UNIVERSITI PUTRA MALAYSIA

FUNDAMENTAL STUDY OF OIL PALM FRUIT DIGESTION PROCESS

YAYAT NURHIDAYAT

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FUNDAMENTAL STUDY OF OIL PALM FRUIT DIGESTION PROCESS

By

YAYAT NURHIDAYAT

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

December 2014

DEDICATION

MY BELOVED FAMILIES

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

FUNDAMENTAL STUDY OF OIL PALM FRUIT DIGESTION PROCESS

By

YAYAT NURHIDAYAT

December 2014

Chairman: Professor Robiah Yunus, PhD
Faculty: Engineering

Oil palm fruit digestion is an important step in palm oil milling process. After sterilization, the fruitlets are stripped and then fed to a digester where the fruitlets are heated with low pressure steam. Although the digestion is a simple process, the underlying fundamental principles governing the process are not well understood. To facilitate better understanding of its mechanism, the experimental work followed by the modelling and simulation of the digestion process were conducted on samples from different sterilized conditions, i.e. 40 and 70 psi. The study included the changes of physical, chemical, and mechanical properties of the samples, such as water and oil diffusivity, oil release rate, true and bulk density, compression test, dimension, mass, and volume, porosity, micro and meso structure of oil palm fruit fiber using SEM and microscope, oil released and water absorption during digestion process, oil extraction using hydraulic press, and also oil quality analysis.

Bulk density of oil palm fruit decreased compared to sterilized fruit. Fracture resistance decreased consecutively, from fresh, sterilized, and digested fruit. In addition, fruit and shell of samples sterilized at 40 psi showed higher fracture resistance than that of 70 psi. However, compared to sterilized samples at 40 psi, samples sterilized at 70 psi demonstrated higher oil release and water absorption during digestion. Hydrolysis of cell walls is believed to promote higher oil liberation. This is indicated by higher sugar concentration in the digestion water condensate. During pressing, the optimum pressure of sterilized samples at 70 psi was lower than that of 40 psi demonstrated higher broken nut (kernel breakage) after oil extraction.

The tests on oil quality namely deterioration of bleachabilty (DOBI), carotene content, free fatty acid (FFA) content, and triglycerides content were also investigated. Based on the analysis on samples of 40 and 70 psi sterilization conditions, no significant changes were found. Based on the standards established by MPOB, generally, the oil has good and acceptable quality.

The computer simulation of microscale and mesoscale using Comsol Multiphysics version 4.4 was aimed to fully understand what really happen in the oil palm fruit digestion process. In the microscale, the study analyzed the fruit in cell levels, where oil globules, water content, cell walls of oil palm fruit exist which applied CFD and heat transfer module. The degree of cell wall rupture greatly affect oil movement. Fully ruptured cell wall promoted oil release. In the mesoscale level, the digestion

process was applied to a single fruit of oil palm, consisting of mesocarp, shell, and kernel, while incorporating mass transfer of water and oil within mesocarp through the boundary and heat transfer. Sliced fruit had higher rate of oil released and water absorption. The results indicated that there is a good agreement between the simulated and experimental data at both scales of modelling.

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

STUDI ASAS PROSES PELUMATAN BUAH KELAPA SAWIT

Oleh

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Meskipun proses pelumatan buah kelapa sawit penting sebelum ekstraksi minyak, fenomena yang berlaku ketika proses tersebut berlangsung belum diketahui secara mendalam. Untuk itu, eksperimen, pemodelan, dan juga simulasi komputer bagi proses pelumatan buah kelapa sawit telah dijalankan dalam kajian ini. Dalam tahap eksperimen, percontohan buah kelapa sawit yang digunakan terlebih dahulu disterilkan di bawah tekanan wap yang berbeza, iaitu 40 dan 70 psi. Beberapa ujikaji telah dilakukan, termasuklah pencirian mencakupi daya keresapan air, kadar pelepasan minyak, isipadu, ujian pemampatan, dimensi, berat, keliangan, struktur mikro dan meso bagi serat buah kelapa sawit menggunakan SEM dan mikroskop cahaya, pengekstrakan minyak menggunakan penekan hidraulik, dan juga kualiti minyak.

