SIMULATION ON THE EXTRACTION OF SUNFLOWER OIL (*heliantus annuus* L.) USING SUPERCRITICAL CARBON DIOXIDE

BY

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Dissertation submitted in partial fulfilment of

the requirements for the

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CERTIFICATION OF APPROVAL

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Tamilarasan Muniandy

A project dissertation submitted to the
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Approved by,

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(**Dr. RAJASHEKHAR PENDYALA**)

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SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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TAMILARASAN MUNIANDY

ABSTRACT

Current technology in separation of Sunflower oil requires relatively large facilities, a large investment, complex mechanical work and the possibility of having a negative impact on the environment. Separation using Supercritical Fluid Extraction (SCFE) especially Carbon Dioxide is proposed as a solution to some of the advantages of conventional extraction methods. The project aims to simulate the extraction of sunflower oil by using supercritical carbon dioxide ($SC\text{-}CO_2$) in a commercial scale. There are many research papers are published to study the pattern of the sunflower oil extraction using $SC\text{-}CO_2$. Hence, this project involves incorporation of the novel findings to configure feasible design route for extraction and separation of sunflower oil by using $SC\text{-}CO_2$. The simulation will be carried out using Aspentech HYSYS simulation software. This comprehensive study can provide the knowledge on the rising SFE separation technology. This project will elaborate and differentiate the conventional vacuum distillation and solvent extraction methods against $SC\text{-}CO_2$ on extracting thermo labile molecule from oil bearing seeds. The process was scaled-up with the aid of the experimental data from Nimet, et al,. (2011) & Kiriamiti, et al., (2001) and optimized to 250 Bar and 40^0C of process operating parameters. Through this scale-up simulation it is identified the yield of sunflower oil is 38-42% w/w, similar to the experimental results. The project was further justified by cash flow of the project with rate of return (ROR) more than 15 % which is 17.9 %.

ACKNOWLEDGEMENT

This project would not have been possible without the assistance and guidance of certain individuals and organization whose contributions have helped in its completion. First of all and most importantly, I would like to express my sincere gratitude and utmost appreciation to the project supervisor, *Dr. Rajashekhar Pendyala* for his valuable input, encouragement and guidance throughout the course of this project. I would also like to extend my thanks to Chemical Engineering Department of *Universiti Teknologi PETRONAS (UTP)* for providing this chance to undertake this remarkable final year research project. The knowledge had been put to a test after completing five years of intensive chemical engineering course. This course has a good coverage on the overall chemical engineering programme whereby students can actually contribute their effort and knowledge towards achieving a greater course. A word of sincere gratitude to the *Final Year Project coordinators* for arranging various seminars as a support and knowledge tool to assist the project activities. The seminars were indeed very helpful and insightful. Special thanks to all lecturers from Universiti Teknologi Petronas who had provided untiring guidance throughout the period of the project. I would like to take this opportunity to express my special thanks to *Dr. Lukman Ismail* for his guidance and kind help on the matter of this project. Last, but certainly not least, I would like to apologize if any party was inadvertently excluded from being mentioned above and would like to thank all parties that were involved in making this project a success.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In the previous years, the world production of sunflower seeds (*Heliantus annuus* L.) has had a significant increase compared to other seed oil cultivation. Sunflower seeds are very rich in oil, about 50 weight percentage, and from a chemical point of view the oil is considered very good for human consumption because of its high ratio polyunsaturated or saturated fatty acids and the high content in Linoleic acid. In addition, sunflower seeds represent an important source of vegetable oil and its protein fraction characterized by relatively well-balanced amino acid pattern, is recognized as a potential source of proteins for human consumption.

The industrialization of oily seeds has become one of the most important agro industrial activities. The products that result from this activity are employed in the formulations of foods, cosmetics and drugs. Thus, the search for oil extraction processes that minimize environmental impacts and produce high quality products is of great importance. These processes will add significant improvement in the socioeconomic value.

In the extraction of vegetable oils the supercritical carbon dioxide extraction method has showed to be a very interesting alternative for conventional extraction methods. Extraction processes with pressurized fluids enable efficient removal of the vegetable oils aiding the step of solvent recovery due to the fluid volatility. Supercritical Carbon dioxide is unlike other supercritical fluid posses the characteristics such as environmentally friendly, recyclable, non-toxic, non-flammable, inexpensive and readily available, no residue formation and it's a tunable solvent. These are the important factors, which make the process more economically attractive and superior to the existing extraction methods.

1.2 PROBLEM STATEMENT

There are several techniques available to extract oil from oily seeds, and industrial extraction is commonly carried out through mechanical pressing followed by solvent extraction or vacuum distillation. Commercial-grade hexane is often the solvent used for the extraction of oil from oily seeds. However, this procedure can result in the production of undesirable residues, and the oil can undergo oxidative transformations during the removal of the solvent. Furthermore, these oxidative transformations can cause deterioration of the oil quality. The flavor of the oils and the foods that contain them can be adversely affected by lipid oxidation which influences the composition of fatty acids and other components, such as tocopherol (Vitamin E) and tocotrienols.

Furthermore, after the oil recovered from the seeds it will undergo a series of oil refining processes such as in the diagram below.

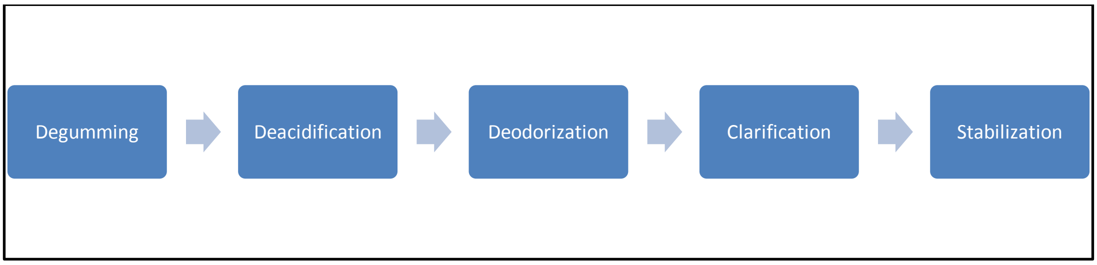

Figure 1.2.1: Conventional Oil Refining Process

The operating conditions in this process are very especially the temperature. Oil constitutes of thermolabile molecules such as fatty acids and proteins which will be denatured if undergo high temperature processes. For example, in the hydrogenation process under stabilization undergo an operating process of 240^{0}C. This will lead to denature of thermolabile molecules [3]. There is a high possibility that high value components such as tocopherol in the oil which is in the minimum level in the oil can be lost completely through this series of oil refining process.

Hence Supercritical Fluid Extraction System (SCFES) is an initiative taken to produce product with zero residue. Theses green technology process will not operate at higher temperature and the solvent will leave no residue in the end product. Furthermore, this green method will assist in accommodating increasing number of consumers' awareness towards natural product industry and expectation of such industry to develop and commercialize green technologies. SCFE is a good example for such matter.

1.3 OBJECTIVES

1. To design a supercritical carbon dioxide extraction and separation system to recover edible oil from sunflower seed.

2. To identify the optimum operating parameters of the supercritical carbon dioxide extraction system to maximize oil recovery by referring to the novel literatures.

3. To configure economically feasible SCFE system route of SC-CO_2 through comprehensive cost analysis.

1.4 SCOPE OF STUDY

The case studies are mainly about supercritical fluid extraction by ranging the operating parameters such as density, temperature, flowrate, pressure, volatility and etc. In depth, the study covers the solubility factor of SC-CO_2 influenced by diffusivity and viscosity of mixtures. Majorly covers on the plant design of oil extraction process by incorporating the phenomenon mentioned above. Thus, the aim of the study is to design a process flow diagram of supercritical carbon dioxide extraction of sunflower seed oil by tuning with ranging operating parameters. Finally a cost analysis will be drawn on studying the feasibility of the separation process in commercialscale. The scope of this study is well defined in this final year project time frame and can be accomplished within the time frame.

1.5 RELEVANCY AND SIGNIFICANCE OF PROJECT

This project based on complex conventional seed oil extracting and refining process. The study on latest SCFE system model is important in defining a new process route of extracting oil from seed oil to underpin these technological advances in a simpler and cost saving way.

This is a good start to support the use of new growing green technology that can extract oil by using SC-CO_2. This is a newer technology addressing the safety, health, environmental concern and cleaner product extraction method which will enhance the food industry quality and reliability. Furthermore thorough this green process high value compounds in oil exist in small quantity such as Vitamin E can be extracted without damaging the components through the process and this type of products will enhance the socioeconomic value of food industry.

CHAPTER 2

LITERATURE REVIEW

2.1 SUPERCRITICAL CARBON DIOXIDE (SC-CO_2)

Carbon dioxide (CO_2) is a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It appears as a gas at standard temperature and pressure. CO_2 is a non-toxic and non-flammable fluid which has high chemical stability as it has a very low energy level compared to other carbon compounds [1]. It's generally regarded as safe (GRAS). It is eventually possess the lower critical temperature and pressure to bring it to the state called supercritical and hence at this state it will be called supercritical fluid. The diagram below shows temperature-pressure diagram of CO_2.

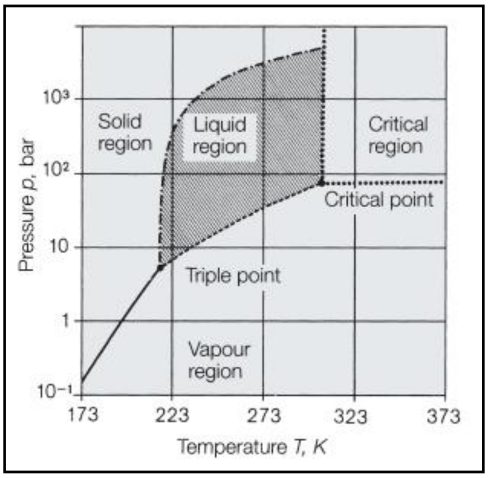

Figure 2.1.1: Phase Diagram of CO_2

Normal Boiling Point (at 1 atm)	-57^0C
Normal Melting Point (at 1 atm)	-78^0C
Critical Temperature	31.2^0C
Critical Pressure	72.9 atm

Table 2.1.1: Properties of CO_2

Supercritical fluid (SCF) is made from a gas or liquid, not a solid. When a gas or liquid is compressed and heated past its critical point, it enters a phase called supercritical phase and it referred as SCF. The critical temperature (T_c) and critical pressure (P_c) at which it happens are unique to each pure substance. The most important properties of SCF are its density, viscosity, diffusivity, heat capacity, thermal conductivity. Manipulating the temperature and pressure above the critical points affects these properties and enhances the ability of the SCF to penetrate and extract targeted molecules from source materials.

