



UNIVERSITI PUTRA MALAYSIA

***DEVELOPMENT OF SUSTAINABLE DESIGN OF COCOA BUTTER
EQUIVALENT (CBE) PRODUCTION FROM RBD OIL USING SUPERPRO
DESIGNER***

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**PROJECT REPORT SUBMITTED IN PARTIALLY FULFILLMENT OF THE
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ABSTRACT

Enzymatic acidolysis of refined palm mid fraction oil and a palmitic–stearic fatty acid mixture produced cocoa butter equivalent (CBE). This study used computer-aided process simulation and SuperPro Designer to develop and evaluate a sustainable design for producing CBE from RBD palm oil. Based on literatures, Block Flow Diagram (BFD) and unit operations for each procedures were developed. Then, input data of parameters of operation were used to develop the design of production of CBE from RBD palm oil in SuperPro Designer. The economic evaluation report was generated by SuperPro Designer was used as the source of evaluation for sustainable design. 1000kg/batch of RBD palm oil was used as the raw material for the production of CBE by using enzymatic interesterification method. The reaction was done between palm mid fraction and palmitic-stearic fatty acid mixture with immobilized lipases as catalyst of reaction in packed bed reactor at 60°C. 183,017 kg of CBE for 572 number of batch per year can be produce and take 7917.67 hours. The design of production of CBE from RBD palm oil used RM 20,243,000 as the capital investment and take 4.44 years payback time. While the CBE is the main revenue of this production, there also other revenue that generated by this design of production which is palm oil stearin and palm oil double olein. Therefore, based on this study it can be concluded that this design of production of CBE from RBD palm oil can be considered as the sustainable.

ABSTRAK

Asidolisis enzimatik diantara pecahan minyak sawit halus dan campuran asid lemak palmitik-stearik menghasilkan setara mentega koko (CBE). Kajian ini menggunakan proses simulasi SuperPro Designer untuk mengembangkan dan menilai reka bentuk mapan untuk menghasilkan setara mentega koko dari minyak sawit. Berdasarkan rujukan, rajah blok proses dan unit operasi untuk setiap prosedur dikembangkan. Kemudian, data input untuk setiap unit operasi digunakan bagi mengembangkan reka bentuk pengeluaran CBE dari minyak sawit di SuperPro Designer. Laporan penilaian ekonomi dihasilkan oleh SuperPro Designer dan digunakan sebagai sumber penilaian untuk reka bentuk mapan. 1000 kg minyak sawit digunakan sebagai bahan mentah untuk pengeluaran CBE dengan menggunakan kaedah pemanfaatan enzimatik. Tindak balas berlaku antara pecahan minyak sawit dan campuran asid lemak palmitik-stearik dengan imobalisasi lipase sebagai pemangkin tindak balas pada reaktor dasar padatan yang dibungkus pada suhu 60 darjah celsius. 183,017 kg CBE untuk 572 bilangan kumpulan setiap tahun dapat dihasilkan dan memakan masa 7917.67 jam. Reka bentuk pengeluaran CBE dari minyak sawit memerlukan RM 20,243,000 sebagai modal pelaburan awal dan mengambil masa 4.44 tahun untuk pembayaran balik. Walaupun CBE adalah pendapatan utama pengeluaran ini, ada juga pendapatan lain yang dihasilkan oleh reka bentuk pengeluaran ini iaitu stearin minyak sawit dan olein ganda minyak sawit. Oleh itu, kajian ini dapat disimpulkan bahawa reka bentuk pengeluaran CBE dari minyak sawit RBD ini dapat dianggap sebagai mapan.

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CHAPTER 1

INTRODUCTION

1.1 Background

Cocoa butter (CB) is pale yellow, edible fat that extracted from the cocoa bean. Cocoa butter is traditional fat used in production of chocolate. It has desirable characteristic which include glossiness and snap ability as well as sensory attributes such as mouth feel and flavor release. CB is a marvelous fat for chocolate as it being capable to melt in the mouth at body temperature while being solid and crystalline at 20°C(Aila et al., 2019).

Refined, bleached and deodorized (RBD) oil is the term used that represent how the crude palm oil was processed. RBD oil is odorless, blend, light yellow colour and semi-solid at room temperature. RBD oil is used as frying oil in food industries, and it also can be used to manufacture margarine, shortening and palm mid fraction.

SuperPro Designer is one of computer-aided process simulation (CAPS) that used for simulation work of processing. There also several software of computer-aided process simulation (CAPS) like Aspen. In this study, SuperPro Designer was used to simulate the production of CBE by adjusting the process condition for each unit operation and process

integration. From the simulation work by SuperPro Designer, the report of the process can be generated for the material and energy balance, throughput analysis, itemized cost, cash flow analysis, economic evaluation and environmental impact.

1.2 Problem Statement

CB is highly expensive when compared to all other natural vegetable fats and oils due to its unique composition and specific characteristics. On the other hand, the limitations of cacao plant cultivation (the world's major cocoa bean growing countries are Ivory Coast, Ghana, Indonesia, Cameroon, Nigeria, Brazil, Ecuador, Dominican Republic, and Malaysia), and the global total cocoa bean production has declined from 3,752 million tons in 2007/2008 to 3,613 million tons in 2009/2010 where contributed to the higher price of CB (Jahurul et al., 2013).

Cocoa butter equivalent (CBE) is modified to possess TAG composition similar to CB so it can be used as an alternative. CBE can also improve chocolate tolerance of milk fat, increase the stability of chocolate at high temperatures, and control chocolate blooming (Wainwright, 1999). Blending natural fat, fractionation, hydrogenation, and interesterification, chemically or enzymatically, are just a few of the methods used to produce CBE.

Many studies have established interesterification as a common method for obtaining CBE, either chemically or enzymatically. Chemical interesterification is the most widely used method in industry due to its low initial investment costs and ease of processing. However, this method has lower conformity for CBE production because the harsh condition process removes the product's fine flavor (Rousseau and Marangoni,

2002). On the other hand, enzymatic interesterification condition process is mild and easy to control. Since the main objective of this study was to develop sustainable design of production of CBE, enzymatic interesterification became the chosen option.

1.3 Objectives

The objectives of this research are to design cocoa butter equivalent (CBE) process plant with enzymatic reactor using SuperPro Designer and to evaluate the economic analysis of CBE process plant towards sustainable design.

1.4 Scope of Study

The scope of study is to design and develop the sustainable design of production of cocoa butter equivalent (CBE) from refined, bleached and deodorized (RBD) oil using SuperPro Designer. Through available literature and researches, the production of CBE by enzymatic interesterification of palm mid fraction, upstream processing section and downstream processing section will be developed. Process conditions for each unit and process integration also be develop and simulate by using SuperPro Designer. Through simulation by SuperPro Designer, the reports generated like material and energy balances, throughput analysis, itemized cost, cash flow analysis, economic evaluation and environmental impact will be evaluated to determine the design sustainability.

CHAPTER 2

LITERATURE REVIEW

2.1 Cocoa butter equivalent

Many researches have been carried out to produce cocoa butter alternative (CBA) to fulfill the function of CB. Cocoa butter equivalent (CBE) is one of the alternatives to replace the function of CB. Natural exotic trees like illipe (*Shorea* spp.), palm oil (*Elaeis guineensis*), shea (*Butyrospermum parkii*), kokum gurgi (*Garcinia indica*), and mango kernel (*Mangifera indica*) can be used to produce the CBE (Mohamed, 2013). As a result, a lot of research is done on CBE because they are the most similar to CB (Xu, 2000). In chocolate production, the additional of vegetable fats other than CB is up to 5% of the product weight that allowed by European legislation and must be provide in the label of chocolate (Ulberth, 2003).

There are two methods of interesterification for obtain CBE which are chemically or enzymatically. Chemical catalysis has a number of advantages over enzyme catalysis, including lower catalyst costs, lower catalyst concentrations, simpler industrial equipment, and faster reaction times. However, as global awareness of health and the environment grows, enzymatic catalysis is becoming more appealing because it produces

fewer or no hazardous and undesirable by-products, uses milder process conditions, and allows the enzymes to be reused (Lo & Akoh, 2012).

2.2 Thermal behavior of cocoa butter and cocoa butter equivalent

Table 2-1: Melting and crystallizing profile(Bahari & Akoh, 2018).

Sample		Onset (°C)	Completion (°C)	ΔH (J g ⁻¹)
Cocoa butter	Melting profile	30.9	38.6	134.3
	Crystallizing profile	15.5	6.3	-83.8
Cocoa butter equivalent	Melting profile	32.7	37.9	122.4
	Crystallizing profile	16.1	6.3	-78.6

From Table 2-1, the melting profile for CB and CBE are not has big different. The melting profile is important for the production of chocolate so, the melting CBE should be similar to CB, and it can be seen at the table above.