Daya tahan keretakan tempurung terhadap tekanan cenderung menurun berturut-turut untuk buah segar, buah yang telah mengalami sterilisasi, dan buah yang sudah mengalami proses pelumatan. Selama proses pelumatan, percontohan yang disterilkan pada 70 psi mempunyai laju kelepasan minyak yang lebih tinggi. Hal ini mungkin disebabkan lebih banyak dinding sel yang terhidrolisis pada sampel yang mengalami sterilisasi 70 psi, yang dicirikan dengan kepekatan gula yang lebih tinggi dalam air luwapan digester. Begitu juga, semasa penekanan berlaku, percontohan tersebut memerlukan tekanan lebih rendah untuk membolehkan minyak dikeluarkan. Walau bagaimanapun, percontohan buah yang disterilkan pada 70 psi mempunyai tekstur yang lebih lembut meningkatkan jumlah lumpur di dalam proses pelumatan. Selain itu, daya tahan keretakannya juga lebih rendah. Sehingga, setelah proses esktraksi minyak, dijumpai lebih banyak biji/ inti sawit yang pecah jika dibandingkan dengan percontohan yang disterilkan pada 40 psi.

Kualiti minyak meliputi DOBI (kadar kerosakan dalam proses pemutihan), asid lemak bebas (FFA), kandungan karoten, dan trigliserida juga diselidiki dalam kajian ini. Berdasarkan analisa pada sampel 40 dan 70 psi, tiada perubahan yang ketara dalam kualiti minyak meskipun sampel telah mengalami proses pelumatan dalam masa yang berbeza, iaitu 10, 20, dan 30 minit. Berdasarkan standard yang ditetapkan MPOB, kualiti minyak masih dianggap bagus dan boleh diterima.

Pemodelan dan simulasi proses pelumatan buah kelapa sawit skala mikro dan meso dengan menggunakan perisian Comsol Multiphysics digunakan untuk mendapat

pemahaman mengenai proses pelumatan lebih mendalam. Pada skala mikro, buah dianalisa pada peringkat sel, gelembung minyak, dan dinding sel. Kadar kerosakan dinding sel mempunyai pengaruh kuat terhadap pergerakan gelembung minyak. Sedangkan dalam proses simulasi skala meso, satu buah kelapa sawit dimodelkan sebagai benda ellipsoid yang komposisinya terdiri daripada serat, biji sawit, dan tempurung. Adapun modul yang digunakan dalam tahap simulasi ini adalah heat transfer dan mass transfer untuk air dan minyak. Mengikut hasil simulasi, buah yang diiris mempunyai tingkat absorpsi air yang lebih tinggi dan laju pelepasan minyak yang lebih besar daripada buah utuh.

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I certify that a Thesis Examination Committee has met on 30 December 2014 to conduct the final examination of **Yayat Nurhidayat** on his thesis entitled "**Fundamental Study of Oil Palm Fruit Digestion Process**" in accordance with the Universities and University College 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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LIST OF ABBREVIATIONS

Term	**Definition**
CPO	Crude palm oil
CBR	California Bearing Ratio
CFD	Computational fluid dynamic
EFB	Empty fruit bunch
FFA	Free fatty acid
FFB	Fresh fruit bunch
MC	Moisture content
MR	Moisture ratio
OER	Oil extraction rate
OC	Oil content
PKO	Palm kernel oil
RBDP	Refined, bleached, deodorized, palm olein
RKA	Redlich Kwong Aspen equation
USB	Unstripped Bunch

CHAPTER 1
INTRODUCTION

1.1 Background

Oil palm tree has undoubtedly gained much attention for decades due to their significant role in human's life. The main products derived from the trees are crude palm oil (CPO) and palm kernel oil (PKO). These perennial tropical trees are source of various multipurpose products, ranging from human diet, fiber materials (particle board, pulp, paper, etc.), source of energy (biodiesel, carbon briquette, etc.), fertilizer, oleochemical products, and even feedstuff for animals. (Fairhurst and Mutert, 1999). It is a versatile product, which is used as an ingredient for food as well as non-food products (Anonymous, 2014). However, most part of its product is traditionally used for human diet that accounts for 80% of total production and the rest is for non-food purpose (Basiron and Chan, 2004).

Palm oil is extracted from oil palm fruit mesocarp while palm kernel oil is similarly extracted from its kernel. The technological development of palm oil extraction process dates back to West Africa, where the oil palm trees originally dispersed throughout the world. The first practise of palm oil extraction used to be for food purposes (such as for cooking oil, local cuisines, etc.) within the native of West African population with very simple methods. At that time, small scale processors use manual/ hand-operated machines in oil extraction with various oil yields from the processes. By using hand operated screw press, oil yield can achieve 70% of total oil content within mesocarp (Georgi, 1938). The oil yield can achieve higher rate when the extraction process uses hydraulic press, reaching over 90% of the total available oil in mesocarp (Hartley, 1967). Nowadays, the commercial extraction process is performed almost similar with that in old days but in better organized trading, particularly in the villages of West Africa. Today, modern palm oil mills employ almost relatively the same machine principles as it was used in the 1950s.

The advancement of palm oil extraction began in first decade of 20^{th} century in Belgium Congo initiated by William Lever. His endeavour in improving machinery equipment and innovating new planting materials led to the revolution of palm oil extraction process worldwide. Thanked to this palm oil production stage, both quality and quantity of oil are improving.

