

**PRELIMINARY DESIGN OF BIODIESEL PLANT FROM
WASTE COOKING OIL WITH CAPACITY OF
45,000 TON/YEAR**

CHEMICAL PLANT DESIGN

Filed as One of the Requirements

To Obtain a Bachelor's Degree in Chemical Engineering



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FACULTY OF INDUSTRIAL TECHNOLOGY
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA**

2025

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USING WASTE COOKING OIL
CAPACITY 45,000 TON/YEARS

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Hereby declare that all results of this Plant Design Project are our own original work. Should it be proven in the future that any part of this work is not the result of our own efforts, we are willing to accept all risks and consequences that may arise.

This declaration is made truthfully, with the hope that it will be used appropriately



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45,000 TON/YEARS

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PREFACE

Assalamu'alaikum Warahmatullahi Wabarakatuh.

All praise is due to Allah SWT for His mercy, guidance, and blessings, through which this Final Project has been successfully completed. May peace and blessings always be upon our Prophet Muhammad SAW, his companions, and his followers.

This Final Project entitled "Preliminary Design of Manufacturing of Biodiesel Using Waste Cooking Oil with a Capacity of 45,000 Tons/Year" has been prepared as an application of the chemical engineering knowledge acquired during the course of study, and as one of the requirements for obtaining the Bachelor of Chemical Engineering degree at the Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta.

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LIST OF SYMBOLS/NOTATION/ABBREVIATIONS

T	: Temperature, °C
D	: Diameter, m
H	: Height, m
P	: Pressure, psia
μ	: Viscosity, cP
ρ	: Density, kg/m ³
Q _s	: Steam Requirement, kg
Q _c	: Cooling Water Requirement, kg
M _s	: Mass of Steam, kg
A	: Cross-sectional Area, ft ²
V _t	: Tank Volume, m ³
t	: Time, hour
m	: Mass, kg
v	: Flow Rate, m ³ /hour
P	: Motor Power, HP
S _g	: Specific Gravity
X	: Conversion, %
V _s	: Shell Volume, m ³
V _h	: Head Volume, m ³
V _t	: Total Volume, m ³
ID	: Inside Diameter, in
OD	: Outside Diameter, in
Re	: Reynolds Number
E	: Welding Efficiency
f	: Allowable Stress, psia
r	: Dish Radius, psia
icr	: Inside Corner Radius, in
ts	: Shell Thickness, in
th	: Head Thickness, in
DI	: Impeller Diameter, m

z	: Reactor Length, m
Z_i	: Distance from Impeller to Tank Bottom, in
L	: Impeller Width, in
N	: Rotational Speed, rpm
UD	: Overall Heat Transfer Coefficient, Btu/hour·ft ² ·°F
UC	: Initial Overall Heat Transfer Coefficient, Btu/hour·ft ²
R_d	: Fouling Factor, Btu/hour·ft ² ·°F
η	: Efficiency
W_f	: Total Head, in
p	: Length, m
l	: Width, m
K	: Thermal Conductivity, Btu/hour·ft ² ·°F
c	: Specific Heat, Btu/lb·°F
JH	: Heat Transfer Factor
h_i	: Inside Film Coefficient, Btu/hour·ft ² ·°F
h_o	: Outside Film Coefficient, Btu/hour·ft ² ·°F
$LMTD$	: Log Mean Temperature Difference, °F
k	: Reaction Rate Constant, L/mol·s

ABSTRACT

Biodiesel is a renewable biofuel that can be synthesized through the transesterification of triglycerides with alcohol in the presence of a catalyst. It is characterized by its biodegradable nature, low toxicity, and favorable environmental impact compared to fossil-based diesel. Biodiesel is widely applied as an alternative fuel in the transportation sector, as well as in industrial and agricultural machinery. The development of a biodiesel production plant in Indonesia is expected to reduce dependency on imported fossil fuels while utilizing waste cooking oil as a primary raw material, especially given its abundant availability from restaurants and food industries in the Indramayu region. The biodiesel plant is planned to be operational by the year 2028 with a production capacity of 45,000 tons/year and will be located in Indramayu, West Java, covering a total area of 48290 m². The plant will operate for 330 days per year. The production process involves two main stages: esterification of Free Fatty Acids (FFA) using sulfuric acid, followed by transesterification with methanol using sodium hydroxide as the catalyst. The plant is supported by several utility components, which include an estimated total water requirement of 128,359.916 tons/year (including a 10% overdesign), 587.285 kW of electricity, 50.976 m³/h of compressed air, and 302,316.41 liters/h of fuel oil. Based on safety and hazard assessment, the plant operation is categorized as low risk due to relatively mild operating conditions. The raw materials are readily available locally, and the chemicals involved in the process are generally considered to be manageable in terms of safety. The projected economic evaluation of the biodiesel plant yields a pre-tax profit of Rp 25,108,900,150.42, and post-tax profit of Rp 20,087,120,120.33. The economic indicators include a Break Even Point (BEP) of 47.64, Shut Down Point (SDP) of 24.93, Return on Investment (ROI) of 23.07% before tax and 18.46% after tax, Pay Out Time (POT) of 3.22 years before tax and 3.78 years after tax, and a Discounted Cash Flow Rate of Return (DCFR) of 22.87%. Based on these economic parameters, the proposed biodiesel plant with a capacity of 45,000 tons/year is considered feasible for further development and meets the criteria for establishment.

