UNIVERSITI PUTRA MALAYSIA

TECHNOECONOMIC STUDY ON PALM OIL REFINERY WITH CHLORIDES, 3-MCPD AND GE MITIGATION

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ABSTRACT

The palm oil (Elaeis guineensis) industry is a significant contributor to Malaysia's economic expansion. The palm oil supply from Malaysia has seemingly expanded during the past two decades because of a substantial rise in production. Currently, in Malaysia, the type of refining used is physical refining. This method involved the processing stages of degumming, bleaching, deodorization, post refinery and extraction. Refined, bleached, and deodorized palm oil (RBDPO) is reported to contain high amount of 3-monochloropropane-1,2-diol esters (3-MCPDE) and glycidyl esters (GE) due to high-temperature deodorization step. High level of 3-MCPD and GE in refined palm oil will affecting people health. 3-MCPD and GE can be found in refined vegetable oils and fats where is generated during the refining of crude oils at various temperatures over an extended period. This project mainly focused on possible methods, physical and chemical refining to reduce 3-MCPD and GE to tolerable limits with the lower cost of production. The methods approached can reduced both 3-MCPD and GE to 0 ppm.

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ABSTRAK

Industri minyak sawit (Elaeis guineensis) merupakan penyumbang penting kepada pengembangan ekonomi Malaysia. Bekalan minyak sawit dari Malaysia nampaknya telah berkembang dalam tempoh dua dekad yang lalu kerana peningkatan yang ketara dalam pengeluaran. Pada masa ini, di Malaysia, jenis penapisan yang digunakan ialah penapisan fizikal. Kaedah ini melibatkan peringkat pemprosesan degumming, pelunturan, penyahbauan, pasca penapisan dan pengekstrakan. Minyak sawit ditapis, diluntur dan dinyahbau (RBDPO) dilaporkan mengandungi jumlah tinggi ester 3-monochloropropane-1,2-diol (3-MCPDE) dan glycidyl ester (GE) disebabkan oleh langkah penyahbauan suhu tinggi. Tahap 3-MCPD dan GE yang tinggi dalam minyak sawit ditapis akan menjejaskan kesihatan orang ramai. 3-MCPD dan GE boleh didapati dalam minyak sayuran dan lemak ditapis yang dijana semasa penapisan minyak mentah pada pelbagai suhu dalam tempoh yang panjang. Projek ini tertumpu terutamanya pada kaedah yang mungkin, penapisan fizikal dan kimia untuk mengurangkan 3-MCPD dan GE kepada had yang boleh diterima dengan kos pengeluaran yang lebih rendah. Kaedah yang didekati boleh mengurangkan kedua-dua 3-MCPD dan GE kepada 0 ppm.

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LIST OF ABBREVIATIONS

AC	Activated Carbon
BFD	Block Flow Diagram
CAPD	Computer Aided Process Design
CFC	Contractor Fees and Contingency
CFR	Cash Flow Analysis
CPO	Crude Palm Oil
DAG	Diacylglycerols
EER	Economic Evaluation
FFA	Free Fatty Acid
FFB	Fresh Fruit Bunch
GE	Glycidyl Esters
ICR	Itemized Cost Report
RBDPO	Refined, Bleached and Deodorization Palm Oil
RBO	Refined Palm Oil

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MAG	Mono-acylglycerols
SPD	SuperPro Designer
TAG	Triacylglycerols
THR	Throughput Analysis
TPDC	Total Plant Direct Cost
TPC	Total Purchase Cost
TPIC	Total Plant Indirect Cost
3-MCPD	3-chloropropane-1,2-diol
2-MCPD	2-chloropropane-1,2-diol

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CHAPTER 1

INTRODUCTION

1.1 Background

Over the last decade or two, the increasing worldwide request for edible oils and animal proteins has resulted in a massive increase in the area under cultivation of oil crops, particularly soybean and oil palm (Hai, 2002). Oil palm cultivation is increase massively as it is essential for people worldwide due to its diverse uses and application. Oil palm orits scientific name known as *Elaeis guineesis Jacq* (Figure 1.1), is the bulk vital species in the genus Elaeis, which is part of the Palmae family, and it is originally from Africa. However, Malaysia is the first country to involve in substantial agriculture and processing. Additionally, oil palm is a monocotyledon perennial tree crop with an economic life cycleof approximately 25 years (Gee, 2007).

In most economically developing countries in the 1990s, edible oil consumption per capita climbed noticeably, by 66% in Indonesia and 94% in India, as affluence increased and increasing in consumption of oil among people (Murphy, 2007). Thus, oil crops have been critical in boosting food and energy security in poor countries. (FAO,

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2000). Basically, palm oil is used in daily life for cooking including cooking oil, shortening as well as margarine (Ho and Chow, 2000). Moreover, palm oil can be applied in non-food industry, for instance cosmetics and washing powder. Generally, there are a lot of unit operations that involved in palm oil refining. According to Ashaari (2021), refining of palm oil is a method of transforming crude palm oil (CPO) into an edible oil where the CPO is extracted from palm oil before the refining process can begin and the refining of palm oil can improve both the production and the quality of palm oil.

Palm oil is the most widely eaten edible oil in the planet, surpassing all others in 2015. Palm oil and palm kernel oil are extracted from the fruit flesh and seed of the oil palm, respectively, and are used as ingredients in a variety of food and personal care goods, as well as a feedstock for biofuel production. Global palm oil production pursues to grow each year, partly as the biofuel markets in the European Union are expanding, and food consumption in China and India is increasing. (Clay, 2004). The palm oil business doe for a key agricultural idustry in Malaysia for the last three decades. This industry is essential to Malaysia's economy not just because the country is heavily reliant on oil palm for foreign exchange revenues, yet also because palm oil has been employed as a development instrument in poverty reduction efforts over three decades.

MacMahon et al. (2013) reported that numerous edible oils are industrially processed to extract the elements that adversely affect their look, flavor, shelf life, protection, and consumer acceptance. Refining oils and fats is critical for maintaining their quality and safety. However, when the oil is exposed to the deodorization stage of the refining process, high temperatures may cause oil convert to lipid matrix, causes the formation of 3-chloropropane-1,2-diol (3-MCPD), glycidyl esters (GE), and possibly

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other processing by-products. Besides, 3-MCPD and GE are contaminants found in edible oils including vegetable oils and foods manufactured with these oils. Edible oils are usedby food makers and customers alike as an element in foods and for cooking. 3-MCPD and GE could develop in edible oils during industrial refining after the oils burned at extremelyexcessive heat to bring out undesirable tastes, colors, or aromas. While refined palm oil and palm olein oil often have the elevated quantities of 3-MCPD and GE, they could alsopresent in other refined vegetable oils including safflower, coconut, sunflower, and soybean oils and refined marine oils.

As a result of the high temperature, chemical changes in oil occur at both allowed and unacceptable levels during the refining process. Besides, 3-MCPD and glycidyl esters are industrial contaminants created by heat-induced processes, most notably deodorization. Recent investigations indicate that when foods heavy in fat and salt are prepared at highertemperatures in the existence of chlorine, 3-MCPD can develop (OEHHA, 2009). Moreover, 3-MCPD is a chloropropanol and the richest sources of 3-MCPD are palm oil and fat, which contain four to six times the quantity found in normal fat margarine (EFSA,2016). 3-MCPD esters have been considered as a possible food processing contaminant since 1980. They have been found in a variety of foods and ingredients, most notably refined edible oils (Cheng et al., 2017). 3-MCPD presence in refined vegetable oils has raised a new global safety concern.

Basically, 3-MCPD esters are chemical contaminants that are suspected to be carcinogenic and the precursor for 3-MCPD is chloride. Short-term consumption of 3-MCPD may result in tumors in a variety of organs; the kidney being the primary target organ (Vispute et. al., 2018). Furthermore, GE are process contaminants that are formed

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whenthe deodorization process is done. They are abundant in refined palm oil. GE are chemicals that are often generated during the refining of vegetable oils at high temperatures, around 200°C, and their precursor is diacylglycerol (DAG). In addition, the formation of GE is accelerated when the DAG content of refined oils exceeds 3% of total lipids.

Application of simulation in the manufacturing process is widely used to imitate the real process and operations since it can reduce the cost and time consumption. The simulation of production process for palm oil refining is implemented by using computer-aided process design (CAPD). The refining process simulation software applied is SuperPro Designer (SPD). According to Kumaresan et. al (2005), SPD is an integrated software for the modelling and optimization of biochemical, pharmaceutical, food and environmental processes, which are operated either in batch or continuous mode and it can also handle economic evaluation for a process design. By using SPD, mass, and energy balance economic evaluation as well as costing can be performed.

Figure 1.1: *Elaeis guineesis*

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1.2 Problem Statement

The problem to be highlighted in this study is either physical refining or chemical refining of palm oil that able to reduce 3-MCPD and GE in palm oil to achieved below than 2.5 ppm of 3-MCPD and 1 ppm of GE. Other than that, when designing a process, thecost analysis is one of the important things that need to be considered. A few processes design need to be proposed to compare in term technoeconomic including capitalcost, operating cost, purchasing equipment and many more.

High level of 3-MCPD and GE in refined palm oil will affecting people health. For example, high level of 3-MCPD can lead to carcinogenic while GE will cause genotoxic. 3-MCPD and GE can be found in refined vegetable oils and fats where is generated during the refining of crude oils at various temperatures over an extended period. Circumstance data revealed that palm oil test result in higher concentrations of these contaminants than other oil types, and as a result, 3-MCPD and GE were also detectedin food items utilizing palm oil as an element (Becalski et al., 2015).

According to Zulkurnain, et. al. (2013), high temperatures relate to thesynthesis of 3-MCPD during the deodorization process of oil refining and as a result, the3-MCPD could formed. Other than that, 3-MCPD may be generated when acid degumming process is done or because of the acidity of the bleaching clay, particularly at high temperatures. Eliminating these antecedents prior to deodorization looks to be a mitigating method. The formation of 3-MCPD could decreased when crude palm oil was washed with water or ethanol. During bleaching, if it contacts with the palm oil, adsorbents such as calcinated zeolite, synthetic magnesium silicate, and ion-exchange resins such as carboxymethyl cellulose can remove enough precursors and significantly lower the

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amount of 3-MCPD in the final refined oil. Mitigation of 3-MCPD also can be performed by removing the chloride in crude palm oil (CPO).

Besides, GE could appear when the refining process is performed at high temperature. Likewise, the formation of GE is due to high temperature during deodorization process and from diacylglycerols (DAG) and mono-acylglycerols (MAG). GE are mostly produced via the intramolecular removal of a fatty acid from DAG and GE isomers generated from DAG heated at temperature more than 140°C were recognized asoxopropyl esters (Nagy, et. al., 2012). In this study, there are a few techniques that will beproposed to reduce the GE. First and foremost, the GE can be reduced by loweringthe temperature and residence time (Alfa Laval, 2021). According to Alfa Laval (2021), the removal of GE can be performed by re-refine the GE with activated bleaching clay followed with mild deodorization and by using GE stripping.

Both physical refining and chemical refining have pros and cons in reducing the 3-MCPD and GE in palm oil. Physical refining is projected to have lower total operating costs than chemical refining. Besides, physical refining is beyond price in terms of operational and capital inputs, has less waste oil, less polluting, and more efficient than chemical refining (Yusoff and Thiagarajan,1993)

The primary distinction between these two varieties is the process of eliminating the FFA. Chemical refining uses an alkali to neutralize most of the fatty acids extracted as soap. The alkaline neutralization technique has significant downsides, including low oil production, oil losses owing to emulsification and saponification of neutral oils, and partial loss of tocopherols and sterols throughout the process (Johanssonand Hoffmann,

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1979). Physical refining entails exposing the oil to steam distillation at elevated temperatures and under vacuum in removing the FFA. Increased yields, high- quality fatty acids as by-products, good oil stability, simultaneous FFA and deodorizationdistillation, lower equipment costs, and ease of operation are the benefits of the physical refining process compared to the chemical approach in palm oil refinery (Yusoff and Thiagarajan, 1993; Yusoff, 1994).

1.3 Objectives

- To design the palm oil refinery with 3-MCPD and GE mitigation
- To analyses technoeconomic of the designed palm oil refinery with 3-MCPD and GE mitigation

1.4 Scope of Study

The comparison of physical and chemical refining of palm oil will be undertaken in this study utilizing the software SuperPro Designer. Three types of physical refining and two types of chemical refining of palm oil will be simulated using a 5000kg/h capacity and 4350 hours of annual running time. Mass and energy balances for each technique will be constructed using accessible literature and researchers. This simulation includes specifies economic evaluation criteria, equipment data, operating costs, resources, revenues, and capital costs. The information generated by SuperPro Designer will be used to compare physical and chemical refinement. Economic analysis, cash flow analysis, throughput analysis, itemized cost analysis, and environmental effect analysis are all included in the reports. The feasibilityof the two techniques of processing palm

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oil will be examined.

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CHAPTER 2

LITERATURE REVIEW

2.1 Oil Palm

Oil palms are classified as Dura, Pisifera, and Tenera, a crossbreed between Dura and Pisifera. According to Ohimain (2012), the Tenera species generates the most oil, and Tenera is preferred in Malaysia due to its high yield ratio of palm oil to palm kernel oil. Oil palm genotypes are distinguished by their shell thickness, a monogenic and co-dominantly inherited characteristic. Dura genotypes have a thick shell, whereas Pisifera genotypes have a thinner shell (Mathur et al., 2017). Additionally, Mathur discovered that the Tenera genotype has a thin shell and produces more mesocarp and oil than Dura or Pisifera. Furthermore, Tenera serves as the foundation for commercial palm oil production

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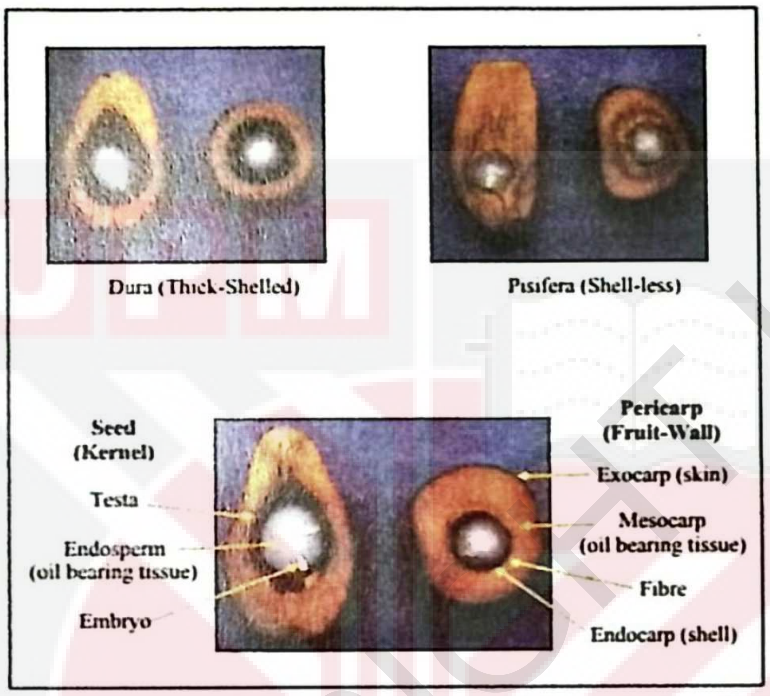
in all oil palm growing regions worldwide. The development of Tenera genotypes derived from the cross of Dura and Pisifera genotypes is depicted in Figure 2.1.

Figure 2.1: The production of Tenera genotypes obtained from the cross between



Dura and Pisifera genotypes.Source: Noor Azian (1995)

2.2 Composition of Palm Oil Fruit

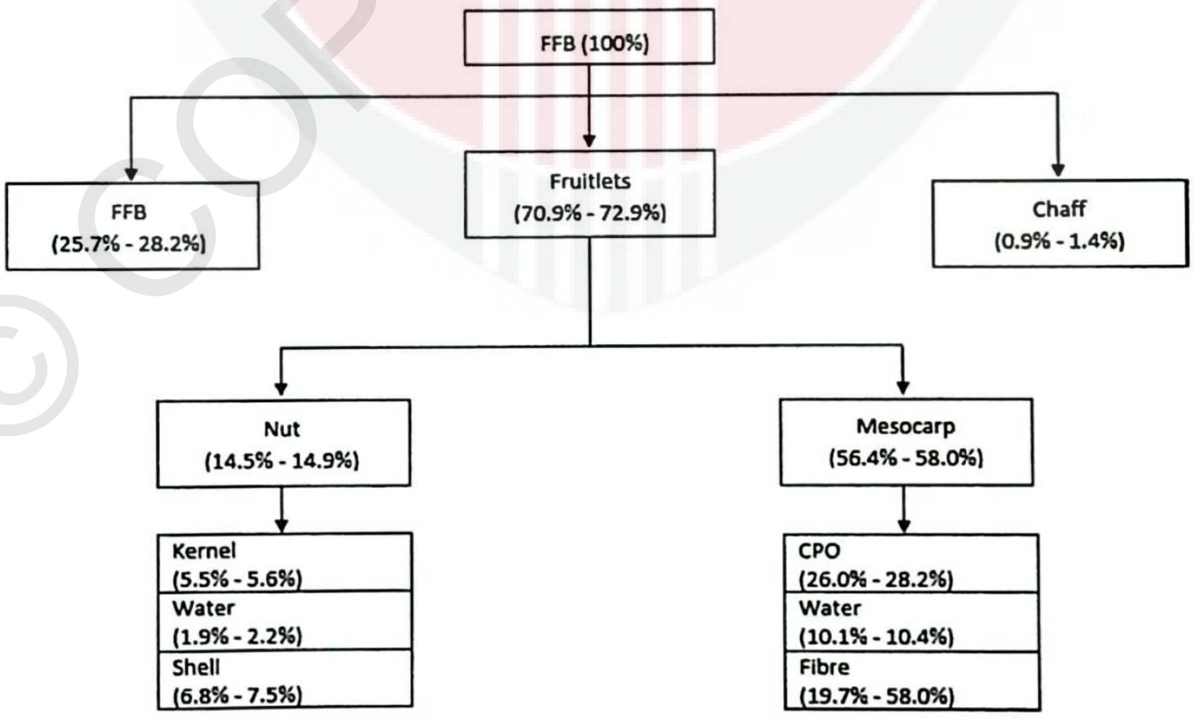


Figure 2.2: The percentage of Fresh Fruit Bunch (FFB)

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In Figure 2.2, the percentage fraction of Fresh Fruit Bunch (FFB) is depicted. Tenera bunches, on average, weigh between 14.7kg and 15.1kg, according to Ohimain etal. (2013). It is composed of 25.7–28.2 percent empty fruit bunches (EFB), 70.9–72.9 percent fruitlets, and 0.9–1.4 percent chaff. The fruitlets, which consist of a mesocarp and a nut, contain between 56.4 and 58.0 percent and 14.5 to 14.9 percent FFB, respectively. It is composed of crude palm oil (CPO), water, and fibre in the following proportions: 26.0–28.2 percent CPO, 10.1–10.4 percent water, and 19.1–20.3 percent fibre. The nut ismade of three components: kernel, shell, and water, which contribute 5.5–5.6%, 6.8–7.5%,and 1.9–2.1%, respectively, to FFB. Besides, mesocarp constitutes around 60% of the overall composition of palm oil fruit and is the source of crude palm oil (Figure 2.3).

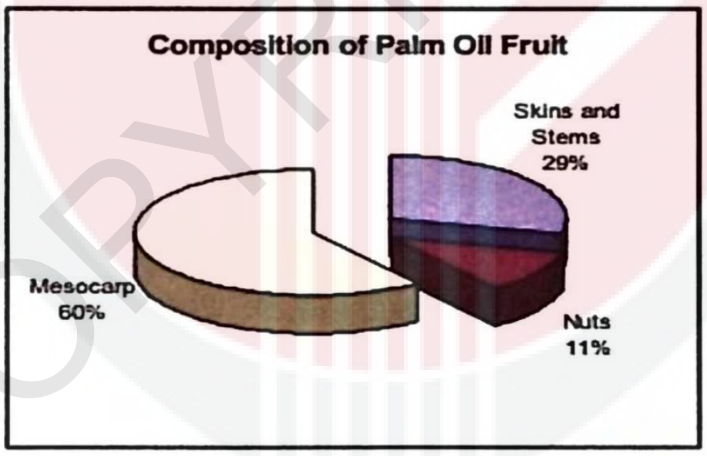

Figure 2.3: The composition of Palm Oil Fruit. Source: Noor Azian (1995)

2.3 Crude Palm Oil

Palm fruit mesocarp is the source of crude palm oil (CPO). Figure 2.4 depicts the procedures that fresh fruit bunches (FFB) experience to become CPO. Produced crude palm oil (CPO) is further refined into red or bleached cooking oil and detergents.

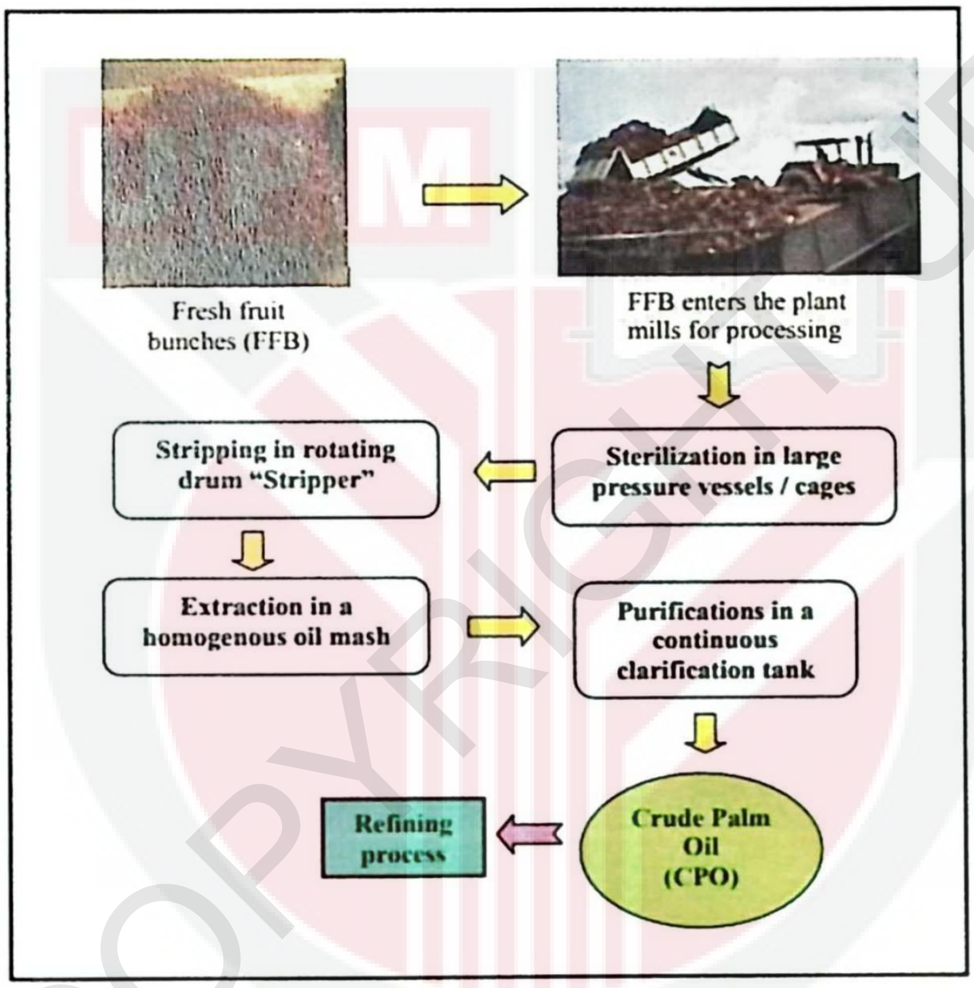

Figure 2.4: Flowchart of crude palm oil (CPO) production. Source: Noor Azian (1995)

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2.4 Composition of Crude Palm Oil

According to Higuchi (1983), crude vegetable oil consists of desirable triglycerides, unsaponifiable materials, and a tiny quantity of contaminants. Most of these contaminants impart unwanted properties to the oil, such as color, flavor, odor, instability, and foaming. A purification phase is required to remove these pollutants to create refined oil of high quality with little oil loss or damage to the oil and desired materials such as tocopherols and carotenes. Table 2.1 shows the composition of crude palm oil.

Table 2.1: The composition of CPO

Group	Components in the group
Oil	-Triglyceride, Diglyceride, Monoglyceride -Phospholipids, Glycolipid and Lipoprotein - Free fatty acids
Oxidized products	-Peroxides, Aldehydes, Ketones, Furfurals (from sugars)
Non-oil	- Carotene - Tocopherols - Squalene - Sterols
Impurities	-Metal particles - Metal ions - Metal complexes
Water solubles	-Water (moisture) - Glycerol - Chlorophyll pigments - Phenols

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	-Sugars (soluble carbohydrates)

Source: Ashaari, A., Ahmad, T., Awang, S. R., & Shukor, N. A. (2021)

Some of these chemical groups must be eliminated totally or partially throughout the refining process to produce edible oils with enhanced stability and shelf life. To obtain refined, bleached, and deodorized oil, CPO undergoes degumming, bleaching, and deodorization in palm oil refineries (RBDPO).