The liquid like density of a SCF solvent provides its high solvent power where she gas like viscosity and diffusivity with zero surface tension enhance the transport properties of SCF solvent. The SCF then can penetrate into porous solid materials more effectively than liquid solvents resulting in faster mass transfer and extractions. The main principle plays role here is the pressure. Manipulating the pressure of the system will selectively increase the density of SC-CO_2. This will enhance the solvating power of SC-CO_2 in the mixture lead to higher extraction. Adding to that, by manipulating the temperature as well can affect the compounds extraction. At different pressure range we can extract different compound presence in the oil. Below listed are the fundamental properties of SC-CO_2 which help to distinguish the reason for the behaviour of CO_2 in supercritical fluid compared to its normal gas and liquid state.

PHASE	DENSITY (g/cm^3)	DIFFUSION (cm^2/s)	VISCOSITY (g/cm.s)
Gas at 1 atm & 21^{0}C	10^{-3}	10^{-1}	10^{-4}
Supercritical Fluid	0.3 to 0.8	10^{-3} to 10^{-4}	10^{-4} to 10^{-3}
Liquid	1	$<10^{-5}$	10^{-2}

Table 2.1.2: Transport Phenomena Properties of CO_2

These are the major properties involved the transport phenomena of the SC-CO_2. In a simple word, density represent the solvent capacity of the SC-CO_2 in mixture, viscosity represent the shear stress which is the resistant of SC-CO_2 against the mixture and the diffusity resemble the diffusion of SC-CO_2 which means the movement of $SC\text{-}CO_2$ in the mixture. Together these three properties dominate the extraction of $SC\text{-}CO_2$ in the oil mixture.

Many solvents are candidates for supercritical extraction. However the most desirable SCF solvent for extraction of natural products for foods and medicines is carbon dioxide (CO_2) due to its relatively non-toxic, inexpensive, easily available, odourless, tasteless and environmentally friendly with convenient critical parameters [2].

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2.2 SUPERCRITICAL FLUID EXTRACTION (SCFE)

Continuous efforts are being made worldwide to develop newer processes for the production of better quality edible oils with simultaneous value addition by recovering valuable nutrients and oleo chemicals. Supercritical fluid extraction (SCFE) holds promise in this regard. SCFE is a unit operation that exploits the dissolving power of fluids at temperatures and pressures above their critical values, the most popular fluids being carbon dioxide and water. A lot of work published on SCFE in the food processing industry has dealt with extraction of vegetable oils. Supercritical carbon dioxide (SC–CO2) has been established as a good alternative solvent for several lipid processing operations such as separation of free fatty acids (FFA) from vegetable oils, separation of polyunsaturated fatty acids (PUFA) from animal lipids, refining and deodorization of vegetable oil, fractionation of glycerides, recovery of oil from oil bearing materials, deoiling of lecithin and decholesterolization and delipidation of food products [4].

Generally, SCFE is a two-step process which uses a dense gas as a solvent e.g., carbon dioxide (CO2) for extraction, above its critical temperature (31^{o}C) and critical pressure (74 bar). The feed, generally ground solid, is charged into the extractor. Supercritical CO2 is fed to the extractor through a high pressure pump (100-500 bar). The extract laden CO_2 is sent to a separator (60-120 bar) via a pressure reduction valve. At reduced temperature and pressure conditions, the extract precipitates out in the separator. The extract free CO_2 stream, leaving the separator is then recycled to the extractor. In the case of liquid feed, the extractor is modified into a column through which feed and the supercritical CO_2 is fed either concurrently or concurrently [5].

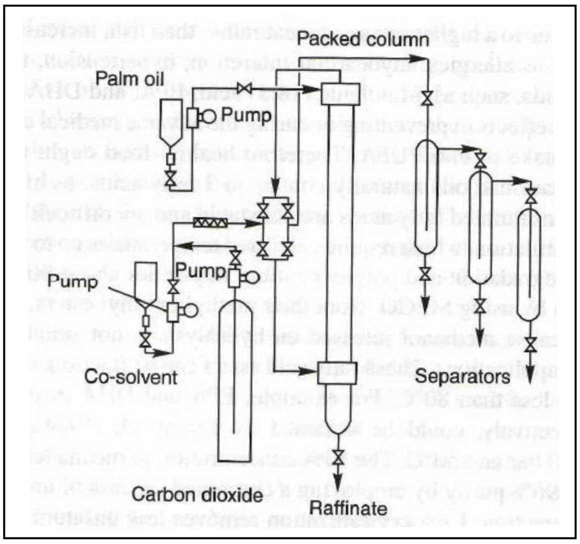


Figure 2.2.1: Schematic Diagram of Contiguous supercritical CO_2 processing of palm oil [4]

The figure above represents the schematic diagram of continuous supercritical carbon dioxide in a lab scale for extraction of palm oil. This is an example of the aforementioned process flow diagram. Supercritical carbon dioxide is a tunable solvent which means it can selectively separate compounds by varying the pressure. For example the above separators will separately collects the compounds such as squalane, sterols, free fatty acids and etc by varying the pressure. It is an important factor contributes to the development of this SCFE process. This also takes advantage of conventional oil refining process such as the need for removal of phospholipids from oil by using process degumming. In SC-CO_2, the process entirely eliminated because SC-CO_2 can selectively remove the compound by varying the pressure which is by ranging the pressure from 80-250 bar.

Another important parameter in oil recovering is the addition of entrainer or co-solvent to enhance further the recovery of oil. Figure below show the improvement in oil yield with the addition of ethanol as a co-solvent in supercritical carbon dioxide extraction.

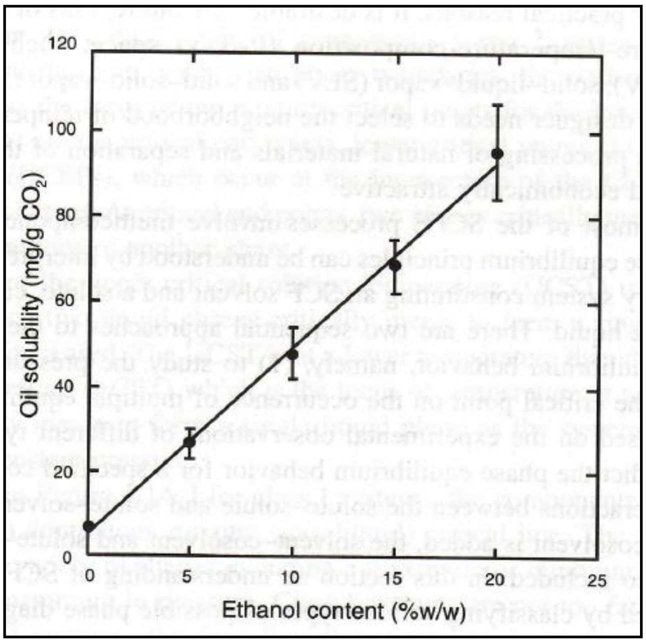


Figure 2.2.2: Solubility of sunflower oil in SC-CO_2, modified with ethanol at 42°C and 300 bar [4]

As we can see from the figure above, the addition of ethanol actually enhances the solubility of SC-CO2 in sunflower oil. This is due to the polar activity of the mixture. CO2 has less polar properties which restricts its movement to diffuse into and further extract the oil. However the situation can be overcome when ethanol is introduced into the system where is increase the polar properties of SC-CO2 and hence increase the oil extraction. The addition of ethanol also can influence the operating parameters. Even though the system is enhanced by addition of co-solvent, for this simulation addition of co-solvent is not considered as it will polarize SC-CO_2 to extract phospholipids which is not a favorable compound in refined sunflower oil. So by not adding the co-solvent we can limit the phospholipids percentage in the extracted sunflower oil.

Hence SFE technology is the latest technology and also environmentally friendly process which needed to implement to enhance quality product recovery and also to reduce the cost.

2.3 SUNFLOWER OIL (*HELIANTUS ANNUUS* L.)

Sunflower seeds contain up 43.4% of good quality, highly nutritive oil, rich in monounsaturated fatty acids (MUFA) esters. Sunflower oil is commonly used in food as frying oil, and in cosmetic formulations as an emollient. Sunflower oil was first industrially produced in 1835 in the Russian Empire. The world's largest sunflower oil producers now are Ukraine and Russia [7]. Healthy, natural sunflower oil is produced from oil type sunflower seeds. Sunflower oil is light in taste and appearance and supplies more Vitamin E than any other vegetable oil. It is a combination of monounsaturated and polyunsaturated fats with low saturated fat levels. The versatility of this healthy oil is recognized by cooks internationally. Sunflower oil is valued for its light taste, frying performance and health benefits. There are three types of sunflower oil available such as NuSun, linoleic and high oleic sunflower oil. All are developed with standard breeding techniques. They differ in oleic levels and each one offers unique properties. With three types of sunflower oil available, sunflower oil meets the needs of consumer and food manufacturers alike for a healthy and high performance non-transgenic vegetable oil [6].

Components	**Unit**	**Value per 100g**	**Components**	**Unit**	**Value per 100g**
Water	g	4.73	Calcium	mg	78
Energy	kcal	584	Iron	mg	5.35
Protein	g	20.78	Magnesium	mg	325
Total lipid (fat)	g	51.46	Phosphorous	mg	660
Carbohydrates	g	20.00	Potassium	mg	645
Fiber	g	8.6	Sodium	mg	9
Sugar	g	2.62	Zinc	mg	5
Vitamin C	mg	1.4	Thiamin	mg	1.48
Niacin	mg	8.335	Folate	mg	227
Vitamin A	IU	50	Vitamin E	mg	35.17
Riboflavin	mg	1.480	Total Monounsaturated Fatty Acids	g	18.528
Total Polyunsaturated Fatty Acids	g	23.137	Total saturated Fatty Acid	g	4.455

Table 2.3.1: Components in Sunflower seed [8]

The table above shows the components in dried sunflower seed. For the simulation purpose we will only select the major components which are the fatty acids & Vitamin E.

Components	Unit	Value per 100g	Components	Unit	Value per 100g
Energy	kcal	884	Total lipid (fat)	g	100
Vitamin E	mg	41.08	Vitamin K	mg	5.4
Total saturated Fatty Acid	g	10.3	Total Monounsaturated Fatty Acids	g	19.5
Total Polyunsaturated Fatty Acids	g	65.7			

Group	Components	Percentage composition
Polyunsaturated Fatty acids (PUFA)	Lineolic Acid	65.7 %
Monounsaturated Fatty Acids (MUFA)	Oleic Acid	25%
Saturated Fatty Acids	Palmatic acid Stearic acid Myristic Acid	9% 7% 0.4%
Phospholipids & Glycolipids	-	2%

Table 2.3.2: Components in Sunflower oil [8]

Table above shows the major constituents of sunflower oil. Sunflower oil to become edible oil it need to reduce the content of saturated fatty acids and increase the PUFA, MUFA, and Vitamins content which is good for the health of the consumers. Furthermore, sunflower oil also contains phospholipids, lecithin, carotenoids and waxes [7]. These compounds need to be minimized in the edible oil of sunflower oil. From this table it assists to identify the main components need to be extracted from the sunflower oil.