2.3 Triacylglycerols (TAG)

Cocoa butter (CB) has a sharp melting temperature around human body temperature which is 35°C – 37°C due to the unique triacylglycerol (TAG) composition. Three main TAG molecular species of CB which consists of three fatty acid that esterified with a glycerol back bone is 15-19% of 1,3-dipalmitoyl-2-oleoylglycerol (POP), 24-31% of 1,3-distearoyl-2-oleoylglycerol (SOS) and 36-41% of 1-palmitoyl-2-oleoyl-3-stearoylglycerol (POS) (P = palmitic, O = oleic, S = stearic) (Bahari & Akoh, 2018). Figure 2-1 illustrate the structure of TAG with fatty acid attached at the end.

Table 2-2: Major TAG in CB, CBE and PMF (Mohamed, 2013).

TAG	Cocoa butter	Cocoa butter equivalent	Palm-mid fraction
POP	18.14	18.69	55.58
SOS	31.63	30.74	1.33
POS	44.68	44.85	10.40
POO	2.26	2.39	29.78
SOO	3.29	3.31	2.92

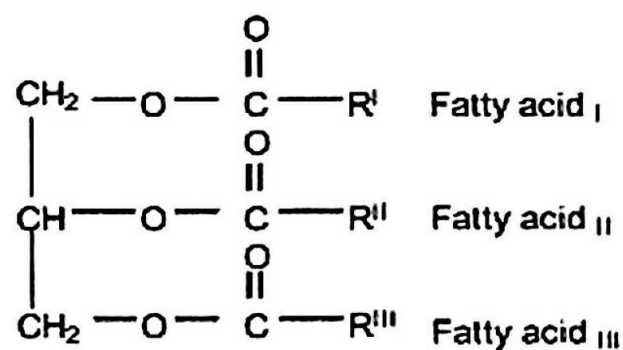


Figure 2-1: Structure of triacylglycerol

From the Table 2-2, there are changing of mass fraction of the major TAG from PMF to CBE. This changing of TAG was from enzymatic interesterification reaction which has similarity to CB. It can see there are only small different of TAG mass fraction between CB and CBE.

2.4 Enzymatic interesterification

There are three group of enzymatic interesterification which is acidolysis, ester-ester exchange and alcoholysis. Enzymatic interesterification is a safe and clean process which conducted at lower temperature using biocatalyst (Gibon, 2011). The most enzymatic interesterification technique used to produce CBE is acidolysis which reversible reaction between TAG of PMF and PSFAM as fatty acid with lipase as catalyst until the equilibrium is achieved. Enzymatic interesterification capable to rearrange the TAG structure of PMF with improved physical and chemical properties until reach similarity with CB.

Effective catalysis for carrying out acidolysis reaction is sn-1,3 specific lipase because its ability to perform regiospecific rearrangement on glycerol backbone of TAG (Kavadia et al., 2018). This clearly shown in Figure 2-2. In this figure, a sn-1,3 specific lipase is used, this means that only the fatty acids in the first and third positions of the TAG will be changed by lipase, in other words, the FFA (Y) will only be used on the first and third positions (Jiménez et al., 2010). Immobilized lipase is a low-cost biocatalyst that can be used in a wide range of industrial applications, including food, cosmetics, and pharmaceuticals (Facin et al., 2019).

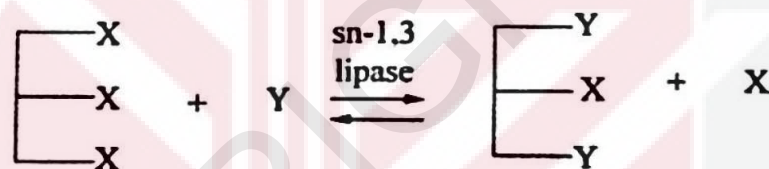
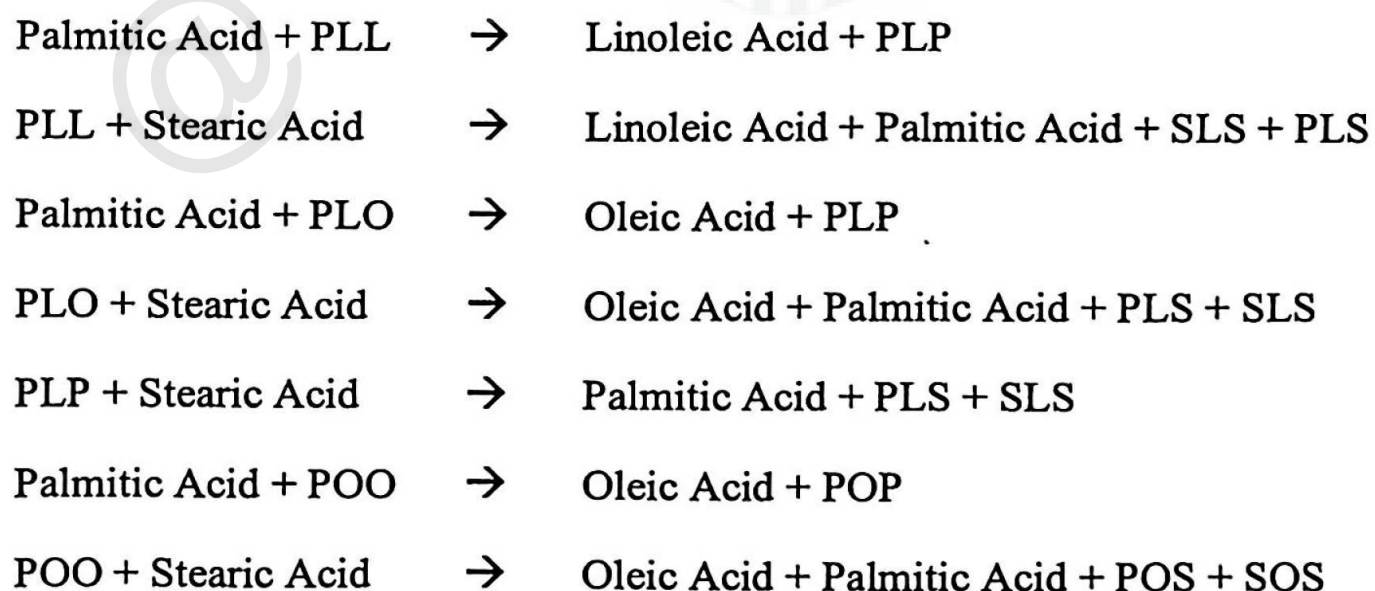


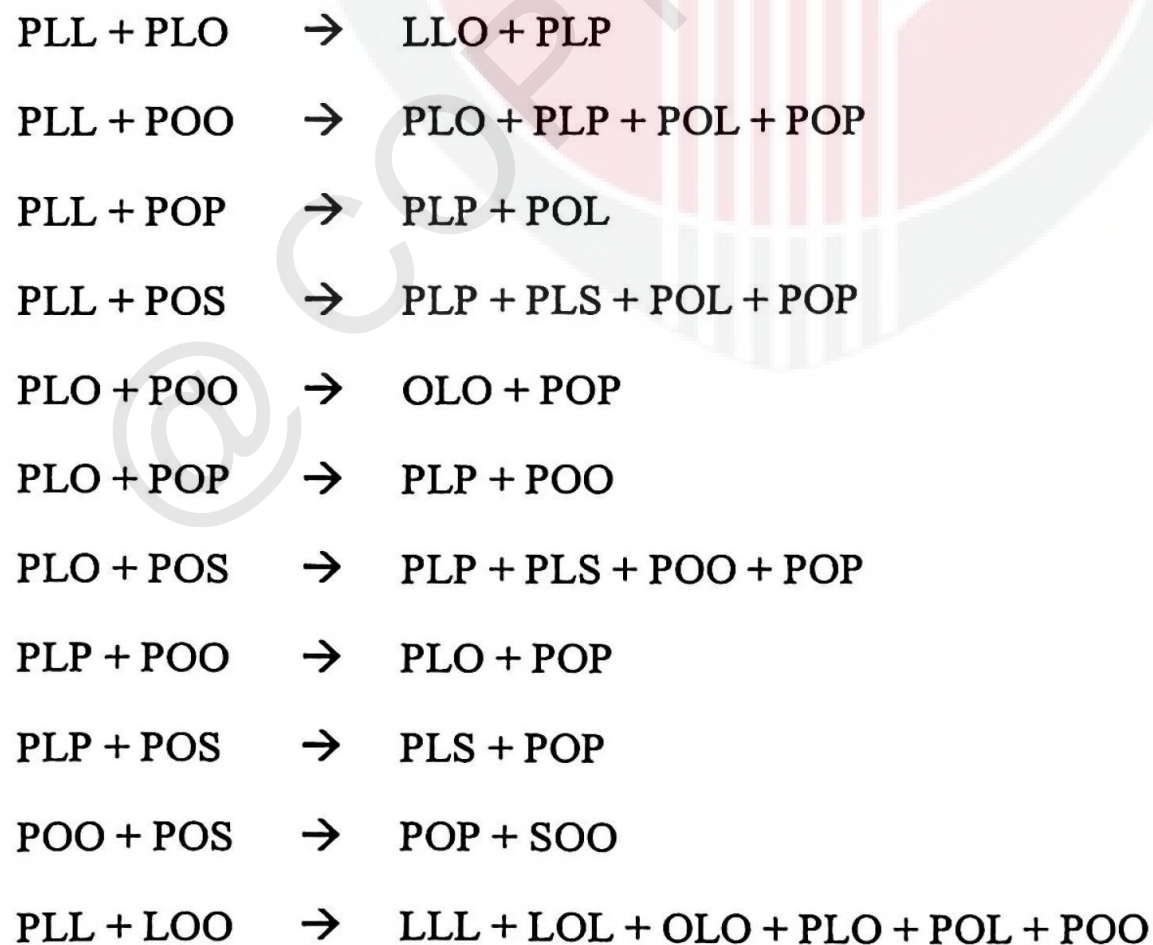
Figure 2-2: The enzymatic acidolysis between TAG (XXX) and FFA (Y) (Xu, 2003)