2.5 Uses of Palm Oil

The oil palm generates two different forms of oil: palm oil from the fibrous mesocarp and palm kernel oil from the palm kernel. About 80% of palm oil and palm kernel oil is used in food applications, while the remainder is a feedstock for a variety of non-food applications (Salmiah., 2000).

Refined, bleached, and deodorized (RBD) olein is mostly utilized as cooking and frying oils, shortenings, and margarine in the food industry, whereas RBD stearin is used to produce shortenings and margarine. RBD palm oil, also known as unrefined palm oil, is utilized in the manufacturing of margarine, shortenings, vanaspati (vegetable ghee), frying fats, and ice cream (Salmiah., 2000). Figure 2.5 shows the examples of products that contain palm oil.

Traditional applications of palm oil in food goods include cooking/frying oil, shortenings, margarine, and confectionery fats. Palm oil is widely utilized in both solid fat products and liquid cooking oils, particularly for industrial frying applications. It has various important technical properties for food applications, including as oxidation

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resistance, which adds to a longer shelf life for final products. Palm oil is perfectly suited for usage as an ingredient in shortenings and margarines due to its solid fat content (SFC) of 20 to 22 percent at 20 degrees Celsius, which aids in the formation of fat products with a plastic range. It tends to crystallize into small beta-prime crystals, a favorable characteristic for certain uses, including table and industrial margarines.

Palm oil possesses additional functional properties that make it a valuable food additive. In several instances, palm oil can be blended with harder fractions, such as palm stearin, to generate products with the desired consistency without the need for hydrogenation. Common palm oil and palm kernel oil products include frying and cooking oils, shortenings, vegetable ghee or vanaspati, margarines and spreads, confectionary, and non-dairy goods, among others.

Figure 2.5: The examples of product that contain palm oil

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2.6 3-MCPD and GE Precursors

Leading to analyzing methods for minimizing the production of 3-MCPD and GE, it is vital in obtaining a working understanding of their precursors and formation processes. At extreme temperatures, MCPD fatty acid esters are formed when monoacylglycerols (MAG, DAG, and TAG) absorb chloride from a chlorin donor material. Numerous chlorine sources exist, including coagulants used to purify water by Chung. (2018), which generate strip steam during deodorization using water. Palm fruit extract contains naturally occurring inorganic chlorides such as calcium chloride, magnesium chloride, and iron [II] chloride. Then, 3-MCPD was developed at the refinery, specifically during deodorization, where high temperatures of 180°C to 260°C were used by Alessia and Carel. (2014). This resulted in the development of both 3-MCPD and GE. 80% of 105 crude palm oils evaluated lacked 3-MCPD esters; however, only one percent of refined, bleached, and deodorized (RBD) palm oil test with 3-MCPD esters below the noticing limit (Razak et al., 2012).

Cheng. (2017) reported that partial acylglycerols such as DAG and MAG serve asprecursors of GE in refined oil. Furthermore, DAG and MAG are produced from TAG via lipase hydrolysis or high-temperature pyrolysis (Shimizu., 2012). In contrast to MCPD esters, GE were generated in the absence of chlorine; Charge migration was used to remove GE, and intramolecular rearrangement varied depending on the type of intermediate or leaving group (Rahn et al., 2011). The cyclic acyloxonium ion, an extensively studied active intermediate in organic chemistry, could involve in the production of GE (Weißhaar et al., 2010). Only a trace of GE was discovered between 180 and 230°C, however a dramatic increase in GE concentration was reported above

230°C (Hrnik et al., 2011). Numerous competing processes occur concurrently in the existance of MCPD esters and GE. Even within the same group, competition exists to produce distinct forms of chloropropanol (CP), which explains why neither partial acylglycerol nor chlorinated material was found to be significantly associated with the amount of 3- MCPD generated during thermal heating (Ermacora et al., 2014).

2.7 Refining Methods of Palm Oil

To be appropriate for people consumption, most of the edible oil need to be cleansed (Gibon et. al., 2007). As the demand for palm oil increased, it is required to refine the oil to obtain a product of sufficient quality to support a healthy lifestyle. When crude palm oil is ingested, it may contain phosphatides, colorants, peroxides, and other pollutants that are harmful to human health. The refining process is a fundamental and practical approach for removing these contaminants from oil. Vegetable oil production entails several industrial procedures, the most critical of which is refining (Khan., 2015). The crude palm oil is typically refined and fractionated to yield liquid palm olein and solid palm stearin (Clemens et al., 2017). Palm oil is made with oil mill by pressing, stripping, sterilizing, and clarifying the fruits of the oil palm.

Refining is the process of converting crude palm oil (CPO) to edible oil. The purpose of this procedure is to eliminate contaminants and other components that degrade the quality of the final product. Flavor, shelf-life stability, and color are the characteristics of the finished product that must be monitored (Leong, 1992). During the procedure, the presence of contaminants and other substances is eliminated. To begin, CPO is derived through palm fruit. It is mostly made of beneficial triglycerides and

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unsaponifiable, with trace amounts of pollutants. Eliminating all the impurities during the refining process is a must since they diminish the quality of palm oil, affecting its color, flavor, odor, stability, and ability to create foams.

Refining's primary objective, from an industrial standpoint, is to turn crude oil into high-quality edible oil by efficiently removing unwanted contaminants to the desired levels. This also necessitates the minimization and cost-effectiveness of losses in the desirable components.

The unpleasant material or impurities in palm oil may be biogenic, i.e., synthesized by the plants themselves, but they may also be environmental pollutants absorbed by the plants (Borner et al., 1999). The contaminants may have been acquired during the extraction, storage, or transit of crude palm oil from the mill to the refinery, which occur upstream of the bleaching process.

It is essential to have a suitable refining process to generate high-quality finished products within a specific quality range and satisfy the needs of consumers. Basically, there are two types of refining method for palm oil which are physical refining and chemical refining. The differences between physical and chemical are the type of chemicals used and the mode of removing the FFA.

2.7.1 Physical Refining Process

Physical refining of oil is often referred to as oil steam refining. During degumming stage of the palm oil milling facility, the gum in palm oil will be eliminate using phosphoric acid. Then, the application of phosphoric acid separates the fatty acids and gums found in palm oil and palm kernel oil from foreign contaminants such as trace minerals, iron, copper, and others. This procedure lays the groundwork for the subsequent refining phase. The coloring matter and other metal ions is eliminated adjacent to the bleaching region. It utilizes a vacuum method to purify crude palm oil and crude palm kernel oil of contaminants and color pigments. The crude palm oil is next deacidified and deodorized under low pressure and high temperature in the deacidification and deodorization unit. The Free Fatty Acid (FFA) will be eliminated, and the scents and colors will be eliminated or absorbed via live stem. Figure 2.6 shows the stages in physical refining process.

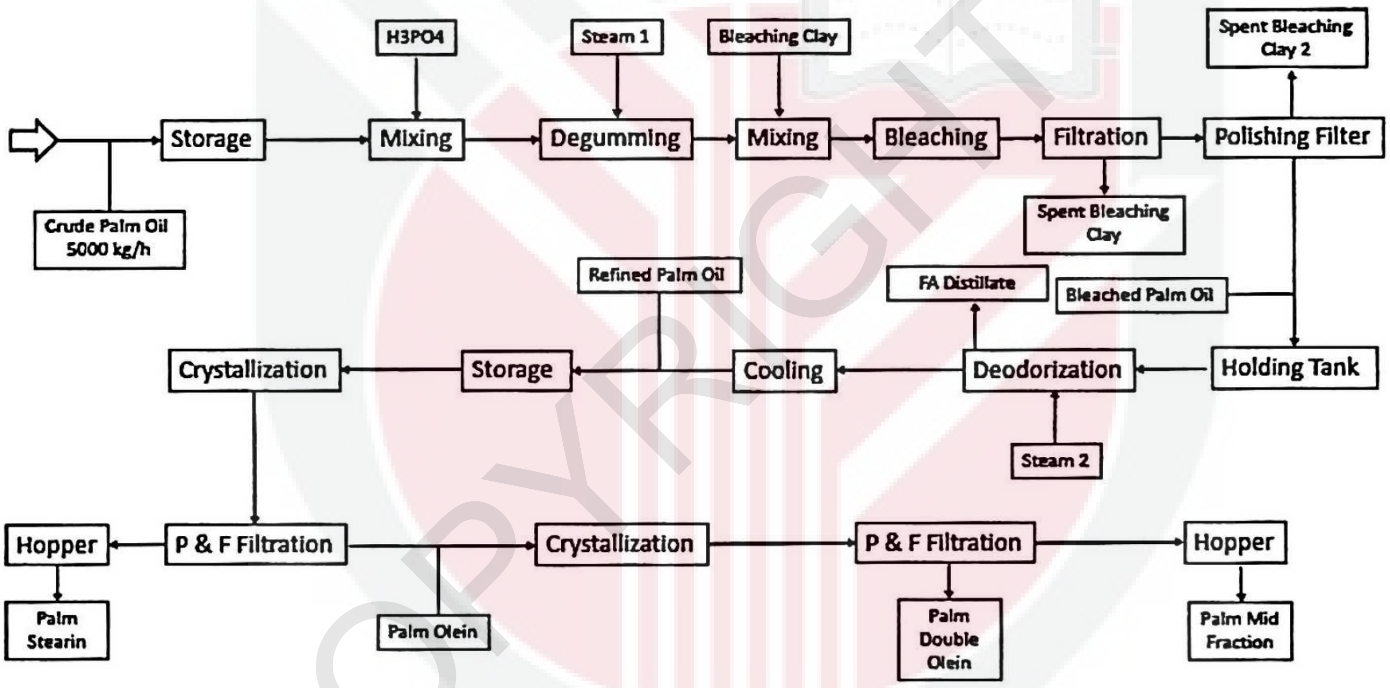

Figure 2.6: BFD of stages in physical refining

Physical refining is sometimes referred to as deodorization by steam distillation, in which free fatty acids and other volatile components are removed from the oil using an efficient stripping agent, which is often steam, under optimum processing conditions (Meirelles and Ceriani, 2005). During the final stage of physical refining, FFA is extracted in the form of palm fatty acid distillate (PFAD), which contains carotenoids colours, volatile contaminants, and oxidation products. There are a few advantages of physical refining over chemical refining which are;

- Better yields
- High Quality of fatty acids as by-products
- Good oil stability
- Simultaneous distillation of fatty acids and deodorization
- Lower cost of equipment
- Simplicity of operation

2.7.1.1 Degumming Section

The primary purpose of this degumming process is to eliminate gums that will subsequently compromise the stability of oil products. The purpose is attained by processing crude palm oil (CPO) with the appropriate amount of food-grade acid, often phosphoric or citric acid of a specific concentration.

Phosphatide is the primary component that must be extracted from the gums. It is essential to remove the phosphatides from the crude oil, as their presence imparts an unpleasant flavor and color and reduces the oil's shelf life. The emulsifying activity of phosphatides is the primary source of the oxidative instability of crude palm oil (CPO).

Before being treated with phosphoric acid, the arriving crude palm oil is heated at 90°C in this unit operation. The normal dosage of phosphoric acid is between 0.05 and 0.1% by weight of the oil, while the acid content is between 80% and 85%. It is intended to breakdown non-hydratable phosphatides and coagulate phosphatides, rendering them

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insoluble and therefore easily removed during bleaching. Phosphoric acid in excess must be avoided since it may create an increase in phosphorus acid, which may be difficult to remove and contribute to other refining issues.

2.7.1.2 Bleaching Section

Before entering the vacuum bleacher, degummed oil is treated with bleaching earth and heated to around 100 °C during the bleaching process in palm oil refineries. Typically, the dosage of acid activated clay is between 0.5% and 2.0% by weight of oil, and the contact duration with continuous agitation is approximately 30 minutes.

During this phase, trace metal complexes including iron and copper, pigments, phosphatides, and oxidation products are removed by the bleaching earth's adsorptive effect. Any remaining phosphoric acid is also eliminated at this stage. The oil is subsequently filtered using industrial filters such as plate and frame filter presses or vertical leaf pressure filters.

2.7.1.3 Deodorization Section

The filtered oil (DBPO) is then routed to the deodorizer for deacidification and deodorization. This technique employs a combination of high temperature heating at roughly 240°C - 260°C, under vacuum (2 - 4 mmHg), and direct steam injection of around 2.5% - 4.0% of oil by weight (Leong, 1992).

In the upper section of the deodorizer, free fatty acid (FFA) in the form of palm fatty acid distillate (PFAD) is extracted as refining waste during the deodorization process. In addition to FFA, carotenoids pigments, primary and secondary oxidation products are

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eliminated because they can contribute to off-flavors. The deodorized oil is subsequently cooled and filtered using a polishing filter before being delivered to storage tanks.

2.7.2 Chemical Refining Process

Chemical refining is a procedure that utilizes strong bases to balance the majority of FFA and extract them as soaps (Abc Machinery., 2022). Additionally, it is referred to as the alkali refining process. Additionally, the FFA is eliminated throughout the crude oil chemical refining process, and the neutralized crude oil and soap stock will be created and utilizing a high-speed separator, the soap stock will be separated from the oil. Additionally, the neutralized oil's color pigments and metal ions will be eliminated. If the crude oil has a high level of carotene, a high level of FFA (more than 5%), and a low level of phosphatides, it will be advantageous to use a chemical refining method to minimize refining losses and operating costs. Figure 2.7 shows the stages in chemical refining process.

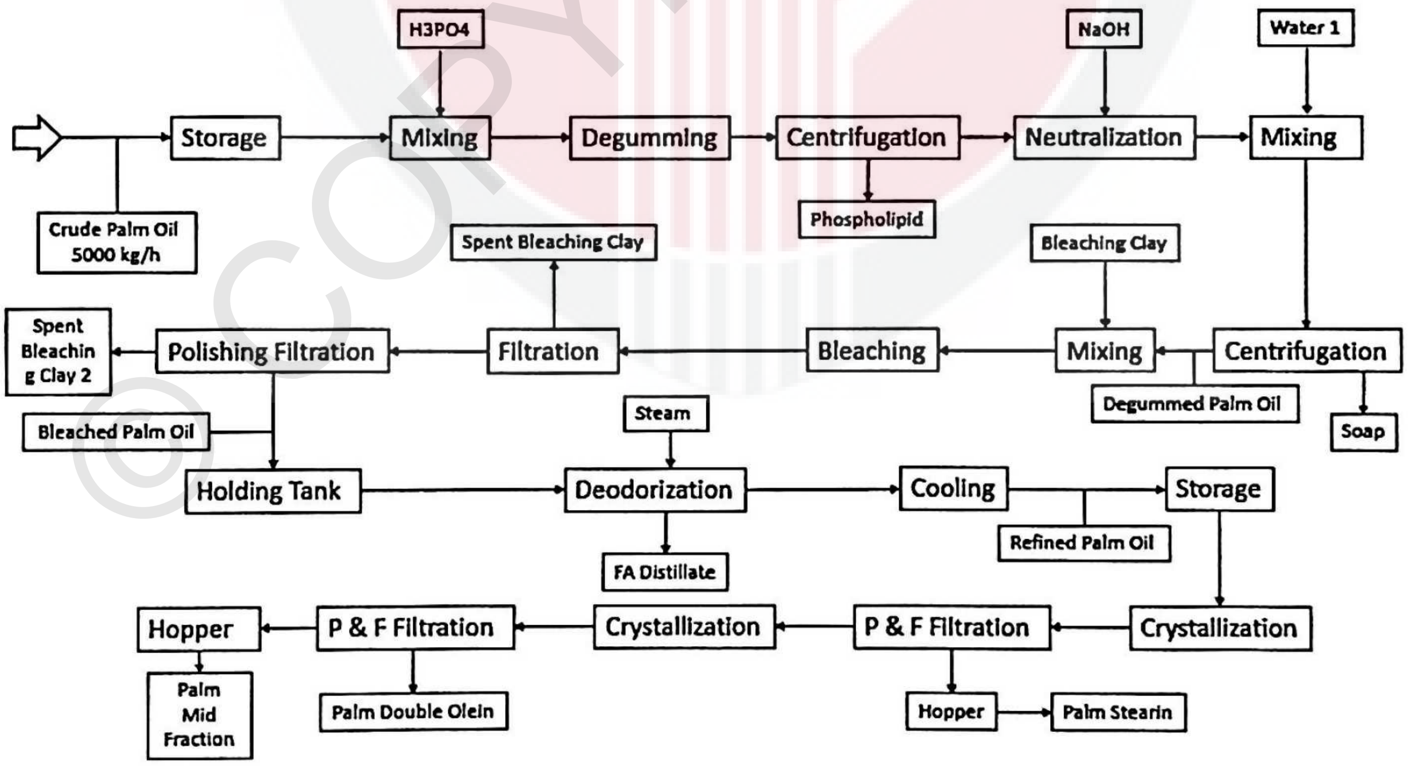

Figure 2.7: BFD of stages in chemical refining

2.7.2.1 Degumming Section

During degumming and neutralization, the phosphatide part of the oil is either removed or conditioned by the addition of specific additives or agents. Phosphoric acid and citric acid are the most used additions for this purpose. A set amount of any one or combination of these additives/agents is blended with the oil charge for a predetermined period and process conditions. This results in the separation of phosphatides from oil, which is then extracted after a period of settling. Occasionally, these split gums are not removed directly but rather with soap stock created during neutralization. The oil mass is next neutralized with alkali to remove free fatty acid as soap stock. This soap stock is extracted from the oil mass by gravity separation. Oil is rinsed with hot water to remove alkali residues.

2.7.2.2 Bleaching Section

The neutralized, washed oil is subsequently bleached, the second step in the refining process. In this process, the oil is placed in a cylindrical vessel with an agitator called a Bleacher, held under vacuum, and heated to 90°C with steam. Thus, the oil's moisture is evaporated, and the oil becomes dry. With bleaching earth (fuller's earth) and carbon, the oil is processed. After neutralization, these bleaching agents will absorb most of the residual color of the remaining oil. To separate the oil and bleaching chemical mixture, a typical plate and frame press is utilized. Clear oil is bleached oil that is significantly lighter in color than neutralized oil. To prevent additional deterioration caused by oxygen, the oil charge is dehydrated in a vacuum. Under these conditions, the colored pigments in the oil are absorbed by bleaching agents.

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2.7.2.3 Deodorization Section

After bleaching, the oil is nearly pure, but contains trace amounts of the original odoriferous substance and the neutralization process's chemicals. This oil is then transported to a cylindrical cylinder known as a deodorizer. The deodorizer is maintained under a very high vacuum, and the bleached oil is heated to 200°C with high-pressure steam and fed through with open steam. The volatile substances are evaporated with a carrier (commonly direct steam). Using a Filter Press, this oil is then cooled and refined to produce sparkling oil. The objective of deodorization is to render oil tasteless and odorless. In this method, the peroxide value of oil is reduced to an absolute minimum.

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2.8 Refining Mitigation Strategies

The refining process is defined as the process of converting oil into edible form by removing undesired elements including oxidation products, FFA, phospholipids, metals, pesticide residue, and other impurities (Ramli et al., 2011). Generally, CPO can be refined chemically in four stages (degumming, neutralization, bleaching, and deodorization) or physically in three steps (degumming, neutralization, bleaching, and deodorization). As for now, the palm oil industry prefers physical refining due to the related benefits, which include a lower environmental impact.

2.9 Removal of the Reactant by Washing

The discussed technique for obtaining domination over the exitances of 3-MCPD and GE appears is to remove reactants from the raw material prior to refining, as this allows the refining process to proceed properly. The fundamental rationale for developing DAGs prior to palm oil processing is that TAGs are rapidly degraded enzymatically upon maturity. To overcome this problem, a faster inactivation of the lipase via shorter harvest cycles or quicker treatment in the oil mill, or the development of palm fruits witha lower lipase activity should be done. However, all the options are time consuming and labor intensive. Prior to further processing, enzymatic esterification of DAGs to TAGs would similarly reduce the amount of DAGs in the raw material, but correctly steering this balancing reaction in the direction of the TAGs is problematic. Crude oils can be washed prior to processing to eliminate precursors such as chloride.

Figure 2.8 illustrates the effect of washing crude palm oil with water and ethanol followed by a simulated deodorization phase, on the raw material's ability to create 3-MCPD and GE. As a result of the washing processes, palm oil contains much less 3-MCPD and associated compounds than unwashed palm oil. The reduction was due to a drop in the concentration of 3-MCPD, whereas the concentration of GE remained constant. A possible explanation for these findings is that the washing stage reduced the quantity of chloride present, causes the decrease in the concentration of 3-MCPD.

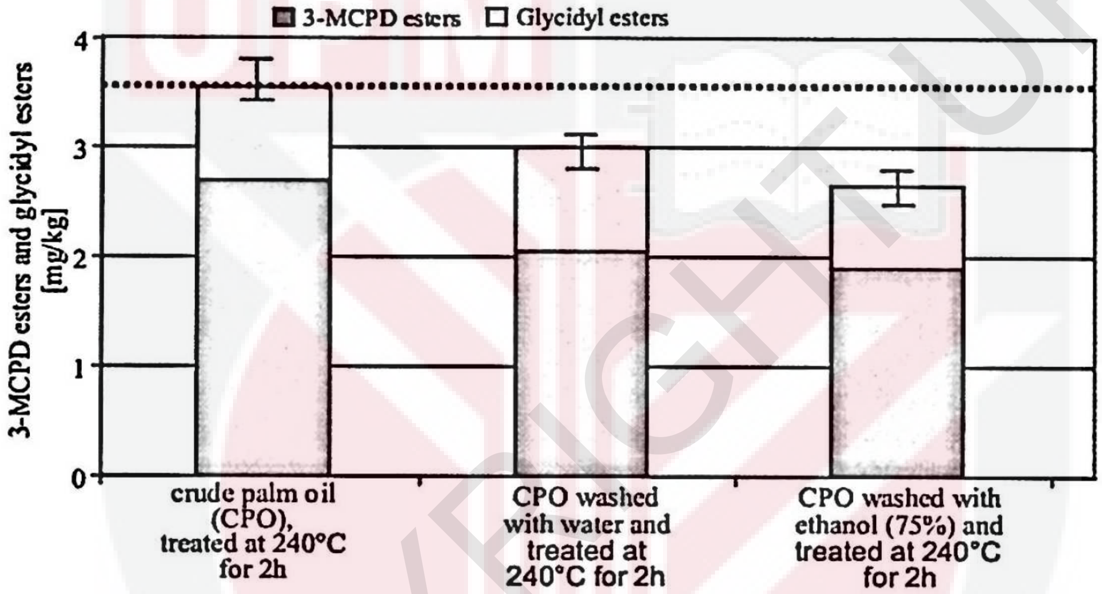

Figure 2.8: The Effect of Washing CPO. Source Matthäus, B., Pudel, F., Fehling, P., Vosmann, K., & Freudenstein, A. (2011)

2.10 Post Refining Strategies

Adsorption or chemical degradation can be used to eliminate 3-MCPD and GE from RBD oil. Physical adsorption is a technique that employs adsorbents including activated carbon, magnesium silicate, zeolite, and activated bleaching earth to effectively remove 3-MCPD and GE without altering their molecular structure. This is accomplished by using the fact that 3-MCPD and GE contain polarity that differs from that of the oil. Strijowski et al. (2011) found that both calcinated zeolite and synthetic magnesium silicate are capable of absorbing reducing polar chemicals, for instance DAG, MAG, 3-MCPD and GE with the two adsorption materials having significantly different transposition rates. They discovered that calcinated zeolite and synthetic magnesium silicate effected the greatest overall decrease at various temperatures and periods. Shimizu et al. (2012) examined RBD oil using acid-activated bleach earth (ABE). They discovered that GE transforms into glycerol mono-palmitate, glycerol palmitate oleate, and glycerol dipalmitate rather than adsorbing. This occurs because of the GE absorbed by ABE going through a molecular ring opening process

2.11 Before Deodorization

Several researchers recommended optimizing the refining process in reducing the development of 3-MCPD and GE. For instance, degumming with a low quantity of acid and bleaching with a bleaching earth in natural type rather than bleaching earth with acid (Vispute et al., 2018). Moreover, Ramli et al. (2011) discovered that the highest amount of 3-MCPD production which is 3.89 ppm occurred when a high concentration of phosphoric acid 0.1% was combined with acid-activated clay. When degumming of water is done and natural bleaching clay were utilized, the generation of 3-MCPD was the lowest (0.25 ppm). Nevertheless, the disadvantage to utilizing water degumming are it degrades the oil's quality due to inadequate iron and phosphorus component removal. This work lends itself to the use of high-quality CPO. Even the oil is in poor quality, it will need to be blended with another process, particularly to eliminate metallic contaminants. Schurz (2010), on the other hand, argued for a high dose of activated clay since it can absorb a portion of the 3-MCPD precursors found in the oil. Additionally, as mentioned previously, natural clay is wonderful for bleaching. On the other hand, natural bleaching earths may have a deleterious effect on the color of the oil. Besides, chemical

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refining appeared to be an option for reducing 3-MCPD and GE emissions. Since the neutralization process eliminates FFA before to deodorization (Vispute et al., 2018), it enhances the oil's pH prior to deodorization.

The addition of additives to bleached oil has the potential to limit the formation of 3-MCPD. Throughout the procedure, additives such as chlorine-donating agents compete with precursors and are then eliminated following deodorization.