2.4 MARKET STUDY

Historically, demand for oilseed sunflower depended heavily on the export market for either seed or oil sales. With the advent of high oleic sunflower, the market has switched almost exclusively to a United States and Canadian base. Both of these oils are very stable and do not require hydrogenation as do competitive oils, such as traditional soybean and canola oils, when used in a frying application. Oilseed sunflower prices now are more determined by their relationship to corn, cotton and canola oil prices. Oilseed sunflower producers have the advantage of multiple market options: selling to oilseed crushers, the hulling seed market, or the bird food market. Supply and demand drive prices in all three markets. These markets are very specific and unique, with different values associated with them. The sunflower oil production of the world is around 8-9 million tons in a normal year. The exports are traditionally around 30% of the total production. It is expected that around 3 million tons of oil will be exported in 2005-06. Russia and Ukraine are the first and second largest producers respectively of sunflower seed in the World. The other major producers are Argentina, France, Romania, Hungary, China, India and United States of America. Currently, sunflower seed accounts for around 8% of the world's total oilseed production and sunflower oil accounts for 9% of the global edible oil production (Refined Sunflower Oil, 2012). Below listed are the market price of sunflower seed, oil and meal and their specification.

Item	Specification	Price (US Dollar/MT)
Sunflower Oil	(High Linoleic Oil Content) -Refined Oil	2045
Sunflower Seed	High Linoleic Oil seed	500
Sunflower Meal	35% Protein Content	480

Table 2.4.1: Price of Commodities based on the year of 2008. (Source: http://lipidlibrary.aocs.org & http://www.fao.org)

CHAPTER 3
METHODOLOGY

3.1 Project Flow

Figure 3.1 depicts the methodology employed in all phases of the project. Aspentech HYSYS is used to perform the simulation of SC-CO_2 and cost analysis respectively. Matlab software will be used to compute complex equations.

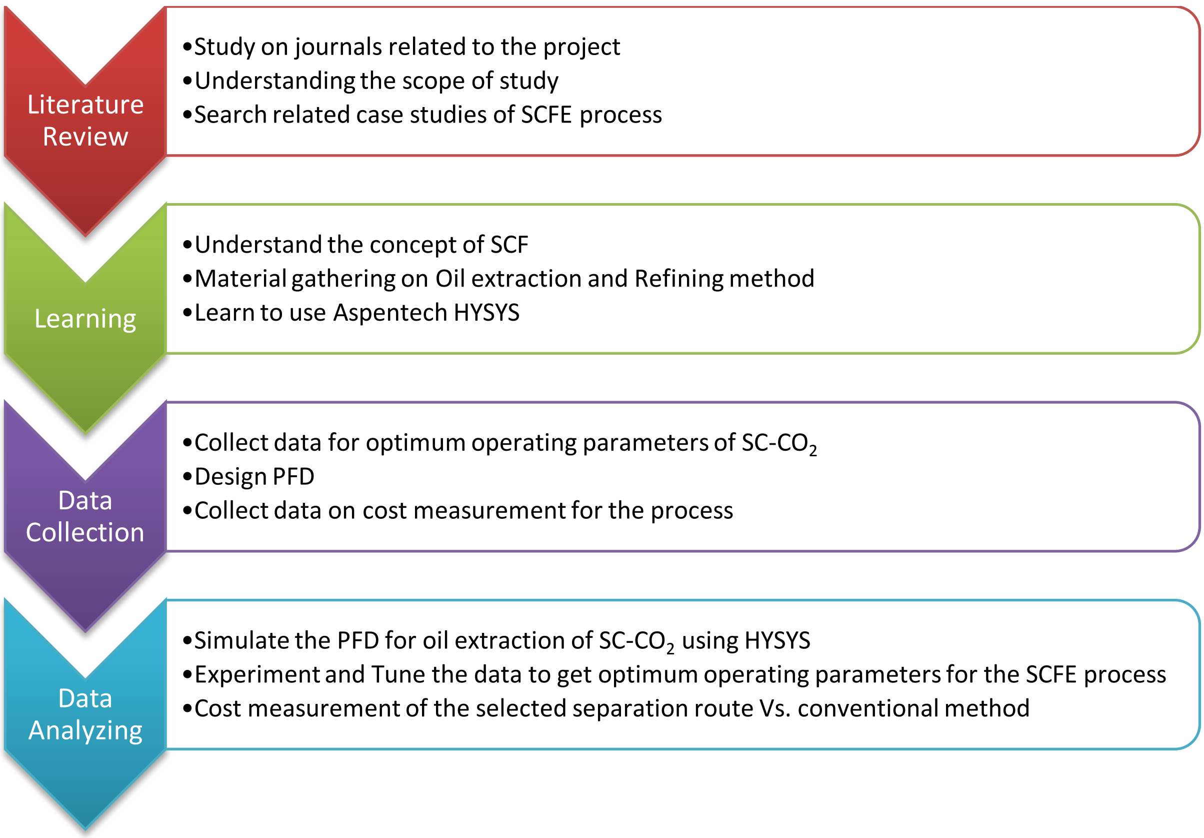


Figure 3.1.1: Overview of Project Flow

Above explained is the overview of the project flow. The breakdown of the project flow is further elaborated in points form below. The points elaborated below are the work flow for the simulation modelling.

1. Preliminary Step: (FYP I)

   - Use HYSYS Simulation Software to Design the Process flow Diagram

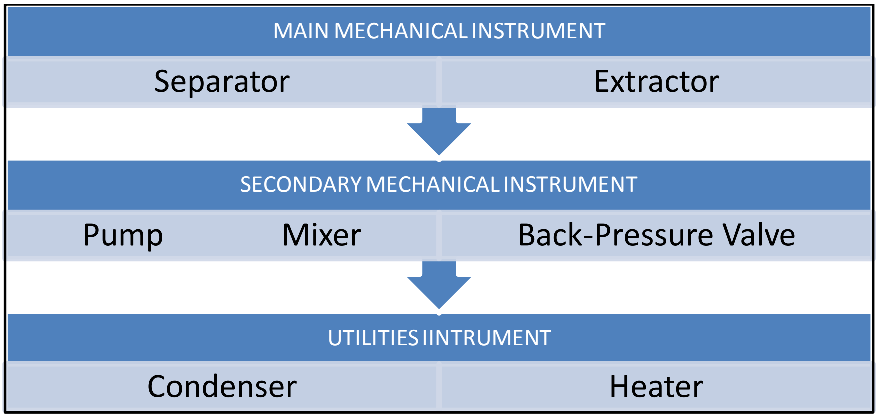


Figure 3.1.2: Basic Instrument for SC-CO_2 extraction of Sunflower Oil

The process is very simple and constitute a fewer instrument compared to the conventional methods. HYSYS Simulation software already has the equipment database and for the simulation for this project will use the existing equipment provided in the database.

- Configure Existing Fluid Package: UNIQUAC-UNIFAC

The thermodynamic package that will be used in HYSYS is the UNIQUAC (universal quasi chemical model). This will be the first option. HYSYS is famous for oil and gas related cases. So if the fluid package does not sufficient enough to provide the required result second option will be undertaken. The second option is to manually establish the condition in the HYSYS. This is done by introducing user mathematical model. In this project, the Sovova Mathematical model is chosen from literature review.

Furthermore, as mentioned earlier, HYSYS does not have most of the edible oil compound. So hypothetical feature need to be used by configure UNIFAC (universal function group activity coefficient model) to create hypothetical components to introduce the oil components not present in the HYSYS.

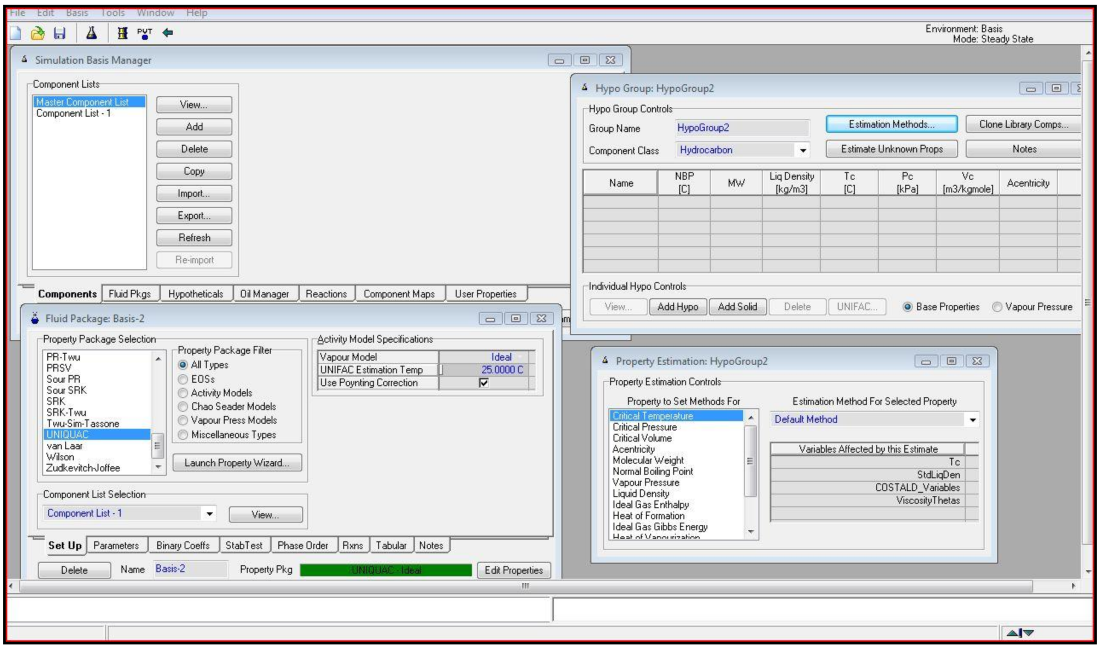


Figure 3.1.3: HYSYS Simulation Environment Interface to select the Fluid Package and identify Hypothetical components

2. FYP II

- Optimize the operating conditions of equipments in HYSYS for better oil yield
- Comparison of the data with Theoretical data by developing graph for operating parameters versus the oil yield
- If existing model using UNIQUAC package failed, adopt Sovova Model to introduce to the HYSYS simulator.
- Finally, Preliminary Cost Analysis of SC-CO_2 process versus conventional method

3.2 PROJECT TIMEFRAME

The Gantt chart and key milestone of the project flow for FYP II is shown below:

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Learning VBA Code for programming in HYSYS															
2	Simulate the process in HYSYS															
3	Optimization of selected process															
4	Market Study of Sunflower oil															
5	Preliminary project cost estimation															
6	Submission of Progress Report															
7	Project Work Continues															
8	Pre-SEDEX															
9	Submission of Draft Report															
10	Submission of Project dissertation (Softbound)															
11	Submission of Technical Paper															
12	Oral Presentation															
13	Submission of Project dissertation(Hardbound)															