Acidolysis between TAG of PMF and FFA.





Interesterification between TAG molecules.



PLL + OOO → LLO + LOO + OLO + PLO + POL + POO
 PLL + PPP → PLP + PPL
 PLL + SOO → LOS + OLS + PLO + PLS + POL + POO
 PLL + SOS → LOS + PLS + POL + POS + SLL + SLS
 PLO + LOO → LLO + OLO + POL + POO
 PLO + OOO → OLO + POO
 PLO + PPP → PLP + PPO
 PLO + SOO → OLO + OLS + OOO + PLS + POO + POS
 PLO + SOS → OLS + PLS + POO + POS + SLS + SOO
 LOO + PLP → PLL + PLO + POL + POP
 PLP + OOO → OLO + PLO + POO + POP
 PLP + SOO → OLS + PLO + PLS + POO + POP + POS
 PLP + SOS → PLS + POP + POS + SLS
 LOO + POO → OOO + POL
 POO + PPP → POP + PPO
 POO + SOO → OOO + POS
 POO + SOS → POS + SOO
 LOO + POP → POL + POO
 OOO + POP → POO
 POP + SOO → POO + POS
 POP + SOS → POS
 LOO + POS → LOS + POL + POO + SOO
 OOO + POS → POO + SOO
 POS + PPP → POP + PPS
 POS + SOO → POO + SOS

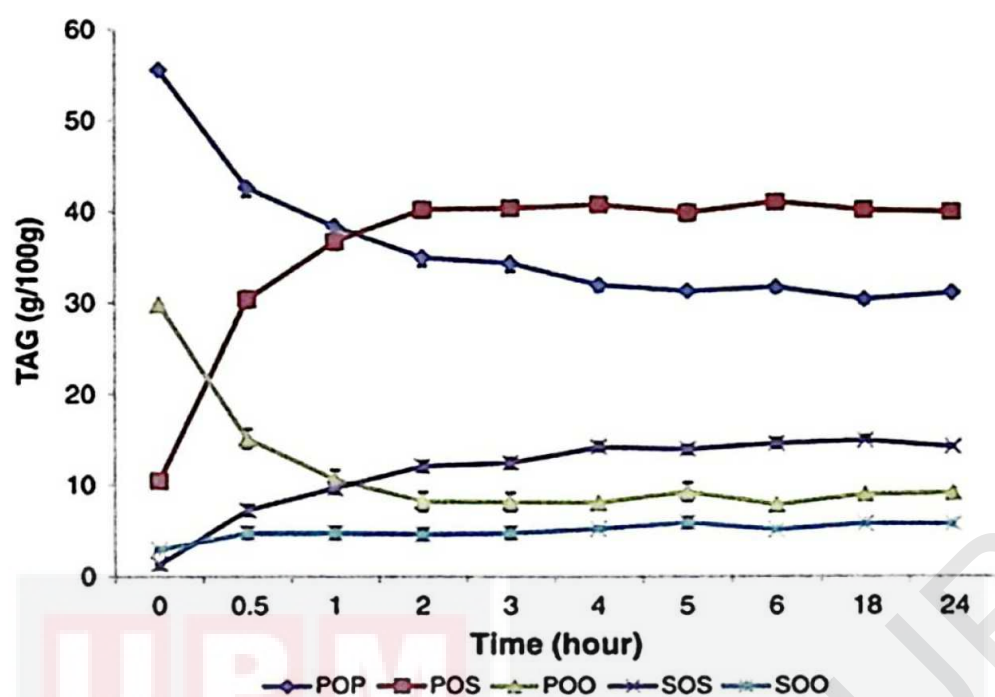


Figure 2-3: Reaction time on TAG composition of CBE (Mohamed, 2013).

Figure 2-1 shows the formation and decreases of TAG effected by reaction time. At time zero, it represents the mass fraction of TAG for PMF. After a few hours, the mass fraction of TAG for PMF started to change and it clearly shown POP and POO are decreases along the reaction time. While POS, SOS and SOO are increasing.

2.5 Refined, bleached and deodorized (RBD) palm oil

RBD palm oil is obtained by refining crude palm oil (CPO). CPO was extracted from the mesocarp of the fruit of oil palm called *Elaeis guineensis*. CPO is normally processed by a physical refining which turn the oil into yellow refined oil or called RBD oil. Table 2-3 shown the TAG composition for RBD palm oil, palm oil stearin, palm oil olein and palm mid fraction (PMF).

Table 2-3: Triacylglycerol (TAG) composition of RBD palm oil, palm oil stearin, palm oil olein and palm mid fraction (Nusantoro, 2016; Nusantoro & Flora, 2009).

TAG	Wt%			
	RBD palm oil	Stearin	Olein	PMF
LLO	0.56	0.21	0.59	-
PLL	2.38	1.02	1.98	0.88
MLP	0.15	0.16	0.11	-
OOL	2.12	0.55	2.80	0.92
POL	11.13	5.69	12.87	4.51
PLP	8.90	8.52	9.62	6.18
MPP	0.48	1.66	-	-
OOO	4.21	1.80	6.24	0.83
POO	24.51	13.11	30.75	5.63
POP	27.88	31.93	26.62	61.05
PPP	5.74	21.89	0.25	2.85
SOO	3.22	1.01	3.24	1.02
POS	6.28	5.61	4.45	11.76

PPS	1.54	5.20	-	3.13
SOS	0.64	0.86	0.48	1.24
PSS	0.26	0.78	-	-

2.5.1 Palm-mid fraction (PMF)

Palm-mid fraction (PMF) is obtained from double fractionation process of RBD palm oil. The fractionation process involves a physical process which crystallization of the RBD oil then followed by filtration. First fractionation process will separate liquid olein and solid stearin and second fractionation process will produce super olein and palm-mid fraction (PMF). Different product of fractionation has different properties and function. PMF has high in POP triacylglycerol which results in a sharp melting profile and slip melting point about 27.6°C (Jin et al., 2018). The TAG composition of PMF can be seen at Table 2-2.

2.6 Fractionation

The method of physically separating high melting point fractions from low melting point fractions is known as fractionation (Naessens, 2012). There are two main steps in the fractionation procedure. The first step is crystallization, which involves a cooling process that produces solid crystals in a liquid matrix. The liquid phase is separated from the crystals in the next step, which is a filtration process (Nusantoro, 2016). To destroy all

crystal memory, the oil was melted and homogenized at 70°C. The melted oil was poured into a water-jacketed crystallizer, agitated with a stirrer, and cooled with circulating chilled water until solid crystal growth occurred. The crystal and oil phases appeared as thick semi-solid slurries after stabilization. Filtration was used to separate the slurry into olein and stearin (Zaliha et al., 2004).

2.7 FFA stripping

Free fatty acids (FFA) and other minor volatile compounds are removed from oils during the steam stripping and physical refining processes. After the CBE reaction, the FFA and other minor compounds are stripped from the mixture in a column known as a deodorization column. This process is commonly carried out with slightly superheated steam to reduce the partial pressure of these volatile compounds (stripping agent) (Usseglio et al., 2019).