2.12 Deodorization

Deodorization settings ranging from 180°C to 230°C and residence duration ranging from 1 to 5 hours had an influence on the level of GE but not on the amout of 3-MCPD in neutralized bleached and bleached palm oil. Hrnik et al. (2011), as indicated in Figures 2.9. The 3-MCPD ester concentration remained rather stable between 3.5 and 4.7 mg/kg regardless of the deodorization process. On the other hand, increased in deodorization process to 230°C will increased the GE concentration to 2.2 mg/kg, as illustrated in Figure 2.9. Additionally, the statistics indicate that lowering the deodorization temperature to 180°C resulted in a decrease in the GE level. It proved, however, insufficient to completely remove FFA from the oil, with only 20% removal left after five hours of deodorization.

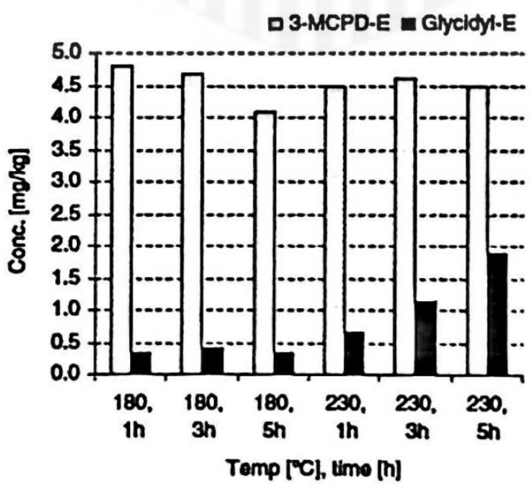

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Figure 2.9: The Effect of Deodorization Process to GE level.
Source: Hrnčiřík, K. and Van Duijn, G. (2011)

Matthäus et al. (2014) proposed that dual deodorization might be used to reduce 3-MCPD and GE. The approach entails a longer deodorization period at a lower temperature of 120 minutes at 200°C followed by a shorter deodorization time at a higher temperature of five minutes at 250°C, or vice versa. As Craft et al. (2012) describe, GE can be distilled or degraded at between 250°C and 290°C, or at a reduced temperature of200°C but with a longer deodorization duration. of two hours.

2.13 Computer Aided Process Simulation (CAPS)

The production process, along with the inherent instructions and direction for achieving the product, is the focal point of every process plan. Process planning is a stage in the design-to-manufacturing process. The primary problem of management in manufacturing firms is how to make a product at a low cost while maintaining a high level of quality in order to remain competitive. Process plans are highly dependent on a variety of variables, including production rate, cost, operations, tools, equipment, surface finish, and quality. When process plans were created manually, the likelihood of errors rose, and manufacturing process decisions frequently became less acceptable.

2.14 SuperPro Designer

Techno-economic analyzes (TEA) are critical for establishing a project's feasibility, and they must be tailored to the specific area. TEA frequently integrates process simulation, design development, and economic evaluation by determining a

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process's economic viability and identifying sensible and cost-risk points during the planning and implementation phases (Viswanathan et. al., 2020). SuperPro Designer® is a process simulator that makes it simple to create, evaluate, and optimize integrated processes. It was built primarily for simulating bioprocess unit operations; hence, it is capable of handling schemes for batch and continuous processing. Additionally, SuperPro Designer® be used throughout the process growth lifecycle, from conceptual design to process operation and optimization. Apart from process modelling, the software includes other additional useful features such as material and energy balances, vast databases for chemical components and mixes, as well as equipment and resources, detailed process economics, and waste stream characterization. Due to its straightforward and user-friendly approach, it is an advantageous resource for large-scaleprocedures. This approach is user-friendly, facilitating its use by amateur person, particularly during the technology development stage, when TEA can assist in identifyingcost-effective features. As with Excel® and Aspen Plus®, SuperPro Designer® Providesdefault values for a huge number of the input parameters requested for simulation, but hasless rigorous thermodynamic packages, and certain streams during continuous processes must be known in advance (Qureshi et. al., 2013). Compared to Aspen Plus®, SuperPro Designer is a user friendly that can be use by non-experts while Aspen Plus® is difficult for amateur person as it takes a significantquantity of practical knowledge as inputs, which makes it time intensive, and it has limitations for downstream and economic evaluations of large-scale operations. Furthermore, Aspen Plus® lacks a unified purpose for calculating the energy content of the streams that comprise a process, as well as a feature for evaluating techno-economic costs. As a result, extra software applications are required to conduct the analysis.

CHAPTER 3

METHODOLOGY

3.1 Process Design

SuperPro Designer was used to design and simulate palm oil refining process. Through simulation, the physical and chemical refining processes were explored in this study. The initial assumption was that crude palm oil (CPO) would be produced at a rate of 5000kg/h for a total of 4350 operational hours per year. To begin, a process in SuperPro Designer was stimulated using the block flow diagram (BFD) depicted in Figure 2.6 and Figure 2.7. Then, using data from prior research, all the operating conditions required by SuperPro Designer were determined, including temperature and pressure, as well as the mass and energy balances for each procedure. Additionally, the SuperPro Designer requires input data for raw material components, equipment costs, stream categorization, income, and capital costs. Following that, SuperPro's modelling of the processes creates several reports, including an Economic Evaluation (EER), a Cash Flow Analysis (CFR), an Itemized Cost Report (ICR), and a Throughput Analysis (THR).

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3.2 Assumption and Data Collection

3.2.1 Raw Material Components

Components used in the simulation can be referred in Table 3.1.

Table 3.1: Components used in simulation flowsheet

Component	Molecular Weight (g/gmol)	Density at 25°C
2-DMAE	89.14	890.00
2-MCPD diester	656.41	883.60
2-MCPD monoester	391.95	883.60
3-MCPD diester	656.41	883.60
3-MCPD monoester	391.95	883.60
Bleaching Earth	147.60	1050.00
DAG	621.00	898.80
Degummed Phospholipid	885.45	898.80
FFA	284.00	883.60
Glycerol	92.09	1258.08
Glycidyl Ester	340.50	883.60
Impurities	885.45	898.80
MAG	356.50	898.80
Nitrogen	28.01	1000.00
Oxygen	32.00	42.33
Phospholipid	885.45	898.80
Phosphoric Acid	98.00	1869.83
Soap	306.00	898.80

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Sodium Hydroxide	40.00	1913.35
Sodium Phosphate	163.94	2536.00
TAG	885.45	898.80
Total Chloride	35.45	2400.01
Used Bleaching	300.00	994.70
Water	18.02	994.70

Source: SuperPro Designer

3.2.2 Fixed Cost

Facilities and equipment expenses have a substantial impact on the estimation of fixed costs. Costs include total plant direct costs (TPDC), total plant indirect costs (TPIC), contractor fees, and contingency expenses (CFC). Costs associated with TPDC include facility construction, installation, processing pipe connections, and instrumentation, whereas costs associated with TPIC include engineering and construction.

The plant's total cost was determined by adding the TPDC and TPIC. Meanwhile, the totalcapital investment for the complete processing line was determined by adding the total purchase cost (TPC), the capital expenditure component (CFC), the starting costs, and working capital. The purchase charge was used to estimate fixed costs, which were then compounded by a variety of factors. Table 3.2 contains the multiplier for estimating directed cost and total capital investment.

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Table 3.2: The multiplier for directed cost and total capital investment estimation

Costs	Categories	Multipliers
Total Plant Direct Cost (TPDC)	Purchase Cost (PC)	
	Installation	0.47 x PC
	Piping	0.68 x PC
	Instrumentation	0.26 x PC
	Insulation	0.08 x PC
	Electrical	0.11 x PC
	Buildings	0.18 x PC
	Yard Improvement	0.10 x PC
	Auxiliary Facilities	0.55 x PC
	TPDC	2.43 x PC
Total Plant Indirect Cost (TPIC)	Engineering	0.30 x TPDC
	Construction	0.35 x TPDC
Total Plant Cost (TPC)	TPDC + TPIC	
Contractor's Fee and Contingency	Contractor's Fee	0.06 x TPC
	Contingency	0.08 x DFC
Direct Fixed Cost (DFC)	TPC + CFC	
Working Capital (WC)		0.15 x DFC
Startup Capital (SC)		0.05 x DFC
Total Capital Investment	TPC + CFC + WC + SC	

Source: SuperPro Designer

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3.2.3 Operating Cost

Total operating cost consist of raw materials, labor-dependent, facility dependent, consumables and utilities. Crude palm oil, water, phosphoric acid, sodium hydroxide, activated carbon, and bleaching earth were used in palm oil refining process. For labor dependent, the assumption is that equipment operator is set in the software. For the whole process, a few labors dependent was set which were clerk, safety officer, manager, engineer, security guard, maintenance staff, and quality control analyst. Other than that, for utilities, it includes std power, steam, steam for high pressure, cooling water, chilled water as well as air. Table 3.3 and Table 3.4 shows the operating cost inputs for physical and chemical refining, respectively.

Table 3.3: Operating cost input for physical refining

Item		Unit Cost (MYR)	Reference
Raw Materials	Bleaching Earth	1474.00/MT	https://www.alibaba.com/product-detail/Bleaching-Earth-High-Quality-Activated-Bleaching_60319413722.html?spm=a2700.7724857.topad_classic.d_title.ac2233fadXgWnf
	CPO	5500.00/MT	https://bepi.mpob.gov.my/admin2/price_local_daily_view_cpo_msia.php?more=Y&jenis=1Y&tahun=2022
	Phosphoric Acid	45.2/L(stp)	https://www.ksfe.com.my/product/753/Phosphoric-acid-(o-Phosphoric-Acid)/
	Sodium Hydroxide	19.9/kg	https://www.lazada.com.my/products/sodium-hydroxidecaustic-sodalye-1kg-i2496552251-s10945033964.html?clickTrackInfo=query%253Asodium%252Bhydroxide%252Blye%253Bnid%253A2496552251%253Bsrc%253ALazadaMainSrp%253Brn%253Af0d692a13f518a63fa2afd5f254cb5cb%253Bregion%253Amy%253Bsku%253A2496552251_MY%253Bprice%253A19.90%253Bclient%253Adesktop%253Bsupplier_id%253A100062667%253Basc_category_id%253A10002406%253Bitem_id%253A2496552251%253Bsku_id%253A10945033964%253Bshop_id%253A2090&freeshipping=1&search=1&spm=a2o4k.searchlist.list.4
			SuperPro Database

	Water	$1.28m^3(STP)$	
Labor Dependent	Manager	40.46/hr	SuperPro Database
	Engineer	26.59/hr	SuperPro Database
	Clerk	17.89/hr	SuperPro Database
	Safety Officer	25.90/hr	SuperPro Database
	Equipment operator	21.04/hr	SuperPro Database
	Maintenance Staff	17.89/hr	SuperPro Database
	QC Analyst	25.90/hr	SuperPro Database
	Security Guard	15.87/hr	SuperPro Database
Utilities	Std Power	0.41	SuperPro Database
	Steam	49.56	SuperPro Database
	Steam (High P)	82.60	SuperPro Database
	Cooling Water	0.21	SuperPro Database
	Chilled Water	1.65	SuperPro Database
	Air	0	SuperPro Database

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3.2.4 Revenues

Palm mid fraction, palm stearin and palm double olein are the products of whole processing line and palm mid fraction is the main revenue. Table 3.4 shows the selling prices for revenues products.

Table 3.4: Selling price for revenues product

Material		Selling Price (MYR/MT)	Reference
Revenue	Palm mid fraction	12200.00	MPOB
	Palm stearin	6880.00	MPOB
	Palm double olein	7018.00	MPOB

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3.3 Process Approach

For simplification purpose, the processes were split into six section which areextraction, degumming, bleaching, separation, deodorization, and fractionation.

3.4 Overall Research

The whole research study can be divided into 5 main parts:

1. By using physical refining where the process involved are degumming, bleaching, deodorization, and fractionation.
2. By using physical refining with extraction where the process involved are

degumming, bleaching, extraction, deodorization, and fractionation.

3. By using physical refining with post refinery where the process involved are degumming, bleaching, deodorization, post refinery, and fractionation.

4. By using chemical refining that include neutralization process where the process involved are degumming, bleaching, deodorization, and fractionation.

5. By using chemical refining with post refinery where the process involved are degumming, bleaching, deodorization, and fractionation.

The main objective of this research study is to design the palm oil refinery with 3-MCPD and GE removal and to analyses technoeconomic of the designed palm oil refinery with 3-MCPD and GE removal. The research started with the finding the information about the different section that involved in this study.

3.4.1 Degumming

Degumming is a technical term for the purification of seed oils, which typically contain contaminants in the colloidal or dissolved condition (Bernardini, 1985). Phospholipids (phosphatides) or, more commonly, gums are complex organo-phosphorus compounds found in fats and oils. Phospholipids must be removed due to their strong emulsifying activity; if they are not removed, the oil would undergo excessive darkening during high-temperature deodorization (Kim et al.,2002).

During processing, phospholipids (phosphatides) are removed by several procedures known collectively as degumming. Compared to other vegetable oils, palm oil contains comparatively low levels of phospholipids, between 5 to 130 ppm. Sambanthamurthi et al., (2000) reported that solvent-extracted mesocarp oil often contains

1000-200 ppm phospholipids, but commercial crude palm oil only has 20-80 ppm. Typically, the treatment consists of hydration with water, orthophosphoric acid, and polybasic organic acids, either separately or in combination, followed by centrifuging the precipitated material or adsorption on bleaching earth or filter. In simpler terms, degumming is the act of eliminating gums that will interfere with the long-term stability of oil products.

The purpose is attained by processing crude palm oil (CPO) with the appropriate amount of food-grade acid, often phosphoric or citric acid of a specific concentration. There are two types of degumming agents that are usually being used in palm oil refining industry, which are phosphoric acid and citric acid. In this study, the degumming agents used is phosphoric acid. Liquid phosphoric acid (H3PO4) is odorless and colorless. Typically, an 85% concentration of food-grade phosphoric acid is utilized in the palm oil refining process. It a colorless and odorless liquid. In addition, the cost factor is vital to be considered in running a refinery plant. On the current market, citric acid is priced significantly higher than phosphoric acid.

3.4.2 Bleaching

The term bleaching refers to the process of removing color-producing chemicals and purifying the fat or oil further. Typically, bleaching is accomplished by adsorption of the color-producing chemicals on an adsorbent material. In addition, during the bleaching process, some particles or pigments that contribute to the deterioration of oil quality are removed, primarily due to their pro-oxidative qualities that encourage oxidation (Bockish, 1998). In the vegetable oil sector, numerous adsorbent materials are utilized, including acid activated bleaching earth, natural bleaching earth, activated carbon, and synthetic silicates. In this plant refinery, neutral bleaching earth is used as it can remove soaps and phospholipid as well as minimizes FFA increase during bleaching.

3.4.3 Deodorization

Deodorization is a stripping process in which a specific amount of a stripping agent (often steam) is pushed through hot oil at low pressure for a given amount of time. Consequently, it is mostly a physical process in which volatile components are extracted. However, since it is typically performed at high temperatures (> 200°C), chemical and thermal consequences may also occur.

Those components of a liquid combination having the lowest boiling points (and therefore the most volatility) evaporate first, leaving behind the less volatile chemicals with higher boiling points. By decreasing the system's pressure, the temperature at which the more volatile components evaporate can be lowered, yet the order in which the components distil remains unchanged.

The removal efficiency of these volatile compounds is mostly determined by their vapour pressure and concentration in the oil. The vapour pressure of a given component is a function of temperature and rises as the temperature rises. The lower the vapour pressure, the lower the volatility and the greater the difficulty in removing the component from the oil. Utilizing an inert (non-reactive) stripping agent improves the vaporisation of volatile components.

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3.4.4 Fractionation

Refined palm oil should go through fractionation process to separate solid phases (Stearine) and liquid phases (Olein). In the fats & oils industry, fractionation is a well-established procedure. It involves the separation of low and high melting triacylglycerol under controlled chilling conditions into fractions of olein and stearin with distinct chemical and physical properties. In the past few decades, palm oil has been one of the most fractionated vegetable oils, mostly due to its semisolid qualities. The diverse fractions of palm oil make it suitable for usage in a variety of food products, including margarine, frying oil, and cocoa butter substitute. Controlling the fractionation conditions properly is essential for producing fractions with suitable stearin and olein qualities.

3.5 Different Methods to Remove 3-MCPD and GE

3.5.1 Physical Refining

Physical refining started with degumming section where gums and other sticky materials by adding phosphoric acid. The main purpose of degumming is to remove the phospholipids from the crude palm oil. The CPO is stored first in a buffer tank and passes through a heat exchanger to raise the temperature. 5000kg/h of CPO from storage tank is heated at 80°C before it is mix with 6.26kg/h of phosphoric acid to remove the to remove the phospholipids from the crude palm oil. The amount of phosphoric acid injected is dependent on both the gum content and the type of oil being processed. The subsequent stage of this procedure is the degumming tank, where hot process water is combined with oil and acid. Here, the gums and oil separate. When a liquid enters a separator, the gum particles separate from the oil and become a waste stream.

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The next section is bleaching section where bleaching is used as adsorbent. CPO was mixed with 51.58kg/h of bleaching clay to remove the phospholipids, sulfuric acid, sludge, sulfonic acid, free fatty acids, and traces of metal in oils. In this operation, the oil is taken into cylindrical vessel with agitator called bleacher and kept under vacuum and heated up to 95°C with steam. To separate the oil and bleaching chemical mixture, a typical plate and frame press is utilized. The transparent oil obtained is bleached oil with a significantly lighter hue. During filtration, spent bleaching clay is rejected.

Next, the deodorization section is done to remove free fatty acid (FFA) to obtain a bland and odorless oil. Bleached palm oil is transferred to holding tank at 65°C for one hour before it is heated to undergoes deodorization process. Then, refined palm oil is produced and stored in storage tank for fractionation section. During deodorization, there are four reactions happened producing MCPD and GE. The first reaction is when monoacylglycerol (MAG) reacts with chloride compounds to form 2-MCPD and 3-MCPD under high temperature. Dubois et. al. (2012) studied that 2-MCPD ester makes up about 1/3 to 1/2 of the total MCPD ester. Diacylglycerol (DAG) as the precursor reacts with chloride forming 1312.82g total mass of 2-MCPD and 3-MCPD. Triacylglycerol which is one of major components in palm oil reacts with chloride to form 2-MCPD, 3-MCPD and FFA. Then, the reaction of DAG forming FFA and GE.

During fractionation section, refined palm oil is heated before it undergoes crystallization process to separate the low and high melting triacylglycerol under controlled cooling conditions into olein and stearin fractions with distinct chemical and physical properties. It will undergo double fractionation to produces palm mid fraction. Figure 3.1 shows the flowsheet of basic physical refining.

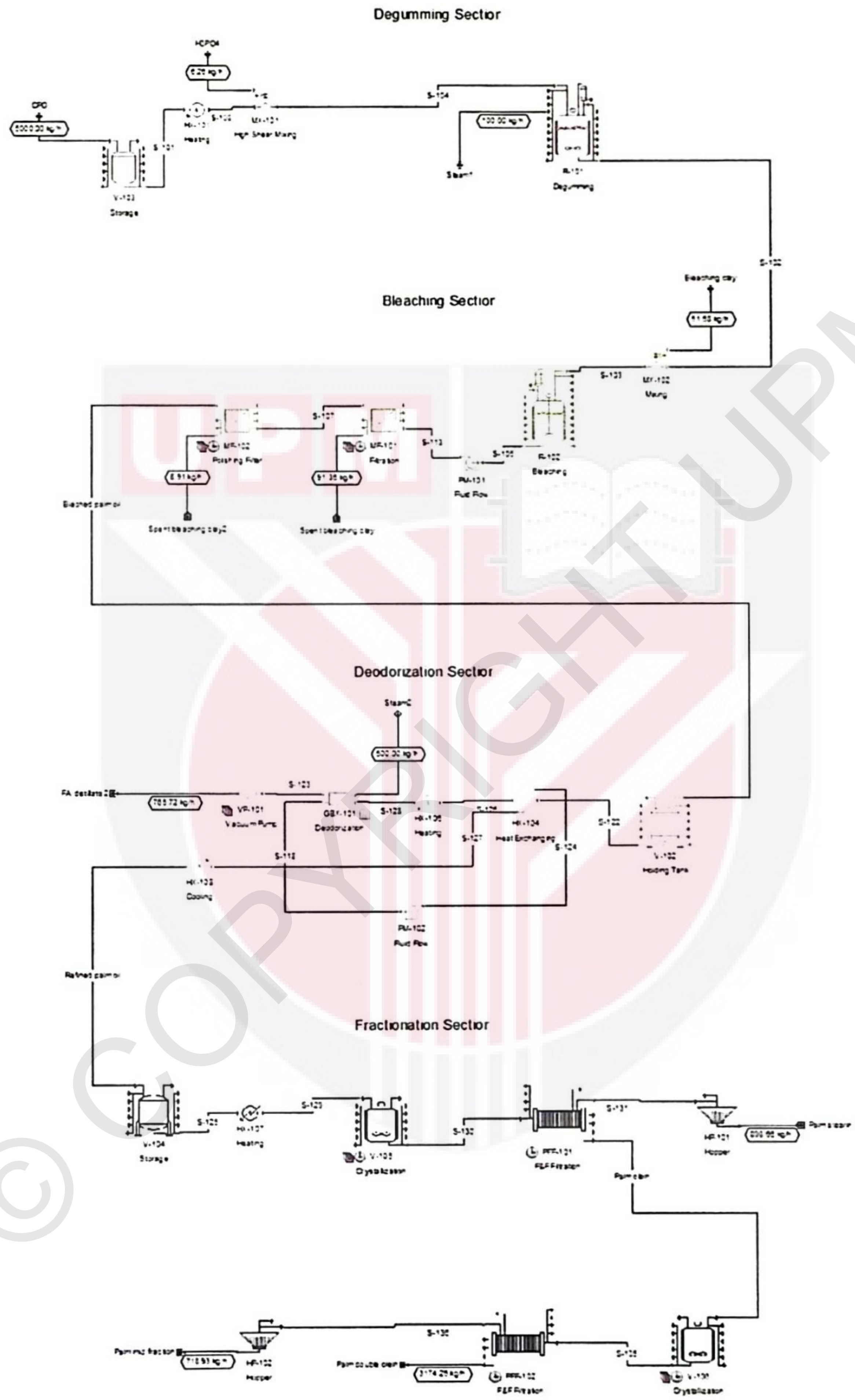

Figure 3.1: Flowsheet of basic physical refining

3.5.2 Physical Refining with Extraction

Physical refining with extraction started with degumming section, bleaching section. Then, it will undergo extraction section.

Bleached palm oil will further process with extraction. Bleached palm oil is heated at 98.8°C and enter rotary disc contactor to remove impurities in the bleached palm oil. Then, the bleached palm oil will undergo distillation process to separate the FFA's. Moreover, remaining palm oil will be decreased in temperature and mix with solvent before entering the rotary disc contactor again to remove impurities after distillation process.

Next, the deodorization section is done to remove free fatty acid (FFA) to obtain a bland and odorless oil. Bleached palm oil is transferred to holding tank at 65°C for one hour before it is heated to undergoes deodorization process. Then, refined palm oil is produced and stored in storage tank for fractionation section. During deodorization, there are four reactions happened producing MCPD and GE. The first reaction is when monoacylglycerol (MAG) reacts with chloride compounds to form 2-MCPD and 3-MCPD under high temperature. Dubois et. al. (2012) studied that 2-MCPD ester makes up about 1/3 to 1/2 of the total MCPD ester. Diacylglycerol (DAG) as the precursor reacts with chloride forming 1312.82g total mass of 2-MCPD and 3-MCPD. Triacylglycerol which is one of major components in palm oil reacts with chloride to form 2-MCPD, 3-MCPD and FFA. Then, the reaction of DAG forming FFA and GE.

During fractionation section, refined palm oil is heated before it undergoes crystallization process to separate the low and high melting triacylglycerol under controlled cooling conditions into olein and stearin fractions with distinct chemical and physical properties. It will undergo double fractionation to produces palm mid fraction. Figure 3.2 shows the flowsheet of physical refining with extraction.