However, with similar amount of fruits, palm oil obtained from the extraction may vary depending on the performance of oil palm processor. This performance measures the ratio of output (oil produced) to input (fresh fruit bunch of oil palm). Technically, it is well known with term of oil extraction rate (OER). OER simply indicates percentage of output (palm oil) to input (fresh fruit bunch). OER plays an important indicator of palm oil mill productivity. It is used as a tool to assess performance of a mill or plantation. By producers, governments, and organizations, it can be used to estimate loss or gain in revenue.

Very commonly, the process of palm oil extraction process begins with sterilization of fresh fruit bunches (FFBs) after harvesting. Sequentially, the fruit will go into thresher for threshing and digester for digestion process. In spite of that, prior to oil expression in screw press, sterilization and digestion process are very crucial stages to achieve optimum condition to facilitate oil extraction. A study reported that properly sterilized and digested fruit result in high oil extraction rate. Then, degree of fruitlet maceration in digestion process greatly determines the effectiveness of oil extraction process in screw press. In other words, it leads to how much oil yield can be obtained from fiber (mesocarp of fruit) (Owolarafe, 2002). However, the similar study stated that over sterilized or over digested oil palm fruit has led to nut cracking or kernel breakage. Thus it increases the rate of kernel oil losses (Owolarafe and Babatunde, 2008). Oil loss during digestion process is also considerable and has significant impact to mill expenditure. Practitioners have calculated that 0.5% of oil loss increase has caused a financial loss of five to six digit figures per annum for a 30 tonnes/ hour CPO capacity mills (Vugts et al, n.d.). The result of the study indicates that the digestion process needs to be properly run at certain level to reach optimum condition for oil extraction, to gain maximum oil, to avoid kernel breakage, and to reduce oil loss.

Thus, both sterilization and digestion process correlate to optimum oil extraction rate. The change of parameters in sterilization will affect to the condition of digestion process. Current sterilization practice as well as digestion process in commercial mills still pose several drawbacks. After sterilization and threshing, the fruitlets are expected to be all detached from the bunch. Yet, these process still leave unstripped bunch (USB) which contributes to oil loss even after using double thresher. Likewise, it is difficult to measure the effectiveness of digestion process in mills by analyzing the fruit characteristics since the digester outlet is installed directly with screw press. Thus, to obtain fruit mash before pressing for analysis is challenging.

There still lack studies to correlate fundamental aspects of sterilization and digestion process. As a consequence, the fundamental aspect of digestion process as well as sterilization is not well understood yet. To address this gap, there is a strong need for conducting in-depth research in these areas. In addition, the other way to improve the deep understanding the fundamental principles of these processes could be attained by incorporating experimental studies with modelling and simulation. Simulating the process is considered a robust and fastest way to do but it requires a model to initially be established. Then, experiment together with simulation eventually achieves deeper knowledge and understanding in the digestion process in particular. Yet, no model depicting oil palm fruit digestion process nor oil palm fruit is present.

1.2 Problem Statement

The palm oil processing has been established for considerable period of time. With distinctive purpose and treatment, this process generally evolves into several divisions. However, thorough overview on primary stage of palm oil processing leads to some problems emerging from the introduction in this study which can be summed up in the following sentences.

- The basic principles of oil palm fruit digestion process are not fully understood.
- Sterilized fruit (fruit after sterilization and before going to a digester) and digested fruit mash are not well-characterized.

- No model represents the process of oil palm fruit digestion nor of the oil palm fruit for the purpose of simulation of the process.

1.3 Objectives

Regarding the problems of existing digester as mentioned above, by conducting the research, we expect that the study aims:

- To study the effects of different sterilization conditions on the performance of oil palm digestion process based on the existing design.
- To characterize the sterilized oil palm fruit and digested oil palm fruit mash properties.
- To study the fundamental aspects of oil palm fruit digestion process based on the existing design and to apply them in simulation of oil palm fruit digestion process.

1.4 Scope of Research Work

The study examined the effect of sterilization and digestion on properties of oil palm fruit. In simulation, the study will focus on establishing model of oil palm fruit as well as digestion process. Study will incorporate experimental works with computer simulation using Comsol Multiphysics software. The model and simulation are performed in micro- and meso-scale of geometry and the process. The simulation results are compared with experimental data obtained from digestion process. In addition, to investigate the effect of sterilization to digestion process, the study also used two different pressure of sterilization, 40 and 70 psi.

