UNIVERSITI TEKNOLOGI MALAYSIA

BORANG PENGESAHAN STATUS TESIS[υ]

JUDUL: BIODEGRADATION OF OIL AND GREASE IN UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR FOR PALM OIL MILL EFFLUENT TREATMENT

SESI PENGAJIAN: 2005/2006

Saya LEE CHEE SIANG
(HURUF BESAR)

mengaku membenarkan tesis (~~PSM~~/Sarjana/~~Doktor Falsafah~~)* ini disimpan di Perpustakaan Universiti Teknologi Malaysia dengan syarat-syarat kegunaan seperti berikut:

1. Tesis adalah hakmilik Universiti Teknologi Malaysia.
2. Perpustakaan Universiti Teknologi Malaysia dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (4)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ TIDAK TERHAD

Disahkan oleh

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:
41, Jalan Banda Kaba
75000 Melaka
Melaka

Prof. Ir. Dr. Zaini Ujang
Nama Penyelia

Tarikh: 5th May 2006 Tarikh: 5th May 2006

CATATAN:
* Potong yang tidak berkenaan.
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.
υ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

"I hereby declare that I have read this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of the degree of Master of Engineering (Civil- Environmental Management)"

Signature : ....

Name of Supervisor : Prof. Ir. Dr. Zaini Ujang

Date : 5th May 2006

BAHAGIAN A – Pengesahan Kerjasama*

Adalah disahkan bahawa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara ______________________ dengan ______________________

Disahkan oleh:

Tandatangan : .... Tarikh : ....

Nama : ....

Jawatan : ....
(Cop rasmi)

* *Jika penyediaan tesis/projek melibatkan kerjasama.*

BAHAGIAN B – Untuk Kegunaan Pejabat Sekolah Pengajian Siswazah

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat Pemeriksa Luar : ....
....
....

Nama dan Alamat Pemeriksa Dalam : ....
....
....

Nama Penyelia Lain (jika ada) : ....
....
....
....

Disahkan oleh Penolong Pendaftar di SPS:

Tandatangan : .... Tarikh : ....

Nama : ....

BIODEGRADATION OF OIL AND GREASE IN UPFLOW ANAEROBIC SLUDGE BLANKET REACTOR FOR PALM OIL MILL EFFLUENT TREATMENT

LEE CHEE SIANG

A project report submitted in partial fulfillment
of the requirements for the award of the degree
of Master of Engineering (Civil- Environmental
Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

May 2006

I declare that this project report entitled "Biodegradation of Oil and Grease in Upflow Anaerobic Sludge Blanket Reactor for Palm Oil Mill Effluent Treatment" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Lee Chee Siang

Date : 5th May 2006

To my beloved mother and father

ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main project report supervisor, Professor Ir. Dr. Zaini Ujang, for encouragement, guidance, critics and friendship. Without his continued support and interest, this project report would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for provide facilities for my master project. Librarians at UTM, also deserve special thanks for their assistance in supplying the relevant literatures.

My fellow postgraduate students should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

The upflow anaerobic sludge blanket (UASB) reactor is a system in which substrate passes first through an expanded sludge bed containing a high concentration of biomass. The sludge in the reactor may exist in granular or flocculent form. Most of the substrate removal takes place in sludge bed and the remaining portion of the substrate passes through a less dense biomass, sludge blanket. UASB reactor is one of the innovative high rate anaerobic digester that able to biodegrade the oil and grease (O&G) in palm oil mill effluent (POME). This study aimed to evaluate the biodegradation of O&G in raw POME using UASB. The objectives of this study were to determine the O&G biodegradation and chemical oxygen demand (COD) removal efficiencies for the treatment of POME using UASB and evaluate the UASB's performance in relation to various control variables. The characteristic of the raw POME were determined for 5 respective samples collected from Bukit Besar, Kulai. Hexane was used as the solvent for O&G extraction by using separatory funnel. The experiments of O&G biodegradation and COD removal were designed using full factorial design. The selected factors were hydraulic retention time (HRT), influent strength based on COD and influent pH. The steady state of the UASB was achieved after 26 days acclimatization with the COD removal constant at 62%. Then, the factorial designed experiments were conducted and percentage of O&G biodegradation and COD removal as the responses. The optimum combination of operating parameters was HRT 12.9 hrs, influent 5000 mg/L COD and influent pH 7 which success to remove 61.7% COD and biodegrade 62.9% O&G. Statistical analysis was used to study the UASB's performance in relation to various control operating parameters. The main factors that have significant effect on O&G biodegradation and COD removal were defined statistically.