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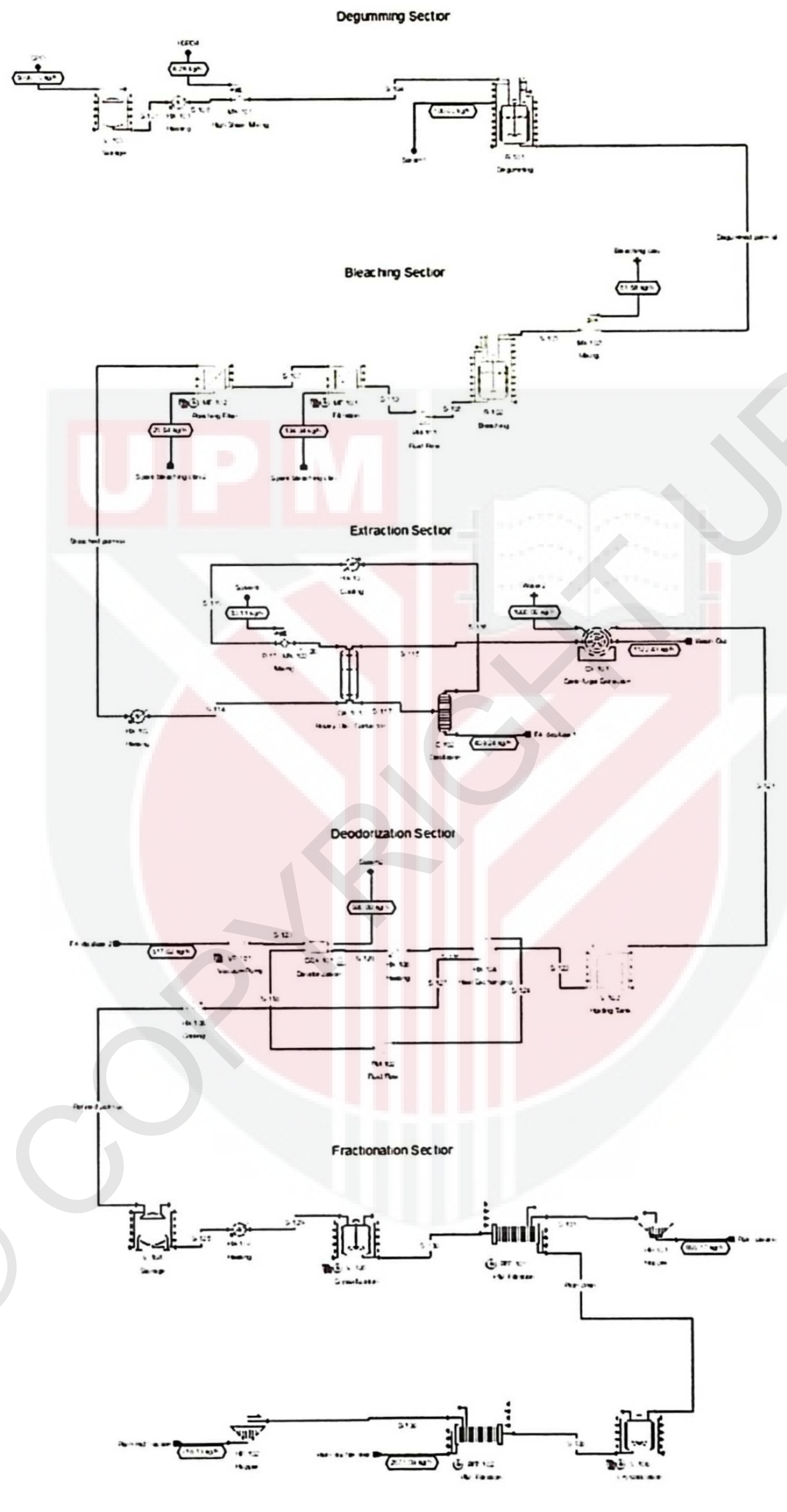

Figure 3.2: The flowsheet of physical refining with extraction

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3.5.3 Physical Refining with Post Refinery

Physical refining with post refinery started with degumming section, followed by bleaching section, deodorization section, post refinery section and fractionation section.

The, the next section is post refinery section where refined palm oil will enter the mixer to be mix with activated clay before undergo bleaching process. The function of activated carbon is to remove contaminants from refined palm oil through the process of physical adsorption. Then refined palm oil is filtered again to remove the unwanted impurities. During filtration process, spent activated carbon is removed.

Before post refinery section, palm oil will undergo degumming section, bleaching section, and deodorization section. During deodorization, there are four reactions happened producing MCPD and GE. The first reaction is when monoacylglycerol (MAG) reacts with chloride compounds to form 2-MCPD and 3-MCPD under high temperature. Dubois et. al. (2012) studied that 2-MCPD ester makes up about 1/3 to 1/2 of the total MCPD ester. Diacylglycerol (DAG) as the precursor reacts with chloride forming 1312.82g total mass of 2-MCPD and 3-MCPD. Triacylglycerol which is one of major components in palm oil reacts with chloride to form 2-MCPD, 3-MCPD and FFA. Then, the reaction of DAG forming FFA and GE.

During fractionation section, refined palm oil is heated before it undergoes crystallization process to separate the low and high melting triacylglycerol under controlled cooling conditions into olein and stearin fractions with distinct chemical and physical properties. It will undergo double fractionation to produces palm mid fraction. Figure 3.3 shows the flowsheet of physical refining with post refinery.

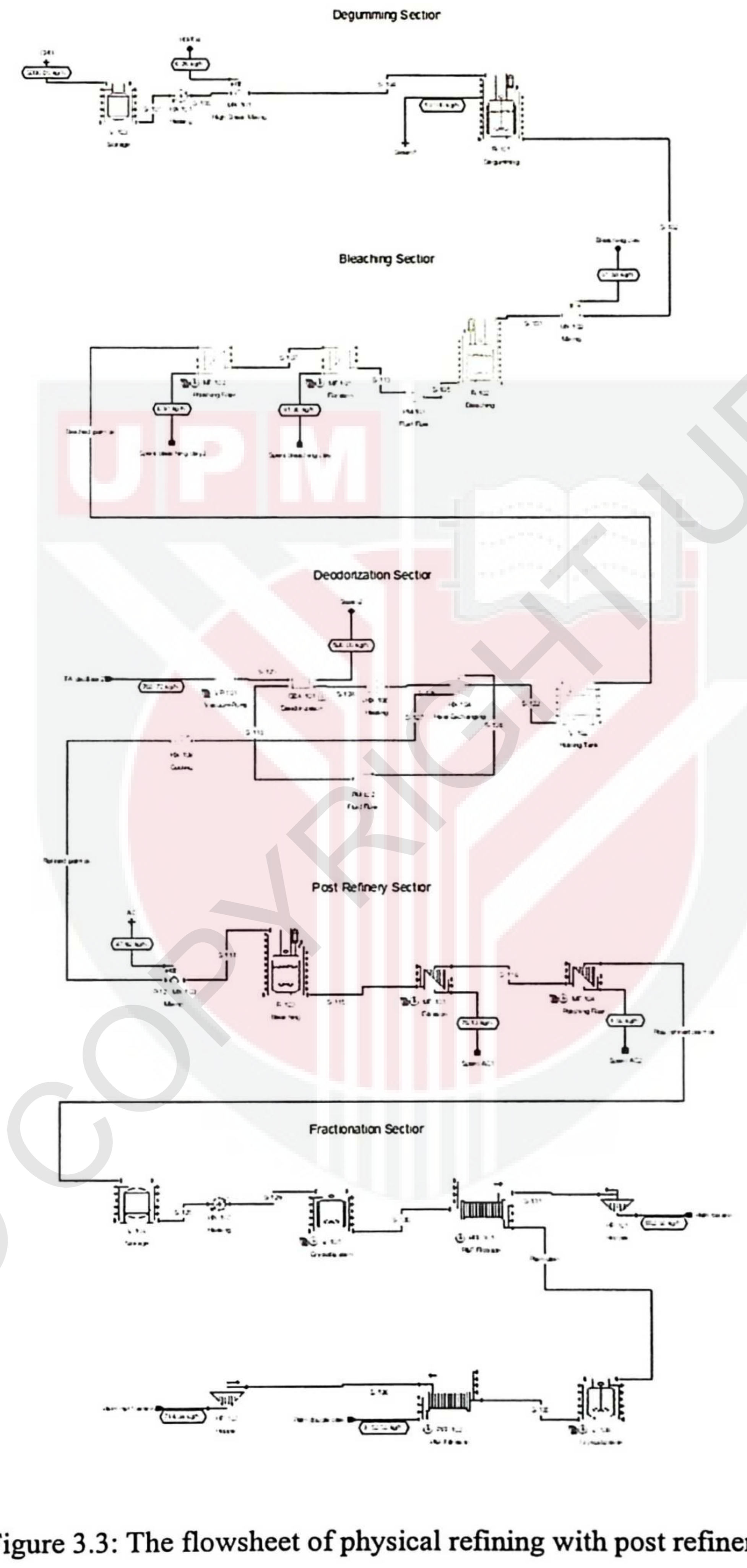

Figure 3.3: The flowsheet of physical refining with post refinery

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3.5.4 Chemical Refining

Chemical refining started with degumming section where gums and other sticky materials by adding phosphoric acid. The main purpose of degumming is to remove the phospholipids from the crude palm oil. The CPO is stored first in a buffer tank and passes through a heat exchanger to raise the temperature. 5000kg/h of CPO from storage tank is heated at 80°C before it is mix with 6.26kg/h of phosphoric acid to remove the to remove the phospholipids from the crude palm oil. The amount of phosphoric acid injected is dependent on both the gum content and the type of oil being processed. The subsequent stage of this procedure is the degumming tank, where hot process water is combined with oil and acid. Here, the gums and oil separate. When a liquid enters a separator, the gum particles separate from the oil and become a waste stream. Then, palm oil will enter centrifuge to splits the CPO with the solid cakes. The oil mass is next neutralized with alkali which is sodium hydroxide (NaOH) to remove free fatty acid as soap stock. This soap stock is extracted from the oil mass by gravity separation. Oil is rinsed with hot water to remove alkali residues. To remove the soap, CPO is firstly mix with the water before entering the centrifugation, then the soap will be removed in the centrifuge.

Then, degummed palm oil is heated to 105°C before it is mixed with bleaching clay to undergo bleaching process. During bleaching, the oil is taken into cylindrical vessel with agitator called bleacher and kept under vacuum and heated up to 95°C with steam. To separate the oil and bleaching chemical mixture, a typical plate and frame press is utilized. The transparent oil obtained is bleached oil with a significantly lighter hue. During filtration, spent bleaching clay is rejected.

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Next, the deodorization section is done to remove free fatty acid (FFA) to obtain a bland and odorless oil. Bleached palm oil is transferred to holding tank at 65°C for one hour before it is heated to undergoes deodorization process. Then, refined palm oil is produced and stored in storage tank for fractionation section. During deodorization, there are four reactions happened producing MCPD and GE. The first reaction is when monoacylglycerol (MAG) reacts with chloride compounds to form 2-MCPD and 3-MCPD under high temperature. Dubois et. al. (2012) studied that 2-MCPD ester makes up about 1/3 to 1/2 of the total MCPD ester. Diacylglycerol (DAG) as the precursor reacts with chloride forming 1312.82g total mass of 2-MCPD and 3-MCPD. Triacylglycerol which is one of major components in palm oil reacts with chloride to form 2-MCPD, 3-MCPD and FFA. Then, the reaction of DAG forming FFA and GE.

During fractionation section, refined palm oil is heated before it undergoes crystallization process to separate the low and high melting triacylglycerol under controlled cooling conditions into olein and stearin fractions with distinct chemical and physical properties. It will undergo double fractionation to produces palm mid fraction. Figure 3.4 shoes the flowsheet of basic chemical refining.

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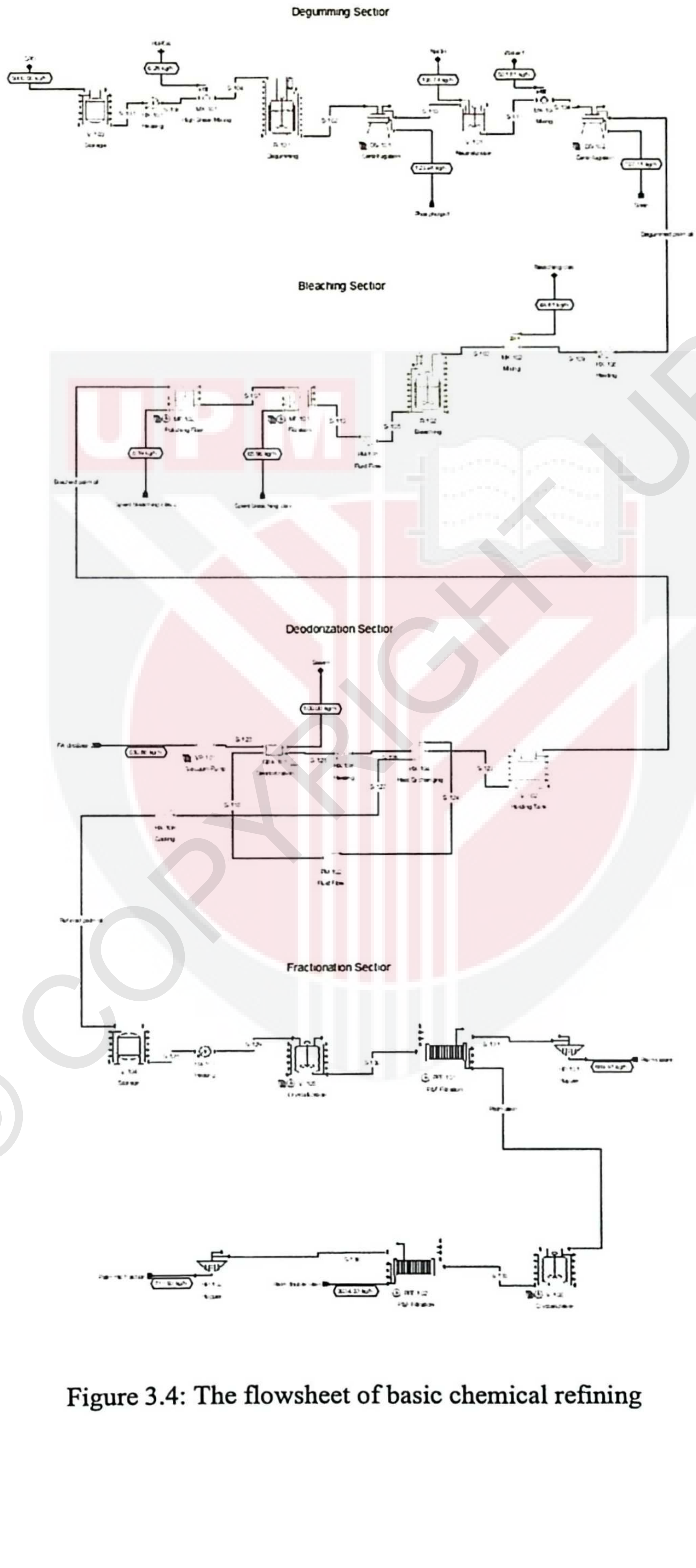

Figure 3.4: The flowsheet of basic chemical refining

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3.5.5 Chemical Refining with Post Refinery

Chemical refining with post refinery also started with degumming section, followed by bleaching section and deodorization section.

After that, refined palm oil will continue with post refinery section. Refined palm oil is mix with activated carbon first before it undergoes the bleaching process. The function of activated carbon is to remove contaminants from refined palm oil through the process of physical adsorption. Then refined palm oil is filtered again to remove the unwanted impurities. During filtration process, spent activated carbon is removed.

Before post refinery section, palm oil will undergo degumming section, bleaching section, and deodorization section. During deodorization, there are four reactions happened producing MCPD and GE. The first reaction is when monoacylglycerol (MAG) reacts with chloride compounds to form 2-MCPD and 3-MCPD under high temperature. Dubois et. al. (2012) studied that 2-MCPD ester makes up about 1/3 to 1/2 of the total MCPD ester. Diacylglycerol (DAG) as the precursor reacts with chloride forming 1312.82g total mass of 2-MCPD and 3-MCPD. Triacylglycerol which is one of major components in palm oil reacts with chloride to form 2-MCPD, 3-MCPD and FFA. Then, the reaction of DAG forming FFA and GE.

During fractionation section, refined palm oil is heated before it undergoes crystallization process to separate the low and high melting triacylglycerol under controlled cooling conditions into olein and stearin fractions with distinct chemical and physical properties. It will undergo double fractionation to produces palm mid fraction. Figure 3.5 shows the flowsheet of chemical refining with post refinery.

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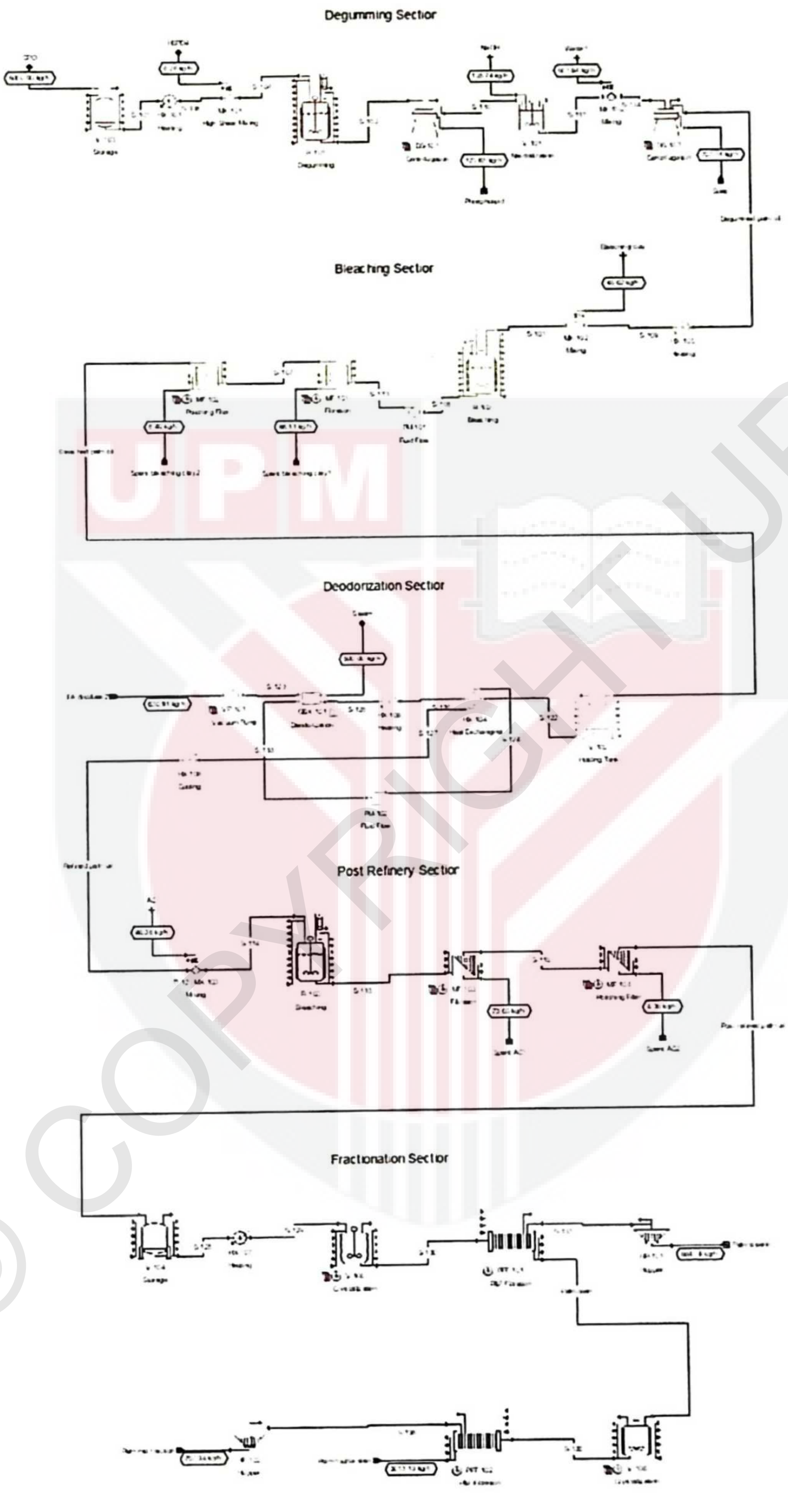

Figure 3.5: The flowsheet of chemical refining with post refinery

3.6 Cost Estimation

3.6.1 Purchased Cost Equipment

The specifications, purchase and installation costs of major equipment outlined in Table 3.5.

Table 3.5: The specifications, purchase, and installation costs of major equipment

Equipment	Max Size/ Capacity (each unit)	Unit	Material of Constr.	Purchase Cost (MYR/unit)	References
Storage tank	200000	L	Stainless steel	19791.00	https://www.alibaba.com/product-detail/Tanks-Vertical-Oil-Tank-Factory-Direct_1600374623095.html?spm=a2700.galleryofferlist.normal_offer.d_title.38073a297KXxHj&s=p
Mixer	10000	L	Stainless steel	21990.00	https://www.alibaba.com/product-detail/Best-Price-Liquid-Emulsifying-Homogenizer-Tank_62528088788.html
CSTR	5000	L	Stainless steel	129741.00	https://www.alibaba.com/product-detail/Reactor-Stirred-Reactor-Automatic-Customize-Chemical_62414388343.html?spm=a2700.pccps_detail.normal_offer.d_title.4bf04f73LQVGqO&s=p
Filtration	10000	kg/h	SS304	43980.00	https://www.alibaba.com/product-detail/Henan-Eternalwin-Higher-oil-extraction-rate_60781668392.html

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Holding tank	50000	L	SS304	87960.00	https://www.alibaba.com/product-detail/Storage-Tank-Oil-Palm-Vertical-Food_1600502227814.html?spm=a2700.7724857.normal_offer.d_title.7e2764b2SZjdKL&s=p
Heat exchanger	100	m2	CS	4037.00	SuperPro
Deodorizer	60	tonnes	Stainless steel	105552.00	https://www.alibaba.com/product-detail/Oil-Refining-Deodorized-Palm-For-Edible_62127792272.html?spm=a2700.7724857.normal_offer.d_title.5bfc74b4OCn8vq&s=p
Vacuum pump	40000	Watt	SS316	66250	SuperPro
Heater	100	m2	CS	4037.00	SuperPro
Cooler	100	m2	CS	4037.00	SuperPro
Centrifugal pump	5	hp	Iron	39901.64	McMaster-Carr catalogue
Crystallizer	80	m3	SS304	879600.00	https://www.alibaba.com/product-detail/crystallizer-machine-for-palm-oil-sunflower_60739220217.html
P&F filtration	80	m2	SS316	259000.00	SuperPro
Distillation column	Different models available for different capacity	CS	Stainless steel	19791.00	https://www.indiamart.com/proddetail/j-p-metals-distillation-structured-column-packing-24730428430.html
Centrifugal extractor	230	gal	SS304	96316.20	https://www.alibaba.com/product-detail/Industrial-Extraction-Extract-Centrifuge-Centrifugal-Extractor_62394211760.html?spm=a2700.7724857.normal_offer.d_title.2dcb207f7KAdUw&s=p

Centrifuge	50	m3/h	Stainless steel	87080.40	https://dlreyes.en.made-in-china.com/product/wvWnzARraNYp/China-3-Phase-Decanter-Centrifuge-for-Palm-Oil-Industry-with-Efficient-and-Cost-Effective-Operation.html
Neutralizer	500	m3	CS	163000.00	SuperPro

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CHAPTER 4

RESULTS AND DISCUSSION

The SuperPro Designer v10 has been installed, and various tutorials have been completed to gain a deeper understanding of the software's functionality. In essence, the software assesses a product or system from the beginning of its life to the conclusion; in simplest terms, it studies its life cycle. First, all the unit procedures must be defined by the users so that the scope of the study may be determined. Then, each of the materials and procedures is defined to include in this study. This is essential since each can contribute to the global environmental impact.

After defining the objective, scope, and system boundary of their research, the inventory data is filled out in terms of inputs and outputs to ensure that they are consistent. Inputs can be stated as either the materials required to produce the desired product or the materials necessary for the system to begin running. In the meantime, the outputs can be categorized as the system's output and the "by-products" created during production, such as the emissions of environmentally hazardous gases into the air, land, or water. For this study, the inventory data was divided for five different methods in palm oil refining process.

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4.1 Results Overview

In this study, there are five methods in designing the palm oil refinery with 3-MCPD and GE removal which are basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining, and chemical refining with post refinery is done via SuperPro Designer.

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4.2 Economic Evaluation

Table 4.1: Economic evaluation of five different refining methods

Method of Refining	Physical Refining			Chemical Refining	
	Basic Physical Refining	Physical Refining with Extraction	Physical Refining with Post Refinery	Basic Chemical Refining	Chemical Refining with Post Refinery
Total Capital Investment (MYR)	62,279,000	65,632,000	68,904,000	69,299,000	74,350,000
Capital Investment Charged to This Project (MYR)	62,279,000	65,632,000	68,904,000	69,299,000	74,350,000
Annual Operating Cost (MYR yr)	134,504,000	138,802,000	139,019,000	139,471,000	141,219,000
Main Revenue (MYR /yr)	38,154,000	38,005,000	37,894,000	37,782,000	37,539,000
Other Revenues (MYR /yr)	123,811,606	114,451,601	122,965,845	119,277,806	118,458,050
Total Revenues (MYR/yr)	161,965,000	152,457,000	160,860,000	157,060,000	155,997,931

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Cost Basis Annual Rate (kg MP/yr)	3,127,343	3,115,175	3,106,076	3,096,885	3,076,931
Unit Production Cost (MYR/kg MP)	43.01	44.56	44.76	45.04	46.55
Net Unit Production Cost (MYR/kg MP)	43.01	44.56	44.76	45.04	46.55
Unit Production Revenue (MYR/kg MP)	51.79	48.94	51.79	50.72	50.70
Gross Margin (%)	16.96	8.96	13.58	11.20	8.19
ROI (%)	32.46	18.56	25.24	25.52	16.68
Payback Time (yr)	3.08	5.39	3.96	3.92	6.00
IRR (After Taxes) (%)	26.48	13.67	19.92	41.02	11.64
NPV (at 7.0% Interest) (MYR)	91,081,000	29,738,000	64,115,000	77,703,000	22,890,000

MP = Total Flow of Stream 'Palm mid fraction'

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4.2.1 Gross Margin, ROI, and Payback Time

Table 4.1 shows the executive summary (2022) prices for five different methods in palm oil refinery which are basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining, and chemical refining with post refinery. Based in table above, the gross margin for basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining and chemical refining with post refinery are 16.96%, 8.96%, 13.58% 11.20% and 8.19% respectively. Besides, the ROI for basic physical refining is 32.46%, 18.56% for physical refining with extraction and 25.24% for physical refining with post refinery. Then, for chemical refining, the ROI for basic chemical refining and chemical refining with post refinery are 25.52% and 16.68% respectively. Moreover, from the gross margin and ROI value, SuperPro Designer (SPD) computes the payback time for each method.