1.5 Thesis Outline

This study report consists of five chapters. Chapter 1 titled Introduction encompasses the background of study, the problem statement, objectives of the study, and scopes of work. Chapter 2 which is attributed Literature Review delivers detailed reviews and results on previous studies related to digestion process and palm oil extraction in general. These previous data and results are a base for this study to further investigate each aspect of digestion process. Chapter 3 Research Methodology explains equipment, materials, and methods employed in this study. Further on, Chapter 4 is written to present study result and analysis based on both the experiment and simulation. At the end, Chapter 5 covers conclusion and recommendation.

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APPENDICES

Appendix A

Value of Density, Specific Heat Capacity, and Thermal Conductivity as Temperature Dependence

Density

Water : $997.18 + 3.1439e\text{-}3T - 3.7574e\text{-}3T^2$ kg/m^3

Fat (Oil) : $925.59 - 0.41757T$ kg/m^3

Carbohydrate : $1599.1 - 0.31046T$ kg/m^3

Ash : $2423.8\text{-}0.28063T$ kg/m^3

Specific Heat Capacity

Water : $4176.2 - 9.0862e\text{-}5T + 5473.1e\text{-}6T^2$ J/kg ^oC

Fat (oil) : $1984.2+1473.3e\text{-}3T- 4800.8e\text{-}6T^2$ J/kg ^oC

Carbohydrate : $1548.8+1962.5e\text{-}3T- 5939.9e\text{-}6T^2$ J/kg ^oC

Ash : $1092.6+1889.6e\text{-}3T\text{-}3681.7e\text{-}6T^2$ J/kg ^oC

Fiber : $1845.9+1930.6e\text{-}3T\text{-}4650.9e\text{-}6\ T^2$ J/kg ^oC

Thermal Conductivity

Water : $0.57109+1.7625e\text{-}3T\text{-}6.7306e\text{-}6\ T^2$ W/m ^oC

Fat (oil) : $0.1807+2.7604e\text{-}3T\text{-}1.7749e\text{-}7\ T^2$ W/m ^oC

Carbohydrate : $0.2014+1.3874e\text{-}3T- 4.3312e\text{-}6\ T^2$ W/m ^oC

Ash : $0.3296+1.401e\text{-}3T\text{-}2.9069e\text{-}6\ T^2$ W/m ^oC

Note: Value of T is in ^oC

Appendix B
Calibration Curve for Oil Concentration Measurement

The calibration curve of refractive index (RI) and concentration of crude oil in hexane solution based on five different solutions is presented below. The concentration of oil used in the binary solution of oil in hexane was 0.00, 0.02, 0.04, 0.06, 0.08, and 0.10 g/ mL. From the graph, it can be deducted that RI value and concentration has linear relation.

Table Refractive index of standard curve

Samples	Ratio Hex:Oil(w/w)					
	0.00	0.17	0.25	0.5	0.8	1
RI_1	1.38288	1.39541	1.40182	1.42219	1.45685	1.47148
RI_2	1.3827	1.39574	1.40204	1.42235	1.45524	1.47123
RI_3	1.38315	1.39573	1.4022	1.42328	1.45499	1.4705
average	1.38291	1.395627	1.40202	1.4226067	1.455693	1.47107

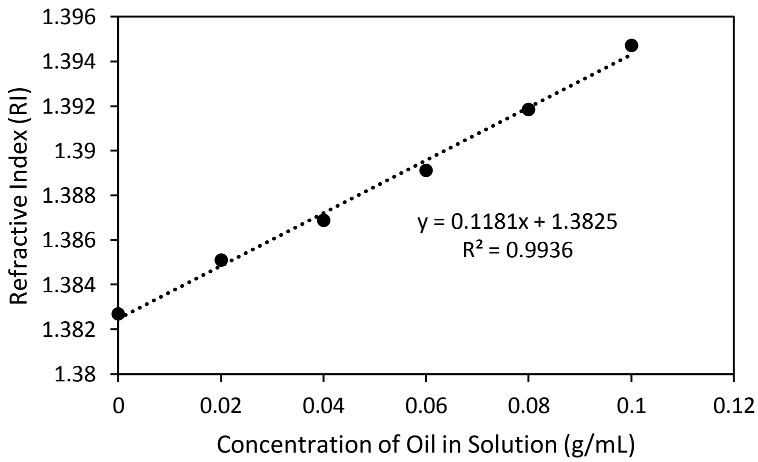

Figure Refractive Index Standard Curve

Appendix C
Measurement of Crude Palm Oil CPO) Density

Crude oil density was then determined with the equation below:

$$\rho_{cpo} = \frac{m_{cpo}}{m_{H_2O}} \cdot \rho_{H_2O}$$

Where ρ_{cpo} and m_{cpo} are density of crude palm oil and mass crude palm oil respectively, while m_{H_2O} and ρ_{H_2O} are mass of distilled water (gram) and density of distilled water (g/ml) respectively.