ABSTRAK

Pencerna lapisan enap cemar anaerobik alir-naik (UASB) adalah satu sistem di mana bahan pemula akan bergerak melalui satu lapisan kembangan enap cemar terpendam yang mengandungi biojisim yang tinggi kepekatannya. Biojisim yang ada dalam pencerna boleh wujud dalam bentuk butiran atau gumpalan. Kebanyakan pencernaan bahan pemula berlaku dalam biojisim terpendam dan baki bahan pemula bergerak melalui satu lapisan yang kurang tumpat, iaitu lapisan kembangan enap cemar. Pencerna lapisan enap cemar anaerobik alir-naik adalah salah satu pencerna anaerobik berkadar tinggi yang mampu membiodegradasi minyak dan lemak (O&G) yang terkandung dalam effluen kilang minyak sawit (POME). Kajian ini bertujuan untuk mengkaji biodegradasi bagi minyak dan lemak yang terkandung dalam effluen kilang minyak sawit mentah dengan menggunakan pencerna lapisan enap cemar anaerobik alir-naik. Objektif-objektif bagi kajian ini adalah menentukan kecekapan biodegradasi bagi minyak dan lemak dan pengurangan permintaan oksigen secara kimia (COD) dalam rawatan effluen kilang minyak sawit dan juga menaksir prestasi pencerna berhubung dengan pelbagai kawalan parameter-parameter operasi. Ciri-ciri bagi 5 sampel berlainan effluen kilang minyak sawit mentah dari Bukit Besar, Kulai ditentukan. Heksana digunakan sebagai pelarut untuk pengekstrakan minyak dan lemak dengan menggunakan corong pemisah. Eksperimen-eksperimen biodegradasi minyak dan lemak dan pengurangan permintaan oksigen secara kimia direka secara faktoria penuh. Faktor-faktor yang dipilih adalah masa penahanan hidrolik (HRT), kekuatan influen berdasarkan permintaan oksigen secara kimia and pH influen. Keadaan mantap bagi pencerna tersebut dicapai selepas 26 hari penyesuaian dengan pengurangan permintaan oksigen secara kimia malar pada 62%. Seterusnya, eksperimen-eksperimen yang direka mula dijalankan dan peratusan bagi biodegradasi minyak dan lemak serta pengurangan permintaan oksigen secara kimia sebagai reaksi-reaksinya. Kombinasi parameter-parameter operasi yang terbaik adalah HRT 12.9 jam, kekuatan influen 5,000 mg/L COD dan pH 7 di mana ia berjaya mengurangkan 62% COD dan sebanyak 63% minyak dan lemak terbiodegradasi. Analisis secara statistik digunakan untuk mengkaji pretasi pencerna berhubung dengan pelbagai kawalan parameter-parameter operasi. Faktor-faktor utama yang mempunyai kesan nyata dan penting kepada biodegradasi minyak dan lemak dan pengurangan permintaan oksigen secara kimia telah dikenalpasti secara statistik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

$(CH_3)_3N$	-	Methylamine
2D	-	Two dimensions
ABR	-	Anaerobic baffled reactor
AMBR	-	Anaerobic migrating blanket reactor
Am-N	-	Ammoniacal nitrogen
BOD	-	Biochemical oxygen demand
C	-	Carbon
$Ca(OH)_2$	-	Calcium hydroxide
$Ca_5OH(PO_4)_3$	-	Calcium Hydroxide Phosphate
$CaCO_3$	-	Calcium carbonate
CB	-	Cocoa butter
CH_3COOH	-	Acetic acid
CH_3OH	-	Methanol
CH_4	-	Methane
CNO	-	Coconut oil
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
COD	-	Chemical oxygen demand
CPO	-	Crude palm oil
DS	-	Dissolved solids
ECP	-	Extracellular polymer
EQA	-	Environmental Quality Act
FAD	-	Flavin adenine dinucleotide
Fe	-	Ferum
FELCRA	-	Federal Land Consolidation and Rehabilitation Authority
FELDA	-	Federal Land Development Authority

FeS	-	Ferrous sulfide
FFB	-	Fresh fruit Bunch
GSS	-	Gas-solid separator
H_2	-	Hydrogen
H_2O	-	Water
HA	-	Homoacetogen
HCOOH	-	Formic acid
HPKS 35	-	Hydrogenated palm kernel stearin of melting point 35 ºC
HRT	-	Hydraulic retention time
IV	-	Iodine value
MARDI	-	Malaysian Agricultural Research Development Institute
Mn	-	Manganese
MPOB	-	Malaysian Palm Oil Board
NAD	-	Nicotinamide adenine dinucleotides
$NaHCO_3$	-	Natrium bicarbonate
NaOH	-	Natrium Hydroxide
NBD	-	Neutralized, bleached and deodorized
NH_3	-	Ammonia
$NH_4(HCO_3)$	-	Ammonium bicarbonate
NO_3^-	-	Nitrate
NRB	-	Nitrate reducing bacteria
O&G	-	Oil and grease
O_2	-	Oxygen
OHPA	-	Obligate hydrogen producing acetogens
PKO	-	Palm kernel oil
PKS	-	Palm kernel stearin
PO	-	Palm oil
POME	-	Palm oil mill effluent
PORIM	-	Palm Oil Research Institute of Malaysia
PORLA	-	Palm Oil Registration and Licensing Authority
R&D	-	Research and development
RBD	-	Refined, bleached and deodorized
RISDA	-	Rubber Industry Smallholders' Development Authority
RM	-	Ringgit Malaysia