Table 3.2.1: Gantt chart of the project flow for FYP II

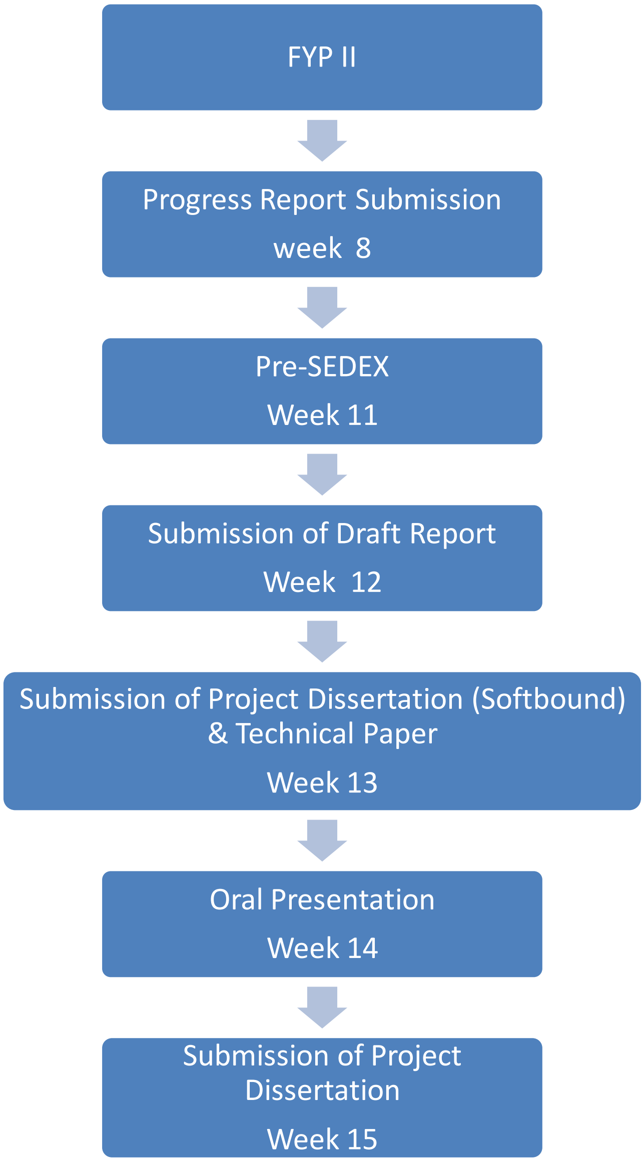


Figure 3.2.2: Key Milestone of the FYP II

3.3 SOFTWARE REQUIRED

1. Aspentech HYSYS
2. Microsoft Excel
3. Microsoft Visual Basic

The Aspentech HYSYS Simulation software will be used to simulate the process. Microsoft Excel will be used to calculate complex mathematical model as well as to develop complex graphs and Microsoft Visual Basic will be used to write programming language to communicate with hypothetical process in HYSYS.

CHAPTER 4
RESULTS & DISCUSSION

4.1 HYSYS Simulator Configuration

Sunflower oil is a complex mixture made by several complex components, and most of the components are not present in the HYSYS Simulator. First, it was necessary to create in the simulator hypothetical components, which take into account the structure of the molecules, in order to be possible to count the groups and the number of groups present in each molecule according to the methodology presented in the software, using the UNIFAC group contribution. So, they are automatically introduced in the simulator database and the physical properties can be predicted. After creating, the components can be used to simulate the process in the simulator HYSYS. Furthermore, it was necessary to adapt the existing units in the simulator to simulate the supercritical extraction process. In the HYSYS database, the thermodynamic package that was chosen was UNIQUAC (Universal Quasi Chemical Model). For this study, the components used are described in the Table 4.1.1. There are five components identified for this simulation although sunflower oil consists of many components. Here the components contribute the large quantity in sunflower oil take into consideration to prevent the complexity in simulation. To make the extraction, a component splitter column was used as unit operation present in the simulator, called here as “extractor.” The solvent was the supercritical carbon dioxide (SC-CO_2) and the feed was made by the components presented in Tab le 4.1.1. A process simulator was not used for extractor column instead it was calculated separately by excel spread sheet. However for the whole process in term of energy consumption and operating parameters were optimized and solved using HYSYS solver.

Components of Sunflower Seed	Mass Percentage (%)
Linoleic Acid, $C_{18}H_{32}O_2$	28.4
Oleic Acid, $C_{18}H_{34}O_2$	8.4
Palmitic Acid, $C_{16}H_{32}O_2$	3.9
Stearic Acid, $C_{18}H_{36}O_2$	3.0
Alpha-Tocopherol, $C_{29}H_{50}O_2$	0.02
Glutamic Acid, $C_5H_9NO_4$	56.3
Components of Sunflower Oil	**Mass Percentage (%)**
Linoleic Acid, $C_{18}H_{32}O_2$	68.7
Oleic Acid, $C_{18}H_{34}O_2$	18.8
Palmitic Acid, $C_{16}H_{32}O_2$	8.0
Stearic Acid, $C_{18}H_{36}O_2$	4.4
Alpha-Tocopherol, $C_{29}H_{50}O_2$	0.07

Table 4.1.1: Components of sunflower seed and oil used in HYSYS Simulator

4.2 Process Description

In the process, Sunflower seed is first charged to Extractor-1, the extraction vessel. The sunflower seed is sonicated and dried to remove the wet contents prior to feed into the extractor and the process is in batch form. Supercritical CO_2 is then fed from the holding tank, to the extractor. The CO_2 Liquid was supplied at the pressure of 150 bar and temperature estimated at 22^0C. This is the normal manufacturing condition supplied in the market. Then the liquid CO_2 stream will pass through two pumps where it will be pressurized to 250 bar. Then it will be channelled to a heater where it will heat up the stream from 22^0C to 40^0C. After the heater the stream exists in supercritical state and then it will be fed to the extractor. The SC-CO_2 is then passed through the extraction vessel for a total of ten hours. Here the SC-CO_2 is fed in a continuously to the extractor vessel 1 and 2. The process operates in a semi-continuous manner. At this point, 98% of the sunflower oil, which is assumed to has been removed from the sunflower seed. The SC-CO_2 and extracted sunflower oil leave the extractor and pass through PRV-1 and PRV-2, the pressure reducing valve, respectively where the mixture is reduced from 250 bar to 4.5 bar. The pressure reduction will throttle the SC-CO_2 to become gas CO_2. The two-phase mixture then enters the flash vessel, Separator, where essentially all of the liquid sunflower oil exits from the bottom of the flash vessel. Essentially all of the CO_2 exits the top of the flash vessel and then enters compressor and condenser, where it is compressed and cooled back to supercritical pressure and temperature. The recycled CO_2 is then sent back to Holding Tank. The process is operated such that the entire amount of CO2 in the holding tank is circulated through the process only once over the ten-hour extraction period. Once a given amount of CO_2 has passed through all the pieces of equipment, it is sent back to the storage tank where it is accumulated for extraction of the next batch of sunflower seed. There will be some CO_2 lost in the process and it has been replaced in the system through a Make-up CO_2 stream to remain the quantity of CO_2 in the system. There are also possibilities to run the process by making two extractor running at the same time while the other two idle until the extraction time of the first one to complete. Once the CO_2 used for the previous extractors are ready in the holding tank then the process for the next two extractors can occur simultaneously. This option will be considered once the initial cost study finalised to see the profitability of the current process. The production rate is specified in Table 4.2.1. The data of the total stream table are attached in Appendix 1. The Process flow diagram is also attached in Appendix 2.

Stream	**Sunflower Feed-1**	**SC-CO_2 Feed-11**	**Sunflower Feed-2**	**SC-CO_2 Feed-12**	**Extractor-1 Bottom**	**Extractor-1 Top**	**Extractor-2 Bottom**	**Extractor-2 Top**	**Separator Top**	**Separator Bottom**
Temperature (^{0}C)	30	40	30	40	40	40	40	40	20	20
Pressure (Bar)	-	150	-	150	-	250	-	250	4.5	4.5
State	Solid	Supercritical	Solid	Supercritical	Solid	Supercritical	Solid	Supercritical	Vapour	Liquid
Components Mass Flow (Kg/hr)										
Linoleic Acid	141.91	-	141.91	-	2.8381	139.07	2.8381	139.07	-	278.26
Oleic Acid	41.748	-	41.748	-	0.83497	40.913	0.83497	40.913	-	82.304
Stearic Acid	15.119	-	15.119	-	0.30239	14.817	0.30239	14.817	-	29.39
Palmitic Acid	19.439	-	19.439	-	0.38879	19.051	0.38879	19.051	-	38.212
Alpha-Tocopherol	0.00995	-	0.00995	-	-	0.00995	-	0.00995	-	0.157
Glutamic Acid	281.69	-	281.69	-	281.69	-	281.69	-	-	-
Carbon Dioxide	-	24000.00		24000.00	-	24000.00	-	24000.00	48996.00	-
Total Flow	**500.00**	**24000.00**	**500.00**	**24000.00**	**286.05**	**24213.95**	**286.05**	**24213.95**	**48996.00**	**428.97**

Table 4.2.1: HYSYS Simulation results of Sunflower oil extraction using supercritical carbon dioxide (SC-CO_2)

4.3 Process Optimization

In the study of the extraction processes, and also of the chemical processes, one of the aspects that require most attention is the extension and application of the results obtained on a laboratory scale to pilot plant and industrial scales. This process is in most cases very complex and it is known as scale up. The methodology applied to the scale up requires the application of the theory of similarity and involves the use of systems of magnitudes and units. In the work described here, it is considered that the extractor is under isothermal conditions and chemical reaction does not take place. Consequently, the only similarity relationships that are considered are those corresponding to geometry and dynamics. For this reason, it is only necessary to keep constant in scales, laboratory and industrial, the geometric factors and the dimensionless numbers related to the dynamic similarity. For this scale-up procedure the experimental results were taken from *(Nimet, et al., 2011)*. Only certain parameter such as the mass flow of feed, extraction time, mass flow of Carbon dioxide were taken into consideration for process optimization purpose as well as to identify the mass of oil extract. The optimization was carried out into three segments which are comprised of the following to identify optimum oil extraction parameters as well as cost effective.

1. Temperature and Pressure effects over yield
2. Extraction time over yield
3. Solvent flow rate over yield

<u>Temperature & Pressure Effects over Yield</u>

From the experimental data obtain from the journal *(Nimet, et al., 2011),* used a pressure range of 190 bar to 250 bar and temperature range of 40^0C to 60^0C. The important factor played by this temperature and pressure changes are the influence of density of the SC-CO2. Density is the main driving force of this SCF process. The following table will describe the trend of density over pressure and temperature.