Keywords: Biodiesel, Esterification, Transesterification, Waste Cooking Oil

CHAPTER I.

INTRODUCTION

1.1 Background

In recent years, Indonesia's manufacturing sector has shifted from a commodity-based to a manufacturing-based economy. As of 2022, Indonesia is the largest manufacturing hub in ASEAN, accounting for 20.27% of the national economy. The administration remains committed to changing the economy to stimulate growth in the non-oil and gas businesses. In the third quarter of 2022, the non-oil and gas processing industry expanded by 4.83%, outpacing the previous year's increase of 4.12%. This demonstrates that the domestic industrial sector is robust despite global economic worries.

The chemical sector has received a lot of attention because of its fast development. It is critical in delivering raw materials to other manufacturing industries that are experiencing increased demand. As a result, the government is aggressively fostering the expansion of the domestic chemical sector, which will serve as a driving force in the national economy. Establishing new chemical factories is critical to meeting local demands, and one such requirement is the manufacturing of biodiesel from waste cooking oil (WCO).

Biodiesel is a sustainable, biodegradable fuel made from organic materials like vegetable oils and animal fats. It is an alternative to traditional diesel fuel, providing environmental benefits by lowering greenhouse gas emissions and reliance on fossil fuels. Using WCO as a feedstock for biodiesel production is a sustainable approach that addresses waste management concerns while also contributing to energy security.

The transesterification process converts WCO into biodiesel and glycerol in the presence of a catalyst. This method not only adds value to waste materials, but it also contributes to the circular economy by transforming them into useful energy resources.

Indonesia has introduced a nationwide biodiesel mandate, seeking to combine diesel with palm-based Fatty Acid Methyl Ester (FAME) to minimize fuel imports, promote domestic palm oil consumption, and reduce emissions (Indonesian Palm Oil Facts, 2024).

However, the use of WCO as a feedstock for biodiesel production is yet developing. Establishing a biodiesel facility using WCO in Indonesia is critical for various reasons:

- a) Meeting Domestic Energy Needs: Producing biodiesel from waste cooking oil may complement the national energy supply, lowering reliance on imported fossil fuels and improving energy security.
- b) Environmental Benefits: Converting WCO into biodiesel reduces waste disposal difficulties, pollution, and greenhouse gas emissions.
- c) Economic Opportunities: The installation of biodiesel manufacturing facilities may provide jobs, boost local economies, and encourage the growth of associated sectors.

1.2 Design Capacity

In determining the production capacity, several factors must be taken into consideration, including:

1.2.1 Supply

Supply refers to demand data consisting of both import figures and domestic production levels.

1. Domestic Production

The increasing volume of biodiesel production in Indonesia can serve as a benchmark for competing with existing biodiesel plants in the country. The following table presents data on biodiesel production facilities currently operating in Indonesia.

Table 1.1 Capacity of the Biodiesel Industry in Indonesia

No.	Name of Company	Location	Capacity (kL)
1	PT. Sintong Abadi	North Sumatra	35,000
2	PT. Musim Mas (Medan)	North Sumatra	459,770
3	PT. Permata Hijau Palm Oleo	North Sumatra	417,214
4	PT. Sari Dumai Oleo	Riau	413,793
5	PT. Intibenua Perkasatama	Riau	442,529
6	PT. Ciliandra Perkasa	Riau	287,356
7	PT. Pelita Agung Agrindustri	Riau	229,885
8	PT. Pelita Agung Agrindustri	Riau	568,966
9	PT. Sari Dumai Sejati	Riau	689,655
10	PT. Wilmar Bioenergi Indonesia	Riau	1,603,448
11	PT. Bayas Biofuels	Riau	862,069
12	PT. LDC Indonesia	Lampung	482,759
13	PT. Tunas Baru Lampung	Lampung	402,299
14	PT. Musim Mas (Batam)	Riau Island	896,552
15	PT. Multimas Nabati Asahan	Banten	568,966