sCOD	-	Soluble chemical oxygen demand
Sdn. Bhd.	-	Sendirian Berhad
SFC	-	Solid fat content
SRB	-	Sulfate reducing bacteria
SRT	-	Solid retention time
SS	-	Suspended solids
SVI	-	Sludge volume index
TN	-	Total nitrogen
TPAD	-	Temperature phased anaerobic digestion
TVS	-	Total volatile solids
UASB	-	Upflow anaerobic sludge blanket
VFA	-	Volatile fatty acid

LIST OF SYMBOLS

v	-	Design upflow superficial velocity
%	-	Percent
$<$	-	Less than
$>$	-	More than
A	-	Reactor cross section area
atm	-	Atmosphere
cm	-	Centimeter
cm^2	-	Centimeter square
d	-	Day
D_{in}	-	Inner diameter
g	-	Gram
g/L.d	-	Gram per liter per day
H	-	Height
hr	-	Hour
K_d	-	Endogenous decay coefficients
$kg/m^3.d$	-	Kilogram per cubic meter per day
L	-	Liter
m	-	Meter
m^2	-	Meter square
m^3	-	Cubic meter
m^3/d	-	Cubic meter per day
mg/L	-	Milligram per liter
mL/min	-	Milliliter per minutes
mm	-	Millimeter
M_p	-	Melting point
ºC	-	Degree of Celsius

Q	-	Influent flowrate
t	-	Tonne
V_r	-	Reactor volume
V_w	-	Working volume
Y	-	Synthesis yield

CHAPTER 1

INTRODUCTION

1.1 The Palm Oil Industry in Malaysia

The oil palm industry in Malaysia had a humble beginning. From a mere four original palms introduced from West Africa to the Bogor Botanical Gardens, Indonesia in 1848, their seeds soon arrived on Malaysian shores in 1871 (Basiron and Chan, 2004). Over the next four decades, the rubber companies in Malaysia saw their planters learning how to grow the crop in the country. The R&D undertaken soon showed the potential of the new crop. Following this effort, the first commercial planting was done in 1911 at Tenammaran Estate, Kuala Selangor. There was the success of the crop that the area expanded quickly, the most rapid increases occurring during the 1930s, 1970s and 1980s. The growth in area during the various decades of the last century in Malaysia is shown in Table 1.1. At the end of 2000, the area stood at 3.376 million hectares, producing 10.842 million tonnes of palm oil, 3.162 million tonnes of palm kernel, 1.384 million tonnes of palm kernel oil and 1.639 million tonnes of palm kernel meal.

Table 1.1: Area of oil palm planting and growth in the decades of the last century (Basiron and Chan, 2004).

Years in decades	Hectares	% Growth
1870-1910	<350	-
1920	400	14.2
1930	20 600	5050.0
1940	31 400	52.4
1950	38 800	23.5
1960	54 638	40.8
1970	261 199	378.0
1980	1 023 306	291.8
1990	2 029 464	98.3
2000	3 376 664	66.3

In the early 1960s, the returns from oil palm were found to be better than rubber and most of the plantation companies soon had a mix of both crops as their core business. It was Tun Abdul Razak Hussein, the then Deputy Prime Minister of Malaysia, who called for greater diversification into oil palm. With diminishing returns from the then two major commodities of the country, tin and rubber, oil palm should be used as the vehicle to eradicate rural poverty. The government's three rural development agencies, Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA) and Rubber Industry Smallholders' Development Authority (RISDA) were responsible for planting oil palm with large areas of land that were rehabilitated or newly opened (Basiron and Chan, 2004).

Landless people were placed as settlers in the newly opened land schemes. Malaysian government provided them housing and infrastructure including community halls, schools, health clinics, shops and roads. Initially, the government supported their livelihoods until the oil palm matured when the income from the crop was sufficient to pay off their loans. In doing so, the government was able to alleviate rural poverty using the oil palm as the vehicle to do so.

Initial R&D into the crop was carried out by the government sector, the Department of Agriculture. Together with the private research companies of the major plantation groups, the work included collecting breeding materials and experimentation in breeding, agronomy and palm oil chemistry. It was in 1969 when the Malaysian

Agricultural Research Development Institute (MARDI) was established that the mandate for oil palm research was taken over from the Department of Agriculture. The task was later handed to the Palm Oil Research Institute of Malaysia (PORIM) following its establishment in 1979. On 1 May 2000, PORIM was merged with the Palm Oil Registration and Licensing Authority (PORLA) to form the Malaysian Palm Oil Board (MPOB) (Basiron and Chan, 2004). The mission of MPOB is to support the well-being of the oil palm industry in Malaysia in all aspects of its activities through research, development and services.