2.8 SuperPro Designer

SuperPro Designer is process simulator that provide the modelling, evaluation and optimization of integrated processes. Besides modelling, this software also has others features that useful for calculation of material and energy balance, databases for chemical component and mixture as well as equipment data from sizing to costing, process economics, waste analysis and others (Canizales et al., 2020). The SuperPro designer used

in widely industries range, for instance pharmaceutical, biotech, food processing and others.

SuperPro Designer is easier to use and provides a user-friendly approach when compared to Aspen Plus, which is also widely used by chemical engineers. However, in order to run the simulation successfully, the user must design the simulation correctly because the results can be wrong. Furthermore, SuperPro Designer provides costing calculation as one of its features. For some Aspen Plus versions, this feature may be unavailable. The user will benefit greatly from knowing the approximate cost of equipment and plant operating costs after the simulation is completed(Ideris, 2020).

This SuperPro Designer offers lots of advantages with wide applications compared to other software. Thus, this might be the best option to simulate sustainable design of CBE production from RBD palm oil.

CHAPTER 3

METHODOLOGY

3.1 Process design

SuperPro Designer 10 was used to design and simulate the production of cocoa butter equivalent from RBD oil. Figure 3-1 showed the Block Flow Diagram (BFD) of production of CBE. RBD oil will undergo double fractionation process as to produce PMF. Then the PMF will mix with PSFAM and lipase act as catalyst for enzymatic interesterification process for 10 hours (Mohamed, 2013). After the reaction was done, the product will undergo FFA stripping process in order to remove excessive fatty acid. Last process is post fractionation which to separate the CBE and byproduct.

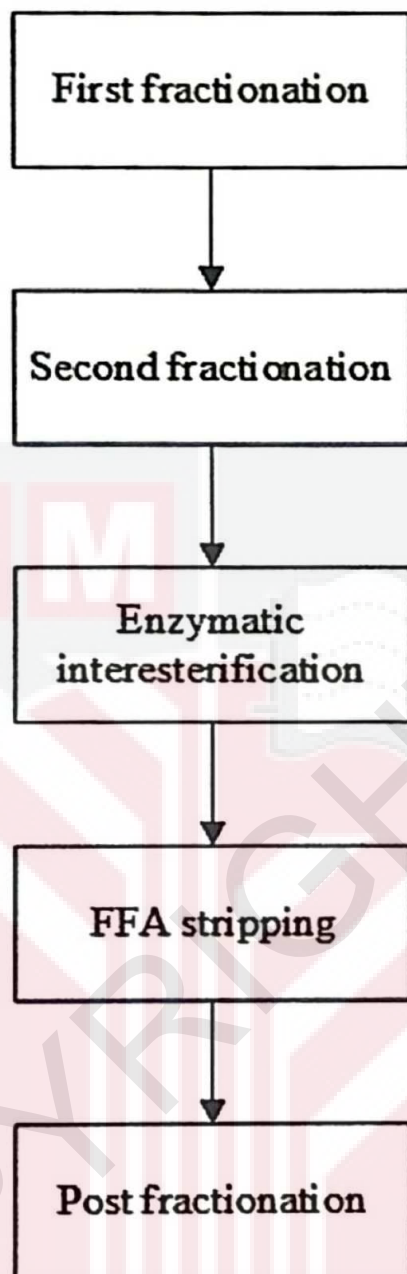


Figure 3-1: Block flow diagram of production of CBE

3.2 Assumption and data collection

3.2.1 Raw material component

Components used for simulation work can be referred in Table 3-2. Some of the components are already have it data in the SuperPro Designer and other components need to be register. Table 3-1 shows the composition of stock mixture consists of several components.

Table 3-1: Composition of stock mixture (Mohamed, 2012; Nusantoro, 2016; Nusantoro & Flora, 2009)

No	Stock mixture	Component	Wt%
1	RBD Palm Oil	LLL	0.5
		LOO	1.9
		MLP	0.2
		MPP	0.4
		OOO	4.1
		PLL	2.7
		PLO	10.7
		PLP	10.4
		POO	22.7
		POP	30.3
		POS	5.5

		PPP	6.1
		PPS	1.2
		PSS	0.1
		SOO	2.5
		SOS	0.7
2	palmitic-stearic fatty acid mixture (PSFAM)	Palmitic acid Stearic acid	43 57

Table 3-2: Components used in simulation flowsheet

No	Component	Molecular weight (g/mol)
1	Linoleic Acid	280.45
2	LLL	879.4
3	LLO	881.41
4	LOL	881.41
5	LOO	883.43
6	LOS	885.42
7	MLP	797.92
8	MPP	777.08

9	Nitrogen	28.013
10	Oleic Acid	282.47
11	OLO	883.43
12	OLS	885.42
13	OOO	885.46
14	Oxygen	31.999
15	Palmitic Acid	256.43
16	PLL	853.92
17	PLO	885.81
18	PLP	829.95
19	PLS	857.68
20	POL	855.81
21	POO	857.71
22	POP	831.73
23	POS	859.59
24	PPL	829.95
25	PPO	831.73
26	PPP	807.34
27	PPS	833.48

28	PSP	833.48
29	PSS	861.47
30	SLL	883.39
31	SLS	887.42
32	SOO	887.46
33	SOS	889.47
34	SPS	861.47
35	Stearic Acid	284.49
36	Water	18.015

3.2.2 Fixed costs

The costs of facility and equipment have the greatest impact on the calculation of fixed costs. The costs include total plant direct cost (TPDC), total plant indirect cost (TPIC), contractor's fees, and contingency (CFC). The cost items in TPDC are facility installation, processing pipe connections, and instrumentation. TPIC, on the other hand, includes engineering and construction fees.

The total cost of the plant was calculated by adding TPDC and TPIC. Meanwhile, TPC, CFC, startup costs, and working capital make up the total capital investment for the entire processing line. The facility purchasing fee (PC) was used as the basis for calculating fixed costs using various multipliers.

Table 3-3 Direct cost and total capital investment estimations multiplier (Cheng & Rosentrater, 2017).

Costs	Categories	Multipliers
Total plant direct cost (TPDC)	Installation	$0.50 \times PC$
	Piping	$0.35 \times PC$
	Instrumentation	$0.40 \times PC$
	Insulation	$0.03 \times PC$
	Electrical	$0.10 \times PC$
	Buildings	$0.45 \times PC$
	Yard improvement	$0.15 \times PC$
	Auxiliary facilities	$0.40 \times PC$
Total plant indirect cost (TPIC)	Engineering	$0.25 \times TPDC$
	Construction	$0.35 \times TPDC$
Total plant cost (TPC)	TPDC + TPIC	
Contractor's fee and contingency (CFC)	Contractor's fee	$0.05 \times TPC$
	Contingency	$0.10 \times TPC$
Direct fixed cost (DFC)	TPC + CFC	
Working capital (WC)	$0.017 \times DFC$	
Startup capital (SC)	$0.05 \times DFC$	
Total capital investment	TPC + CFC + WC + SC	

3.3 Process approach

The unit operations for each process are shown in

Unit operation	Equipment	Parameter	Function	references
First fractionation	Heat exchanger	Exit temperature at 60°C and 15 minutes process time	To destroy all crystal memory	(Zaliha et al., 2004)
	Stirred reactor	Final temperature at 40°C and 60 minutes process time	To crystallize the RBD palm stearin	
	Plate and frame filter	Process time 60 minutes	To filter out RBD palm stearin	
	Hopper	Final temperature at 60°C	To store RBD palm stearin	
Second fractionation	Stirred reactor	Final temperature at 25°C and 60 minutes process time	To crystallize the PMF	(Nusantoro & Flora, 2009)

	Plate and frame filter	Process time 60 minutes	To filter out RBD palm double olein	
	Hopper	Final temperature 45 ⁰ C	To collect and melt the PMF	
Enzymatic interesterification	Blending Tank	Process temperature 60 ⁰ C	To blend PMF and PSFAM	(Hamid et al., 2015)
	Packed Bed Reactor	Adiabatic temperature and 10 hours process time	Alteration of TAG	
FFA Stripping	Heat exchanger	Exit temperature at 230 ⁰ C	To remove FFA content	(Naessens, 2012)
	Flash drum	Process temperature at 230 ⁰ C and 60 minutes process time	To separate vapor and liquid	
	Heat exchanger	Exit temperature at 40 ⁰ C	To cool down the temperature of vapor	