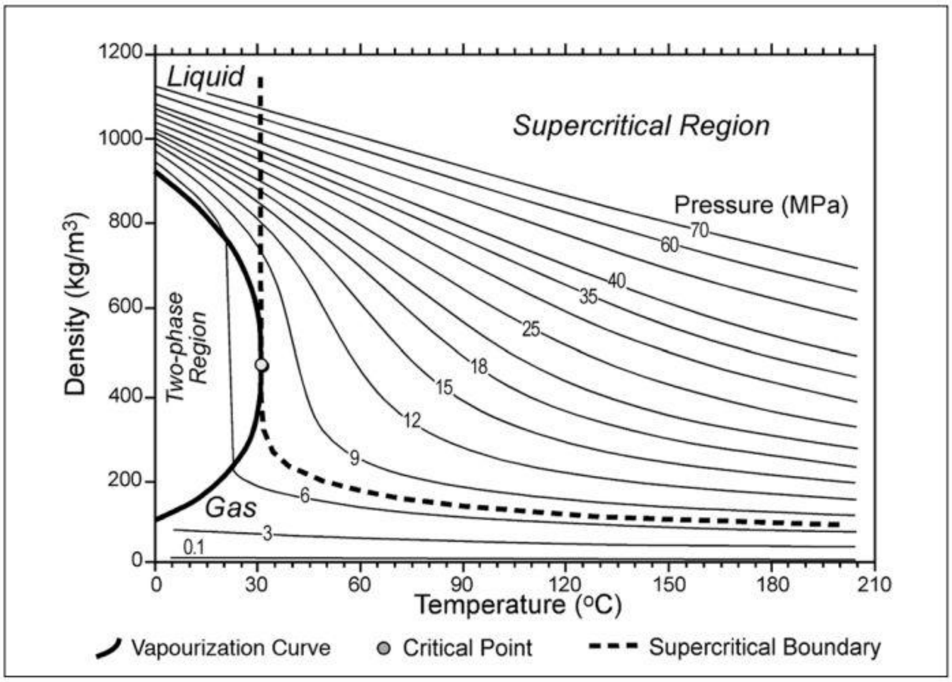
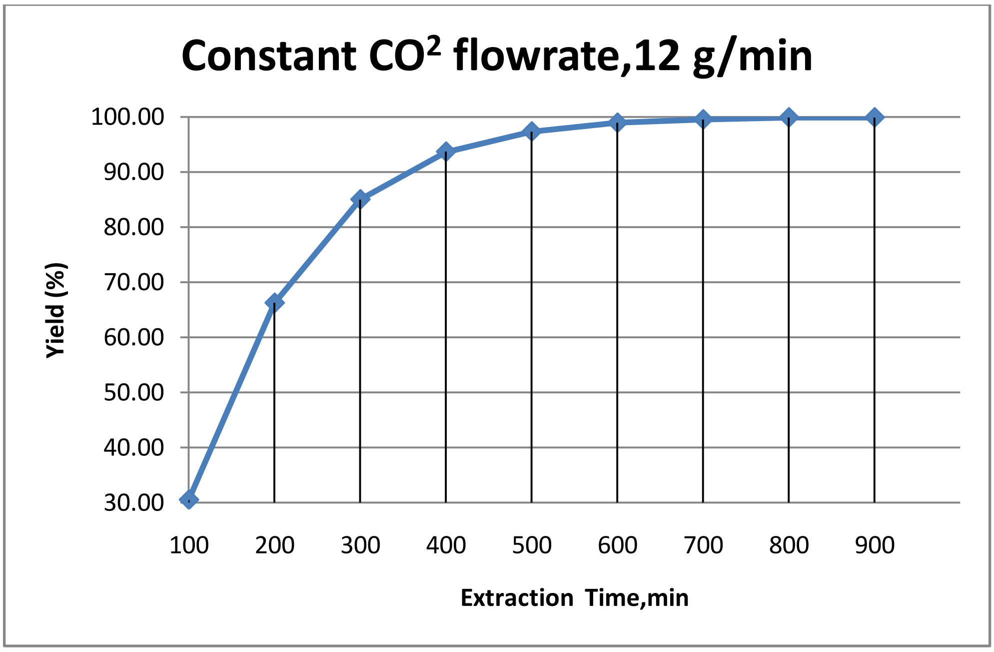


Figure 4.3.1: Variation of CO_2 density as function of Temperature and Pressure

As we can see from the figure above, the density is plotted higher at the highest pressure and the lower temperature. This density is essential part of SCF extraction because it carries the capacity of the SCF at the specific extraction. In this process, the pressure and temperature used are 250 bar and 40^0C yield 0.88 g/cm^3 of density of SC-CO_2 [9 & 10]. From the experimental data also prove that this is the optimal operating parameters results in highest yield of oil which is 0.39 Kg oil/Kg Seed [9]. The further the pressure will result further higher reading of density however the yield fraction are very small. Furthermore the higher the operating parameters the higher will be the energy consumption in the process which will result larger operating cost. Hence the pressure 250 bar with temperature of 40^0C gives the best solvent capacity for the extraction [10].

Extraction Time over Yield

Extraction time plays a bigger role in this SCF process. The higher the extraction time will result in higher operating cost. Hence for a profitable process it is essential to choose the best extraction time. The graph below will show the extraction time of SC-CO2 over oil yield at a constant flow rate.

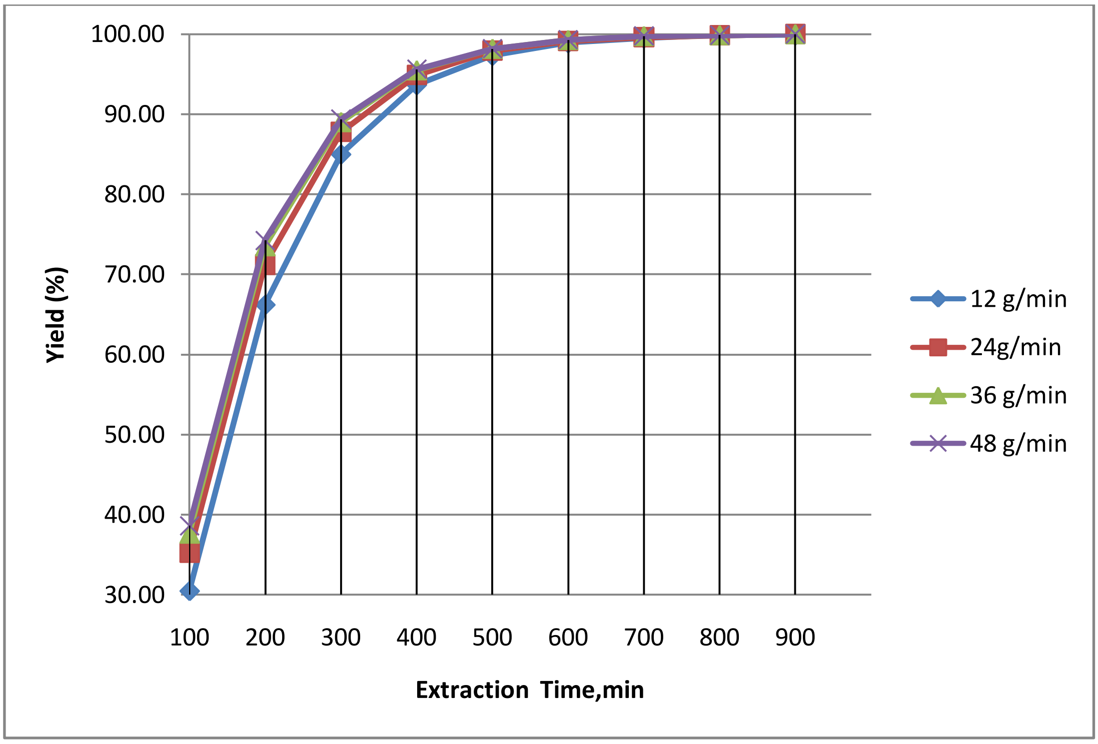


Graph 4.3.2: Effects of extraction time on the yield of sunflower oil [9]

As we can see from the graph above, the higher the extraction time resulting in the highest yield of sunflower oil at the constant CO_2 flowrate. However when the time exceeds 600 min the yield curve becomes linear. This shows that after the 600 min of extraction time the extraction bed become exhausted of the solute, sunflower oil, and hence the solubility trend of SC-CO_2 in the mixture decreases and hence requires more time for it to yield more oil. Hence we can conclude that the process is at optimum extraction time at 600 min which gives 98 % yield of sunflower oil. The more the extraction time will result in more operational cost and hence it is best to optimise the process at its efficient point.

Solvent (SC-CO_2) Flowrate over Yield

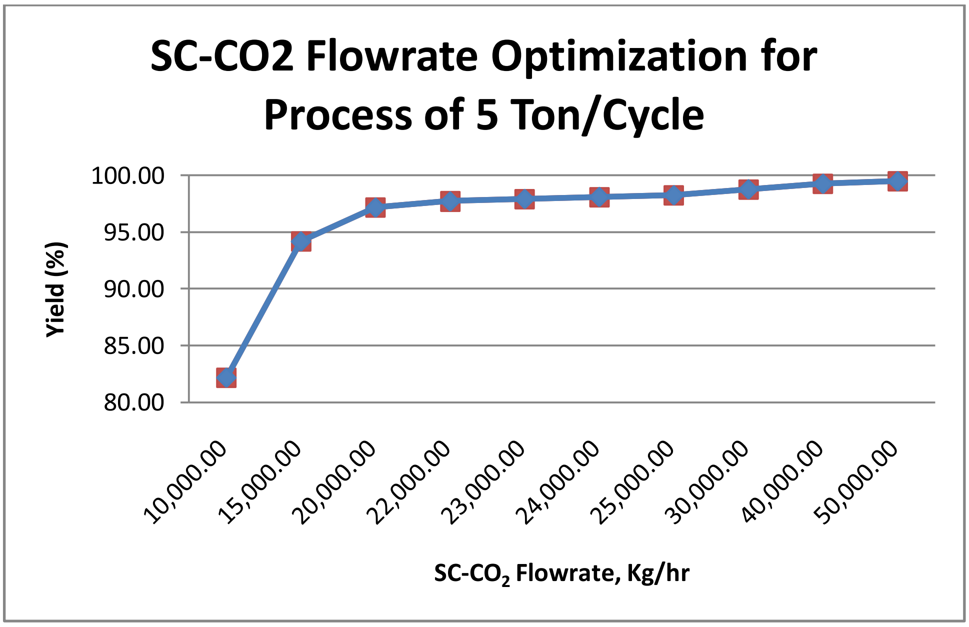
This section we will see the effects of solvent flowrate over the yield of sunflower oil at the different the different extraction time. This will gives the best decision on selecting the optimum solvent rate and at the same time double proof the chosen extraction time for our process. Please refer to the following graph.



Graph 4.3.3: Effects of solvent (SC-CO2) flowrate over yield of sunflower oil

The graph above can be interpreted in two ways. First of all, in term of a solvent flowrate. At the extraction time of 600 min, we can notice the behaviour of oil yield influence by the solvent flowrate. The higher the flowrate the higher the oil yields. As we can see from the graph solvent flowrate of 48 g/min and 36 g/min having the higher solvent flowrate and their yield values are merely the same. Hence in order to save the capital as well as the operational cost the best way is to choose the 36 g/min flowrate of SC-CO2 compare to 48 g/min per say. Also this value indicates the maximum solvent flowrate per mass of feed fed to the system. These values will result in global yield isotherm which comprise of the ratio of solvent mass over mass of feed fed to the system. It will help to identify the required mass of solvent over a known mass of feed. From the experimental observation of this process it was identified the ratio of solvent over feed is 6. Apart from that, there is another factor also need to be notice here. As per mentioned previously, the process were saturated at the extraction time of 600 min even with higher flowrate of solvent. This is due to the exhaustion of the extraction bed which results in difficulty to extract further oil. Hence from this, it is proof 600 min of extraction time is the optimum process extraction time need to be used for scale-up process [9].