Table Calculation of Crude Palm Oil Density Compared with RBDP Olein

T (^{o}C)	Mass(g)*	Mass of oil	density	RBDP Olein
30	47.436	22.8604	0.899768	0.885
40	47.322	22.7464	0.895281	0.88
50	47.193	22.6174	0.890203	0.8751
60	47.037	22.4614	0.884063	0.8702
70	46.874	22.2984	0.877648	0.8654
80	46.696	22.1204	0.870642	0.8607
90	46.529	21.9534	0.864069	0.8561

*: total mass of pycnometer and CPO

Appendix D
Measurement of Crude Palm Oil (CPO) Viscosity

Table CPO and RBDP Olein Viscosity

T (°C)	Kinematic viscosity	Dynamic viscosity	
		Crude palm oil	RBDPO
50	32.1416135	28.87947	23.68
60	23.7137413	21.30696	16.93
70	18.0773918	16.24266	12.75
80	14.1805288	12.7413	9.99
90	11.4304946	10.27038	8.08
100	9.36081255	8.410756	6.72

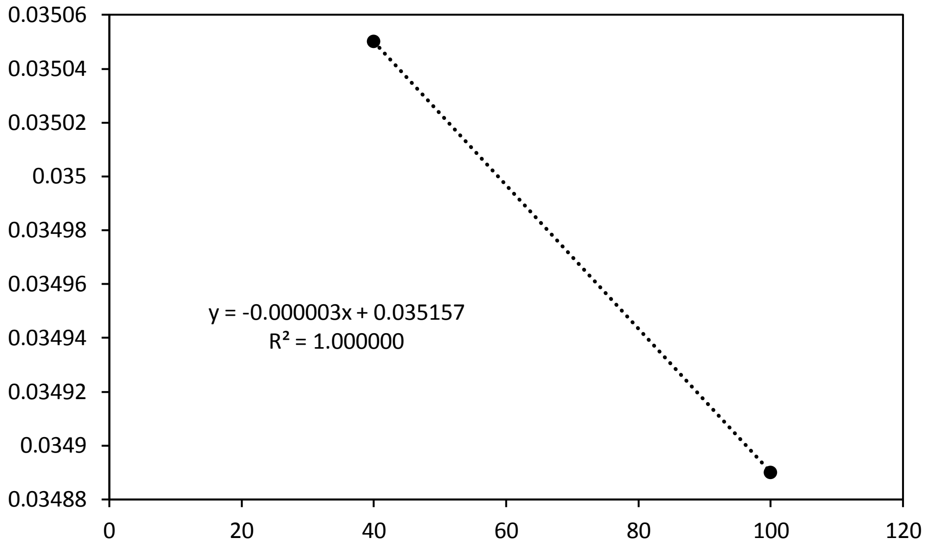

Figure Constant Interpolation

Appendix E
Calibration of Known Area of Geometry for Surface Determination

Table Known Area of Geometries and Their Representative Number of Pixels

Geometry	Dim (mm)	Real area (mm^2)	Number of Pixel	Ratio (pixel/mm^2)	Pixel area (mm^2)
Square1	30 x 30	900	1.24962e+5	138.85	7.2e-3
Square2	50 x 50	2500	3.481e+5	139.24	7.18e-3
Circle1	r = 15	707.143	9.8326e+04	139.047	7.19e-3
Circle2	r = 35	3850	5.3625e+05	139.286	7.179e-3

Appendix F
Matlab Commands

Matlab command (Determining the area of fruit and shell)

```
i = imread ('file_name');

j = im2bw (i,0.8);

k = imshow (j)

a = bwarea (j)
```

Matlab command (determining the concentration of sugar component) to solve matrix

```
e = [18.36557 18.04943; 30.73317 31.5213]

r = inv (e)

  = 1.3030   -0.7461

    -1.2705   0.7592

a = [abs315_1 abs319_1; abs315_2 abs319_2; abs315_3 abs319_3]

C = a*r
```

Appendix G
UV Spectrophotometer Test in Determining Sugar Content

Method of UV/ Vis spectrometry is based on Beer's Law of light absorption, which stated:

$$A = -\log T = \log \frac{P_0}{P} = \varepsilon bc \quad (3.27)$$

Where T is transmittance, A is absorbance, P_0 is incident radiant power, P transmitted radiant power, ε is molar absorptivity, b is path length of sample (cm), c is concentration of absorber (g/ml). Application of Beer's Law to mixture solution, can be expressed with (Skoog et al., 2007):

$$A_{tot} = A_1 + A_2 + \cdots + A_n = \varepsilon_1 bc + \varepsilon_2 bc + \cdots + \varepsilon_n bc$$

Subscript letters refer to absorbing component 1, 2,…, n in solution.