The oil palm only grows well in tropical climates and so all the palm kernel producing countries are in Southeast Asia, Sub-Saharan Africa and South America (Pantzaris and Ahmad, 2001). Figure 1.1 shows the production and exports of the top four producing countries. The largest producer by far is Malaysia, which currently accounts for more than 50% of world production. While two countries, Malaysia and Indonesia together, account for about 80% of production and 88% of exports. No other country produces more than 7% or exports more than 3% of the world total.

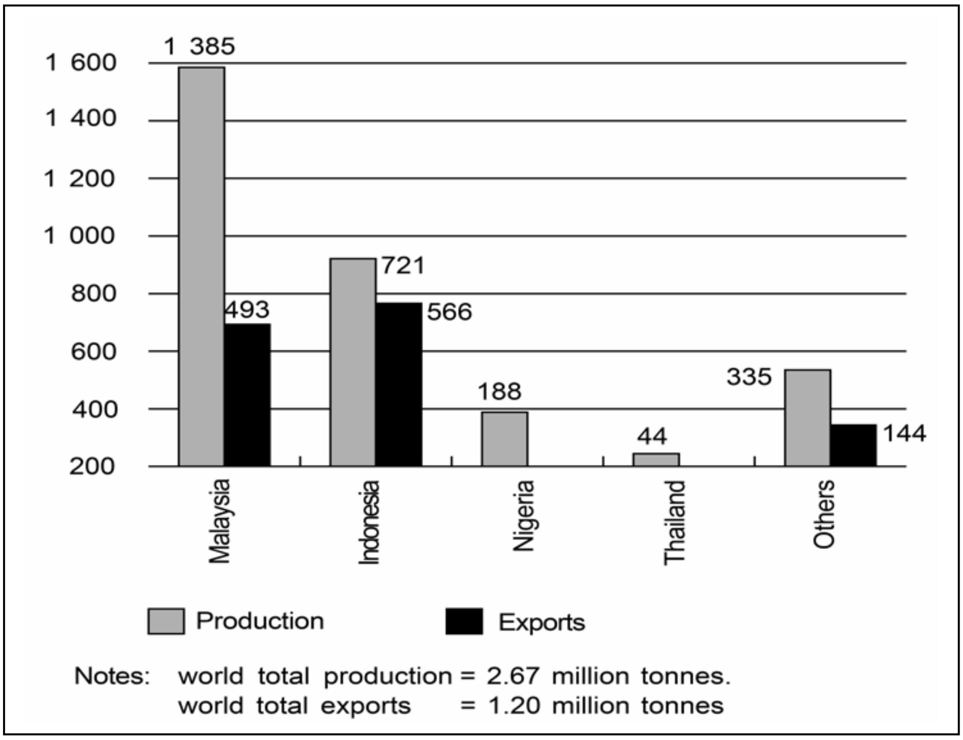

Figure 1.1: The top four palm kernel oil production and exports countries (Pantzaris and Ahmad, 2001).

Until the mid 1970s, Nigeria was the world's largest producer of palm kernels while Europe did most of the crushing and was effectively the world's largest palm kernel oil producer. But now all the crushing is done in the producing countries and Europe does no palm kernel crushing at all. From 1977, Malaysia overtook both Nigeria and Europe to become world's biggest producer of palm kernels and of palm kernel oil. However, in the last few years, her oleochemical industry has been absorbing very large and increasing quantities of the oil and her lead in exports have been reduced. In fact, Indonesia's exports were higher than Malaysia's in 2000 (Pantzaris and Ahmad, 2001).

The oil palm industry worldwide has provided the fastest increase in global oils and fats supplies over the last four decades. World palm oil production increased 20-fold from a mere 1.2 million tonnes in 1962 to 25.0 million tonnes in 2002 (Basiron *et al*., 2004). The share of palm oil production in the world oils and fats complex has increased markedly by five-fold from 4% in 1962 to 20.8% in 2002, as compared to the only two-fold increase experienced by soybean oil during the same period. The spiky increase in palm oil output was mostly triggered by continued worldwide expansion of the oil palm planted area and the mature area coming into production as well as growing world demand for vegetable oils as in Table 1.2.

Table 1.2: Palm oil expansion in production (Basiron *et al*., 2004).