Finally, the above parameters were optimized to get the best operation parameters for a scale-up plant of 5 Ton/cycle.



Graph 4.3.4: Solvent (SC-CO2) flowrate optimization for Sunflower feed of 5Ton/cycle.

Hence from the global yield isotherm it was identified for 5 Ton of sunflower feed it was estimated to use 30,000 Kg/hr SC-CO2 flowrate. However for optimization purpose the flowrate were further breakdown into decimals at constant extraction time of 600 min to identify the best solvent flowrate. Hence it is observed at he flowrate of 24,000 Kg/hr the process were saturated with the oil as we can observe the trend of the curve getting flat. At his point it was observed 98 % oil yield or oil recovery from the sunflower seed.

4.4 Feasibility Studies

TOTAL PRODUCTION COST ESTIMATION

Cost estimation is a specialized subject and profession in its own right which involves the systematic evaluation of the economic merits of proposed solutions to engineering problems. The purpose of economics analysis is to determine the project evaluation and it’s economically feasibility. Estimation of the investment and the cost of production are required before the profitability of a project can be assessed. In this section, the project evaluation is done through the steps listed as follows:

i. Total Process Equipment Cost
ii. Total Investment Estimation
iii. Operating Cost Estimation

Although SCF is a new emerging technology, it is essential to identify the feasibility of the process in term of the cost. Hence this section will cover the economic potential of Supercritical Carbon dioxide process in recovering sunflower oil from sunflower seed will be analysed. The Total Production Cost, TPC for the Project is as below. The detail calculation was attached in Appendix III.

Manufacturing Expenses	**Specification**	**Cost (RM/yr)**
Direct Production Cost		
Raw Material	$/MT	
Sunflower Seed	580	3,200,000.00
Utilities		
Electricity	2.86	199,513.60
Steam (per kg steam)	0.003	80,000.00
Chilled Water (per 1000kg CW)	0.50	25,600.00
Make-Up CO2 (per Kg)	0.92	16,486.00
Fuel (per kWh)	0.015	176,353.92
Others		
Maintenance and Repairs	2% FCI	287,507.74
Operating Supplies	10% Maintenance and Repairs	28,750.77
Operating Labour	10 person/day (RM1200/month each person)	48,000.00
Direct Supervision & Clerical Labour	10% Operating Labour	4,800.00
Laboratory Charges	5% Operating Labour	2,400.00
Patents and Royalties	1% Total Expenses	40,694.12
Indirect Production Cost		
Local Taxes	1.5% FCI	215,630.81
Insurance	0.5% FCI	718,769.35

Plant Overhead	60% of the sum of operating labour, supervision and maintenance	204,184.64
Total Manufacturing Expenses (excluding depreciation), A_{ME}		**5,248,690.95**
Depreciation, A_{BD}	**10%FCI**	**1,437,538.70**
General Expenses		
Administration Cost	25% Overhead	51,046.16
Distribution & Selling Expenses	10% Total Expenses	406,941.20
Research and Development	5% Total Expenses	203,470.60
Total Production Cost (TCI)	**A_{ME} + A_{GE}**	**5,910,148.92**
Total General Expenses, A_{GE}		**661,457.97**
Total Expense, A_{TE}	**A_{ME} + A_{GE} + A_{BD}**	**7,347,687.62**
Revenue from Sales	RM/kg	
Sunflower Oil	2045	5,611,480.00
Sunflower Meal	480	1,756,800.00
Sales Income, A_S		**7,368,280.00**
Net Annual Profit, A_{NP}	**Sales Income-A_{TE}**	**20,592.38**
Income Taxes	30%	6,177.71
Net Annual Profit After Income Taxes, A_{NNP}		**14,414.67**
After Rate of Return, I	$\left(\frac{A_{NNP} + A_{BD}}{TCI}\right) \times 100$	**8.08**

Table 4.4.1: Total Investment for Sunflower oil Extraction Plant

PROFITABILITY ANALYSIS

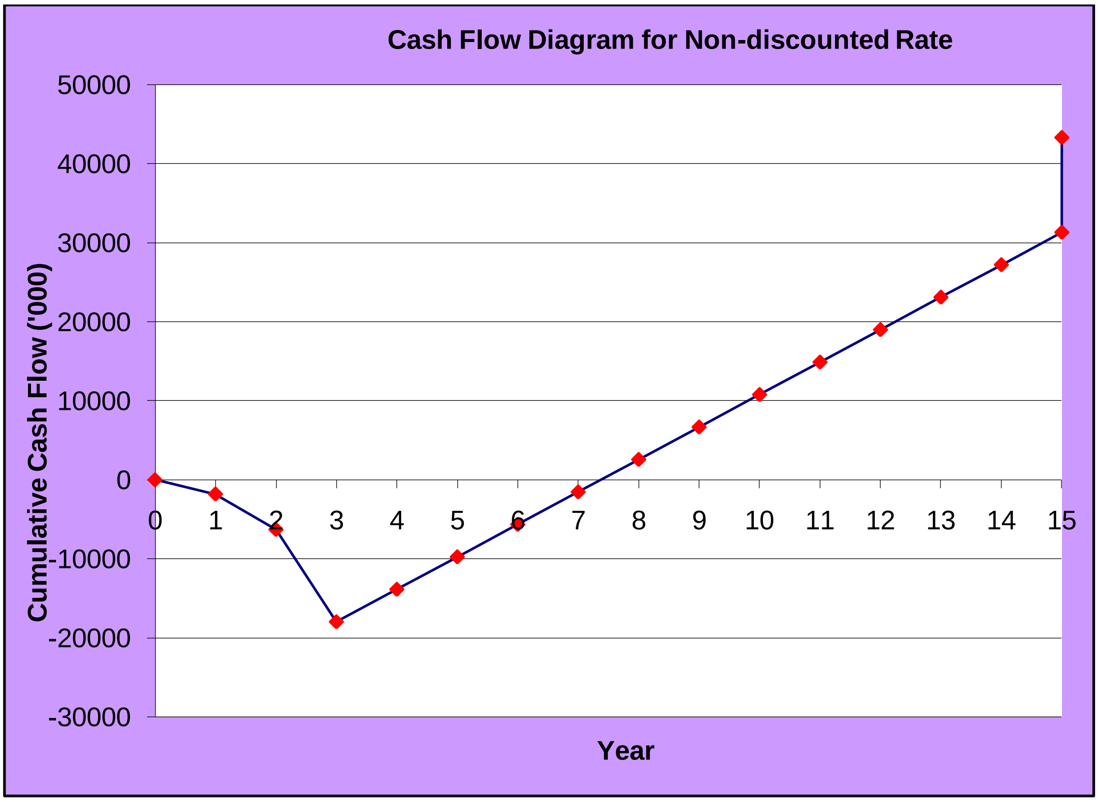
In the process of making an investment decisions, the profit anticipated from an investment must be judged relative to some profitability analysis. A profitability analysis is a quantitative measure of profit with respect to the investment required to generate that profit. In determining the economic attractiveness of a project, it is important to base the decision on three important economic parameters which are:

1. After Tax Cash Flow (ATCF)
2. Pay Back Period (PBP)
3. Return on Investment (ROI)
4. Net Present Worth (NPW)

Economic Assumptions:

1) The plant has a project plant life of 15 years.
2) The plant construction period is 3 years before commencing production. Hence, the total investment cost is distributed evenly between the 3 years.
3) The operating cost, income and raw material cost is assumed to maintain throughout the lifetime of the project.
4) Local Taxes is assumed to be at 30% annually.

Here, the net cash flow in each year of the project is brought to its "present worth" at the start of the project by discounting it at some chosen compound interest.

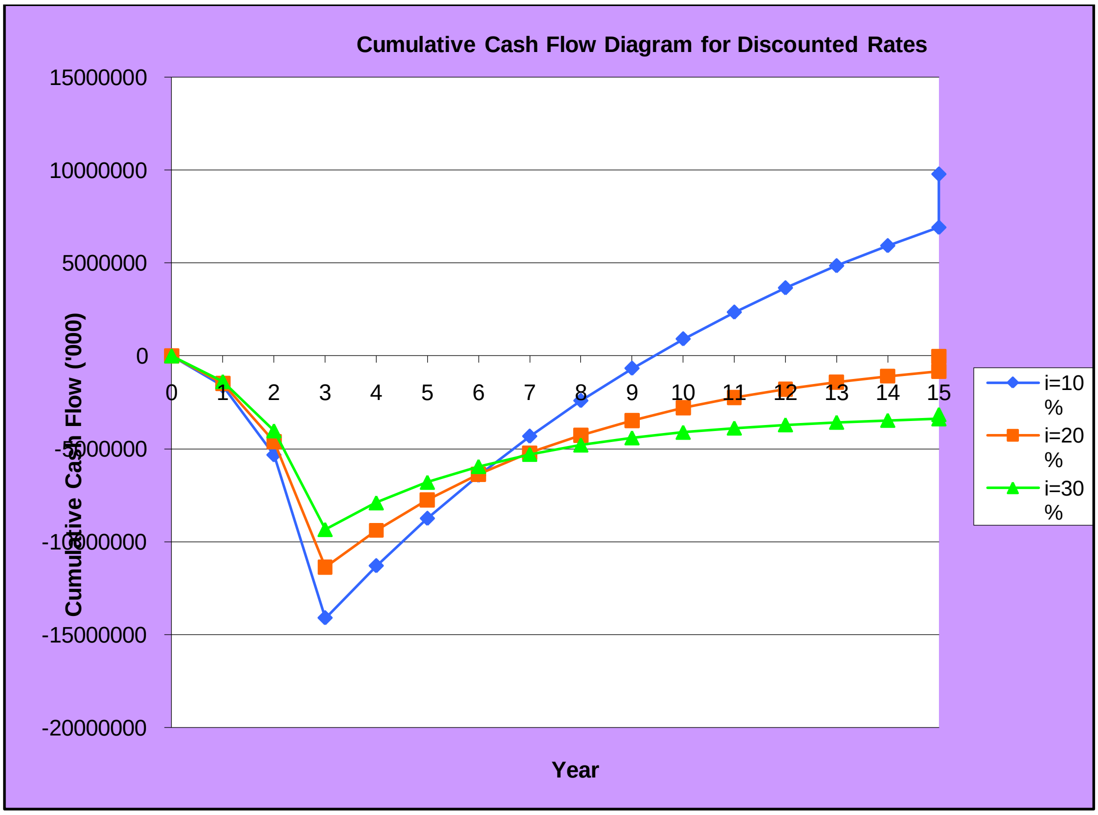


Graph 4.4.2: Non-Discounted Cash Flow of the Project

Year	Annual Capital Investment	Sales Income	Operating costs	Depreciation	Income Before Tax	Income Tax (30%)	Income After Tax	Cash Income	Net Cash Flow	Cumulative Cash Flow
An	A(I)	A(SI)	A(OI)	A(BD)	A(IBT)		A(IAT)	A(CI)	A(NCF)	
1	1,796,923								-1,796,923	-1,796,923
2	4,492,308								-4,492,308	-6,289,232
3	11,680,002								-11,680,002	-17,969,234
4		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	-13,861,079
5		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	-9,752,923
6		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	-5,644,768
7		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	-1,536,613
8		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	2,571,542
9		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	6,679,697
10		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	10,787,853
11		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	14,896,008
12		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	19,004,163
13		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	23,112,318
14		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	27,220,473
15		7,368,280	3,553,114	1,437,539	3,815,166	1,144,550	2,670,616	4,108,155	4,108,155	31,328,628
15	-12,000,000								12,000,000	43,328,628