Table 1.2 Capacity of the Biodiesel Industry in Indonesia (Continued)

16	PT. Sinar Mas Bio Energy	West Java	455,400
17	PT. Sumiasih	West Java	114,943
18	PT. Darmex Biofuel	West Java	287,356
19	PT. Wahana Abdi Tritatehnika Sejati	West Java	13,200
20	PT. Anugerah Inti Gemanusa	East Java	160,920
21	PT. Batara Elok Semesta Terpadu	East Java	780,459
22	PT. Wilmar Nabati Indonesia	East Java	2,250,000
23	PT. Energi Baharu Lestari	East Java	229,885
24	PT. Eterindo Nusa Graha	East Java	568,966
25	PT. Eco Prima Energi	East Java	579,310
26	PT. SMART Tbk	South Kalimantan	440,517
27	PT. Jhonlin Agro Raya	South Kalimantan	568,966
28	PT. Sukajadi Sawit Mekar	Central Kalimantan	402,299
29	PT. Sinar Alam Permai	Central Kalimantan	47,586
30	PT. Kutai Refinery Nusantara	East Kalimantan	1,143,247
31	PT. Energi Unggul Persada	East Kalimantan	1,221,000
32	PT. Multi Nabati Sulawesi	North Sulawesi	475,862

Table 1.3 Capacity of the Biodiesel Industry in Indonesia

ISLAND	CAPACITY (kL)
Sumatra	7,791,295
Java	6,009,405
Kalimantan	3,823,615
Sulawesi	475,862
Total	18,100,177

Source: Soni S. Wirawan, Maharani D. Solikhah, Hari Setiaprada, ,2023

Considering the existing biodiesel plant capacities in Indonesia, the capacity of a biodiesel plant utilizing used cooking oil (UCO) as feedstock is relatively small. However, from another perspective namely its potential to reduce environmental pollution caused by waste cooking oil and to minimize the misuse of UCO this plant presents a promising opportunity for development.

2. Imports

Based on the data 2019 - 2023, it can be observed that the biodiesel industry in Indonesia still relies on imports of waste cooking oil (WCO) to meet the demand for raw materials in its production processes. The import data indicates a consistent increase in the volume of WCO imported each year. From the import data presented, a graph can be constructed with the years on the x-axis and the import data on the y-axis, as shown in the following graph:

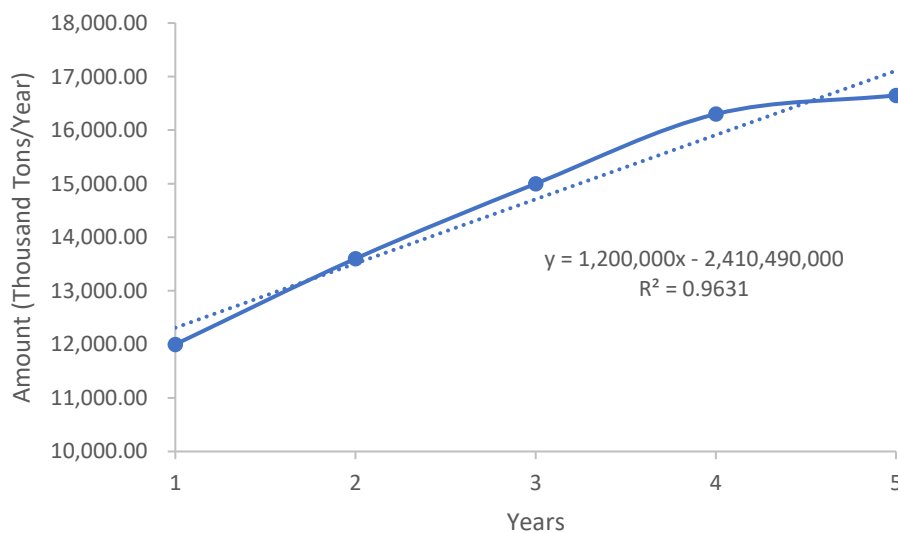


Figure 1. Linear Curve of Biodiesel Import Volume in Indonesia

Source: Badan Pusat Statistik

Estimated imports of Biodiesel in Indonesia in the coming year during the construction of the factory can be calculated using the equation $y = 1,200,000x -$

2410490000 where the value of x is the year and y is the amount of import. With the equation above, it is estimated that for 2028 the need for Biodiesel imports in Indonesia is:

$$y = 1,200,000x - 2,410,490,000 \quad (1.1)$$

$$y = 23,110,000 \text{ ton/year}$$

Where y represents the projected production capacity of the planned plant, and x denotes the target year. Based on this equation, the projected import volume of Biodiesel in Indonesia for the year 2028 is approximately 23,110,000 tons/year.