	Heat exchanger	Exit temperature at 40°C	To cool down the temperature of liquid	
Post Fractionation	Stirred reactor	Final temperature at 35°C and 60 minutes process time	To crystallize the byproduct	(Mohd Hassim et al., 2018)
	Plate and frame filter	Process time 60 minutes	To separate CBE and byproduct	

CHAPTER 4

RESULT AND DISCUSSION

4.1 Simulation Output

4.1.1 Summary of Stream Details

Table 4-1 Production Stream Details

PROCEDURE	INPUT		OUTPUT	
	STREAM	AMOUNT (kg/batch)	STREAM	AMOUNT (kg/batch)
P-01	RBD Palm Oil	1000	S-113	1000
P-02	S-113	1000	S-101	1000
P-03	S-101	1000	S-112	195.17
			RBD Palm Olein	804.83

P-04	S-112	195.17	RBD Palm Stearin	195.17
P-05	RBD Palm Olein	804.83	S-102	804.83
P-06	S-102	804.83	Double Olein	402.93
			S-115	401.90
P-07	S-115	401.90	S-114	401.90
P-1	S-114	401.90	S-117	1205.71
	PSFAM	803.81		
P-08	S-117	1205.71	S-103	1205.71
	S-104	1205.95	S-105	1205.95
P-09	S-103	1205.71	S-105	1205.95
P-10	S-105	1205.95	S-106	1205.95
P-11	S-106	1205.95	S-107	1230.07
	STEAM	24.12		
P-12	S-107	1230.07	S-110	814.63

			S-109	415.44
P-13	S-110	814.63	DISTILLATE	814.63
P-14	S-109	415.44	S-111	415.44
P-15	S-111	415.44	S-108	415.44
P-16	S-108	415.44	BYPRODUCT	95.48
			CBE	319.96

4.1.2 Scheduling summary

Table 4-2 Scheduling summary for production of CBE from RBD palm oil.

OVERALL PROCESS DATA	
Annual Operating Time	7917.67 hours
Annual throughput	183,017 kg MP/year
Batch throughput	319.96 kg MP
Batch time	18.83 hours
Number of batches per year	572
MP = total flow of stream of CBE	

Table 4-2 is the scheduling summary for production of CBE from RBD palm oil which generated by SuperPro Designer. The production of CBE was in batch production and each batch need 18.83 hours to complete and produce 316.96 kg of CBE. Reaction section consumed longer time which 10 hours where the enzymatic interesterification occur. In one year, 572 batch can be done and produce 183,017 kg of CBE within 7917.67 hours. Figure 4-1 shown the gantt chart generated by SuperPro Designer for production of CBE for one complete cycle.

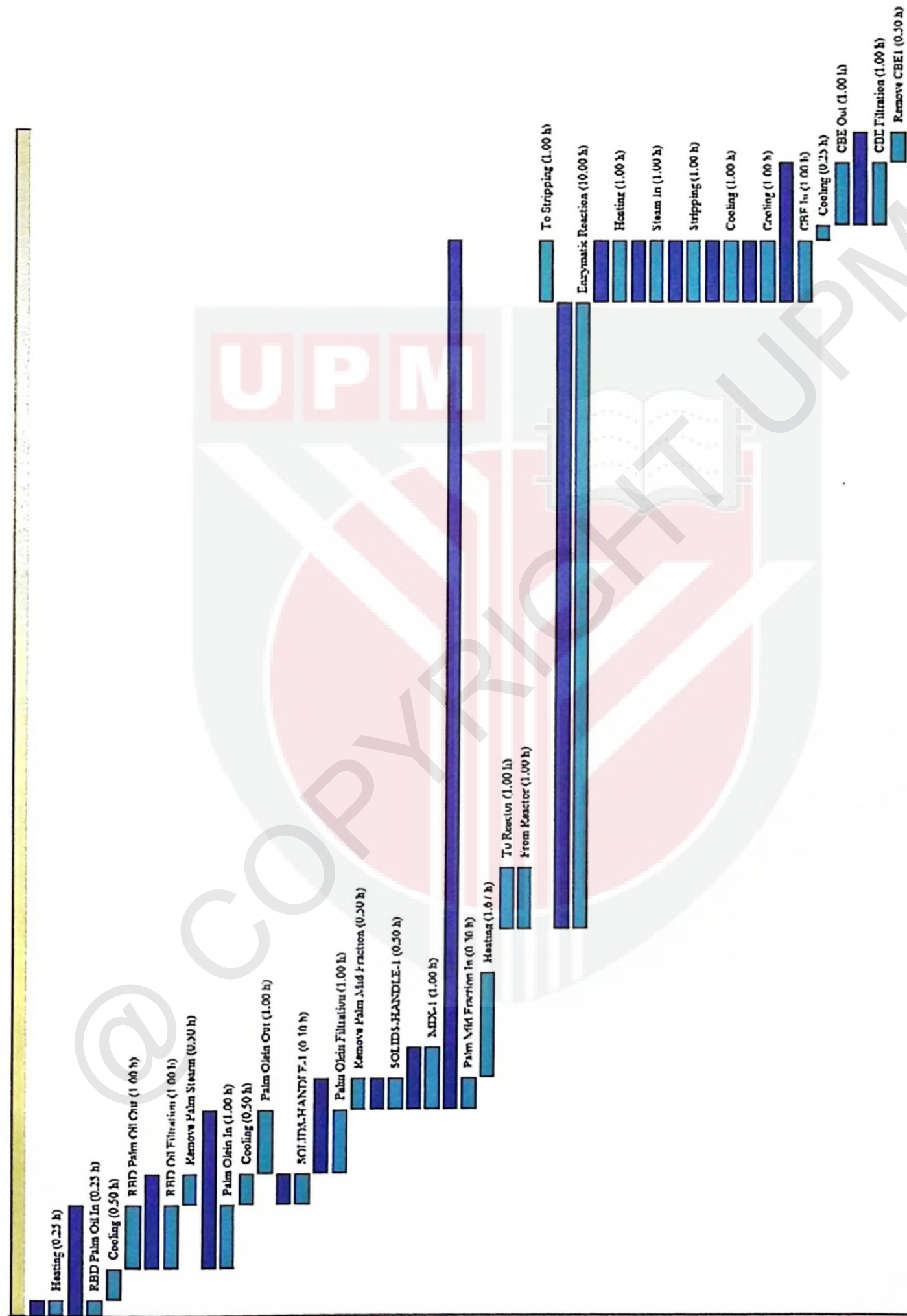


Figure 4-1 Gantt chart for CBE production.

4.2 Economic Evaluation

4.2.1 Fixed Capital Estimate Summary

Table 4-3 Total Plant Direct Cost (TPDC)

TOTAL PLANT DIRECT COST (TPDC)	
Equipment purchase cost	RM 3,159,000
Installation	RM 1,210,000
Process piping	RM 1,106,000
Instrumentation	RM 1,264,000
Insulation	RM 95,000
Electrical	RM 316,000
Building	RM 1,422,000
Yard improvement	RM 474,000
Auxiliary facilities	RM 1,264,000
Total	RM 10,309,000

Total plant direct cost (TPDC) is sum of equipment purchase cost, installation, process piping, instrumentation, insulation, electrical, building, yard improvement and auxiliary facilities. For this simulation of production of CBE from RBD palm oil the total plant direct cost (TPDC) is RM 10,309,000. Detail of equipment purchase cost can be shown at Table 4-10. RM 1,210,000 for installation cost is cost needed for installation of the equipment at the new plant site and includes the cost of foundations, slabs, supports, and local equipment services. Process piping cost which is RM 1,106,000 is a cost of process fluid piping that connects the equipment, as well as connections to the main utility headers and vents. Also, included the valves, piping supports, insulation, and other items associated with equipment piping.

RM 1,264,000 of instrument cost is the costs of transmitters and controllers with all required wiring and tubing for installation, field and control room terminal panels, alarms and enunciators, indicating instruments both in the field and in the control room, on-stream analyzers, control computers and local data-processing units, and control room display graphics. RM 316,000 for electrical cost needed for build electrical facilities for the plant. The cost for construction of plant building is RM 1,422,000 and this cost include the construction office, cafeteria, warehouse and others. Before constructing the building, there are cost for yard improvement which is RM 474,000 and this cost is for excavation, site grading, roads, fences, fire hydrants, parking spaces, and others.