Table 4.4.3: Non-Discounted Cash Flow of the Project

The discounted cash flow is used to calculate the present worth of future earnings. By calculating the net present worth (NPW) for various interest rates, it is possible to find an interest rate at which the cumulative net present worth at the end of the project is zero. It is a measure of the maximum rate that the project could pay and still break even by the end of the project life. From the results shown in Table 4.4.5 it is seen that the rate to give zero present worth will be about 39.14%. This is the DCFRR for the project and it is the maximum rate the project could pay and still break even by the end of project life. Thus 39.14% represents the internal earning rate of this project that causes the unrecovered investment balance to exactly equal to zero at the end of 15 years. Since the DCFRR is 39.14%, which is more than 15%, the project is worth investing.



Graph 4.4.4: Discounted Cash Flow of the Project

Year of Completion	Net Cash Flow A (NCF)	Discounted Cash Flow for 0% cumulative	Discount Factor, fd (i = 10%)	Discounted Cash Flow for 10% [A(NCF)*fd]	Discounted Cash Flow for 10% Cumulative	Discount Factor, fd (i = 30%)	Discounted Cash Flow for 30% [A (NCF)*fd]	Discounted Cash Flow for 30% Cumulative	Discount Factor, fd (i = 20%)	Discounted Cash Flow for 20% [A (NCF)*fd]	Discounted Cash Flow for 20% Cumulative
0	0	0			0			0			0
1	-1,796,923	-1,796,923	0.9091	-1,633,583	-1,633,583	0.7692	-1,382,193	-1,382,193	0.8333	-1,497,376	-1,497,376
2	-4,492,308	-6,289,232	0.8264	-3,712,444	-5,346,027	0.5917	-2,658,099	-4,040,292	0.6944	-3,119,459	-4,616,835
3	-11,680,002	-17,969,234	0.7513	-8,775,185	-14,121,212	0.4552	-5,316,737	-9,357,029	0.5787	-6,759,217	-11,376,052
4	4,108,155	-13,861,079	0.683	2,805,870	-11,315,342	0.3501	1,438,265	-7,918,764	0.4823	1,981,363	-9,394,689
5	4,108,155	-9,752,923	0.6209	2,550,754	-8,764,589	0.2693	1,106,326	-6,812,438	0.4019	1,651,068	-7,743,622
6	4,108,155	-5,644,768	0.5645	2,319,054	-6,445,535	0.2072	851,210	-5,961,228	0.3349	1,375,821	-6,367,800
7	4,108,155	-1,536,613	0.5132	2,108,305	-4,337,230	0.1594	654,840	-5,306,388	0.2791	1,146,586	-5,221,214
8	4,108,155	2,571,542	0.4665	1,916,454	-2,420,775	0.1226	503,660	-4,802,728	0.2326	955,557	-4,265,657
9	4,108,155	6,679,697	0.4241	1,742,269	-678,507	0.0943	387,399	-4,415,329	0.1938	796,160	-3,469,497
10	4,108,155	10,787,853	0.3855	1,583,694	905,187	0.0725	297,841	-4,117,488	0.1615	663,467	-2,806,030
11	4,108,155	14,896,008	0.3505	1,439,908	2,345,095	0.0558	229,235	-3,888,253	0.1346	552,958	-2,253,072
12	4,108,155	19,004,163	0.3186	1,308,858	3,653,954	0.0429	176,240	-3,712,013	0.1122	460,935	-1,792,137
13	4,108,155	23,112,318	0.2897	1,190,133	4,844,086	0.033	135,569	-3,576,444	0.0935	384,113	-1,408,025
14	4,108,155	27,220,473	0.2633	1,081,677	5,925,763	0.0254	104,347	-3,472,097	0.0779	320,025	-1,087,999
15	4,108,155	31,328,628	0.2394	983,492	6,909,256	0.0195	80,109	-3,391,988	0.0649	266,619	-821,380
15	12,000,000	43,328,628	0.2394	2,872,800	9,782,056	0.0195	234,000	-3,157,988	0.0649	778,800	-42,580

Table 4.4.5: Discounted Cash Flow of the Project

DISCUSSION

Cash flow is very important in any commercial organization. The cash flows are related to the material flows of a process plant. The inputs are the cash needed to pay for research and development, plant design and construction and plant operation. The output is goods for sale. A cash flow diagram, as shown in previous tables, shows the forecast cumulative net cash flow over the life of a project. The cash flows are based on the best estimates of investment, operating costs, sales volume and sales price that can be made for the project. The figures shown give a clear picture of the resources required for the project and timing of the earning. The life of this project is 15 year excluding 3 years of design and construction period. Rate of return (ROR) is at 17.88% which is more than the minimum acceptable rate of return of 15%. Hence, it is worth investing in this project. Besides that, the discounted cash flow rate of return (DCFRR) for the project is at 39.15% and it is the maximum rate the project could pay and still break even by the end of project life. The payback time is at the end of year seven (7). This value shows that this project is profitable and the plant will recover back all the investment cost in the 7th year of operation. For a detail evaluation on the economic evaluation of this SC-CO2 extraction of sunflower oil plant, the overall cash flow together with the discounted net cash flow obtain at different rate is shown as in Table 4.4.3 and Table 4.4.5. The sample of cash flow calculations is provided in Appendix III.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

In conclusion, a comprehensive study on supercritical carbon dioxide extraction has been studied. The technological advancement of SCF process was able to identify and relate to the project. Thorough literature review findings clearly show the feasibility of this project. As per the timeframe given for FYP I, the necessary studies and works has completed successfully. The work represents the extraction of sunflower oil using supercritical carbon dioxide using HYSYS to simulate the reliability of the process. The process flow diagram has been drawn and the necessary information for the simulation has been identified. As per first objective, it is true and realisable to design a supercritical carbon dioxide extraction system. The identified operating parameters for the scale-up process is 250 bar and 40 ^{0}C respectively. The process has been identified from many novel research papers and a process flow diagram has been developed for the simulation. From the simulation the energy behaviour of the SCF process were able to identify and optimization were carried out to strengthen the process. From the findings, flowrate of Carbon dioxide of 24 000 Kg/hr were selected as optimum solvent flowrate. Furthermore to justify the project in tern of profitability 4 cycles of sunflower seed extraction which is 20 Metric Ton per day were established. The rate of return (ROR) of the project is above the minimum MARR value 15 % and the project is justifiable.

5.2 Recommendation

There were series of problem arise during the preliminary step activities execution. The problem mainly related to the HYSYS simulation software. As per mentioned earlier, HYSYS is less experienced in term of edible oil extraction. Hence the user needs to specify the details manually to configure the fluid package. Many of the oil components in HYSYS do not have. So to solve this problem it is recommended to use the Hypothetical model creator to create the oil components into the fluid package. Furthermore, the user must be able to initialise solid object into the HYSYS extraction equipment. This is necessary because the system must be able to understand the composition of sunflower seed in the extractor. One of the solution maybe, manually configure mathematical model for solid for the extractor. This will assist the HYSYS to calculate manually for that particular equipment. Furthermore, it is advisable to carry out this project further in a pilot plant scale for better understanding of the process and henceforth can be scaled-up for commercial purpose.

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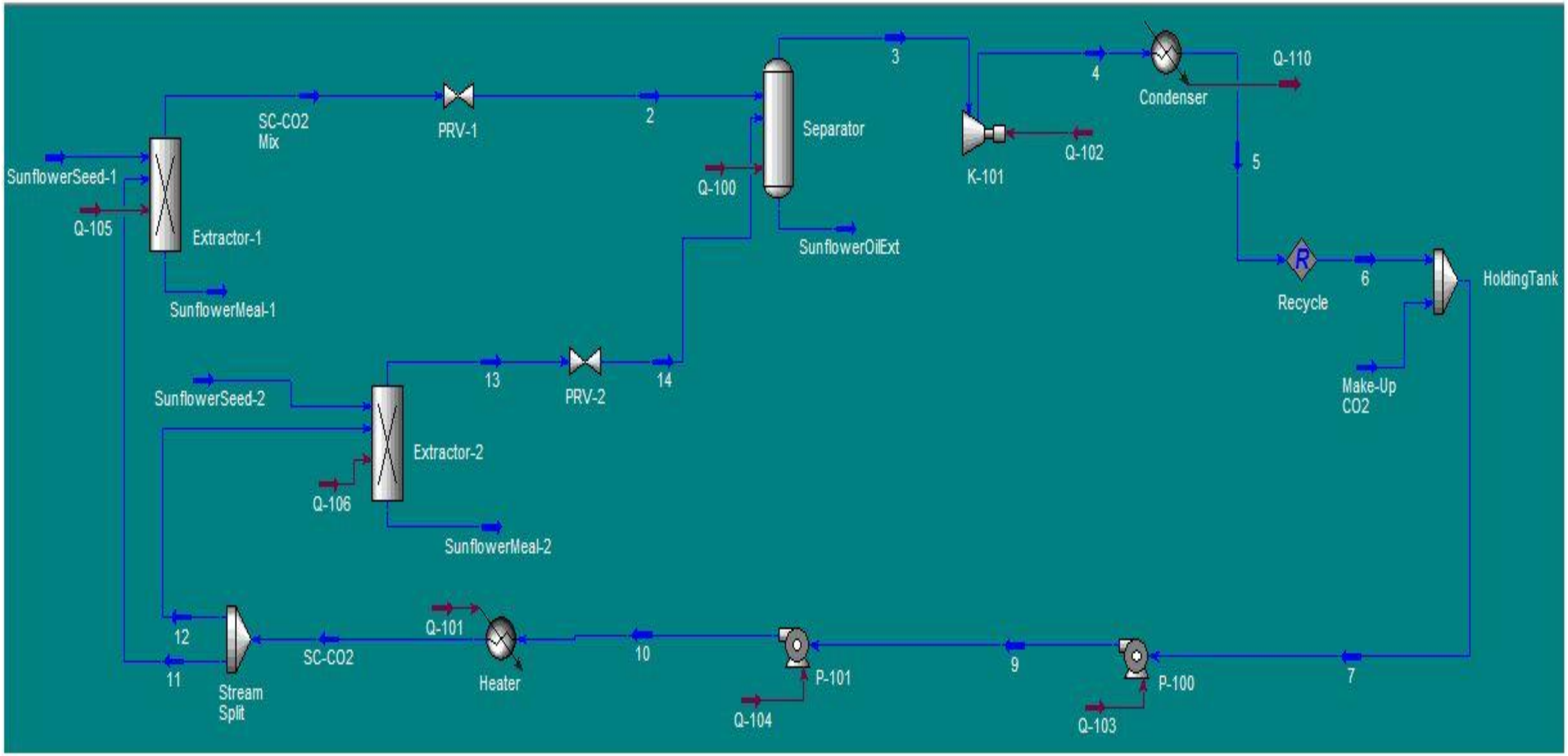
APPENDIX 1