Then, the payback time for basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining and chemical refining with post refinery are 3.08 years, 5.39 years, 3.96 years, 3.92 years, and 6.00 years, respectively. From the result obtained, basic physical refining is the most feasible among other methods because the payback time for basic physical refining is the shortest which is only 3.08 years. Besides, basic physical refining also has the highest NPV at 7% rate which is MYR 91,081,000. However, chemical refining with post refinery has the longest payback time which is 6.00 years.

For chemical refining, chemical refining with post refinery shows the lowest gross margin which is only 8.19% and the among the lowest of ROI which is 16.68% with the

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longest payback time. While for physical refining, physical refining with extraction shows the lowest gross margin and ROI which is only 8.96% and 18.56% respectively, with the longest payback time for 5.39 years.

Payback time is the amount of time it takes to recover the cost of an investment. It is important to ensure the payback time for the production is at least below than at five years because the shorter the discounted payback time, the more rapidly the project generates cash flows and achieves breakeven. Even all the five methods have the average of total revenues, lower ROI, and longer payback time for chemical refining with post refinery is affected by the total capital investment cost, which can be seen from the table above where chemical refining with post refinery has the highest total capital investment, MYR 74,350,000.

However, since the payback time for all methods are allocated within 15 years, thus all the methods approach can obtain the profits within the service period. In addition, from the table, it shows that all the methods have the IRR that higher than 7% interest rate. It can be concluded that, all the refining methods is economically feasible with basic physical refining is the best option.

4.2.2 Total Capital Investment

Total capital investment including of direct fixed capital (DFC), the costs required to purchase necessary process equipment, the costs of labor and materials for installing the equipment, the costs of site preparation and buildings; other costs such as engineer, construction and field expenses, fees to contractors, startup and performance tests, and contingencies; land for the process equipment and working capital for the process equipment; and land for the process equipment. Figure 4.1 shows the total capital investment for five types of refining.

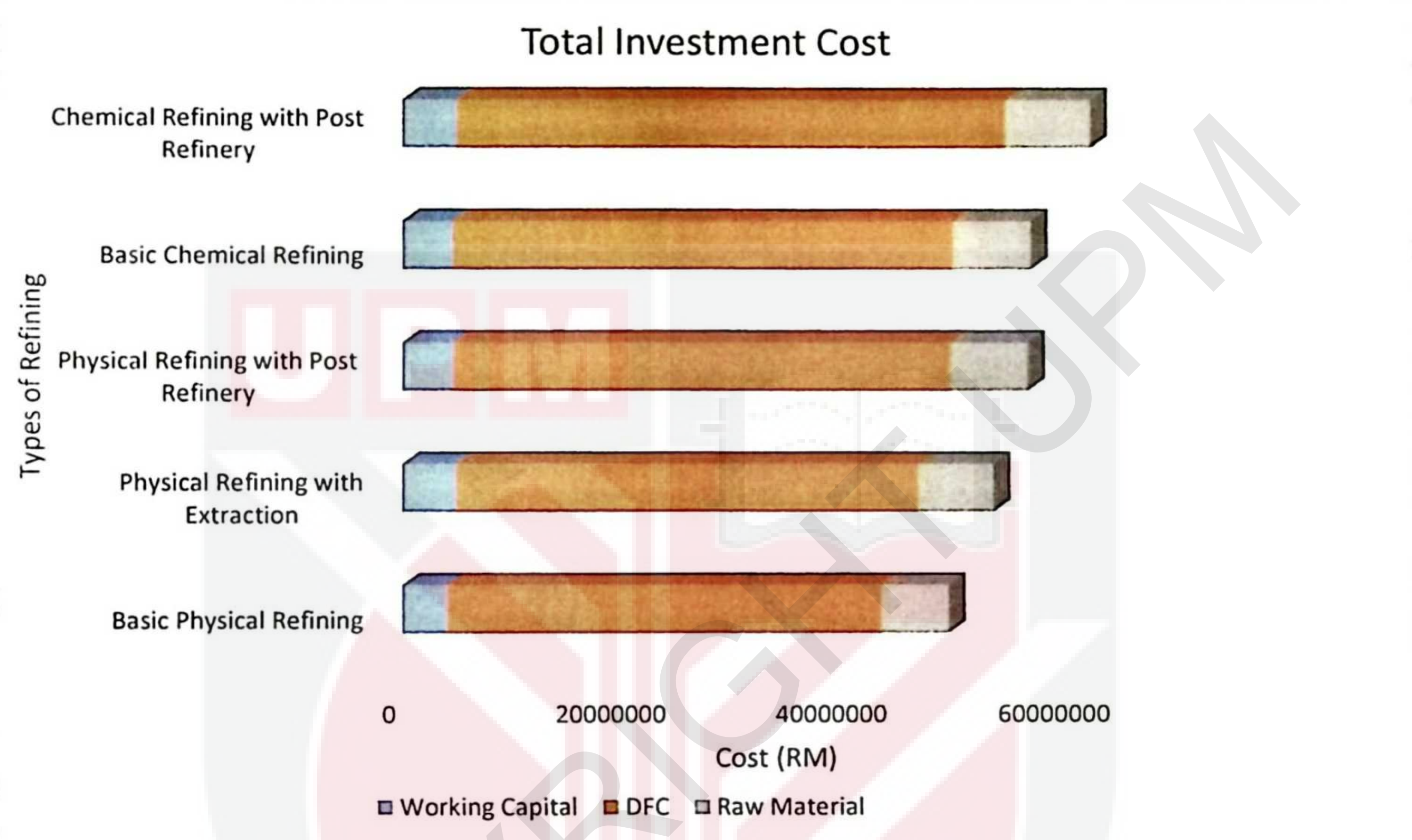

Figure 4.1: Total investment cost of five different refining methods

From the figure above, DFC has the highest value compared to working capital and raw materials. This is because the equipment purchase cost is include in DFC as in DFC, the equipment purchase cost is important in estimating the plant. Besides, all the factor used to estimate DFC value is the same for all the types of refining including contingency, contractor's fee, engineering, and contingency.

The total equipment purchase cost for basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining and chemical refining with post refinery are MYR 6,091,000, MYR 6,779,000, MYR 6,982,000, MYR 7,034,000, and MYR 7,709,000, respectively. From the result obtained, chemical refining with post refinery has the highest total equipment purchase cost and the lowest is from basic physical refining. Based on Table 4-1, chemical refining with post refinery having the highest total capital investment which is about MYR 74,061,000 and since it has the highest cost, it can be concluded that the higher the total equipment purchase cost, the higher the value of DFC.

4.2.3 Annual Operating Cost

The annual operating cost in physical and chemical palm oil refining including the materials, facility-dependent, labor-dependent, quality control and quality assurance, utilities, and waste treatment. Figure 4.2 shows the annual operating cost of five different method of palm oil refining.

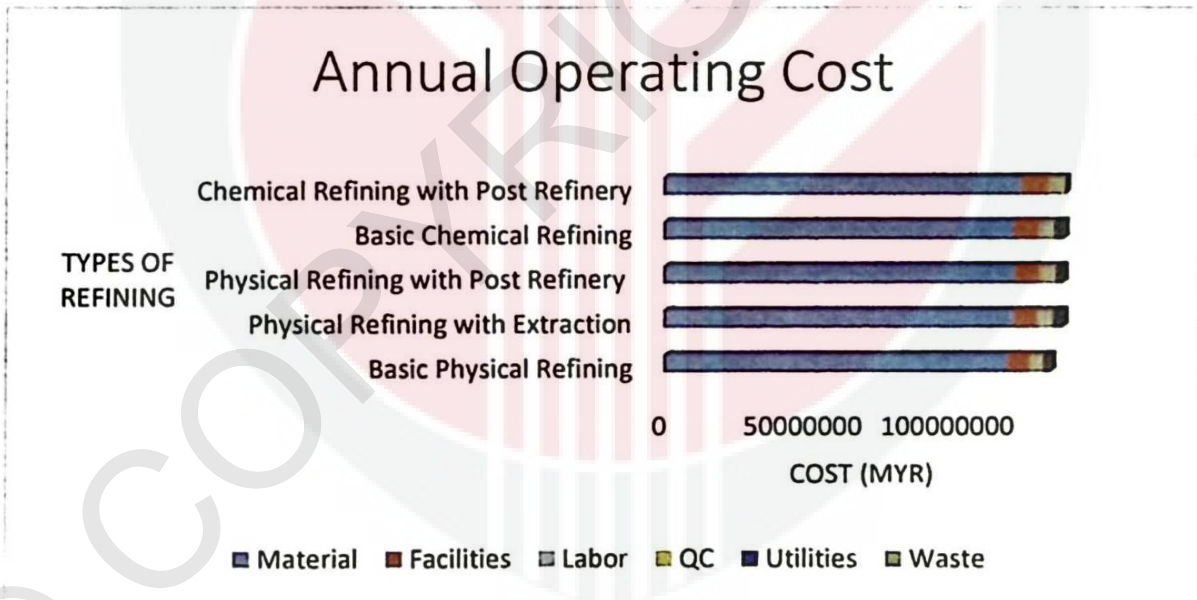

Figure 4.2: Annual operating cost of five different refining methods

Based on Table 4.1, the annual operating cost for basic physical refining, physical refining with extraction, physical refining with post refinery, basic chemical refining and chemical refining with post refinery are MYR 134,504,000, MYR 138,802,000, MYR

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139,019,000, MYR 139,471,000, and MYR 141,219,000, respectively. Chemical refining with post refinery has the highest annual operating cost as the raw material, facilities, labor, and quality control are higher than other types of refining. However, chemical refining with post refinery produces lower waste than basic physical refining which produce the highest waste. Table 4.2 shows the labor cost for different refining methods.

Table 4.1: Labor cost of five types of refining methods

Types of Refining	Labor Cost (MYR)
Basic Physical Refining	4,056,849
Physical Refining with Extraction	4,841,526
Physical Refining with Post Refinery	4,623,701
Basic Chemical Refining	4,579,827
Chemical Refining with Post Refinery	4,959,953

Based on the table above, chemical refining with post refinery has the highest cost for labor which is MYR 4,959,953. The labor cost is higher compared to others refining as it has large plant scale than others. After deodorization, refined palm oil will undergo post refinery section where it will be bleach again to remove unwanted color pigments and a wide range of other impurities by using activated carbon as it is a good adsorbent and it also have more process during degumming section. This also contribute to the higher annual operating cost. According to Yang and Rosentrater (2019), higher total capital investment and annual operating cost is due to larger plant scale.

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Furthermore, major contribution to the high annual operating cost by all types of palm oil refining is the raw materials. Table 4.3 shows the raw materials used in all types of palm oil refining.

Table 4.2: Raw materials used in all types of palm oil refining

Raw Materials	Cost (MYR)
Bleaching Earth	1474.00 /MT
Crude Palm Oil	5500.00 /MT
Phosphoric Acid	42.50 /m3(STP)
Water	1.29 /m3(STP)
2-DMAE	35.00 /kg
Activated Carbon	13.00 /kg
Sodium Hydroxide	19.90 /kg

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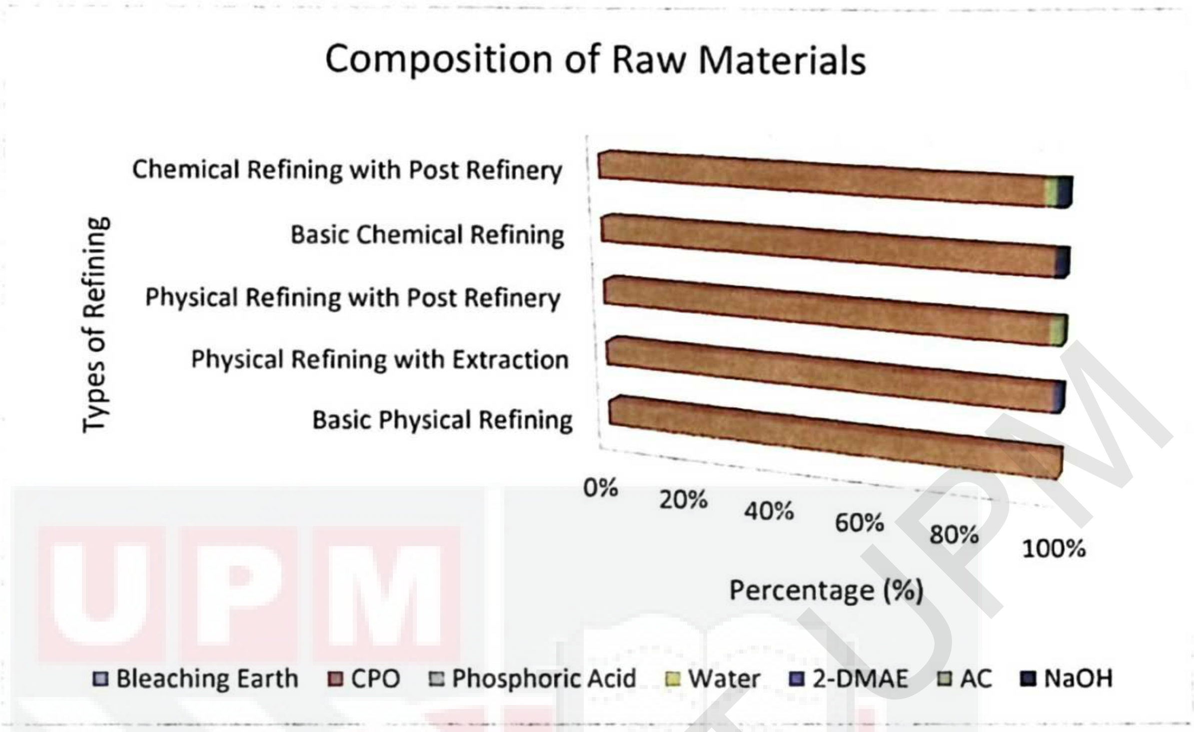

Figure 4.3: Composition of raw materials use in alyy types of refining methods

Figure 4.3 shows the composition of raw material use in all types of palm oil refining. From figure above, the highest composition used is crude palm oil (CPO). Compared to all the raw material used, CPO is the most expensive and it is used in the large quantity. This is one of the factors that contribute to the large amount of annual operating cost. According to Yang and Rosentrater (2019), the studied shows that raw material are the largest operating cost in any production.

4.2.4 Unit and Net Unit Production Cost

For unit and net unit production cost, as shown in Table 4-1, chemical refining with post refinery has the highest value among the others refining which is at 46.55 MYR/kg MP. It has higher value as the operating cost is high due to chemical refining with post refinery required more process and equipment compared to other methods.

4.2.5 Revenues

Palm mid fraction is the main revenue in refining process and the other revenues in this process are palm stearin and palm olein. The total revenues of all the methods of palm oil refining are shown in Table 4.4. Basic physical refining has the highest amount of total revenues compared to others which are MYR 161,965,189 while physical refining with extraction has the lowest amount of total revenues which is MYR 152,456,742. Figure 4.4 shows the total revenues of palm stearin, palm double olein and palm mid fraction. Based on the graph, majority of the methods from SPD simulator show the palm double olein as the primary source of revenues where MYR 96,904,730 for basic physical refining, MYR 87,649,410 for physical refining with extraction and MYR 96,241,948 for physical refining with post refinery. Meanwhile, basic chemical refining contributes MYR 92,632,982 and MYR 91,984,908 for chemical refining with post refinery. In fact, product pricing has a significant impact on the total revenues. On the present local market, 5 kg cooking oil costs roughly MYR 40-45 for each bottle. Depending on the product quality, the price of some cooking oil products was found much higher.

Table 4.3: Total revenues of all methods of palm oil refining

Methods	Basic physical refining	Physical refining with extraction	Physical refining with post refinery	Basic chemical refining	Chemical refining with post refinery
	(MYR/YR)				
Revenues					
Palm stearin	26,906,876	26,802,191	26,723,897	26,644,824	26,473,142
Palm double olein	96,904,730	87,649,410	96,241,948	92,632,982	91,984,908
Palm mid fraction	38,153,583	38.005,141	37,894,121	37,781,996	37,538,554

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Total	161,965,189	152,456,742	160,859,967	157,059,802	155,996,605

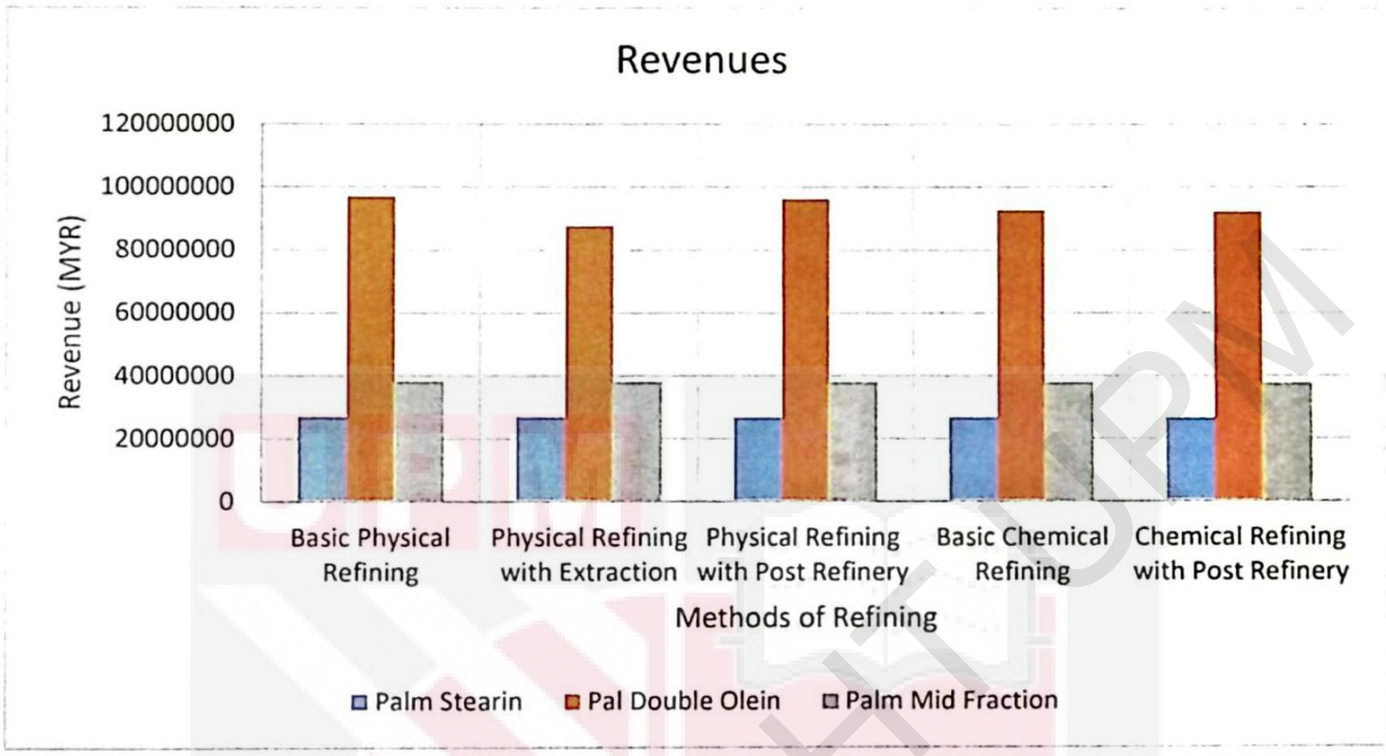

Figure 4.4: Total revenues of palm stearin, palm double olein and palm mid fraction

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4.3 Environmental Impact

4.3.1 Waste Generation Per Section

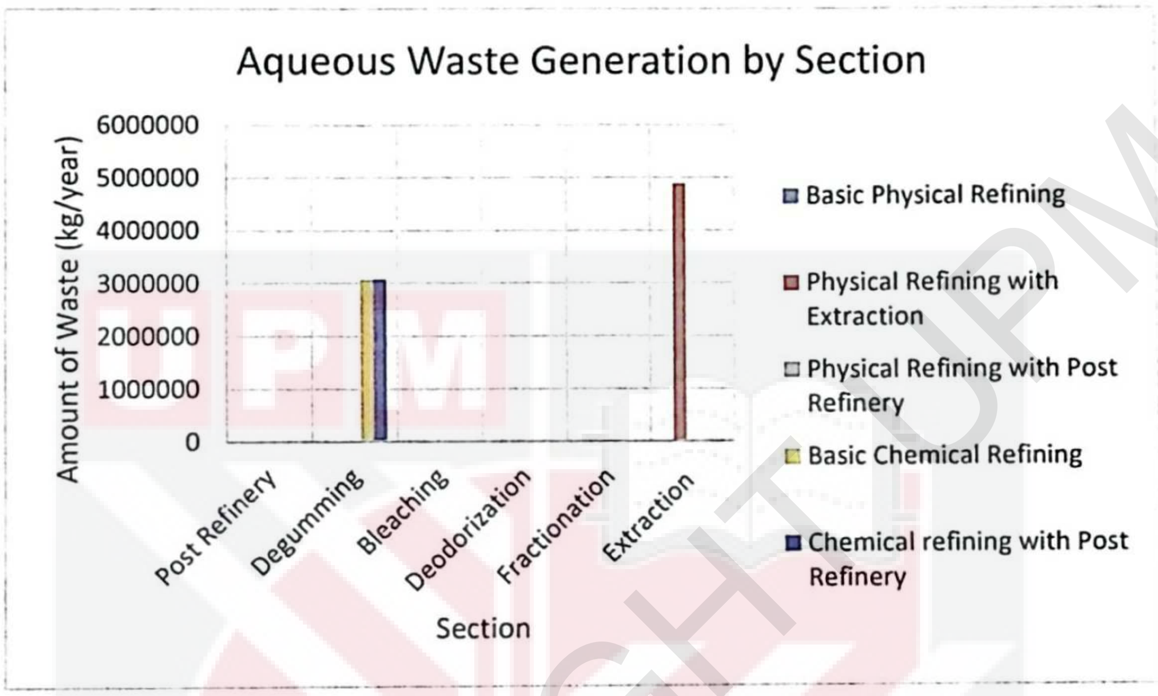

Figure 4.5: Aqueous waste generation by section

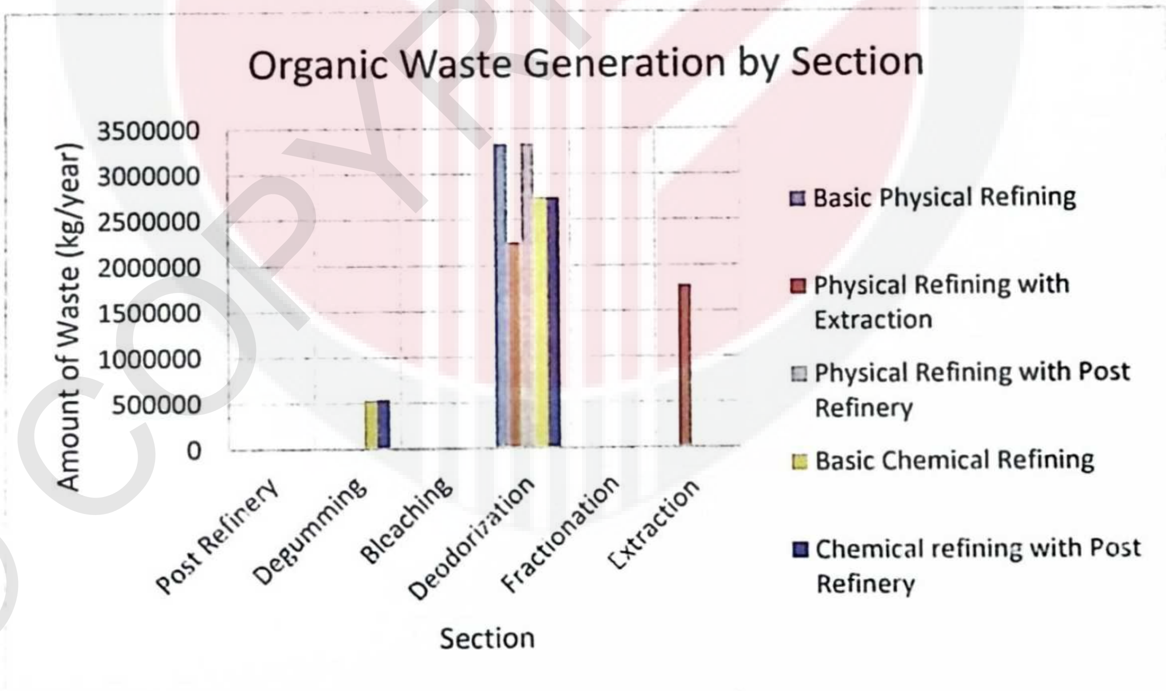

Figure 4.6: Organic waste generation by section

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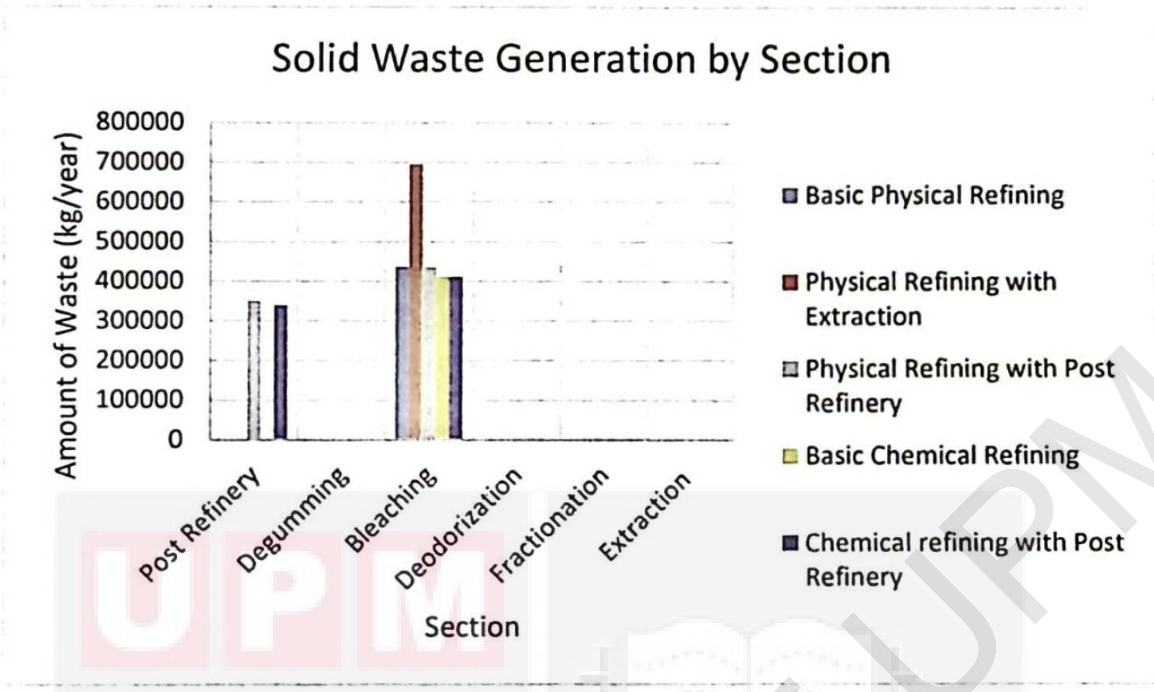

Figure 4.7: Solid waste generation by section

Figure 4.5 shows the aqueous waste generation per section by five different refining methods. Based on Figure 4.5, aqueous waste generation is contributed by degumming section and extraction section. Both basic chemical refining and chemical refining with post refinery showed relatively equal aqueous waste generation where the waste is from degumming section. During degumming, DAG, FFA and impurities were removed. Meanwhile, waste is produced for physical refining with extraction at extraction section. In this section, a few components were removed including DAG, phosphoric acid, impurities, and phospholipid.