Table 4-4 Total Plant Indirect Cost (TPIC)

TOTAL PLANT INDIRECT COST (TPIC)	
Engineering	RM 2,577,000
Construction	RM 3,608,000
Total	RM 6,186,000

Table 4-5 Total Plant Cost (TPC)

TOTAL PLANT COST (TPC)	
Total plant direct cost (TPDC)	RM 10,309,000
Total plant indirect cost (TPIC)	RM 6,608,000
Total	RM 16,495,000

Table 4-6 Contractor's Fee and Contingency (CFC)

CONTRACTOR'S FEE AND CONTINGENCY (CFC)	
Contractor's fee	RM 825,000
Contingency	RM 1,650,000
Total	RM 2,474,000

Table 4-7 Direct Fixed Capital Cost (DFC)

DIRECT FIXED CAPITAL COST (DFC)	
Total plant cost (TPC)	RM 16,495,000
Contractor's fee and contingency (CFC)	RM 2,474,000
Total	RM 18,969,000

Total plant indirect cost (TPIC) in Table 4-4 is sum of indirect cost which is engineering and construction. Engineering cost is including the preparation of design books that document the whole process like the design of equipment, specification sheets for equipment, instruments, plant drawing and other engineering-related costs. While construction is cost associated with the organization of the total construction effort. The

sum of TPDC and TPIC is denoted as Total Plant Cost (TPC). Table 4-5 shown the Total Plant Cost (TPC) for this simulation of production of CBE which RM 16,495,000.

Direct Fixed Capital (DFC) can be referred to fixed assets of an investment, such as plant and equipment. DFC can calculate by total up the Total Plant Cost (TPC) and Contractor's fee and Contingency (CFC). From this simulation the Direct Fixed Cost (DFC) is RM 18,969,000.

4.2.2 Labor Cost

Table 4-8 Type of labor and annual cost for labor

LABOR TYPE	UNIT COST (RM/hours)	ANNUAL AMOUNT (hours)	ANNUAL COST (RM/hours)
Operator	RM 9.20	6,120	RM 56,306
Plant engineer	RM 16.10	240	RM 3,869
QC analyst	RM 11.50	1,829	RM 21,036
Supervisor	RM 12.60	360	RM 4,530
Reactor operator	RM 11.50	1,590	RM 18,284
Worker	RM 6.90	3,339	RM 23,037
Total			RM 127,062

Table 4-8 shown the type of labors for production of CBE from RBD palm oil and its annual cost. There are six types of labors for this production, which is operator, plant engineer, QC analyst, supervisor, reactor operator and normal worker. Different type of labors has different rate of cost per hours. RM 127,062 per year need to be spend for labors cost for production of CBE.

4.2.3 Material Cost

Table 4-9 Raw Materials Cost

RAW MATERIAL	UNIT COST	ANNUAL AMOUNT (kg)	ANNUAL COST
RBD Palm Oil	RM 2.29	572,000	RM 1,311,024
PSFAM	RM 4.50	459,778	RM 2,069,001
Total			RM 3,380,056

4.2.4 Equipment Cost

Table 4-10 Equipment purchase cost

EQUIPMENT	QUANTITY	COST
Heat exchanger	4	RM 16,000
Flash drum	1	RM 4,000
Plate and frame filter	3	RM 291,000
Stirred reactor	3	RM 1,626,000
Packed bed reactor	5	RM 360,000
Blending tank	1	RM 220,000
Hopper	2	RM 12,000
Unlisted equipment		RM 632,000
Total		RM 3,159,000

Table 4-10 shown the equipment cost for production of CBE from RBD palm oil which RM 3,159,000. There are seven types of equipment needed for this production and there is also unlisted equipment cost that generated by SuperPro Designer. The price of equipment is based on SuperPro Designer databanks.

4.2.5 Utilities Cost

Table 4-11 Utilities Cost per Section

SECTION	COST
Pre-fractionation	RM 1,156
Reaction	RM 26,366
FFA stripping	RM 13,439
Post-fractionation	RM 53
Total	RM 41,014

Utilities cost is cost of heating and cooling utilities and also for power utilized in a process. Table 4-11 shown the utilities cost per section and it shown that reaction section has high cost. Reaction section has high cost because high consumption of heating agent needed to complete the reaction process of CBE production.

4.2.6 Annual Operating Cost

Table 4-12 Annual Operating Cost

COST ITEM	
Raw material	RM 3,380,000
Labor- dependent	RM 127,000
Facility-dependent	RM 3,572,000
Laboratory/QC/QA	RM 19,000
Waste treatment	RM 21,000
Utilities	RM 41,000
Total	RM 7,161,000

Annual operating cost is the total operating cost for production of CBE from RBD palm oil per year. RM 7,161,000 is total of operating cost for the production of CBE. Operating cost consists of raw materials, labor-dependent, facility-dependent, laboratory/QC/QA, waste treatment and utilities.

4.2.7 Executive Summary

Table 4-13 Executive Summary for Production of CBE from RBD Palm Oil

Total Capital Investment	RM 20,243,000
Capital Investment Charged for This Project	RM 20,243,000
Annual Operating Cost	RM 7,161,000
Main Revenue	RM 10,981,000
Other Revenue	RM 774,651
Cost Basis Annual Rate	183,017 kg CBE
Unit production cost	RM 39.13/kg CBE
Net Unit Production Cost	RM39.13/kg CBE
Unit production Revenue	RM 64.23/kg CBE
Gross Margin	39.08%
Return of Investment (ROI)	22.52%
Payback Time	4.44 years
IRR (after tax)	16.48%
NPV (at 7% interest)	RM 12,736,000

Table 4-13 shown the executive summary for production of CBE from RBD palm oil from the simulation work generated by SuperPro Designer. Based on the table the total capital investment needed for production of CBE from RBD palm oil is RM 20,243,000. The capital investment is initial cost needed for production of CBE from RBD palm oil. The capital investment is sum of direct fixed cost, working capital and startup cost.

CBE is the main revenue for this simulation while there are others two revenues from this production which are RBD palm stearin and RBD palm double olein. The revenues are shown at Table 4-13, where the CBE revenue is RM 10,981,000 per year and RBD palm stearin and RBD palm double olein revenue is RM 774,651 per year.

Gross margin is a percentage of profit per year. Gross margin generated from this simulation is quite high and it shown that the production of CBE can be profitable with 39.08% of gross margin. The percentage of gross margin was generated by dividing annual gross profit with annual revenues where annual gross profit is the remaining revenues after minus the annual operating cost. This simulation of production of CBE from RBD palm oil also has percentage of return of investment (ROI) which is 22.52%. The business with high percentage of return of investment (ROI) are attracted to the investor because the percentage for profit earned is high.

The payback time refers to the amount of time needed to recover the initial cost of investment. Simply put, the payback time is the amount of time it takes for an investment to reach a break-even point. Shorter payback time mean the investment is effective and good where preferable to have 5 year or lower. For this simulation, the payback time for production of CBE is 4.44 years and it can be considered good.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

To conclude, the develop of sustainable design of production of CBE from RBD palm oil using enzymatic interesterification between PMF and PSFAM with immobilized lipases was accomplished. RM 20,243,000 of total capital investment can be paid off within 4.44 year and it good because the payback time is lower than 5 years. The return of investment (ROI) also shown the positive result which is 22.52% with gross margin 39.08%. Annually this design of production of CBE from RBD palm oil can generate RM 11,755,651 total revenues with CBE as the main product and palm oil stearin and palm oil double olein as other revenues. It also recommended to increase the production of CBE from RBD palm oil to generate more profit by increasing the input of raw materials.

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APPENDICES

APPENDIX A

Economic Evaluation Report for CBE DrNan circulated PFR

August 13, 2021

1. EXECUTIVE SUMMARY (2021 prices)

Total Capital Investment	20,242,000 MYR
Capital Investment Charged to This Project	20,242,000 MYR
Operating Cost	7,160,000 MYR/yr
Main Revenue	10,981,000 MYR/yr
Other Revenues	774,651 MYR/yr
Total Revenues	11,756,000 MYR/yr
Batch Size	319.96 kg MP
Cost Basis Annual Rate	183,017 kg MP/yr
Unit Production Cost	39.12 MYR/kg MP
Net Unit Production Cost	39.12 MYR/kg MP
Unit Production Revenue	64.23 MYR/kg MP
Gross Margin	39.09 %
Return On Investment	22.52 %
Payback Time	4.44 years
IRR (After Taxes)	16.48 %
NPV (at 7.0% Interest)	12,741,000 MYR
MP = Total Flow of Stream 'CBE'	

2. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2021 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost (MYR)	Cost (MYR)
1/0/0	C-101	Stirred Reactor Vessel Volume = 1236.22 L	569,000	569,000
1/0/0	F-101	Plate & Frame Filter Filter Area = 20.00 m2	75,000	75,000
1/0/0	C-102	Stirred Reactor Vessel Volume = 994.94 L	552,000	552,000
1/0/0	F-102	Plate & Frame Filter Filter Area = 30.00 m2	108,000	108,000
1/0/0	T-101	Blending Tank Vessel Volume = 2000.00 L	220,000	220,000
5/0/0	R-101	Plug Flow Reactor Vessel Volume = 5000.00 L	72,000	360,000
1/0/0	C-103	Stirred Reactor Vessel Volume = 513.95 L	505,000	505,000
1/0/0	H-103	Heat Exchanger Heat Exchange Area = 1.18 m2	4,000	4,000
1/0/0	F-103	Plate & Frame Filter Filter Area = 30.00 m2	108,000	108,000
1/0/0	H-102	Heat Exchanger Heat Exchange Area = 1.29 m2	4,000	4,000
1/0/0	V-101	Flash Drum Vessel Volume = 252.48 L	4,000	4,000
1/0/0	H-104	Heat Exchanger Heat Exchange Area = 0.31 m2	4,000	4,000
1/0/0	H-101	Heat Exchanger Heat Exchange Area = 0.51 m2	4,000	4,000
1/0/0	HP-101	Hopper Vessel Volume = 2.55 L	6,000	6,000
1/0/0	HP-102	Hopper Vessel Volume = 5.25 L	6,000	6,000
		Unlisted Equipment		632,000
		TOTAL		3,159,000

3. FIXED CAPITAL ESTIMATE SUMMARY (2021 prices in MYR)

3A. Total Plant Direct Cost (TPDC) (physical cost)

1. Equipment Purchase Cost	3,159,000
2. Installation	1,210,000
3. Process Piping	1,106,000
4. Instrumentation	1,264,000
5. Insulation	95,000
6. Electrical	316,000
7. Buildings	1,422,000
8. Yard Improvement	474,000
9. Auxiliary Facilities	1,264,000
TPDC	10,309,000

3B. Total Plant Indirect Cost (TPIC)

10. Engineering	2,577,000
11. Construction	3,608,000
TPIC	6,186,000

3C. Total Plant Cost (TPC = TPDC+TPIC)

TPC	16,495,000
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3D. Contractor's Fee & Contingency (CFC)

12. Contractor's Fee	825,000
13. Contingency	1,650,000
CFC = 12+13	2,474,000

3E. Direct Fixed Capital Cost (DFC = TPC+CFC)

DFC	18,969,000
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4. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost (MYR/h)	Annual Amount (h)	Annual Cost (MYR)	%
Operator	9.20	6,120	56,306	44.31
Plant engineer	16.10	240	3,869	3.05
QC Analyst	11.50	1,829	21,036	16.56
Supervisor	12.60	360	4,530	3.56
Reactor Operator	11.50	1,590	18,284	14.39
worker	6.90	3,339	23,037	18.13
TOTAL		13,478	127,062	100.00



5. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost (MYR)	Annual Amount		Annual Cost (MYR)	%
PSFAM	4.50	459,778	kg	2,069,001	61.23
RBD Palm Oil	2.29	572,000	kg	1,309,880	38.77
Water	2.28	14	m3(STP)	31	0.00
TOTAL				3,378,912	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)

9. ANNUAL OPERATING COST (2021 prices) - PROCESS SUMMARY

Cost Item	MYR	%
Raw Materials	3,379,000	47.19
Labor-Dependent	127,000	1.77
Facility-Dependent	3,572,000	49.90
Laboratory/QC/QA	19,000	0.27
Consumables	0	0.00
Waste Treatment/Disposal	21,000	0.30
Utilities	41,000	0.57
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	7,160,000	100.00

APPENDIX B

Itemized Cost Report
for CBE DrNan circulated PFR

August 13, 2021

1. OVERALL PROCESS PARAMETERS

Annual Operating Time	7,917.67 h/yr
Unit Production Ref. Rate	183,017 kg MP/yr
Batch Size	319.96 kg MP
Recipe Batch Time	18.83 h
Recipe Cycle Time	13.83 h
Number of Batches Per Year	572.00
MP = Total Flow of Stream 'CBE'	

APPENDIX C

3. STREAM DETAILS

Stream Name	RBD Palm Oil	S-113	S-101	S-112
Source	INPUT	P-01	P-02	P-03
Destination	P-01	P-02	P-03	P-04
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	60.00	40.00	39.98
Pressure (bar)	1.01	1.01	10.64	1.19
Density (g/L)	898.80	898.80	898.80	898.80
Total Enthalpy (kW-h)	14.86	35.66	23.77	4.71
Specific Enthalpy (kcal/kg)	12.78	30.68	20.45	20.76
Heat Capacity (kcal/kg-°C)	0.51	0.51	0.51	0.52
Component Flowrates (kg/batch)				
LLL	5.00	5.00	5.00	0.60
LOO	19.00	19.00	19.00	2.20
MLP	2.00	2.00	2.00	0.02
MPP	4.00	4.00	4.00	3.20
OOO	41.00	41.00	41.00	0.37
PLL	27.00	27.00	27.00	3.00
PLO	107.00	107.00	107.00	11.80
PLP	104.00	104.00	104.00	15.00
POO	227.00	227.00	227.00	25.79
POP	303.00	303.00	303.00	54.99
POS	55.00	55.00	55.00	9.60
PPP	61.00	61.00	61.00	53.00
PPS	12.00	12.00	12.00	10.60
PSS	1.00	1.00	1.00	1.00
SOO	25.00	25.00	25.00	3.00
SOS	7.00	7.00	7.00	1.00
TOTAL (kg/batch)	1,000.00	1,000.00	1,000.00	195.17
TOTAL (L/batch)	1,112.59	1,112.59	1,112.59	217.15

Stream Name	RBD Palm Olein	S-102	RBD Palm Stearin	S-115
Source	P-03	P-05	P-04	P-06
Destination	P-05	P-06	OUTPUT	P-07
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	39.98	25.00	60.00	25.00
Pressure (bar)	1.01	10.13	1.19	1.19
Density (g/L)	898.80	898.80	898.80	898.80
Total Enthalpy (kW-h)	19.05	11.91	7.07	5.98
Specific Enthalpy (kcal/kg)	20.37	12.74	31.15	12.80
Heat Capacity (kcal/kg-°C)	0.51	0.51	0.52	0.51
Component Flowrates (kg/batch)				
LLL	4.40	4.40	0.60	1.18
LOC	16.80	16.80	2.20	5.54
MLP	1.98	1.98	0.02	0.37
MPP	0.80	0.80	3.20	0.15
OOO	40.63	40.63	0.37	7.52
PLL	24.00	24.00	3.00	22.79
PLO	95.20	95.20	11.80	28.45
PLP	89.00	89.00	15.00	41.15
POO	201.21	201.21	25.79	66.90
POP	248.01	248.01	54.99	171.60
POS	45.40	45.40	9.60	34.14
PPP	8.00	8.00	53.00	8.00
PPS	1.40	1.40	10.60	1.40
PSS	0.00	0.00	1.00	0.00
SOO	22.00	22.00	3.00	6.72
SOS	6.00	6.00	1.00	6.00
TOTAL (kg/batch)	804.83	804.83	195.17	401.90
TOTAL (L/batch)	895.45	895.45	217.15	447.16

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Stream Name	Double Olein	S-114	PSFAM	S-117
Source	P-06	P-07	INPUT	P-1
Destination	OUTPUT	P-1	P-1	P-08
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	25.00	45.00	25.00	31.67
Pressure (bar)	1.01	1.19	1.01	1.01
Density (g/L)	898.80	898.80	873.64	879.06
Total Enthalpy (kW-h)	5.93	10.76	11.97	22.73
Specific Enthalpy (kcal/kg)	12.67	23.04	12.81	16.22
Heat Capacity (kcal/kg-°C)	0.51	0.51	0.51	0.51
Component Flowrates (kg/batch)				
LLL	3.22	1.18	0.00	1.18
LOO	11.26	5.54	0.00	5.54
MLP	1.61	0.37	0.00	0.37
MPP	0.65	0.15	0.00	0.15
OOO	33.10	7.52	0.00	7.52
Palmitic Acid	0.00	0.00	345.64	345.64
PLL	1.21	22.79	0.00	22.79
PLO	66.75	28.45	0.00	28.45
PLP	47.86	41.15	0.00	41.15
POO	134.31	66.90	0.00	66.90
POP	76.41	171.60	0.00	171.60
POS	11.26	34.14	0.00	34.14
PPP	0.00	8.00	0.00	8.00
PPS	0.00	1.40	0.00	1.40
SOO	15.28	6.72	0.00	6.72
SOS	0.00	6.00	0.00	6.00
Stearic Acid	0.00	0.00	458.17	458.17
TOTAL (kg/batch)	402.93	401.90	803.81	1,205.71
TOTAL (L/batch)	448.29	447.16	920.06	1,371.60