PROCESS FLOW DIAGRAM OF SC-CO2 IN HYSYS SIMULATOR



APPENDIX II

PROCESS STREAM DATA OF SC-CO2 EXTRACTION OF SUNLFOWER OIL

Stream	SunflowSeed-1	11	SunflowerSeed-2	12	SC-CO2 Mix	2	SunflowerMeal-1	13
Temperature (^{0}C)	30.0	40.0	30.0	40.0	40.0	-61.4	40.0	40.0
Pressure (Bar)	-	150.0	-	150.0	250.0	4.5	-	250.0
State	Solid	Supercritical	Solid	Supercritical	Supercritical	Vapour	Solid	Supercritical
Components Mass Flow (Kg/hr)								
Linoleic Acid	141.9	-	141.9	-	139.1	139.1	2.8	139.1
Oleic Acid	41.7	-	41.7	-	40.9	40.9	0.8	40.9
Palmitic Acid	15.1	-	15.1	-	14.8	14.8	0.3	14.8
Stearic Acid	19.4	-	19.4	-	19.1	19.1	0.4	19.1
alpha-Tocopherol	0.0	-	0.0	-	0.0	0.0	-	0.0
Glutamic Acid	281.7	-	281.7	-	-	-	281.7	-
Carbon Dioxide	-	24000.0		24000.0	24000.0	24000.0	-	24000.0
Total Flow (Kg/hr)	**500.0**	**24000.0**	**500.0**	**24000.0**	**24214.0**	**24214.0**	**286.1**	**24214.0**

Stream	SunflowerMeal-2	14	3	SunflowerOilExt	4	5	6	7
Temperature (^{0}C)	40.0	-61.4	20.0	20.0	334.9	22.0	22.0	22.0
Pressure (Bar)	-	4.5	4.5	4.5	120.0	150.0	150.0	150.0
State	Solid	Vapour	Vapour	Liquid	Vapour	Liquid	Liquid	Liquid
Components Mass Flow (Kg/hr)								
Linoleic Acid	2.8	139.1	-	278.3	-	-	-	-
Oleic Acid	0.8	40.9	-	82.3	-	-	-	-
Palmitic Acid	0.3	14.8	-	29.4	-	-	-	-
Stearic Acid	0.4	19.1	-	38.2	-	-	-	-
alpha-Tocopherol	-	0.0	-	0.2	-	-	-	-
Glutamic Acid	281.7	-	-	-	-	-	-	-
Carbon Dioxide	-	24000.0	48996.0	-	47994.0	47994.0	47994.0	48000.0
Total Flow (Kg/hr)	**286.1**	**24214.0**	**48996.0**	**429.0**	47994.0	47994.0	47994.0	48000.0

Stream	9	10	SC-C02	Make-Up CO2
Temperature (^{0}C)	33.0	32.5	40.0	22.0
Pressure (Bar)	200.0	250.0	250.0	150.0
State	Liquid	Liquid	Supercritical	Liquid
Components Mass Flow (Kg/hr)				
Linoleic Acid	-	-	-	-
Oleic Acid	-	-	-	-
Palmitic Acid	-	-	-	-
Stearic Acid	-	-	-	-
alpha-Tocopherol	-	-	-	-
Glutamic Acid	-	-	-	-
Carbon Dioxide	48000.0	48000.0	48000.0	5.6
Total Flow (Kg/hr)	48000.0	48000.0	48000.0	5.6

APPENDIX III

CALCULATION ON THE PROJECT CASH FLOW

ESTIMATION OF CAPITAL INVESTMENT

CAPITAL COST

Equipment Costs

Total Purchase Cost of Major Equipment Items (PCE)

Estimated price in 2007

Equipment	Quantity	Cost per equipment ($) in 2007	Total ($)
Extractor	2	135,200	270,400
Separator	1	45,300	45,300
Compressor	1	1,697,000	1,697,000
Pump	2	40,000	80,000
Carbon Dioxide (500,000 KG CO2)	0.92 $ /KG	460,000	460,000
Tank	3	100,000	300,000
Heat Exchanger	2	31,600	63,200
		TOTAL	**2,915,900**

FIXED CAPITAL COST

Item	Process Type (Fluids)
a) Major equipment, total purchase cost, (PCE)	**2,915,900**
f_1 Equipment Erection	0.40
f_2 Piping	0.70
f_3 Instrumentation	0.20
f_4 Electrical	0.10
f_5 Buildings, process	0.15
f_6 Utilities	0.50
f_7 Storages	0.15
f_8 Site Development	0.05
f_9 Ancillary Buildings	0.15
b) Total physical cost (PPC)	
	3.40
PPC ($)	**9,914,060**
f_{10} Design and Engineering	0.30
f_{11} Contractor's fee	0.05
f_{12} Contingency	0.10
$Fixed\ Capital = PPC(1 + f_{10} + f_{11} + f_{12}) = PPCx$	
	1.45
Fixed Capital ($)	**14,375,387**

TOTAL CAPITAL INVESTMENT

Working capital ($)	2,156,308	(15% of Fixed Capital)
Start-up Cost ($)	1,437,539	(10% of Fixed Capital)

Total Capital Investment ($) **17,969,234**

ESTIMATION OF TOTAL OPERATING COST

VARIABLE PRODUCTION COSTS

1) Raw Material

Retail Price

Component	Price
Sunflower Seed	$ 580/MT
Sunflower Oil-Refined	$ 2045/MT
Sunflower Meal	$ 425/MT
Carbon Dioxide	$ 0.92/KG

CONSUMPTION OF RAW MATERIAL

Raw Material	$/MT	MT/year	$/year
Sunflower Seed	500	6400	**3,200,000**
TOTAL COST			**3,200,000**

PRODUCTS MANUFACTURED

Product	$/MT	MT/year	$/year
Sunflower Oil-Refined	2045	2,744	**5,611,480**
Sunflower Meal	480	3,660	**1,756,800**
REVENUE			**7,368,280**

Annual Profit ($) **4,168,280**

2) Utilities

a) Electricity

	Duration	$/kW.h	$/kW.day
Peak period	0800-2200 (12hr)	0.286	1.12
Off-peak	2200-0800 (12hr)	0.286	0.4634

So, electricity price for 1 day: 2.86 $/kW.day
Price per unit = $ 1.24/kWday

Electricity consumption

Equipment	Power Consumption (KW)
Pump	208.00
Extractor	10.00
Total Power Consumption (kW)	**218.00**

Total power consumption /year = Total Power Consumption X Price per day x Working days/year

Annual Electricity Cost ($)	**199,513.60**

b) Steam & Cold Water

Steam Cost ($)	0.003	per kg steam
Cold Water Cost ($)	0.50	per 1000kg CW

Unit	**Usage (kW)**
Cold Utility	13,000.00
Hot Utility	900.00

Utility	**Cost per Day ($)**	**Cost per Annum ($)**
Cold water	80.00	**25,600.00**
Steam	250.00	**80,000.00**

c) Make-Up CO2

CO2 Cost ($/Kg)	0.920	**Cost per Annum ($)**
Usage	5.6 kg/hr	**16,486.00**

d) Fuel for Compressor

Fuel Cost ($)	0.015	per kWh

Unit	**Usage (kW)**	**Usage per Annum (kW)**
Compressor	7,200.00	23,040,000.00
		Cost per Annum ($)
		352,512.00

e) Total Utility Cost

Utility	Cost per Annum ($)
Electricity	199,513.60
Cold Water	25,600.00
Steam	80,000.00
Make-Up CO2	16,486.00
Fuel	352,512.00
TOTAL UTILITIES	**305,113.60**

FIXED COSTS

1) Operating Labour Costs

Shifts/day =	2
People /day =	10
Salary ($)/month =	400

Costs per month ($)	4000
Operating costs per year ($)	**48,000.00**

Manufacturing Expenses	**Specification**	**Cost (RM/yr)**
Direct Production Cost		
Raw Material	$/MT	
Sunflower Seed	580	3,200,000.00
Utilities		
Electricity	2.86	199,513.60
Steam (per kg steam)	0.003	80,000.00
Chilled Water (per 1000kg CW)	0.50	25,600.00
Make-Up CO_2 (per Kg)	0.92	16,486.00
Fuel (per kWh)	0.015	176,353.92
Others		
Maintenance and Repairs	2% FCI	287,507.74
Operating Supplies	10% Maintenance and Repairs	28,750.77
Operating Labour	10 person/day (RM1200/month each person)	48,000.00
Direct Supervision & Clerical Labour	10% Operating Labour	4,800.00
Laboratory Charges	5% Operating Labour	2,400.00
Patents and Royalties	1% Total Expenses	40,694.12
Indirect Production Cost		
Local Taxes	1.5% FCI	215,630.81
Insurance	0.5% FCI	718,769.35
Plant Overhead	60% of the sum of operating labour, supervision and maintenance	204,184.64
Total Manufacturing Expenses (excluding depreciation), A_{ME}		**5,248,690.95**
Depreciation, A_{BD}	**10%FCI**	**1,437,538.70**
General Expenses		
Administration Cost	25% Overhead	51,046.16
Distribution & Selling Expenses	10% Total Expenses	406,941.20
Research and Development	5% Total Expenses	203,470.60
Total Production Cost (TCI)	**$A_{ME} + A_{GE}$**	**5,910,148.92**
Total General Expenses, A_{GE}		**661,457.97**
Total Expense, A_{TE}	**$A_{ME} + A_{GE} + A_{BD}$**	**7,347,687.62**
Revenue from Sales	RM/kg	
Sunflower Oil	2045	5,611,480.00
Sunflower Meal	480	1,756,800.00
Sales Income, A_s		**7,368,280.00**
Net Annual Profit, A_{NP}	**Sales Income-A_{TE}**	**20,592.38**
Income Taxes	30%	6,177.71

Net Annual Profit After Income Taxes, A_{NNP}		**14,414.67**
After Rate of Return, I	$\left(\dfrac{A_{NNP} + A_{BD}}{TCI}\right) \times 100$	**8.08**