To find each concentration from the mixture, the matric equation was employed:

$$\begin{bmatrix} C_{g1} & C_{x1} \\ C_{g2} & C_{x2} \\ C_{gn} & C_{xn} \end{bmatrix} x \begin{bmatrix} \varepsilon_{g315} & \varepsilon_{g319} \\ \varepsilon_{x315} & \varepsilon_{x319} \end{bmatrix} = \begin{bmatrix} A_{1_{315}} & A_{1_{319}} \\ A_{2_{315}} & A_{2_{319}} \\ A_{n_{315}} & A_{n_{319}} \end{bmatrix}$$

Where Cg is concentration of glucose in the mixture, Cx is xylose concentration, is mass absorptivity for glucose and xylose respectively, A is total absorbance at wavelength 305 and 309. 1,2,…n is the number of repetition. The 305 nm is the wavelength at which absorbance of glucose has the highest value, while that of xylose is at wavelength 309 nm. Then to find each concentration in each repetition:

$$\begin{bmatrix} C_{g1} & C_{x1} \\ C_{g2} & C_{x2} \\ C_{gn} & C_{xn} \end{bmatrix} = \begin{bmatrix} A_{1_{315}} & A_{1_{319}} \\ A_{2_{315}} & A_{2_{319}} \\ A_{n_{315}} & A_{n_{319}} \end{bmatrix} x \begin{bmatrix} \varepsilon_{g315} & \varepsilon_{g319} \\ \varepsilon_{x315} & \varepsilon_{x319} \end{bmatrix}^{-1}$$

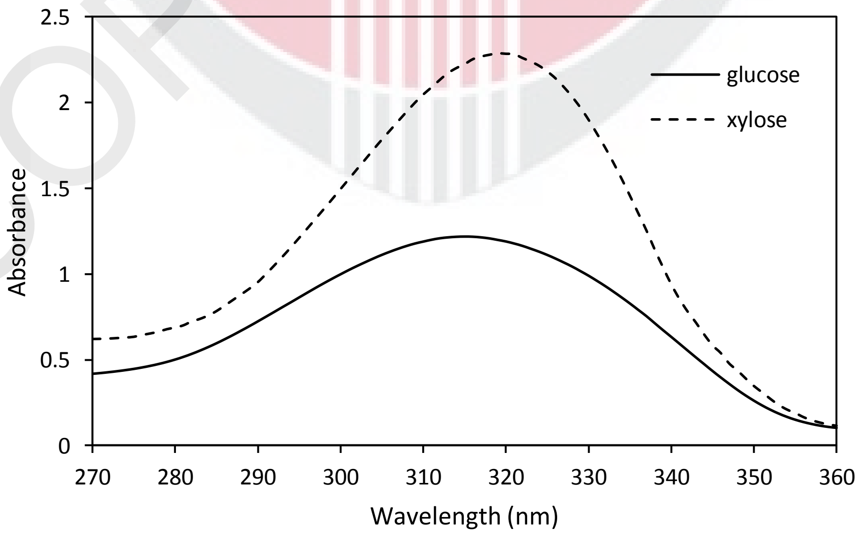

Figure Maximum Absorbance (Peak) for Glucose and Xylose Solution

Table Mass Absorptivity of Glucose at Dual Wavelength

λ (nm)	Concentration (g/L)						ε
	0	0.02	0.04	0.06	0.08	0.1	
315	0	0.5608	0.6234	0.9338	1.2186	1.7407	15.696
319	0	0.545	0.6173	0.922	1.1992	1.7208	15.530

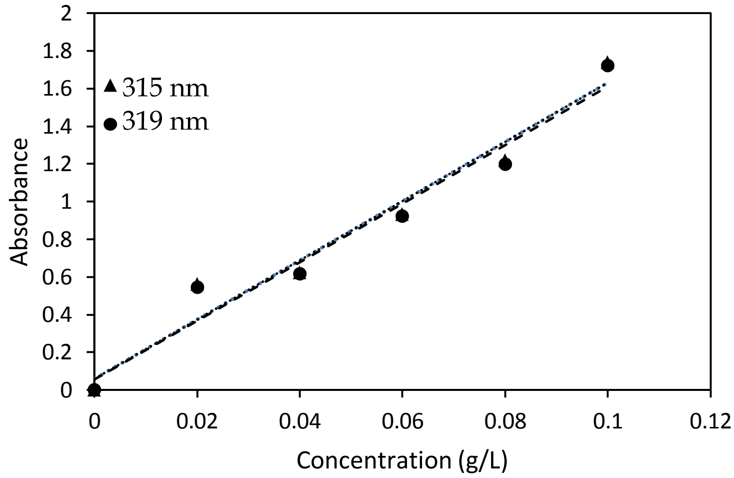

Figure Absorbance vs Concentration of Glucose

Table Mass Absorptivity of Xylose at Dual Wavelength

λ (nm)	Concentration (g/L)						ε
	0	0.02	0.04	0.06	0.08	0.1	
315	0	0.7584	1.1385	1.8869	2.224	2.8035	27.375
319	0	0.7786	1.1687	1.9113	2.2872	2.9014	28.251