Stream Name	S-104	S-103	S-105	S-106
Source	P-09	P-08	P-08	P-10
Destination	P-08	P-09	P-10	P-11
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	62.10	60.00	62.10	230.00
Pressure (bar)	1.01	11.29	11.39	11.39
Density (g/L)	866.86	867.01	866.87	792.14
Total Enthalpy (kW-h)	44.11	43.07	44.11	163.37
Specific Enthalpy (kcal/kg)	31.47	30.74	31.47	116.56
Heat Capacity (kcal/kg-°C)	0.51	0.51	0.51	0.51
Component Flowrates (kg/batch)				
Linoleic Acid	8.28	0.00	8.28	8.28
LLL	1.19	1.18	1.19	1.19
LLG	0.13	0.00	0.13	0.13
LOL	0.00	0.00	0.00	0.00
LOO	0.00	5.54	0.00	0.00
LOS	0.25	0.00	0.25	0.25
MLP	0.37	0.37	0.37	0.37
MPP	0.15	0.15	0.15	0.15
Oleic Acid	37.77	0.00	37.77	37.77
OLO	0.50	0.00	0.50	0.50
OLS	0.83	0.00	0.83	0.83
OOO	0.13	7.52	0.13	0.13
Palmitic Acid	393.19	345.64	393.19	393.19
PLL	0.01	22.79	0.01	0.01
PLO	1.23	28.45	1.23	1.23
PLP	1.29	41.15	1.29	1.29
PLS	46.68	0.00	46.68	46.68
POL	2.51	0.00	2.51	2.51
POO	2.72	66.90	2.72	2.72
POP	95.24	171.60	95.24	95.24
POS	193.58	34.14	193.58	193.58
PPL	0.00	0.00	0.00	0.00
PPO	0.62	0.00	0.62	0.62
PPP	0.10	8.00	0.10	0.10
PPS	5.22	1.40	5.22	5.22
SLL	0.00	0.00	0.00	0.00
SLS	44.76	0.00	44.76	44.76
SOO	0.41	6.72	0.41	0.41
SOS	5.70	6.00	5.70	5.70
SPS	3.84	0.00	3.84	3.84
Stearic Acid	359.26	458.17	359.26	359.26
TOTAL (kg/batch)	1,205.95	1,205.71	1,205.95	1,205.95
TOTAL (L/batch)	1,391.17	1,390.65	1,391.16	1,522.40

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Stream Name	Steam	S-107	S-110	S-109
Source	INPUT	P-11	P-12	P-12
Destination	P-11	P-12	P-13	P-14
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	140.00	228.38	230.00	230.00
Pressure (bar)	1.01	1.01	0.00	0.00
Density (g/L)	0.53	21.73	0.01	895.30
Total Enthalpy (kW-h)	18.90	182.27	197.49	56.09
Specific Enthalpy (kcal/kg)	674.14	127.50	208.59	116.18
Heat Capacity (kcal/kg-°C)	0.46	0.51	0.54	0.51
Component Flowrates (kg/batch)				
Linoleic Acid	0.00	8.28	8.20	0.08
LLL	0.00	1.19	0.00	1.19
ULL	0.00	0.13	0.00	0.13
LOL	0.00	0.00	0.00	0.00
LOO	0.00	0.00	0.00	0.00
LOS	0.00	0.25	0.00	0.25
MLP	0.00	0.37	0.00	0.37
MPP	0.00	0.15	0.00	0.15
Oleic Acid	0.00	37.77	37.39	0.38
OLO	0.00	0.50	0.00	0.50
OLS	0.00	0.83	0.00	0.83
OOO	0.00	0.13	0.00	0.13
Palmitic Acid	0.00	393.19	389.26	3.93
PLL	0.00	0.01	0.00	0.01
PLO	0.00	1.23	0.00	1.23
PLP	0.00	1.29	0.00	1.29
PLS	0.00	46.68	0.00	46.68
POL	0.00	2.51	0.00	2.51
POO	0.00	2.72	0.00	2.72
POP	0.00	95.24	0.00	95.24
POS	0.00	193.58	0.00	193.58
PPL	0.00	0.00	0.00	0.00
PPO	0.00	0.62	0.00	0.62
PPP	0.00	0.10	0.00	0.10
PPS	0.00	5.22	0.00	5.22
SLL	0.00	0.00	0.00	0.00
SLS	0.00	44.76	0.00	44.76
SOO	0.00	0.41	0.00	0.41
SOS	0.00	5.70	0.00	5.70
SPS	0.00	3.84	0.00	3.84
Stearic Acid	0.00	359.26	355.67	3.59
Water	24.12	24.12	24.12	0.00
TOTAL (kg/batch)	24.12	1,230.07	814.63	415.44
TOTAL (L/batch)	45,388.72	56,619.52	59,524,620.28	464.02

Stream Name	Distillate	S-111	S-108	BYPRODUCT
Source	P-13	P-14	P-15	P-16
Destination	OUTPUT	P-15	P-16	OUTPUT
Stream Properties				
Activity (U/ml)	0.00	0.00	0.00	0.00
Temperature (°C)	40.00	40.00	35.00	34.96
Pressure (bar)	0.01	0.01	10.47	1.09
Density (g/L)	868.41	898.13	898.19	898.76
Total Enthalpy (kW-h)	19.78	9.76	8.54	1.97
Specific Enthalpy (kcal/kg)	20.89	20.20	17.68	17.77
Heat Capacity (kcal/kg-°C)	0.52	0.51	0.51	0.51
Component Flowrates (kg/batch)				
Linoleic Acid	8.20	0.08	0.08	0.00
LLL	0.00	1.19	1.19	0.02
LLO	0.00	0.13	0.13	0.00
LOL	0.00	0.00	0.00	0.00
LOO	0.00	0.00	0.00	0.00
LOS	0.00	0.25	0.25	0.00
MLP	0.00	0.37	0.37	0.01
MPP	0.00	0.15	0.15	0.00
Oleic Acid	37.39	0.38	0.38	0.01
OLO	0.00	0.50	0.50	0.01
OLS	0.00	0.83	0.83	0.01
OOO	0.00	0.13	0.13	0.00
Palmitic Acid	389.26	3.93	3.93	0.06
PLL	0.00	0.01	0.01	0.00
PLO	0.00	1.23	1.23	0.02
PLP	0.00	1.29	1.29	0.02
PLS	0.00	46.68	46.68	0.76
POL	0.00	2.51	2.51	0.04
POO	0.00	2.72	2.72	1.09
POP	0.00	95.24	95.24	38.10
POS	0.00	193.58	193.58	48.40
PPL	0.00	0.00	0.00	0.00
PPO	0.00	0.62	0.62	0.01
PPP	0.00	0.10	0.10	0.00
PPS	0.00	5.22	5.22	0.08
SLL	0.00	0.00	0.00	0.00
SLS	0.00	44.76	44.76	0.73
SOO	0.00	0.41	0.41	0.40
SOS	0.00	5.70	5.70	5.59
SPS	0.00	3.84	3.84	0.06
Stearic Acid	355.67	3.59	3.59	0.06
Water	24.12	0.00	0.00	0.00
TOTAL (kg/batch)	814.63	415.44	415.44	95.48
TOTAL (L/batch)	938.08	462.56	462.52	106.23

Stream Name	CBE
Source	P-16
Destination	OUTPUT
Stream Properties	
Activity (U/ml)	0.00
Temperature (°C)	34.96
Pressure (bar)	1.01
Density (g/L)	898.03
Total Enthalpy (kW-h)	6.55
Specific Enthalpy (kcal/kg)	17.63
Heat Capacity (kcal/kg-°C)	0.50
Component Flowrates (kg/batch)	
Linoleic Acid	0.08
LLL	1.17
LLO	0.13
LOL	0.00
LOO	0.00
LOS	0.25
MLP	0.36
MPP	0.15
Oleic Acid	0.37
OLO	0.49
OLS	0.82
OOO	0.13
Palmitic Acid	3.87
PLL	0.01
PLO	1.21
PLP	1.27
PLS	45.93
POL	2.47
POO	1.63
POP	57.15
POS	145.19
PPL	0.00
PPO	0.61
PPP	0.10
PPS	5.13
SLL	0.00
SLS	44.03
SOO	0.01
SOS	0.11
SPS	3.78
Stearic Acid	3.53
TOTAL (kg/batch)	319.96
TOTAL (L/batch)	356.29