Figure 4.6 shows the organic waste generation per section by five different refining methods. Based on Figure 4.6, organic waste generated is contributed by deodorization section, degumming section, and extraction section. The higher waste removed is during deodorization section and all the methods produces waste during this section. The components that are removed were average of 30000-700000 kg/year of FFA, water and degummed phospholipids. The huge amount of water is removed by all the refining methods which average from 2-4 million kg/year. Two methods produced waste during degumming section which are basic chemical refining and chemical refining with post refinery. There were slightly difference in the amount of waste produced by these two methods. The components removed as organic waste were DAG, degummed phospholipid, FFA, impurities and phosphoric acid.

Figure 4.7 shows the solid waste generation per section by five different refining methods. Based on Figure 4.7, the highest solid waste generation is from bleaching section followed by post refinery section. In bleaching section, the bleaching earth, DAG, and some impurities were removed for all the methods. For post refinery section, physical refining produced slightly higher waste than chemical refining where the solid waste for both refining were 350899 kg/year and 339471 kg/year respectively. Activated carbon removed by physical refining is slightly higher than chemical refining.

At the time of the invention of chemical refining, environmental contamination, and the use of chemicals in the food processing sector were likely not major concerns; hence, the chemical refining stages appear to have been perfectly acceptable. Meanwhile, as consumers become more worried about the health hazards connected with consuming oil that has been chemically refined and as regulatory bodies become more stringent regarding environmental pollution, physical refining appears to be the superior alternative for food processing.

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4.4 Equipment

Table 4.4: Equipment cost

Equipment	Material of Constr.	Unit	Basic Physical (MYR/unit)	Unit	Physical Extraction (MYR/unit)	Unit	Physical Post Refinery (MYR/unit)	Unit	Basic Chemical (MYR/unit)	Unit	Chemical Post Refinery (MYR/unit)
Storage tank	Stainless steel	1	19791.00	1	19791.00	1	19791.00	1	19791.00	1	19791.00
Mixer	Stainless steel	1	21990.00	1	21990.00	1	21990.00	1	21990.00	1	21990.00
Stirred Reactor	Stainless steel	2	129741.00	2	129741.00	3	129741.00	2	129741.00	3	129741.00
Microfilter	SS304	2	43980.00	2	43980.00	4	43980.00	2	43980.00	4	43980.00
Holding tank	SS304	2	87960.00	2	87960.00	2	87960.00	2	87960.00	2	87960.00
Heat exchanger	SS304	5	4037.00	7	4037.00	4	4037.00	5	4037.00	3	4037.00
Deodorizer	Stainless steel	1	105552.00	1	105552.00	1	105552.00	1	105552.00	1	105552.00
Hopper	Carbon Steel	2	10000.00	2	10000.00	2	10000.00	2	10000.00	2	10000.00
Vacuum pump	SS316	1	66250	1	66250	1	66250	1	66250	1	66250
Centrifugal pump	Iron	2	39901.64	2	39901.64	2	39901.64	2	39901.64	2	39901.64
Crystallizer	SS304	2	879600.00	2	879600.00	2	879600.00	2	879600.00	2	879600.00
P&F filtration	SS316	2	118719.00	2	118719.00	2	118719.00	2	118719.00	2	118719.00
Extractor	SS304	-	-	1	404000.00	-	-	-	-	-	-
Distillation column	Stainless steel	-	-	1	19791.00	-	-	-	-	-	-
Centrifugal	SS304	-	--	1	96316.20	-	-	-	-	-	-

extractor											
Centrifuge	Stainless steel	-	-	1	87080.40		-	2	87080.40	2	87080.40
Neutralizer	Carbon Steel	-	-	-	-		-	1	170000.00	1	170000.00
Total		6,091,453		6,804,166		7,059,416		7,094,000		7,733,710	

Table 4.5 shows the equipment cost for all five methods of palm oil refining. The capacity size of the equipment used for five different methods is the same so that the price is the same for same equipment that involved. Based on the table above, chemical refining with post refinery having the highest equipment cost which is MYR 7,733,710. More equipment used in chemical refining with post refinery is one of the sources contribute to it high equipment cost. Neutralizer cost, for example has the higher cost and it contribute to high cost for this method.

The equipment such as extractor, distillation column, centrifugal extractor and centrifuge is only used for physical refining with extraction during extraction process. Since the extractor cost is computed by Superpro Designer. So, the cost is quite higher than market price. The equipment used for physical refining with extraction is more than physical refining with post refinery, however, the cost of physical refining with post refinery much higher. This is because used is bigger in size compared to physical refining with extraction.

Among the five methods of refining, basic physical refining has the lowest cost of equipment because it only involved the simple process with low number of equipment.

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4.5 3-MCPD and GE Removal

Table 4.5: Final composition of 3-MCPD and GE

Types of Refining	3-MCPD (ppm)	Glycidyl Ester (ppm)
Basic Physical Refining	2	2
Physical Refining with Extraction	0	2
Physical Refining with Post Refinery	2	0
Basic Chemical Refining	1	2
Chemical Refining with Post Refinery	1	0

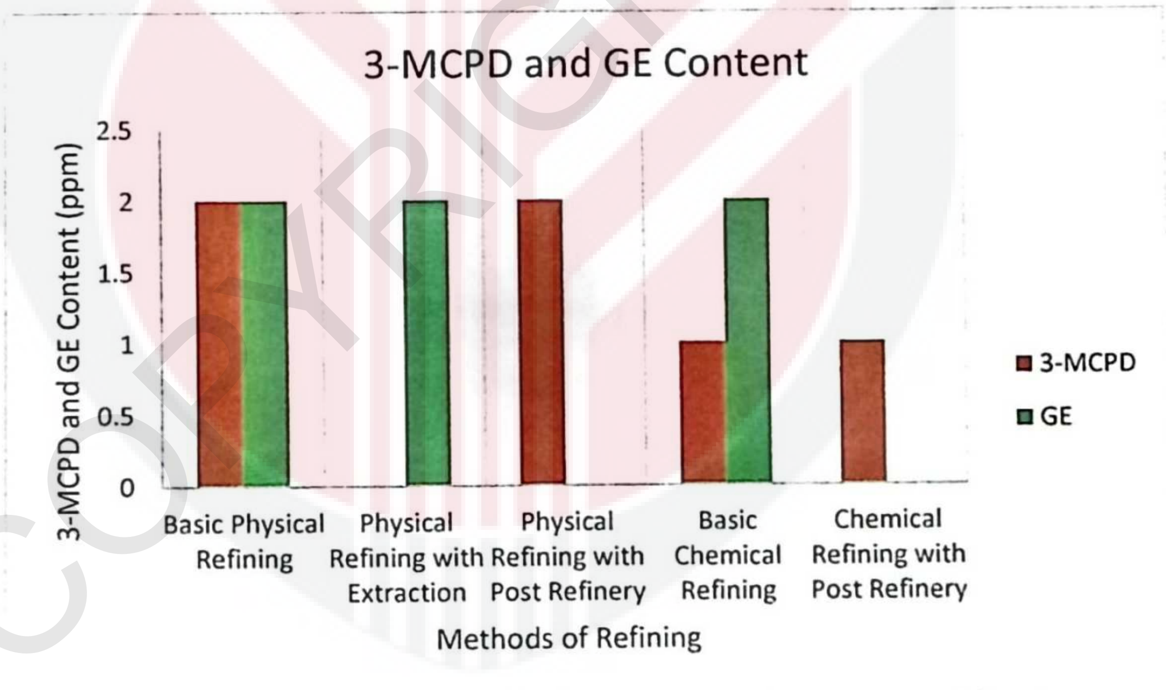

Figure 4.8: 3-MCPD and GE content

It is presumed that glycerol, MAGs, DAGs, and phospholipids are precursors on the route to the creation of 3-MCPD esters and similar chemicals, although the mechanism for their formation is poorly known. Specifically, the precursor for 3-MCPD is chloride

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while the precursor for GE is DAG. The formation of 3-MCPD is depends on the temperature and lipid, glycerol, salt, and water (Velisek et. al., 2003). The presence of 3-MCPD and GE in palm oil is from deodorization process. The formation of 3-MCPD esters and other processing byproducts occurs when the oil is subjected to high temperatures during the deodorization step of the refining process. Self-evidently the precursor of 3-MCPD esters is chloride. It was reasonable to have anticipated that the chloride concentration might be a limiting factor for the level of 3-MCPD esters produced given the low quantities of inorganic chlorides that exist in oils. It is likely that other chlorinated substances are involved in the synthesis of 3-MCPD esters as inorganic chlorides do not decrease during the deodorization process.

4.5.1 Basic Physical Refining

After deodorization process at 200°C, 3-MCPD and GE in 4791.8501 kg/h of refined palm oil was formed at 23 ppm and 27 ppm, respectively. The discovery of glycidyl esters may present an opportunity for the technology to minimize the total amount of esters. From a toxicological standpoint, glycidyl ester is categorized as possibly carcinogenic to humans, but due to the epoxide binding, it should not be very stable in acid solutions. Since most 3-MCPD esters and similar chemicals arising from deodorization at higher temperatures are glycidyl esters, this strategy has a good chance of reducing the total amount of esters. However, after first filtration process of palm olein, 3-MCPD and GE contents in palm olein is increase to 28 ppm and 32 ppm, respectively. Then, it undergoes second filtration and produce palm double olein as by-products. The final composition obtained in palm mid fraction were 2 ppm for both 3-MCPD and GE.

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4.5.2 Physical Refining with Extraction

The composition of 3-MCPD and GE after deodorization process were 0 ppm and 3 ppm, respectively. After the second filtration process, the composition of 3-MCPD is the same at 0 ppm where it is possible content in palm oil meanwhile the composition of GE is decrease to 2 ppm. However, the GE content is over the needed GE in palm oil which is only 1 ppm.

4.5.3 Physical Refining with Post Refinery

The composition of 3-MCPD and GE after deodorization process were 23 ppm and 27 ppm, respectively. Then, refined palm oil will undergo post refinery section to reduce GE by physical adsorption. In post refinery section, activated carbon was used as adsorbent. Utilizing the fact that 3-MCPD esters and GE have a different polarity than the oil, physical adsorption is intended to remove 3-MCPD and GE using activated carbon adsorbents without disrupting the molecular structure of the contaminants. Activated carbon is one of the adsorbents that are possible to reduce 3-MCPD and GE. Then, after filtration process in post refinery section, there is no difference in 3-MCPD composition, however, GE composition is decreased to 1 ppm. 3-MCPD and GE continue reducing after fractionation section where the final composition obtained were 2 ppm and 0 ppm, respectively. Thus, the composition is achieved the objective of below than 2.4 pp of 3-MCPD and 1 ppm of GE.

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4.5.4 Basic Chemical Refining

The composition of 3-MCPD and GE after deodorization process were 13 ppm and 22 ppm, respectively. During deodorization, free fatty acids are expelled from the upper area of the deodorizer as refining waste to obtain odorless oil. The deodorized oil is next cooled and filtered to produce refined palm oil. After filtration process in fractionation section, palm olein was produced with 16 ppm of 3-MCPD and 27 ppm of GE. Then, palm olein further second filtration and 3-MCPD was decreased to 1 ppm while GE was reduced to 2 ppm.

4.5.5 Chemical Refining with Post Refinery

The composition of 3-MCPD and GE after deodorization process were 13 ppm and 22 ppm, respectively. Then, refined palm oil will undergo post refinery section to reduce GE by physical adsorption. In post refinery section, activated carbon was used as adsorbent. Utilizing the fact that 3-MCPD esters and GE have a different polarity than the oil, physical adsorption is intended to remove 3-MCPD and GE using activated carbon adsorbents without disrupting the molecular structure of the contaminants. Activated carbon is one of the adsorbents that are possible to reduce 3-MCPD and GE. Then, after filtration process in post refinery section, there is no difference in 3-MCPD composition, however, GE composition is decreased to 0 ppm. 3-MCPD and GE continue reducing after fractionation section where the final composition obtained were 1 ppm and 0 ppm, respectively. Thus, the composition is achieved the objective of below than 2.4 pp of 3-MCPD and 1 ppm of GE.

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Palm oil is a fundamental edible vegetable oil that is utilized in nearly all food processing businesses. The oil palm is used to extract palm oil. About 80% of oil palm fractions are used for food purposes worldwide. Besides, to meet consumer acceptability, the crude palm oil must be purified. 3-MCPD and GE should be reduced to produced healthy oil that safe to user. 3- MCPD is a process contaminant that occurs when oil is stored at elevated temperatures for an extended period. It is a carcinogenic compound found in many vegetable oils. It is possible to lower 3-MCPD by modifying the refining process and retaining the quality of the raw materials utilized in the process. Five different methods of refining were successfully constructed using SPD simulator. The formation of 3-MCPD and GE is significantly influenced by precursors which were DAG and chloride, respectively. It also could be influenced by parameters such as temperature and pH. Some precursors should be avoided and removed to prevent their accumulation. By taking the consideration of the cost in reducing 3-MCPD and GE

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content, it shows that physical refining with post refinery is a better method in reducing both compositions compared to other methods.

5.2 Recommendation

Based on the results and discussion, these recommendations can be taken into considerations to upgrade future studies of refining methods in reducing 3-MCPD and GE. A further study can be conducted in developing a more simple and accurate process to reduce 3-MCPD and GE to ensure that the cost of production can be reduced.

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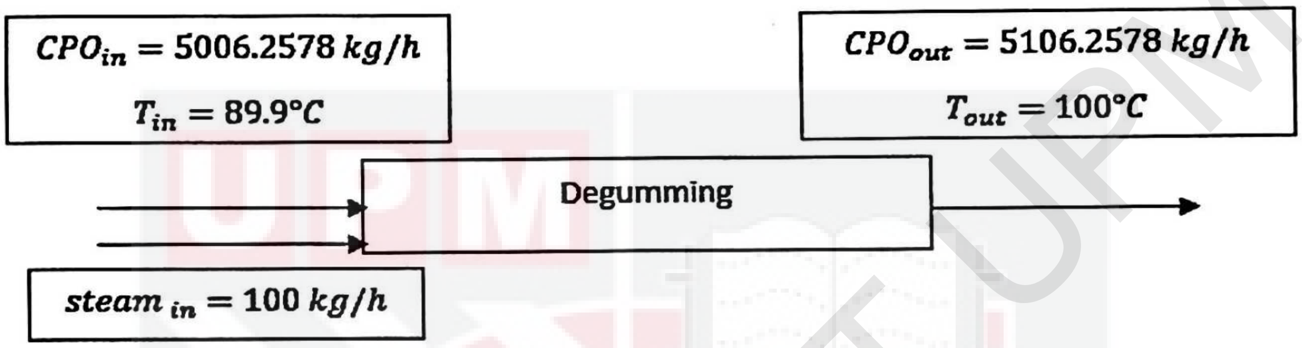
APPENDICES

MASS BALANCE

1. Degumming



$$X_{DAG} = 235.0000\ kg/h$$

$$X_{FFA} = 175.0000\ kg/h$$

$$X_{impurities} = 17.5000\ kg/h$$

$$X_{MAG} = 10.0000\ kg/h$$

$$X_{phispholipid} = 62.5000\ kg/h$$

$$X_{H3so4} = 5.006260\ kg/h$$

$$X_{TAG} = 4499.9600\ kg/h$$

$$X_{chloride} = 0.04000\ kg/h$$

$$X_{water} = 1.25156\ kg/h$$

$$X_{DAG} = 235.0000\ kg/h$$

$$X_{FFA} = 175.0000\ kg/h$$

$$X_{impurities} = 17.5000\ kg/h$$

$$X_{MAG} = 10.0000\ kg/h$$

$$X_{phospholipid} = 18.7500\ kg/h$$

$$X_{H3so4} = 5.006260\ kg/h$$

$$X_{TAG} = 4499.9600\ kg/h$$

$$X_{chloride} = 0.04000\ kg/h$$

$$X_{water} = 101.25156\ kg/h$$

$$X_{d.phos} = 43.7500\ kg/h$$

$$\sum m_{in} = \sum m_{out}$$

$$5006.2578 kg/h + 100\ kg/h = 5106.2578\ kg/h$$

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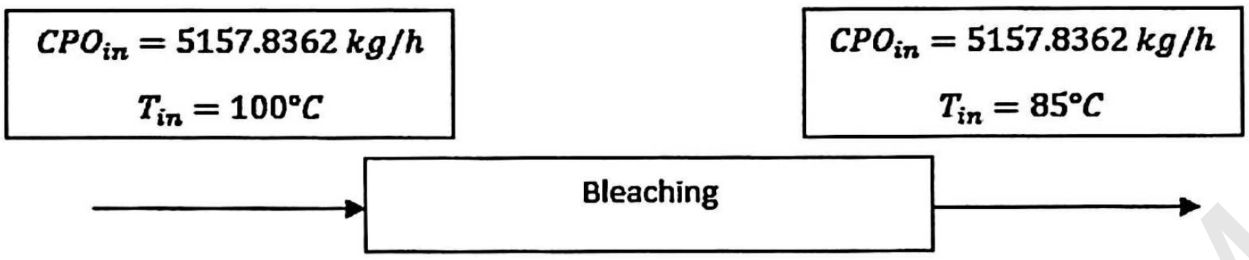
2. Bleaching



$X_{BE} = 51.57836\ kg/h$	$X_{BE} = 12.20336\ kg/h$
$X_{DAG} = 235.00000\ kg/h$	$X_{DAG} = 235.00000\ kg/h$
$X_{d.phos} = 43.75000\ kg/h$	$X_{d.phos} = 43.75000\ kg/h$
$X_{FFA} = 175.00000\ kg/h$	$X_{FFA} = 175.00000\ kg/h$
$X_{impurities} = 17.50000\ kg/h$	$X_{impurities} = 1.75000\ kg/h$
$X_{MAG} = 10.00000\ kg/h$	$X_{MAG} = 10.00000\ kg/h$
$X_{phospholipid} = 18.75000\ kg/h$	$X_{phospholipid} = 18.75000\ kg/h$
$X_{H3SO4} = 5.00626\ kg/h$	$X_{H3SO4} = 5.00626\ kg/h$
$X_{TAG} = 4499.96000\ kg/h$	$X_{TAG} = 4499.96000\ kg/h$
$X_{chloride} = 0.04000\ kg/h$	$X_{chloride} = 0.04000\ kg/h$
$X_{water} = 101.25156\ kg/h$	$X_{used\ bleaching} = 55.12500\ kg/h$
	$X_{water} = 101.25156\ kg/h$

$$\sum m_{in} = \sum m_{out}$$

$$5157.8362\ kg/h = 5157.8362\ kg/h$$

3. Deodorization

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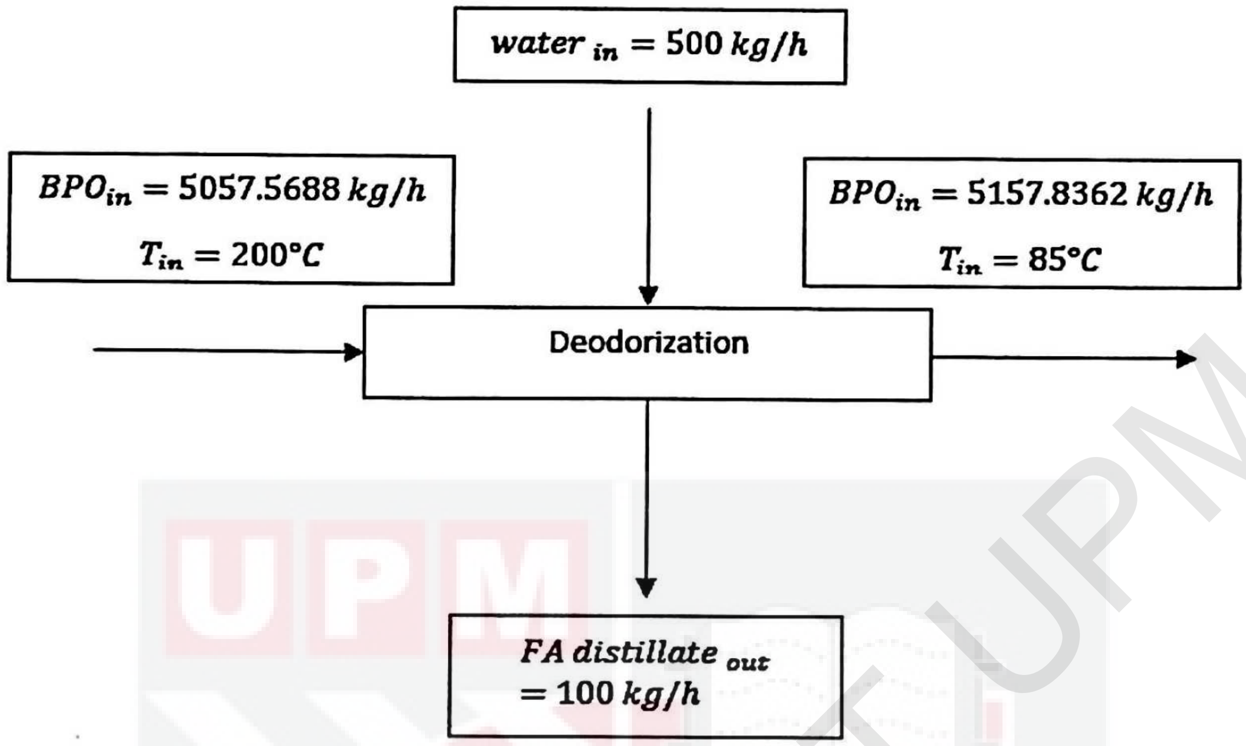