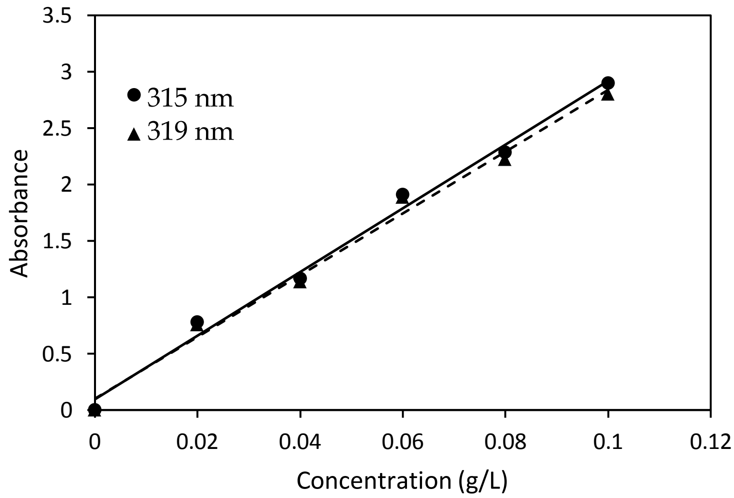

Figure Absorbance vs Concentration of Xylose

Appendix H
Digestion and Oil Extraction Process

During digestion process, mass transfer and heat transfer occur involving water (moisture content and steam), solid (fiber, sludge), and oil within the system (digester vessel). The mass balance within fruit mash is:

$$M_f = M_s + M_w + M_o$$

M_f is mass of oil palm fruit, M_s is mass of solid, M_w is mass of water or moisture content, M_o mass of oil content.

On the other hand, mass balance during digestion process can be depicted below.

$$M_s = M_{s\,in} - M_{slud}$$

$$M_w = M_{w\,in} + M_{w\,abs}$$

$$M_o = M_{o\,in} - M_{o\,dig}$$

Where M_s, M_w, and M_o are mass of solid, water content, and oil content within fruit mash after digestion respectively, $M_{s\,in}$ is mass of initial solid in the fruit mash, M_{slud} is mass of sludge carried in the digestion condensate, $M_{w\,in}$ is initial moisture content, $M_{w\,abs}$ is increase of moisture content due to absorption from steam, $M_{o\,in}$ mass of initial oil in fiber before digestion, $M_{o\,dig}$ is mass of oil released during digestion process.

Digestion process will produce condensate consisting of water, oil, and solid (sludge). This condensate is collected at the bottom of digester and flowed through outlet pipe. The mass balance can be described as below.

$$M_{cond} = M_{o\,dig} + M_{slud} + M_{w\,cond}$$

Where M_{cond} is mass of digestion condensate and $M_{w\,cond}$ is mass of steam condensed and turn into liquid water.

During the process, liquid (mixture of oil, water, and sludge), flowed out of the digester and was collected in a container and the volume was measured. Later, after transferred into conical tubes, the mixture was kept overnight to promote sludge, water, and oil separation. Then, it was put into water bath to elevate the temperature so that the separation can be easily observed.

Since the retained oil within the fiber will immediately be extracted in pressing, the mass balance of oil is expressed:

$$M_{o\,ret} = M_o - M_{o\,press}$$

Where $M_{o\,ret}$ is mass of oil retaining after pressing and $M_{o\,press}$ is mass of oil extracted during pressing. Then, the total oil can be expressed after pressing.

$$M_{o\,in} = M_{o\,dig} + M_{o\,press} + M_{o\,ret}$$

Likewise, mass balance of water and solid in pressing can be described as:

$$M_{w\,ret} = M_w - M_{w\,press}$$

$$M_{s\,ret} = M_s - M_{s\,press}$$

Where $M_{w\,ret}$ and $M_{s\,ret}$ is mass of water content and mass of solid of pressed fiber after pressing respectively, $M_{w\,press}$ and $M_{s\,press}$ are mass of water extracted during pressing and mass of solid (sludge) extracted during pressing respectively.

During pressing, mass change of mixture liquid liberated shown by digital balance reading was monitored manually and recorded. At the same time, stress was increased and recorded by computer. The collected pressed liquid in the container was then moved to conical tube for separation process to determine the amount of each component, i.e. water, oil, and sludge.