Oils/fats	**1962 ('000 t)**	**% Share**	**2002 ('000 t)**	**% Share**	**40yrs Average Growth p.a. (%)**
World oils/fats production	30 779	-	120 477	-	3.5
Palm oil	1 234	4.0	25 034	20.8	7.8
Soybean oil	3 432	11.2	29 748	24.7	5.5
Rapeseed oil	1 163	7.5	13 326	11.1	6.3
Sunflower oil	2 294	3.4	7 611	6.3	3.0
Animal oils/fats	12 040	39.1	22 588	18.7	1.6

The status of palm oil as it is today in the world market is without doubt due to the significant contribution by the Malaysian palm oil industry (Basiron *et al*., 2004). Both Malaysia and Indonesia continue to remain the largest producers of palm oil, accounting for 84% of the world production in 2002. In fact, the country has become a role model for many other palm oil producing countries in their plans to urge economic development in the agricultural sector as well as to gain foreign exchange through exports of surplus production. In addition, oil palm is also featured as an important socio-economic crop in most producing countries especially for alleviating rural poverty amongst poor farmers.

The raw materials used in the manufacture of oleochemicals were mainly tallow, coconut oil or palm and palm kernel oils. Malaysia being the world's largest producer of palm oil and palm kernel oil is undeniably in a particularly favourable position to become a major supplier of raw materials for both the local and overseas oleochemical industries (Ooi and Yeong, 2000). The oleochemicals that produced from palm oil and its products are widely used in lubricants, plastics, resins, soaps, surfactants, emulsifiers, cosmetics, toiletries and textile chemicals.

Over the last three decades, the Malaysian palm oil industry has grown to become an important agricultural based industry. Malaysian palm oil accounted for about 52% of the world palm oil outputs and this industry generated RM 13 billion in export earnings for the country (Ahmad *et al.*, 2005). The palm oil industry faces the challenge of balancing the environmental protection, its economic viability and sustainable development. There is an urgent need to find a way to preserve the environment while keeping the economy growing (Ahmad *et al*., 2003).

1.2 Properties of Palm Oil

The cultivation of palm oil tree *Elaeis Guineensis* has expanded significantly over recent years as the demand for vegetable oils increases (Borja and Banks, 1994). The female bunch bears about 2,500 to 3,000 fruits borne on 100 to 120 spikelets attached to a peduncle from the axil of a frond. The fruits produce two main products, palm oil from the outer mesocarp and palm kernel oil from the kernel within the nut (Basiron and Chan, 2004). This tree is generally believed to have originated in the jungle forests of East Africa and there is some evidence that palm oil was used in Egypt at the time of the Pharaohs, some 5000 years ago, but now its cultivation is confined mostly to Southeast Asia. The variety cultivated in nearly all the world's plantations is the hybrid *Tenera*, the cross between *Dura* and *Pisifera*, which gives the highest yield of oil per hectare of any crop (Pantzaris and Ahmad, 2001).

Generally, the oil palms in Southeast Asia yield about 4 tonnes of palm oil, 0.5 tonnes of palm kernel oil, and 0.5 tonnes of palm kernel meal, with the income equivalent to more than 4.5 tonnes of oil. Nearly for every 8 tonnes of crude palm oil produced at the mill, about 1 tonnes of palm kernel oil is produced. The palm fruit looks like a plum. The outer fleshy mesocarp gives the palm oil, while the kernel, which is inside a hard shell, gives the palm kernel oil and it is rather strange that the two oils from the same fruit are entirely different in fatty acid composition and properties. Unfortunately, the two oils had often been confused by nutritionists in earlier days.

In palm oil, most of the fatty acids are C16 and higher, while in palm kernel oil, they are C14 and lower. Palm oil has iodine value (IV) 50 minimum, while palm kernel oil has 21 maximum. Semi-solid in temperate climates, palm kernel oil can be fractionated into solid and liquid fractions known as stearin and olein respectively. These are then physically refined, bleached and deodorized or chemically neutralized, bleached and deodorized to give the RBD and NBD grades used in the food industry (Pantzaris and Ahmad, 2001). The process of fractionation can be carried out either before or after the refining, according to conditions.

The major fatty acids in palm kernel oil are C12 (lauric acid) about 48%, C14 (myristic acid) about 16% and C18:1 (oleic acid) about 15%. No other fatty acid is present at more than 10% and it is this heavy preponderance of lauric acid, which gives palm kernel oil and coconut oil, their sharp melting properties, meaning hardness at room temperature combined with a low melting point (Pantzaris and Ahmad, 2001). This is the outstanding property of lauric oils, which determines their use in the edible field and justifies their usually higher price compared with most other oils. Because of their low unsaturation, the lauric oils are also very stable to oxidation. Table 1.3 shows the fatty acid composition of palm kernel oil, its similarity to coconut oil and their differences from palm oil, the co-product of palm kernel oil and typical non-lauric fat. Even after full hydrogenation, the melting point of palm kernel oil does not rise much above mouth temperature and fractionation gives a stearin which is even sharper melting.

Sharp melting fats leave a clean, cool, non-greasy sensation on the palate, impossible to match by any of the common non-lauric oils. Figure 1.2 shows the melting behavior in terms of solid fat content (SFC) values of palm kernel oil (PKO), palm kernel stearin (PKS) and hydrogenated palm kernel stearin of melting point 35ºC (HPKS 35), together with cocoa butter (CB) and palm oil (PO) for comparison.