$X_{DAG} = 233.47939\ kg/h$

$X_{d.phos} = 43.46691\ kg/h$

$X_{FFA} = 173.86763\ kg/h$

$X_{impurities} = 1.73868\ kg/h$

$X_{MAG} = 9.93529\ kg/h$

$X_{phospholipid} = 18.62867\ kg/h$

$X_{H3SO4} = 4.97386\ kg/h$

$X_{TAG} = 4470.84222\ kg/h$

$X_{chloride} = 0.03974\ kg/h$

$X_{water} = 100.59640\ kg/h$

$X_{2-MCPD} = 0.10984\ kg/h$

$X_{3-MCPD} = 0.10984\ kg/h$

$X_{DAG} = 233.01243\ kg/h$

$X_{d.phos} = 43.46691\ kg/h$

$X_{FFA} = 8.70401\ kg/h$

$X_{GE} = 0.12738\ kg/h$

$X_{impurities} = 1.73868\ kg/h$

$X_{MAG} = 9.53567\ kg/h$

$X_{phospholipid} = 18.62867\ kg/h$

$X_{H2SO4} = 4.97386\ kg/h$

$X_{TAG} = 4470.84222\ kg/h$

$X_{water} = 0.60060\ kg/h$

$$\sum m_{in} = \sum m_{out}$$

$$5557.5688\ kg/h = 5557.5701\ kg/h$$

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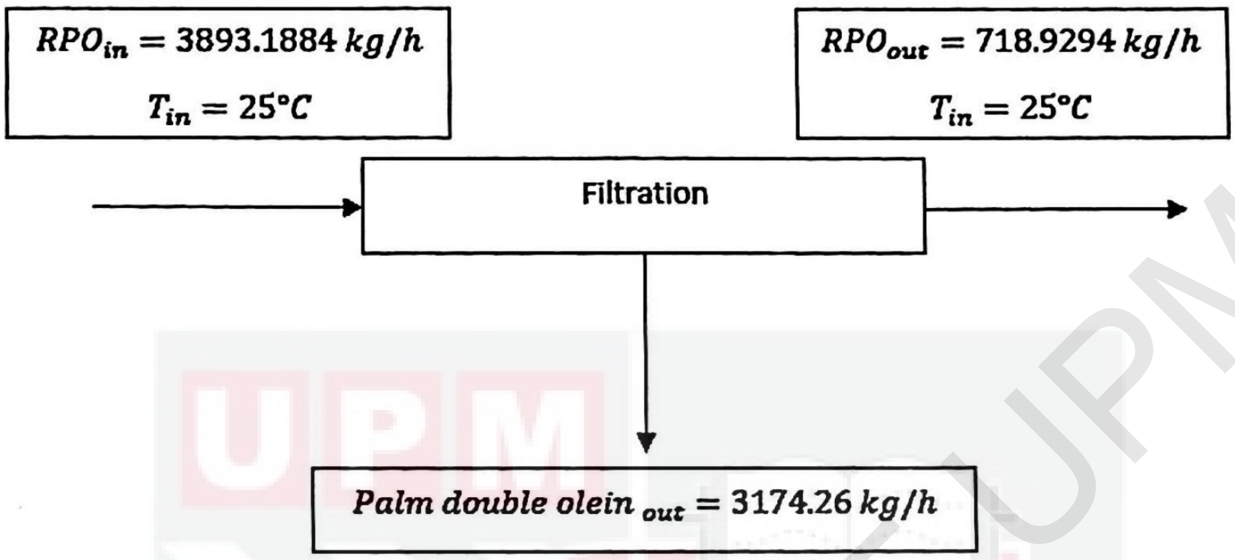
4. Filtration



$X_{2-MCPD} = 0.10830\ kg/h$ $\qquad$ $X_{2-MCPD} = 0.00123\ kg/h$

$X_{3-MCPD} = 0.10830\ kg/h$ $\qquad$ $X_{3-MCPD} = 0.00123\ kg/h$

$X_{DAG} = 229.75084\ kg/h$ $\qquad$ $X_{DAG} = 2.60927\ kg/h$

$X_{d.phos} = 42.85848\ kg/h$ $\qquad$ $X_{d.phos} = 0.48674\ kg/h$

$X_{FFA} = 8.58217\ kg/h$ $\qquad$ $X_{FFA} = 0.09747\ kg/h$

$X_{GE} = 0.12560\ kg/h$ $\qquad$ $X_{GE} = 0.00143\ kg/h$

$X_{impurities} = 1.71434\ kg/h$ $\qquad$ $X_{impurities} = 0.01947\ kg/h$

$X_{MAG} = 9.40220\ kg/h$ $\qquad$ $X_{MAG} = 0.10678\ kg/h$

$X_{phospholipid} = 18.36792\ kg/h$ $\qquad$ $X_{phospholipid} = 0.20860\ kg/h$

$X_{H2SO4} = 4.90424\ kg/h$ $\qquad$ $X_{H2SO4} = 0.05570\ kg/h$

$X_{TAG} = 3576.67377\ kg/h$ $\qquad$ $X_{TAG} = 715.33475\ kg/h$

$X_{water} = 0.59219\ kg/h$ $\qquad$ $X_{water} = 0.00673\ kg/h$

$$\sum m_{in} = \sum m_{out}$$

$$3893.1884\ kg/h = 3893.1894\ kg/h$$

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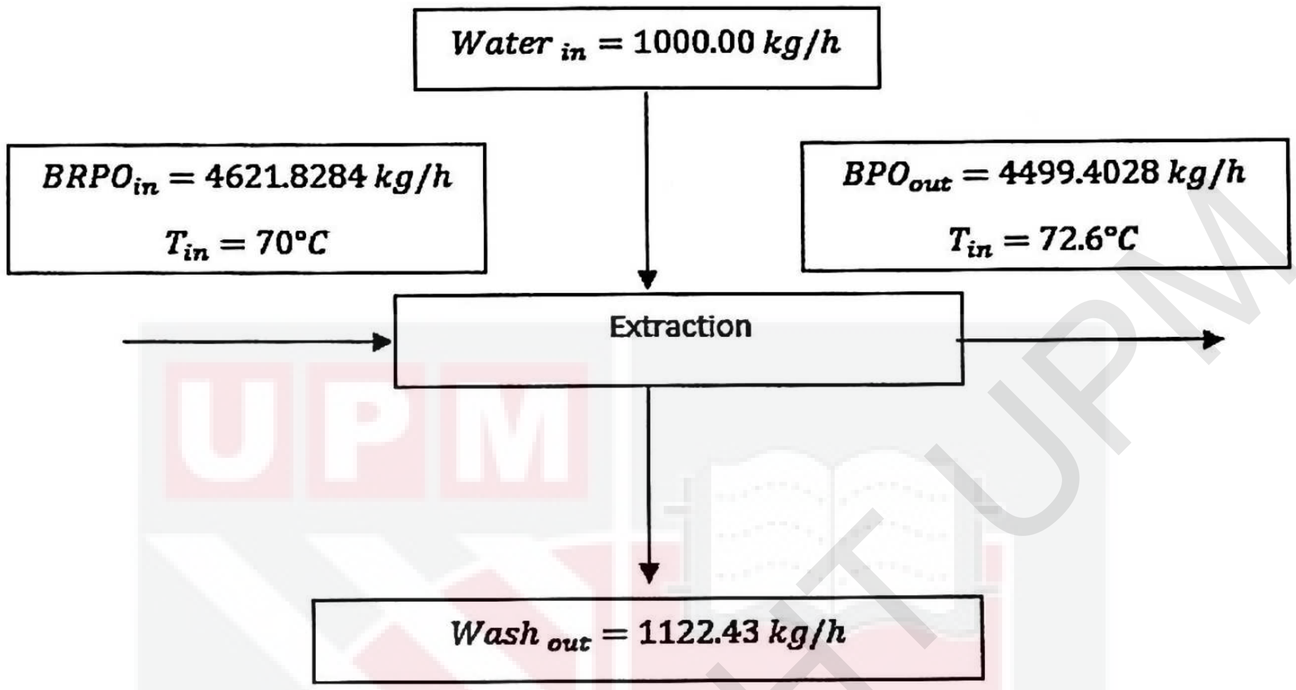
5. Extraction



$X_{2-DMAE} = 13.11470\ kg/h$

$X_{DAG} = 33.41035\ kg/h$

$X_{d.phod} = 0.38027\ kg/h$

$X_{FFA} = 17.33523\ kg/h$

$X_{impurities} = 0.00695\ kg/h$

$X_{MAG} = 1.19186\ kg/h$

$X_{phospholipid} = 2.03797\ kg/h$

$X_{H2SO4} = 0.54414\ kg/h$

$X_{TAG} = 4453.50437\ kg/h$

$X_{chloride} = 0.00435\ kg/h$

$X_{water} = 100.29825\ kg/h$

$X_{2-DMAE} = 0.00633\ kg/h$

$X_{DAG} = 26.19208\ kg/h$

$X_{d.phod} = 0.38027\ kg/h$

$X_{FFA} = 17.33523\ kg/h$

$X_{impurities} = 0.00001\ kg/h$

$X_{MAG} = 0.93436\ kg/h$

$X_{phospholipid} = 0.07916\ kg/h$

$X_{H2SO4} = 0.02114\ kg/h$

$X_{TAG} = 4453.44771\ kg/h$

$X_{chloride} = 0.00017\ kg/h$

$X_{water} = 1.00629\ kg/h$

$$\sum m_{in} = \sum m_{out}$$

$$4621.8284\ kg/h = 4499.4028\ kg/h$$

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Economic Evaluation Report
for PHYSICAL_BASIC

July 23, 2022

1. EXECUTIVE SUMMARY (2022 prices)

Total Capital Investment	62,279,000 MYR
Capital Investment Charged to This Project	62,279,000 MYR
Operating Cost	134,504,000 MYR/yr
Main Revenue	38,154,000 MYR/yr
Other Revenues	123,811,606 MYR/yr
Total Revenues	161,965,000 MYR/yr
Cost Basis Annual Rate	3,127,343 kg MP/yr
Unit Production Cost	43.01 MYR/kg MP
Net Unit Production Cost	43.01 MYR/kg MP
Unit Production Revenue	51.79 MYR/kg MP
Gross Margin	16.96 %
Return On Investment	32.46 %
Payback Time	3.08 years
IRR (After Taxes)	26.48 %
NPV (at 7.0% Interest)	91,081,000 MYR

MP = Total Flow of Stream 'Palm mid fraction'

Appendix 1: Executive summary for basic physical refining

2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2022 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1/0/0	V-103	Receiver Tank Vessel Volume = 6.19 m3	20,000	20,000
1/0/0	R-101	Stirred Reactor Vessel Volume = 2.08 m3	130,000	130,000
1/0/0	R-102	Stirred Reactor Vessel Volume = 4.20 m3	130,000	130,000
1/0/0	MX-101	Mixer Rated Throughput = 5006.26 kg/h	22,000	22,000
1/0/0	HX-101	Heat Exchanger Heat Exchange Area = 1.27 m2	4,000	4,000
1/0/0	MX-102	Mixer Rated Throughput = 5157.84 kg/h	22,000	22,000
4/0/0	MF-101	Microfilter Membrane Area = 70.47 m2	44,000	176,000
4/0/0	MF-102	Microfilter Membrane Area = 70.35 m2	44,000	176,000
1/0/0	V-102	Vertical-On-Legs Tank Vessel Volume = 6.25 m3	88,000	88,000
1/0/0	GBX-101	Generic Box Rated Throughput = 5557.57 kg/h	106,000	106,000
1/0/0	HX-104	Heat Exchanger Heat Exchange Area = 2.20 m2	4,000	4,000
1/0/0	HX-106	Heat Exchanger Heat Exchange Area = 2.11 m2	4,000	4,000
1/0/0	HX-108	Heat Exchanger Heat Exchange Area = 1.41 m2	4,000	4,000
1/0/0	PM-101	Centrifugal Pump Pump Power = 0.23 kW	4,000	4,000
1/0/0	PM-102	Centrifugal Pump Pump Power = 0.21 kW	4,000	4,000
2/0/0	VP-101	Vacuum Pump Power = 274379.95 Watt	66,000	132,000
1/0/0	V-104	Vertical-On-Legs Tank Vessel Volume = 5.92 m3	88,000	88,000
1/0/0	HX-107	Heat Exchanger Heat Exchange Area = 0.36 m2	4,000	4,000
1/0/0	PFF-101	Plate & Frame Filter Filter Area = 21.64 m2	119,000	119,000
2/0/0	V-105	Blending Tank Vessel Volume = 71.05 m3	880,000	1,760,000
2/0/0	V-106	Blending Tank Vessel Volume = 57.72 m3	880,000	1,760,000
1/0/0	PFF-102	Plate & Frame Filter Filter Area = 17.64 m2	119,000	119,000

Appendix 2: Equipment for basic physical refining

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3. FIXED CAPITAL ESTIMATE SUMMARY (2022 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	6,001,000
2. Installation	2,900,000
3. Process Piping	4,142,000
4. Instrumentation	1,584,000
5. Insulation	487,000
6. Electrical	670,000
7. Buildings	1,096,000
8. Yard Improvement	609,000
9. Auxiliary Facilities	3,350,000
TPDC	20,930,000
3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	6,279,000
11. Construction	7,326,000
TPIC	13,606,000
3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	34,536,000
3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	2,072,000
13. Contingency	2,763,000
CFC = 12+13	4,835,000
3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	39,370,000

Appendix 3: Fixed capital for basic physical refining

4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	0.00	0	0	0.00
Equipment Operator	21.05	141,091	2,969,262	73.19
Safety Officer	25.90	7,920	205,112	5.08
Manager	40.46	3,960	160,210	3.95
Engineer	26.59	7,920	210,577	5.19
Quality Control Analyst	25.90	3,960	102,556	2.53
Maintenance Staff	17.89	7,920	141,720	3.49
Security Guard	15.87	7,920	125,690	3.10
Clerk	17.89	7,920	141,720	3.49
TOTAL		188,611	4,056,849	100.00

Appendix 4: Labor for basic physical refining

5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Bleaching earth	1,474.00	224	MT	330,715	0.28
CPO	5,500.00	21,750	MT	119,625,000	99.72
Phosphoric Acid	42.50	12	m3(STP)	490	0.00
Water	1.29	2,605	m3(STP)	3,361	0.00
TOTAL				119,959,566	100.00

NOTE: Bulk material consumption amount includes material used as:
- Raw Material
- Cleaning Agent
- Heat Transfer Agent (if utilities are [illegible] included in the operating cost)

Appendix 5: Material for basic physical refining

7. WASTE TREATMENT/DISPOSAL COST (2022 prices) - PROCESS SUMMARY

Waste Category	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Solid Waste				213,654	61.56
Spent bleaching clay	0.05	397,406	kg	19,870	5.73
Spent bleaching clay2	5.00	38,757	kg	193,784	55.86
Aqueous Liquid				0	0.00
Organic Liquid				133,235	38.41
FA distillate 2	0.04	3,330,878	kg	133,235	38.41
Emissions				0	0.00
TOTAL				346,890	100.00

Appendix 6: Waste for basic physical refining

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8. UTILITIES COST (2022 prices) - PROCESS SUMMARY

Utility	Unit Cost (MYR)	Annual Amount	Ref. Units	Annual Cost (MYR)	%
Std Power	0.41	3,601,075	kW-h	1,487,246	69.02
Steam	49.56	1,797	MT	89,048	4.13
Steam (High P)	82.60	2,131	MT	176,027	8.17
Cooling Water	0.21	356,015	MT	73,517	3.41
Chilled Water	1.65	199,130	MT	329,046	15.27
Air	0.00	3,289,513	MT	0	0.00
TOTAL				2,154,883	100.00

Appendix 7: Utilities for basic physical refining

9. ANNUAL OPERATING COST (2022 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	119,960,000	89.19
Labor-Dependent	4,057,000	3.02
Facility-Dependent	7,377,000	5.48
Laboratory/QC/QA	609,000	0.45
Consumables	0	0.00
Waste Treatment/Disposal	347,000	0.26
Utilities	2,155,000	1.60
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising/Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	134,504,000	100.00

Appendix 8: Annual operating for basic physical refining

Economic Evaluation Report
for PHYSICAL_EXTRACTION

July 23, 2022

1. EXECUTIVE SUMMARY (2022 prices)

Total Capital Investment	65,794,000 MYR
Capital Investment Charged to This Project	65,794,000 MYR
Operating Cost	138,831,000 MYR/yr
Main Revenue	38,005,000 MYR/yr
Other Revenues	114,451,601 MYR/yr
Total Revenues	152,457,000 MYR/yr
Cost Basis Annual Rate	3,115,175 kg MP/yr
Unit Production Cost	44.57 MYR/kg MP
Net Unit Production Cost	44.57 MYR/kg MP
Unit Production Revenue	48.94 MYR/kg MP
Gross Margin	8.94 %
Return On Investment	18.51 %
Payback Time	5.40 years
IRR (After Taxes)	13.67 %
NPV (at 7.0% Interest)	29,602,000 MYR

MP = Total Flow of Stream 'Palm mid fraction'

Appendix 9: Executive summary for physical refining with extraction

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2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2022 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1/0/0	V-103	Receiver Tank Vessel Volume = 6.18 m3	20,000	20,000
1/0/0	R-101	Stirred Reactor Vessel Volume = 2.08 m3	130,000	130,000
1/0/0	R-102	Stirred Reactor Vessel Volume = 4.20 m3	130,000	130,000
1/0/0	MX-101	Mixer Rated Throughput = 5006.26 kg/h	22,000	22,000
1/0/0	HX-101	Heat Exchanger Heat Exchange Area = 1.38 m2	4,000	4,000
1/0/0	MX-102	Mixer Rated Throughput = 5157.84 kg/h	22,000	22,000
4/0/0	MF-101	Microfilter Membrane Area = 69.87 m2	44,000	176,000
4/0/0	MF-102	Microfilter Membrane Area = 69.52 m2	44,000	176,000
1/0/0	DX-101	Differential Extractor Extractor Volume = 8.52 m3	404,000	404,000
1/0/0	HX-102	Heat Exchanger Heat Exchange Area = 0.04 m2	4,000	4,000
1/0/0	C-102	Distillation Column Column Volume = 2.34 m3	20,000	20,000
1/0/0	HX-103	Heat Exchanger Heat Exchange Area = 0.75 m2	4,000	4,000
1/0/0	CX-101	Centrifugal Extractor Rated Throughput = 1.03 m3/h	96,000	96,000
1/0/0	V-102	Vertical-On-Legs Tank Vessel Volume = 5.56 m3	88,000	88,000
1/0/0	GBX-101	Generic Box Rated Throughput = 4999.40 kg/h	106,000	106,000
1/0/0	HX-104	Heat Exchanger Heat Exchange Area = 2.46 m2	4,000	4,000
1/0/0	HX-106	Heat Exchanger Heat Exchange Area = 1.44 m2	4,000	4,000
1/0/0	HX-108	Heat Exchanger Heat Exchange Area = 1.29 m2	4,000	4,000
1/0/0	MX-103	Mixer Rated Throughput = 4000.00 kg/h	22,000	22,000
1/0/0	PM-101	Centrifugal Pump Pump Power = 0.23 kW	4,000	4,000
1/0/0	PM-102	Centrifugal Pump Pump Power = 0.20 kW	4,000	4,000
2/0/0	VP-101	Vacuum Pump Power = 228365.15 Watt	66,000	132,000
1/0/0	V-104	Vertical-On-Legs Tank Vessel Volume = 5.54 m3	88,000	88,000
1/0/0	HX-107	Heat Exchanger Heat Exchange Area = 0.33 m2	4,000	4,000
1/0/0	PFF-101	Plate & Frame Filter Filter Area = 19.96 m2	119,000	119,000
1/0/0	HP-101	Hopper Vessel Volume = 0.02 m3	10,000	10,000
2/0/0	V-105	Blending Tank Vessel Volume = 66.49 m3	880,000	1,760,000
2/0/0	V-106	Blending Tank Vessel Volume = 53.21 m3	880,000	1,760,000
1/0/0	PFF-102	Plate & Frame Filter Filter Area = 15.97 m2	119,000	119,000
1/0/0	HP-102	Hopper Vessel Volume = 0.02 m3	10,000	10,000
		Unlisted Equipment		1,361,000
			TOTAL	6,804,000

Appendix 10: Equipment for physical refining with extraction

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3. FIXED CAPITAL ESTIMATE SUMMARY (2022 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	6,804,000
2. Installation	3,239,000
3. Process Piping	2,523,000
4. Instrumentation	2,662,000
5. Insulation	226,000
6. Electrical	635,000
7. Buildings	2,946,000
8. Yard Improvement	999,000
9. Auxiliary Facilities	2,726,000
TPDC	22,860,000
3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	5,791,000
11. Construction	8,004,000
TPIC	13,795,000
3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	36,664,000
3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	1,857,000
13. Contingency	3,618,000
CFC = 12+13	5,475,000
3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	42,139,000

Appendix 11: Fixed capital for physical refining with extraction

4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	0.00	0	0	0.00
Equipment Operator	21.05	178,377	3,753,940	77.54
Safety Officer	25.90	7,920	205,112	4.24
Manager	40.46	3,960	160,210	3.31
Engineer	26.59	7,920	210,577	4.35
Quality Control Analyst	25.90	3,960	102,556	2.12
Maintenance Staff	17.89	7,920	141,720	2.93
Security Guard	15.87	7,920	125,690	2.60
Clerk	17.89	7,920	141,720	2.93
TOTAL		225,807	4,841,526	100.00

Appendix 12: Labor for physical refining with extraction

5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
2-DMAE	35.00	57,619	kg	2,016,681	1.65
Bleaching earth	1,474.00	224	MT	330,715	0.27
CPO	5,500.00	21,750	MT	119,625,000	98.07
Phosphoric Acid	42.50	12	m3(STP)	490	0.00
Water	1.29	7,025	m3(STP)	9,062	0.01
TOTAL				121,981,948	100.00

NOTE: Bulk material consumption amount includes material used as:
- Raw Material
- [illegible] Agent
- Heat Transfer Agent (if utilities are included in the operating cost)

Appendix 13: Material for physical refining with extraction

7. WASTE TREATMENT/DISPOSAL COST (2022 prices) - PROCESS SUMMARY

Waste Category	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Solid Waste				34,774	17.75
Spent bleaching clay	0.05	584,383	kg	29,219	14.91
Spent bleaching clay2	0.05	111,094	kg	5,555	2.83
Aqueous Liquid				0	0.00
Organic Liquid				161,169	82.25
FA distillate 1	0.04	1,780,205	kg	71,208	36.34
FA distillate 2	0.04	2,249,028	kg	89,961	45.91
Emissions				0	0.00
TOTAL				195,943	100.00

Appendix 14: Waste for physical refining with extraction

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8. UTILITIES COST (2022 prices) - PROCESS SUMMARY

Utility	Unit Cost (MYR)	Annual Amount	Ref. Units	Annual Cost (MYR)	%
Std Power	0.41	3,093,797	kW-h	1,260,216	40.43
Steam	49.56	19,453	MT	964,090	30.45
Steam (High P)	82.60	1,265	MT	104,510	3.30
Cooling Water	0.21	1,818,580	MT	375,537	11.86
Chilled Water	1.65	267,597	MT	442,070	13.96
Air	0.00	2,409,505	MT	0	0.00
TOTAL				3,166,423	100.00

Appendix 15: Utilities for physical refining with extraction

9. ANNUAL OPERATING COST (2022 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	121,962,000	87.88
Labor-Dependent	4,842,000	3.45
Facility-Dependent	7,919,000	5.70
Laboratory/QC/QA	726,000	0.52
Consumables	0	0.00
Waste Treatment/Disposal	196,000	0.14
Utilities	3,166,000	2.28
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising/Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	138,831,000	100.00

Appendix 16: Annual Operating for physical refining with extraction

Economic Evaluation Report
for PHYSICAL_POST_REFINERY July 23, 2022

1. EXECUTIVE SUMMARY (2022 prices)

Total Capital Investment	69,074,000 MYR
Capital Investment Charged to This Project	69,074,000 MYR
Operating Cost	139,049,000 MYR/yr
Main Revenue	37,694,000 MYR/yr
Other Revenues	122,965,845 MYR/yr
Total Revenues	160,660,000 MYR/yr
Cost Basis Annual Rate	3,106,076 kg MP/yr
Unit Production Cost	44.77 MYR/kg MP
Net Unit Production Cost	44.77 MYR/kg MP
Unit Production Revenue	51.79 MYR/kg MP
Gross Margin	13.56 %
Return On Investment	25.18 %
Payback Time	3.97 years
IRR (After Taxes)	19.92 %
NPV (at 7.0% Interest)	63,927,000 MYR

MP = Total Flow of Stream 'Palm mid fraction'

Appendix 17: Executive summary for physical refining with post refinery

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2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2022 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1 / 0 / 0	V-103	Receiver Tank Vessel Volume = 6.18 m3	20,000	20,000
1 / 0 / 0	R-101	Stirred Reactor Vessel Volume = 2.08 m3	136,000	135,000
1 / 0 / 0	R-102	Stirred Reactor Vessel Volume = 4.20 m3	136,000	135,000
1 / 0 / 0	MX-101	Mixer Rated Throughput = 5006.26 kg/h	23,000	23,000
1 / 0 / 0	HX-101	Heat Exchanger Heat Exchange Area = 1.38 m2	4,000	4,000
1 / 0 / 0	MX-102	Mixer Rated Throughput = 5157.84 kg/h	23,000	23,000
4 / 0 / 0	MF-101	Microfilter Membrane Area = 70.47 m2	46,000	184,000
4 / 0 / 0	MF-102	Microfilter Membrane Area = 70.35 m2	46,000	184,000
1 / 0 / 0	V-102	Vertical-On-Legs Tank Vessel Volume = 6.25 m3	91,000	91,000
1 / 0 / 0	GBX-101	Generic Box Rated Throughput = 5557.57 kg/h	110,000	110,000
1 / 0 / 0	HX-104	Heat Exchanger Heat Exchange Area = 2.20 m2	4,000	4,000
1 / 0 / 0	HX-106	Heat Exchanger Heat Exchange Area = 2.11 m2	4,000	4,000
1 / 0 / 0	HX-108	Heat Exchanger Heat Exchange Area = 1.41 m2	4,000	4,000
1 / 0 / 0	PM-101	Centrifugal Pump Pump Power = 0.23 kW	4,000	4,000
1 / 0 / 0	PM-102	Centrifugal Pump Pump Power = 0.21 kW	4,000	4,000
2 / 0 / 0	VP-101	Vacuum Pump Power = 274379.95 Watt	68,000	138,000
1 / 0 / 0	V-104	Vertical-On-Legs Tank Vessel Volume = 5.88 m3	91,000	91,000
1 / 0 / 0	HX-107	Heat Exchanger Heat Exchange Area = 0.36 m2	4,000	4,000
1 / 0 / 0	PFF-101	Plate & Frame Filter Filter Area = 21.50 m2	123,000	123,000
1 / 0 / 0	HP-101	Hopper Vessel Volume = 0.02 m3	10,000	10,000
2 / 0 / 0	V-105	Blending Tank Vessel Volume = 70.57 m3	915,000	1,830,000
2 / 0 / 0	V-106	Blending Tank Vessel Volume = 57.32 m3	915,000	1,830,000
1 / 0 / 0	PFF-102	Plate & Frame Filter Filter Area = 17.52 m2	123,000	123,000
1 / 0 / 0	HP-102	Hopper Vessel Volume = 0.02 m3	10,000	10,000
1 / 0 / 0	MX-103	Mixer Rated Throughput = 4839.77 kg/h	23,000	23,000
1 / 0 / 0	R-103	Stirred Reactor Vessel Volume = 3.96 m3	135,000	135,000
4 / 0 / 0	MF-103	Microfilter Membrane Area = 66.20 m2	46,000	184,000
4 / 0 / 0	MF-104	Microfilter Membrane Area = 66.16 m2	44,000	176,000
		Unlisted Equipment		1,401,000
			TOTAL	7,007,000

