fruit and effect of microwave heating of oil palm fruit to stripping process, and quality of palm oil.

Chapter 3 describes the experimental design and methods involved in this research work includes the method to investigate microwave heating of oil palm fruit and determination of kinetic of lipase inactivation for microwave sterilization. Chapter 3 also describes methods to measure dielectric properties, determination of moisture loss and stripping efficiency. In this chapter, methods to evaluate palm oil quality such as FFA, carotene content, fatty acids composition, content of vitamin E and water are described. Numerical solution for mathematic model developed from transient heat equation to determine interior temperature of palm fruit is also described.

Chapter 4 discusses results microwave heating of oil palm fruit. The role of moisture loss, critical and maximum moisture, dielectric properties (especially dielectric loss factor), penetration depth, electric field, rate of heating and rate of rise of temperature on microwave heating were discussed comprehensively. Furthermore, the critical and maximum moisture can be used to determine critical and maximum time and temperature for microwave heating, that ensure rate of rise of temperature rationally and avoid excessive heating. This chapter also discussed prediction of fruit interior temperature on various fruit diameters.

Chapter 5 discusses the results from investigation on determination of kinetic of lipase inactivation such as *D*-value, *z*-value and kinetic constant for microwave sterilization. This chapter discuss and compare the *D*-value results obtained from regression line method, Stumbo/end point method, and average *D*-value method. In this chapter, statistical significance of differences of these *D*-value results was measured by t test (at P equal to 0.05). Furthermore, effects of microwave power and bunches size or power density on microwave sterilization of oil palm fruit are discussed comprehensively. Meanwhile, to validate *D*-value from microwave sterilization, this *D*-value is compared to *D*-value obtained from lab scale steam batch sterilization. Furthermore, this chapter also determined the *z*-value by using *D*-value curve. The *z*-value is discussed to evaluate temperature sensitivity on this microwave sterilization and to predict temperature to reduce *D*-value by a factor of 10.

Chapter 6 discusses the effect of microwave heating and microwave sterilization on the stripping efficiency. In this chapter, the stripping efficiency is compared to the stripping efficiency of laboratory scale steam batch sterilization. Chapter 6 also discusses relationship between stripping efficiency of microwave sterilization with power density, time of exposure, and moisture loss. Effectiveness the stripping efficiency in microwave sterilization is also evaluated with respect to critical and maximum time and temperature comprehensively.

Chapter 7 discusses the effect of microwave sterilization on palm oil quality (content of FFA, carotene, vitamin E and water, and fatty acids). Quality of palm oil from this study is evaluated and compared to MPOB standard for CPO. In this chapter, safety margin of time and temperature to inactivate lipase and retaining the carotene content in palm oil is also discussed.

Chapter 8 deals with the conclusions and recommendations from this study. This chapter presents the conclusions derived from this study. Recommendations for future studies are also included in this chapter.

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