Table 1.3: Percentage of fatty acid composition in palm kernel, coconut and palm oil (Pantzaris and Ahmad, 2001).

Fatty acids	Palm kernel oil (PKO)[1]	Coconut oil (CNO)[2]	Palm oil (PO)[3]
C6	0.3	0.4	-
C8	4.2	7.3	-
C10	3.7	6.6	-
C12	48.7	47.8	0.2
C14	15.6	18.1	1.1
C16	7.5	8.9	44.1
C18	1.8	2.7	4.4
C18:1	14.8	6.4	39.0
C18:2	2.6	1.6	10.6
Others	0.1	0.1	0.75[4]

Notes: [1]PORIM Survey 1984, n = 68.
[2]Leatherhead Food RA, Surrey, UK, Survey 1990, n = 35.
[3]PORIM Survey of RBD PO 1989, n = 244.
[4]Others = C18:3 0.37%, C20:0 0.38%.

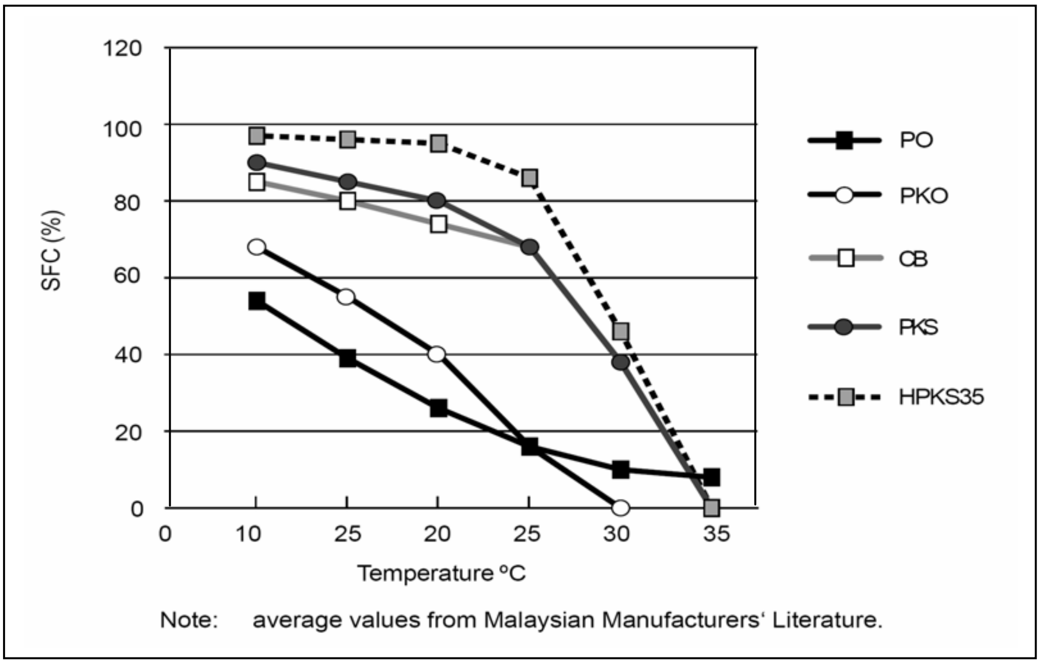

Figure 1.2: Solid fat content of cocoa butter, palm kernel oil product and palm oil (Pantzaris and Ahmad, 2001).

Palm oil contains about 1% minor components. The major constituents are carotenoids, vitamin E and sterols (Basiron and Chan, 2004). The carotene concentration is around 500 to 700 ppm. Carotene has been concentrated from palm oil successfully. The concentrate is rich in pro-vitamin A which is normally destroyed during processing. The major carotenes in the carotenoid concentrate are alpha and beta-carotenes and they can be diluted to various concentrations, from 1% to 30%. The vitamin E content in palm oil is unique in that it is about 600 to 1,000 ppm. It is present as tocotrienols (70%) rather than tocopherols (30%). It confers on the oil a natural stability against oxidation and a longer shelf-life as well as a potent ability to reduce low density lipoprotein-cholesterol and anti-cancer properties. Palm oil also contains 250 to 620 ppm sterols. Beta-sitosterol is the major constituent at 60%. It is potentially hypocholesterolemic.

1.3 Palm Oil Processing

The process flow-sheet for palm oil extraction can be briefly described as follows. The fresh fruit bunches (FFB) are harvested in bunches and sent to the mill for processing as show in Figure 1.3. Each FFB consists of hundreds of fruitlets each containing a nut surrounded by a bright orange pericarp which contains the palm oil (Borja and Banks, 1994). These bunches are steam sterilized at a pressure of 3 bar where the fruits soften and are easily detached from the stalk. These detached fruits are further softened with steam in digesters. The digester mash is then passed to the screw press where oil together with the juice from the fruits is expressed. The crude oil slurry which is expressed may contain approximately 48% oil, 45% water and 7% solids (Chow and Ho, 2000). Some of the water in this slurry is actually steam condensate from the sterilization, digestion and screw pressing where steam is injected into the respective machinery to maintain the high temperature required throughout the milling process.