Appendix 18: Equipment for physical refining with post refinery

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3. FIXED CAPITAL ESTIMATE SUMMARY (2022 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	7,007,000
2. Installation	3,335,000
3. Process Piping	4,765,000
4. Instrumentation	1,835,000
5. Insulation	561,000
6. Electrical	771,000
7. Buildings	1,261,000
8. Yard Improvement	701,000
9. Auxiliary Facilities	3,854,000
TPDC	24,090,000
3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	7,227,000
11. Construction	8,431,000
TPIC	15,658,000
3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	39,748,000
3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	2,385,000
13. Contingency	3,180,000
CFC = 12+13	5,565,000
3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	45,313,000

Appendix 19: Fixed capital for physical refining with post refinery

4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	0.00	0	0	0.00
Equipment Operator	21.05	168,026	3,536,114	76.48
Safety Officer	25.90	7,920	205,112	4.44
Manager	40.46	3,960	160,210	3.46
Engineer	26.59	7,920	210,577	4.55
Quality Control Analyst	25.90	3,960	102,556	2.22
Maintenance Staff	17.89	7,920	141,720	3.07
Security Guard	15.87	7,920	125,690	2.72
Clerk	17.89	7,920	141,720	3.07
TOTAL		215,546	4,623,701	100.00

Appendix 20: Labor for physical refining with post refinery

5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
AC	13.00	208,445	kg	2,709,791	2.21
Bleaching earth	1,474.00	224	MT	330,715	0.27
CPO	5,500.00	21,750	MT	119,625,000	97.52
Phosphoric Acid	42.50	12	m3(STP)	490	0.00
Water	1.29	2,605	m3(STP)	3,361	0.00
TOTAL				122,669,358	100.00

NOTE: Bulk material consumption amount includes material used as:
- Raw Material
- Cleaning Agent
- Heat Transfer Agent (if utilities are included in the operating cost)

Appendix 21: Material for physical refining with post refinery

7. WASTE TREATMENT/DISPOSAL COST (2022 prices) - PROCESS SUMMARY

Waste Category	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Solid Waste				39,345	22.80
Spent bleaching clay	0.05	397,406	kg	19,870	11.51
Spent bleaching clay2	0.05	38,757	kg	1,938	1.12
Spent AC1	0.05	331,181	kg	16,559	9.59
Spent AC2	0.05	19,557	kg	978	0.57
Aqueous Liquid				0	0.00
Organic Liquid				133,235	77.20
FA distillate 2	0.04	3,330,878	kg	133,235	77.20
Emissions				0	0.00
TOTAL				172,580	100.00

Appendix 22: Material for physical refining with post refinery

8. UTILITIES COST (2022 prices) - PROCESS SUMMARY

Utility	Unit Cost (MYR)	Annual Amount	Ref. Units	Annual Cost (MYR)	%
Std Power	0.41	4,178,071	kW-h	1,725,543	71.91
Steam	49.56	1,943	MT	96,320	4.01
Steam (High P)	82.60	2,131	MT	176,027	7.34
Cooling Water	0.21	356,015	MT	73,517	3.06
Chilled Water	1.65	198,672	MT	328,206	13.68
Air	0.00	3,446,187	MT	0	0.00
TOTAL				2,399,613	100.00

Appendix 23: Utilities for physical refining with post refinery

9. ANNUAL OPERATING COST (2022 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	122,669,000	88.22
Labor-Dependent	4,624,000	3.33
Facility-Dependent	8,490,000	6.11
Laboratory/QC/QA	694,000	0.50
Consumables	0	0.00
Waste Treatment/Disposal	173,000	0.12
Utilities	2,400,000	1.73
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising/Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	139,049,000	100.00

Appendix 24: Annual operating for physical refining with post refinery

Economic Evaluation Report
for CHEMICAL_BASIC

July 23, 2022

1. EXECUTIVE SUMMARY (2022 prices)

Total Capital Investment	69,468,000 MYR
Capital Investment Charged to This Project	69,468,000 MYR
Operating Cost	139,501,000 MYR/yr
Main Revenue	37,782,000 MYR/yr
Other Revenues	119,277,806 MYR/yr
Total Revenues	157,060,000 MYR/yr
Cost Basis Annual Rate	3,096,836 kg MP/yr
Unit Production Cost	45.05 MYR/kg MP
Net Unit Production Cost	45.05 MYR/kg MP
Unit Production Revenue	50.72 MYR/kg MP
Gross Margin	11.18 %
Return On Investment	25.45 %
Payback Time	3.93 years
IRR (After Taxes)	40.26 %
NPV (at 7.0% Interest)	77,499,000 MYR

MP = Total Flow of Stream 'Palm mid fraction'

Appendix 25: Executive summary for basic chemical refining

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2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2022 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1/0/0	V-103	Receiver Tank Vessel Volume = 6.18 m3	20,000	20,000
1/0/0	R-101	Stirred Reactor Vessel Volume = 2.07 m3	130,000	130,000
1/0/0	R-102	Stirred Reactor Vessel Volume = 3.90 m3	130,000	130,000
1/0/0	MX-101	Mixer Rated Throughput = 5006.26 kg/h	22,000	22,000
1/0/0	HX-101	Heat Exchanger Heat Exchange Area = 1.09 m2	4,000	4,000
1/0/0	MX-102	Mixer Rated Throughput = 4861.38 kg/h	22,000	22,000
3/0/0	DS-101	Disk-Stack Centrifuge Throughput = 1.26 m3/h	87,000	261,000
1/0/0	V-101	Neutralizer Vessel Volume = 2.27 m3	170,000	170,000
3/0/0	DS-102	Disk-Stack Centrifuge Throughput = 2.03 m3/h	87,000	261,000
4/0/0	MF-101	Microfilter Membrane Area = 66.28 m2	44,000	176,000
4/0/0	MF-102	Microfilter Membrane Area = 66.17 m2	44,000	176,000
1/0/0	HX-105	Heat Exchanger Heat Exchange Area = 1.99 m2	4,000	4,000
1/0/0	V-102	Vertical-On-Legs Tank Vessel Volume = 5.88 m3	88,000	88,000
1/0/0	GBX-101	Generic Box Rated Throughput = 5267.03 kg/h	106,000	106,000
1/0/0	HX-104	Heat Exchanger Heat Exchange Area = 2.05 m2	4,000	4,000
1/0/0	HX-106	Heat Exchanger Heat Exchange Area = 2.06 m2	4,000	4,000
1/0/0	HX-108	Heat Exchanger Heat Exchange Area = 2.81 m2	4,000	4,000
1/0/0	PM-101	Centrifugal Pump Pump Power = 0.21 kW	4,000	4,000
1/0/0	PM-102	Centrifugal Pump Pump Power = 0.20 kW	40,000	40,000
2/0/0	VP-101	Vacuum Pump Power = 224944.21 Watt	66,000	132,000
1/0/0	V-104	Vertical-On-Legs Tank Vessel Volume = 5.73 m3	88,000	88,000
1/0/0	HX-107	Heat Exchanger Heat Exchange Area = 0.51 m2	4,000	4,000
1/0/0	PFF-101	Plate & Frame Filter Filter Area = 20.83 m2	119,000	119,000
1/0/0	HP-101	Hopper Vessel Volume = 0.02 m3	10,000	10,000
2/0/0	V-105	Blending Tank Vessel Volume = 68.76 m3	880,000	1,760,000
1/0/0	MX-104	Mixer Rated Throughput = 5519.87 kg/h	22,000	22,000
2/0/0	V-106	Blending Tank Vessel Volume = 55.56 m3	880,000	1,760,000
1/0/0	PFF-102	Plate & Frame Filter Filter Area = 15.87 m2	119,000	119,000
1/0/0	HP-102	Hopper Vessel Volume = 0.02 m3	10,000	10,000
		Unlisted Equipment		1,412,000
			TOTAL	7,058,000

Appendix 26: Equipment for basic chemical refining

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3. FIXED CAPITAL ESTIMATE SUMMARY (2022 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	7,039,000
2. Installation	3,360,000
3. Process Piping	4,200,000
4. Instrumentation	1,835,000
5. Insulation	565,000
6. Electrical	777,000
7. Buildings	1,271,000
8. Yard Improvement	706,000
9. Auxiliary Facilities	3,683,000
TPDC	24,256,000
3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	7,277,000
11. Construction	8,490,000
TPIC	15,767,000
3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	40,023,000
3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	2,401,000
13. Contingency	3,202,000
CFC = 12+13	5,603,000
3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	45,626,000

Appendix 27: Fixed capital for basic chemical refining

4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	0.00	0	0	0.00
Equipment Operator	21.05	165,942	3,492,241	76.25
Safety Officer	25.90	7,920	205,112	4.48
Manager	40.46	3,960	160,210	3.50
Engineer	26.59	7,920	210,577	4.60
Quality Control Analyst	25.90	3,960	102,556	2.24
Security Guard	15.87	7,920	125,690	2.74
Maintenance Staff	17.89	7,920	141,720	3.09
Clerk	17.89	7,920	141,720	3.09
TOTAL		213,462	4,579,827	100.00

Appendix 28: Labor for basic chemical refining

5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Bleaching earth	1,474.67	211	MT	311,843	0.26
CPO	5,500.00	21,750	MT	119,625,000	97.82
Phosphoric Acid	42.50	12	m3(STP)	430	0.00
Sodium Hydroxid	19.90	118,000	kg	2,349,998	1.92
Water	1.29	4,817	m3(STP)	6,214	0.01
TOTAL				122,293,551	100.00

NOTE: Bulk material consumption amount includes material used as:
- Raw Material
- Cleaning Agent
- Heat Transfer Agent (if utilities are included in the operating cost)

Appendix 29: Material for basic chemical refining

7. WASTE TREATMENT/DISPOSAL COST (2022 prices) - PROCESS SUMMARY

Waste Category	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Solid Waste				20,521	7.47
Spent bleaching day	0.05	373,946	kg	18,697	6.80
Spent bleaching day2	0.05	36,477	kg	1,824	0.66
Aqueous Liquid				123,037	44.76
Soap	0.04	3,075,925	kg	123,037	44.76
Organic Liquid				131,334	47.78
Phospholipid	0.04	539,118	kg	21,565	7.84
FA distillate 2	0.04	2,744,241	kg	109,770	39.93
Emissions				0	0.00
TOTAL				274,893	100.00

Appendix 30: Waste for basic chemical refining

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8. UTILITIES COST (2022 prices) - PROCESS SUMMARY

Utility	Unit Cost (MYR)	Annual Amount	Ref. Units	Annual Cost (MYR)	%
Std Power	0.41	5,037,417	kW-h	2,060,453	66.75
Steam	49.56	3,345	MT	165,965	5.33
Steam (High P)	82.60	2,138	MT	176,568	5.67
Cooling Water	0.21	359,455	MT	74,228	2.38
Chilled Water	1.65	375,063	MT	619,588	19.88
Air	0.00	2,227,495	MT	0	0.00
TOTAL				3,116,822	100.00

Appendix 31: Utilities for basic chemical refining

9. ANNUAL OPERATING COST (2022 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	122,294,000	87.66
Labor-Dependent	4,580,000	3.28
Facility-Dependent	8,549,000	6.13
Laboratory/QC/QA	687,000	0.49
Consumables	0	0.00
Waste Treatment/Disposal	275,000	0.20
Utilities	3,117,000	2.23
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising/Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	139,501,000	100.00

Appendix 32: Annual operating for basic chemical refining

Economic Evaluation Report
for CHEMICAL_POST_REFINERY

July 23, 2022

1. EXECUTIVE SUMMARY (2022 prices)

Total Capital Investment	74,520,000 MYR
Capital Investment Charged to This Project	74,520,000 MYR
Operating Cost	143,249,000 MYR/yr
Main Revenue	37,539,000 MYR/yr
Other Revenues	118,458,050 MYR/yr
Total Revenues	155,997,000 MYR/yr
Cost Basis Annual Rate	3,076,931 kg MP/yr
Unit Production Cost	46.56 MYR/kg MP
Net Unit Production Cost	46.56 MYR/kg MP
Unit Production Revenue	50.70 MYR/kg MP
Gross Margin	8.17 %
Return On Investment	16.64 %
Payback Time	6.01 years
IRR (After Taxes)	11.64 %
NPV (at 7.0% Interest)	22,702,000 MYR

MP = Total Flow of Stream 'Palm mid fraction'

Appendix 33: Executive summary for chemical refining with post refinery

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2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2022 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1/0/0	V-103	Receiver Tank Vessel Volume = 6.18 m3	20,000	20,000
1/0/0	R-101	Stirred Reactor Vessel Volume = 2.07 m3	130,000	130,000
1/0/0	R-102	Stirred Reactor Vessel Volume = 3.99 m3	130,000	130,000
1/0/0	MX-101	Mixer Rated Throughput = 5006.26 kg/h	22,000	22,000
1/0/0	HX-101	Heat Exchanger Heat Exchange Area = 1.38 m2	4,000	4,000
1/0/0	MX-102	Mixer Rated Throughput = 4861.67 kg/h	22,000	22,000
3/0/0	DS-101	Disk-Stack Centrifuge Throughput = 1.66 m3/h	87,000	261,000
1/0/0	V-101	Neutralizer Vessel Volume = 2.27 m3	170,000	170,000
3/0/0	DS-102	Disk-Stack Centrifuge Throughput = 2.03 m3/h	87,000	261,000
4/0/0	MF-101	Microfilter Membrane Area = 66.27 m2	44,000	176,000
4/0/0	MF-102	Microfilter Membrane Area = 66.16 m2	44,000	176,000
1/0/0	HX-105	Heat Exchanger Heat Exchange Area = 0.44 m2	4,000	4,000
1/0/0	V-102	Vertical-On-Legs Tank Vessel Volume = 5.83 m3	88,000	88,000
1/0/0	GBX-101	Generic Box Rated Throughput = 5267.16 kg/h	106,000	106,000
1/0/0	HX-104	Heat Exchanger Heat Exchange Area = 3.17 m2	4,000	4,000
1/0/0	HX-106	Heat Exchanger Heat Exchange Area = 1.63 m2	4,000	4,000
1/0/0	HX-108	Heat Exchanger Heat Exchange Area = 1.36 m2	4,000	4,000
1/0/0	PM-101	Centrifugal Pump Pump Power = 0.21 kW	40,000	40,000
1/0/0	PM-102	Centrifugal Pump Pump Power = 0.20 kW	40,000	40,000
2/0/0	VP-101	Vacuum Pump Power = 264963.85 Watt	66,000	132,000
1/0/0	V-104	Vertical-On-Legs Tank Vessel Volume = 5.69 m3	88,000	88,000
1/0/0	HX-107	Heat Exchanger Heat Exchange Area = 0.35 m2	4,000	4,000
1/0/0	PFF-101	Plate & Frame Filter Filter Area = 20.69 m2	119,000	119,000
1/0/0	HP-101	Hopper Vessel Volume = 0.02 m3	10,000	10,000
2/0/0	V-105	Blending Tank Vessel Volume = 68.29 m3	880,000	1,760,000
1/0/0	MX-104	Mixer Rated Throughput = 5520.19 kg/h	22,000	22,000
2/0/0	V-106	Blending Tank Vessel Volume = 55.18 m3	880,000	1,760,000
1/0/0	PFF-102	Plate & Frame Filter Filter Area = 16.76 m2	119,000	119,000
1/0/0	HP-102	Hopper Vessel Volume = 0.02 m3	10,000	10,000
1/0/0	MX-103	Mixer Rated Throughput = 4682.62 kg/h	22,000	22,000
1/0/0	R-103	Stirred Reactor Vessel Volume = 3.83 m3	130,000	130,000
4/0/0	MF-103	Microfilter Membrane Area = 64.07 m2	44,000	176,000
4/0/0	MF-104	Microfilter Membrane Area = 64.02 m2	44,000	176,000
		Unlisted Equipment		1,547,000
			TOTAL	7,734,000

Appendix 34: Equipment for chemical refining with post refinery

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3. FIXED CAPITAL ESTIMATE SUMMARY (2022 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	7,734,000
2. Installation	3,631,000
3. Process Piping	5,259,000
4. Instrumentation	2,011,000
5. Insulation	619,000
6. Electrical	851,000
7. Buildings	1,392,000
8. Yard Improvement	773,000
9. Auxiliary Facilities	4,254,000
TPDC	26,573,000
3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	7,972,000
11. Construction	9,301,000
TPIC	17,272,000
3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	43,845,000
3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	2,631,000
13. Contingency	3,502,000
CFC = 12+13	6,138,000
3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	49,984,000

Appendix 35: Fixed capital for chemical refining with post refinery

4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	0.00	0	0	0.00
Equipment Operator	19.76	195,991	3,872,367	78.07
Safety Officer	25.90	7,920	205,112	4.14
Manager	40.46	3,960	160,210	3.63
Engineer	26.59	7,920	210,577	4.25
Quality Control Analyst	25.90	3,960	102,556	2.07
Maintenance Staff	17.89	7,920	141,720	2.86
Security Guard	15.87	7,920	125,690	2.53
Clerk	17.89	7,920	141,720	2.86
TOTAL		243,511	4,959,953	100.00

Appendix 36: Labor for chemical refining with post refinery

5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
AC	13.00	201,677	kg	2,621,805	2.10
Bleaching earth	1,474.00	211	MT	311,726	0.25
CPO	5,500.00	21,750	MT	119,625,000	95.76
Phosphoric Acid	42.50	12	m3(STP)	400	0.00
Sodium Hydroxide	19.90	118,092	kg	2,350,032	1.88
Water	1.29	4,817	m3(STP)	6,214	0.00
TOTAL				124,915,267	100.00

NOTE: Bulk material consumption amount includes material used as:
- Raw Material
- Cleaning Agent
- Heat Transfer Agent (if utilities are included in the operating cost)

Appendix 37: Material for chemical refining with post refinery

7. WASTE TREATMENT/DISPOSAL COST (2022 prices) - PROCESS SUMMARY

Waste Category	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
Solid Waste				37,521	12.86
Spent bleaching day 1	0.05	374,580	kg	18,729	6.42
Spent bleaching day 2	0.05	36,530	kg	1,827	0.63
Spent AC1	0.05	320,395	kg	16,020	5.49
Spent AC2	0.05	18,920	kg	946	0.32
Aqueous Liquid				123,042	42.16
Soap	0.04	3,076,042	kg	123,042	42.16
Organic Liquid				131,292	44.99
Phospholipid	0.04	537,873	kg	21,515	7.37
FA distillate 2	0.04	2,744,435	kg	109,778	37.61
Emissions				0	0.00
TOTAL				291,855	100.00

Appendix 38: Material for chemical refining with post refinery

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8. UTILITIES COST (2022 prices) - PROCESS SUMMARY

Utility	Unit Cost (MYR)	Annual Amount	Ref. Units	Annual Cost (MYR)	%
Std Power	0.41	5,596,660	kW-h	2,311,421	77.78
Steam	49.56	2,212	MT	109,614	3.69
Steam (High P)	82.60	1,538	MT	127,036	4.27
Cooling Water	0.21	359,480	MT	74,233	2.50
Chilled Water	1.65	211,622	MT	349,600	11.76
Air	0.00	2,052,625	MT	0	0.00
TOTAL				2,971,903	100.00

Appendix 39: Utilities for chemical refining with post refinery

9. ANNUAL OPERATING COST (2022 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	124,915,000	87.20
Labor-Dependent	4,960,000	3.46
Facility-Dependent	9,366,000	6.54
Laboratory/QC/QA	744,000	0.52
Consumables	0	0.00
Waste Treatment/Disposal	292,000	0.20
Utilities	2,972,000	2.07
Transportation	0	0.00
Miscellaneous	0	0.00
Advertising/Selling	0	0.00
Running Royalties	0	0.00
Failed Product Disposal	0	0.00
TOTAL	143,249,000	100.00

Appendix 40: Annual operating for chemical refining with post refinery

	Component	Flowrate (kg/h)	Mass Comp. (ppm)	Concentration (g/L)
1	2-MCPD monoeste	0.00123	2	0.001538
2	3-MCPD monoeste	0.00123	2	0.001538
3	DAG	2.60927	3629	3.262212
4	Degummed Phosph	0.48674	677	0.608544
5	FFA	0.09747	136	0.121858
6	Glycidyl esters	0.00143	2	0.001783
7	Impurities	0.01947	27	0.024342
8	MAG	0.10678	149	0.133501
9	Phospholipid	0.20860	290	0.260804
10	Phosphoric Acid	0.05570	77	0.069635
11	TAG	715.33475	995000	894.338406
12	Water	0.00673	9	0.008408

Appendix 41: Final composition of 3-MCPD and GE for basic physical refining

	Component	Flowrate (kg/h)	Mass Comp. (ppm)	Concentration (g/L)
1	2-MCPD monoeste	0.00006	0	0.000072
2	3-MCPD monoeste	0.00006	0	0.000072
3	DAG	3.23451	4517	4.059574
4	Degummed Phosph	0.04705	66	0.059057
5	FFA	0.10740	150	0.134796
6	Glycidyl esters	0.00177	2	0.002219
7	Impurities	0.00000	0	0.000002
8	MAG	0.11541	161	0.144845
9	Phospholipid	0.00980	14	0.012294
10	Phosphoric Acid	0.00262	4	0.003282
11	TAG	712.55163	995000	894.310242
12	Water	0.06199	87	0.077808

Appendix 42: Final composition of 3-MCPD and GE for physical refining with extraction

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	Component	Flowrate (kg/h)	Mass Comp. (ppm)	Concentration (g/L)
1	2-MCPD monoeste	0.00122	2	0.001538
2	3-MCPD monoeste	0.00122	2	0.001538
3	DAG	2.59254	3631	3.263481
4	Degummed Phosph	0.48362	677	0.608781
5	FFA	0.09684	136	0.121905
6	Glycidyl esters	0.00003	0	0.000036
7	Impurities	0.01934	27	0.024351
8	MAG	0.10610	149	0.133553
9	Phospholipid	0.20727	290	0.260906
10	Phosphoric Acid	0.05534	78	0.069662
11	TAG	710.47015	995000	894.338474
12	Water	0.00668	9	0.008412

Appendix 43: Final composition of 3-MCPD and GE for physical refining with post refinery

	Component	Flowrate (kg/h)	Mass Comp. (ppm)	Concentration (g/L)
1	2-MCPD monoeste	0.00105	1	0.001329
2	3-MCPD monoeste	0.00105	1	0.001329
3	DAG	3.21577	4517	4.059981
4	Degummed Phosph	0.00294	4	0.003715
5	FFA	0.00675	9	0.008516
6	Glycidyl esters	0.00176	2	0.002219
7	Impurities	0.02533	36	0.031978
8	MAG	0.14090	198	0.177893
9	Phospholipid	0.07077	99	0.089351
10	Soap	0.05458	77	0.068909
11	Sodium Phosphat	0.02810	39	0.035477
12	TAG	708.36793	995000	894.329559
13	Water	0.01063	15	0.013421

Appendix 44: Final composition of 3-MCPD and GE for basic chemical refining

	Component	Flowrate (kg/h)	Mass Comp. (ppm)	Concentration (g/L)
1	2-MCPD monoeste	0.00105	1	0.001340
2	3-MCPD monoeste	0.00105	1	0.001340
3	DAG	3.22088	4554	4.092806
4	Degummed Phosph	0.00015	0	0.000191
5	FFA	0.00676	10	0.008585
6	Glycidyl esters	0.00004	0	0.000045
7	Impurities	0.00129	2	0.001644
8	MAG	0.14113	200	0.179332
9	Phospholipid	0.07089	100	0.090080
10	Phosphoric Acid	0.00000	0	0.000000
11	Soap	0.05467	77	0.069466
12	Sodium Phosphat	0.02815	40	0.035766
13	TAG	703.80368	995000	894.329820

Appendix 45: Final composition of 3-MCPD and GE for chemical refining with post refinery

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