Calculation to Determine Total Oil Content

Assuming that M_{in} is initial mass after digestion.

$$M_{in} = W + O + S$$

Where W, O, and S are mass of water, oil, and solid of the oil palm fruit. During digestion, mass of oil is liberated O_{dig}. Thus, due to oil liberation,

$$M_{dig} = W + (O - O_{dig}) + S$$

From M_{dig}, amount of sample was taken, Ms. the ratio of Ms to Min is:

$$r = \frac{M_s}{M_{dig}}$$

Thus, each component, water, oil, and solid in the sample is

$$M_s = rW + r(O - O_{dig}) + rS$$

Oil extracted is Opress, while oil remaining is Orem, thus

$$r(O - O_{dig}) = O_{press} + O_{rem}$$

$$(O - O_{dig}) = \frac{O_{press} + O_{rem}}{r}$$

$$O = \frac{O_{press} + O_{rem}}{r} + O_{dig}$$

Thus, total initial oil content in the sample is:

$$\left(\frac{O_{press} + O_{rem}}{r} + O_{dig}\right) x \frac{1}{M_{in}}$$

$$\%O_{dig} = 1 - \left\{\frac{O_{press} + O_{rem}}{O_{press} + O_{rem} + rO_{dig}}\right\}$$

$$\%O_{press} = 1 - \left\{\frac{O_{rem} + rO_{dig}}{O_{press} + O_{rem} + rO_{dig}}\right\}$$

$$\%O_{rem} = 1 - \left\{\frac{O_{press} + rO_{dig}}{O_{press} + O_{rem} + rO_{dig}}\right\}$$

The record of mass change and pressure of load were then plotted for analysis.

$$M_{o\,in} = M_{o\,dig} + M_o$$

Where $M_{o\,in}$ is total oil content, $M_{o\,dig}$ is oil released during digestion process, M_o is oil content within fruit mash before pressing.

Appendix I
Density of Oil Palm Fruit Determination

Table Bulk Density

Replication	M(g)	V(ml)	Db(g/ml)
1	201.027	308	0.652685
2	197.578	308	0.641487
3	196.653	308	0.638484
4	138.65	220	0.630227
5	161.306	250	0.645224
6	168.206	280	0.600736
7	179.278	290	0.6182

True Density

Replication	M(g)	V(ml)	D(g/ml)
1	43.628	44	0.991545
2	40.896	41	0.997463
3	46.59	46.5	1.001935
4	49.174	46	1.069
5	50.798	48	1.058292
6	46.413	45	1.0314
7	43.799	47	0.931894

Appendix J
Oil Quality Test

Table Oil FFA Content Test

Sample	Mass(g)	KOH (ml)	FFA
4010	2.5	0.4	0.4096
4020	2.5	0.45	0.4608
4030	2.5	0.4	0.4096
7010	2.5	0.4	0.4096
7020	2.5	0.45	0.4608
7030	2.5	0.45	0.4608

Table DOBI and Carotene Content Test

Sample	Wavelength		DOBI	Carotene
	269	446		
4010	0.156	0.559	3.583333	535.2425
4020	0.157	0.54	3.43949	517.05
4030	0.157	0.569	3.624204	544.8175
7010	0.155	0.612	3.948387	585.99
7020	0.169	0.569	3.366864	544.8175
7030	0.181	0.594	3.281768	568.755

BIODATA OF STUDENT

The student Yayat Nurhidayat, having graduated from SMA (Sekolah Menengah Atas) 12 Yogyakarta, Indonesia, continued his study to Universitas Padjadjaran, Bandung, Indonesia, until he got the degree in Bachelor of Agriculture Technology. After graduation, he worked as editor, freelance author, and journalist for 5 years. He enrolled as a full-time candidate for Master of Science program in the field of Environmental Engineering, at the Department of Chemical and Environmental Engineering, Faculty of Engineering, Universiti Putra Malaysia in February 2012.

LIST OF PUBLICATION

The articles which were published or submitted by the author during his Master study are as follows:

Noerhidajat, R. Yunus, Zurina Z.A., S. Syafiie, T.S. Chang. (2014) Mesoscale Modelling and Simulation of Heat and Mass Transfer of Oil Palm Fruit Digestion Process. Proceeding of International Conference on Agriculture and Food Engineering (CAFEi 2014), Kuala Lumpur, Malaysia, Dec 1 – 3, 2014.

Noerhidajat, R. Yunus, Zurina Z.A., S. Syafiie, Vicknesh R, Umer Rashid. (2015). High Pressurized Sterilization Effect on Oil Palm Fruit Digestion Performance. International Journal on Food Technology (submitted)

Noerhidajat, R. Yunus, Zurina Z.A., S.Syafiie, Vicknesh R, Thang Yin Mee. (2015). High Pressurized Sterilization and Digestion Effect on Oil Extraction Performance and Oil Quality (submitted)