Hot water is further added to the crude oil slurry to reduce the viscosity so that the oil will cream to the surface which assists in its separation in large clarification tanks (Borja and Banks, 1994). The underflow from the lower section of the clarification tank is centrifuged to remove as much of the heavier phase consisting of solids and water. This watery phase or sludge is discharged and any oil found here constitutes oil loss as it is discharged as effluent. The lighter phase from the centrifuge, which consists of oil and water, is recycled to the clarification tank. The creamed palm oil from the surface of the clarification tank is then skimmed and further purified, dried and sold as crude palm oil (CPO) to the refinery for further processing.

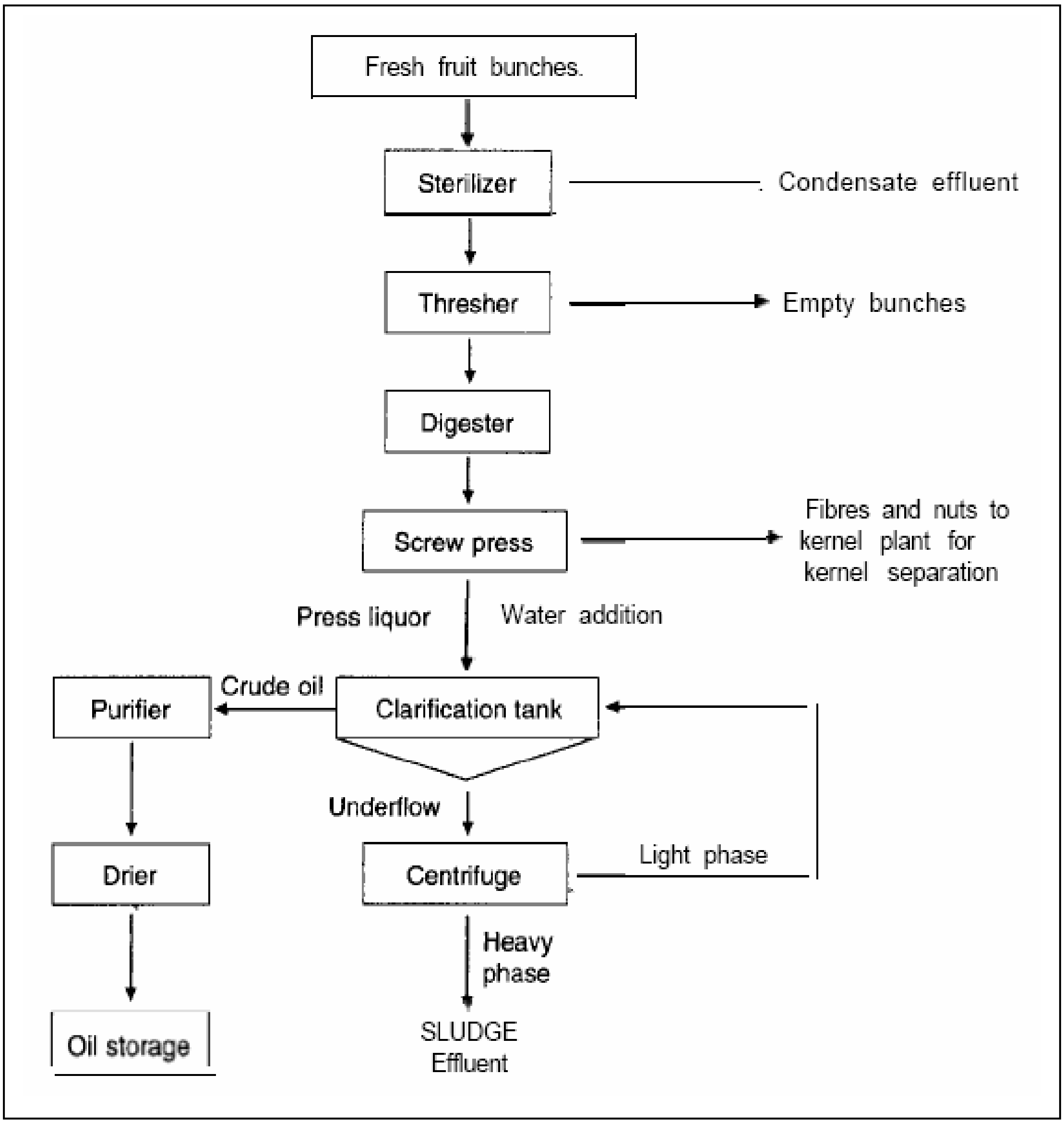

Figure 1.3: Flow diagram of palm oil extraction (Chow and Ho, 2000).

In the refinery, the CPO is processed to remove most of the undesirable impurities thus making the oil bland, colourless and chemically stable according to trade specifications and consumer requirements. There are basically two types of refining practiced by the Malaysian palm oil refiners, chemical and physical refining (Chow and

Ho, 2000). The two processes differ in treatment of the oil and result in differently labeled oils as illustrated in Figure 1.4. In the mill, as the CPO is extracted there is no continuous on-line monitoring of quality but the impurities present are only of botanical origin from the palm fruits. In the final quality assessment when sold to the refineries, only certain contractual specifications are measured. They are free fatty acid, moisture, peroxide value, and impurities which determines the degree of oxidation. Correspondingly, in the trading of refined palm oil, the same sets of contractual specifications are required with the additional requirement of colour. These parameters are used to assess not only the initial quality of CPO but also the amount of bleaching earth required which is one of the major costs incurred in CPO refining. No form of continuous monitoring is known in palm oil refining.

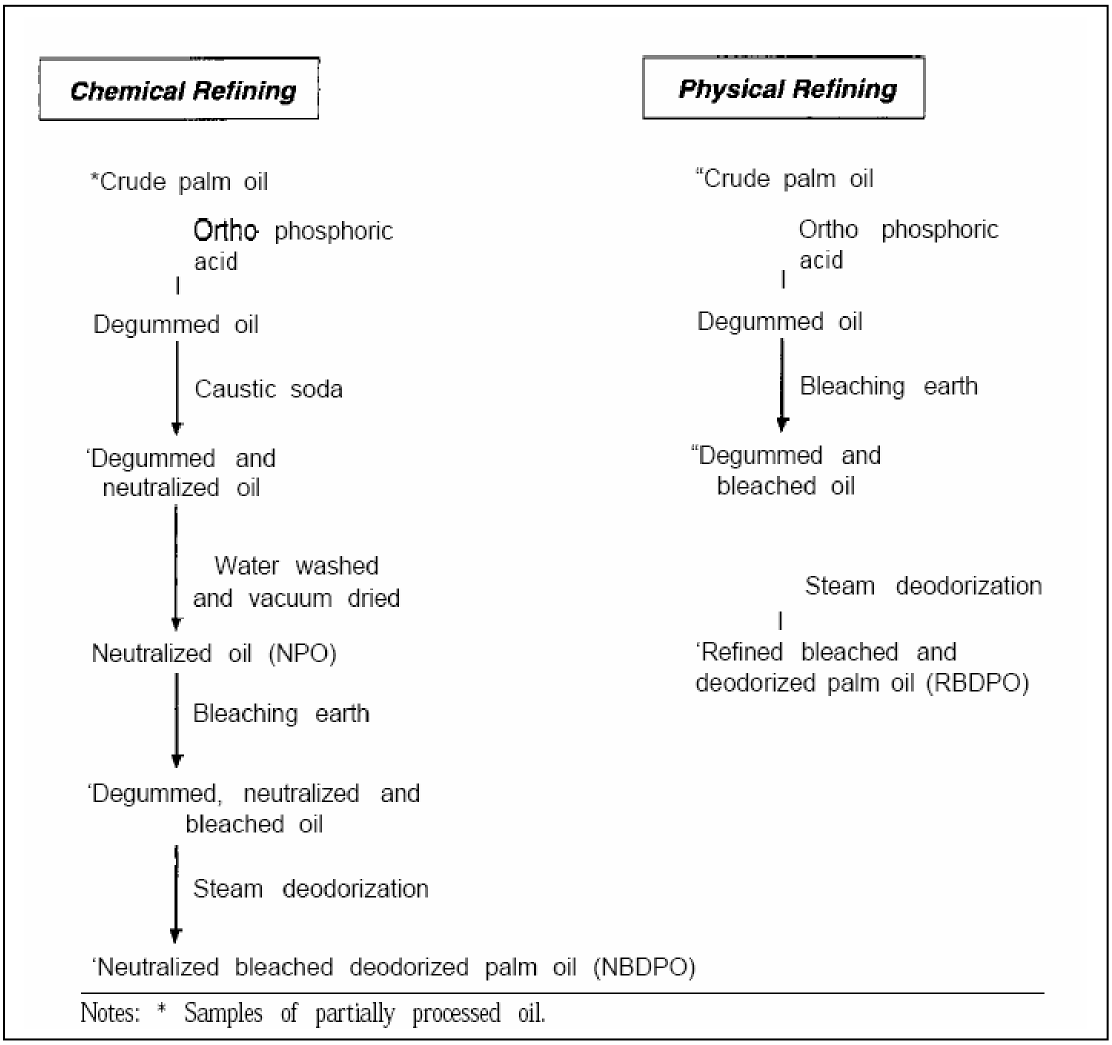

Figure 1.4: Refining processes for crude palm oil (Chow and Ho, 2000).