1.2.2 Demand

Demand refers to the data on market needs, which includes both export data and domestic consumption.

1. Exports

From the data year 2019 - 2023, Biodiesel exports in Indonesia are very small every year. From the export data above, a graph can be made between the year data on the x-axis and the export data on the y-axis shown in the following graph.

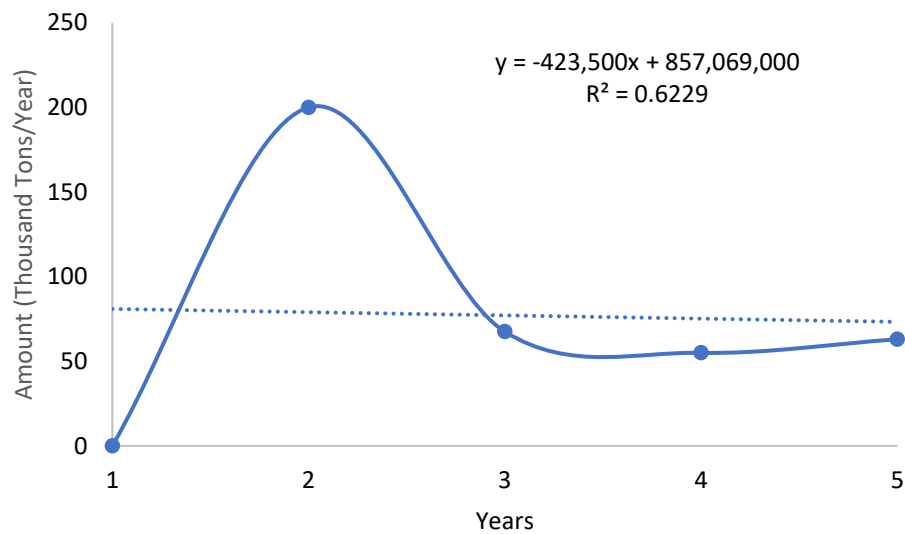


Figure 2. Linear Curve of Biodiesel Expor Volume in Indonesia

The estimated export of Biodiesel in Indonesia in the coming year can be calculated using the equation $y = -423,500x + 857,069,000$ where the value x is the year and y is the number of exports. With the above equation, it is estimated that for 2028 Biodiesel exports in Indonesia will be as follows

$$y = -423,500x + 857,069,000 \quad (1.2)$$

$$y = -423,500x (2028) + 857,069,000$$

$$y = -1,789,000 \text{ ton/year}$$

Where y represents the projected production capacity of the planned plant, and x denotes the target year. Based on this equation, the projected export volume of Biodiesel in Indonesia for the year 2028 is approximately -1,789,000 tons/year.

2. Consumption

Based on the data, biodiesel production has continuously changed from year to year. In this preliminary plant design, the biodiesel plant is planned to be established in 2028. Subsequently, the data from the table is projected using the linear regression method, with the results illustrated in the figure below:

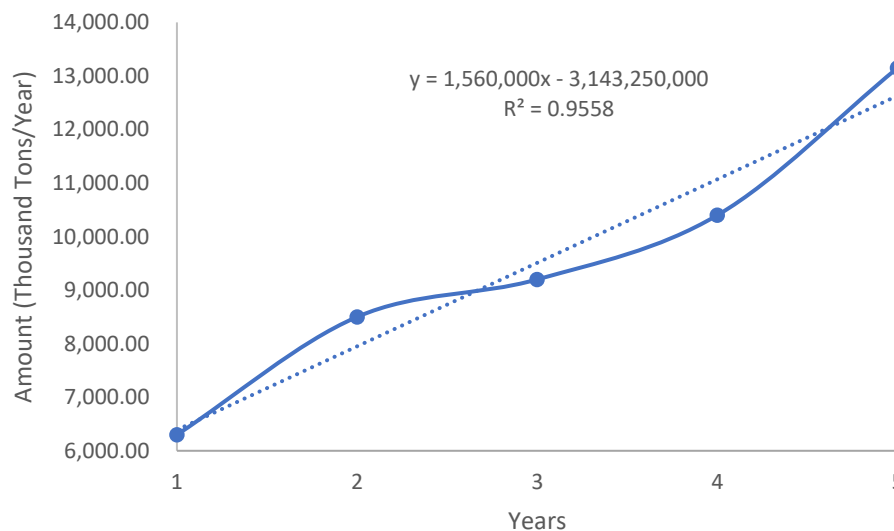


Figure 3. Linear Curve of Biodiesel Consumption Volume in Indonesia

The estimated Consumption of Biodiesel in the coming year can be calculated using the equation $y = 1,560,000x - 3,143,250,000$ where the value x is the year and y is the number of exports. With the above equation, it is estimated that for 2028 Biodiesel exports in Indonesia will be as follows:

$$y = 1,560,000x - 3,143,250,000 \quad (1.3)$$

$$y = 1,560,000 (2028) - 3,143,250,000$$

$$y = 20,397,155 \text{ ton/year.}$$

1.2.3 Raw Material Availability

The location of the plant in close proximity to raw materials provides a significant strategic advantage. The primary feedstock for the proposed biodiesel plant is waste cooking oil. Indramayu has been selected as the plant location due to the high concentration of restaurants and food vendors in the region, which generate large quantities of waste cooking oil. Currently, this waste is not systematically collected or processed through formal systems such as ucollecting, making it a readily available and underutilized resource. The estimated supply is sufficient to meet the production requirement of 5,861 kg/h.

In addition to the main feedstock, the plant will require supporting materials such as catalysts. Sulfuric acid and sodium hydroxide, which are essential catalysts for the biodiesel production process, will be sourced from PT. Petrokimia Gresik, a major chemical producer in Indonesia. Furthermore, methanol an additional catalyst material will be supplied by PT. Kaltim Methanol Industri, located in East Kalimantan, with a production capacity of 660,000 tons per year. The availability of these materials ensures the sustainability of raw material supply for continuous production.

Geographically, Indramayu offers logistical benefits due to its coastal location, which facilitates the maritime transport of raw materials and supporting chemicals. Additionally, Indramayu is traversed by the Pantura Highway, one of Indonesia's main arterial roads, which significantly simplifies land-based distribution logistics for both inbound and outbound transport activities.

1.3 Literature Review

1.3.1 Biodiesel

Biodiesel manufacturing from waste cooking oil (WCO) has emerged as a possible solution to environmental and energy issues. As the globe faces depleting fossil fuel supplies and rising pollution, WCO provides a sustainable feedstock for biodiesel synthesis. This procedure not only aids in waste management, but it also provides an alternative energy source with the potential to dramatically cut greenhouse gas emissions when compared to traditional diesel fuel. WCO usage is especially favorable due to its great availability and cheap cost, making it an economically viable choice for biodiesel production (Aditya, 2021).

Biodiesel is largely produced from waste cooking oil by a chemical reaction known as transesterification, in which triglycerides in the oil combine with an alcohol (usually methanol) in the presence of a catalyst, commonly sodium hydroxide (NaOH) or potassium hydroxide. This process transforms triglycerides into fatty acid methyl esters (FAME), which are used to make biodiesel, and produces glycerol as a byproduct. The effectiveness of this process can be impacted by several parameters, including feedstock quality, the presence of free fatty acids (FFA), and reaction conditions such as temperature and catalyst concentration

(Endang S R, 2018). According to studies, adjusting these factors can result in biodiesel conversion rates of more than 90% (Aditya, 2021).

One of the most major obstacles in employing WCO is its fluctuating quality, which is frequently characterized by high quantities of free fatty acids caused by repeated heating and exposure to pollutants. To overcome this, pre-treatment procedures such as acid-catalyzed esterification are used to lower FFA levels prior to transesterification. This phase is critical since excessive FFA concentration might cause soap production during the process, reducing biodiesel. Furthermore, procedures such as activated charcoal adsorption have been investigated to purify WCO further, hence increasing the overall efficiency of biodiesel synthesis.

Finally, converting waste cooking oil into biodiesel not only provides a waste management solution, but it also contributes significantly to the promotion of sustainable energy sources. By using current waste materials, this technique promotes environmental sustainability while also contributing to energy security. As research continues to optimize production processes and enhance yield efficiency, biodiesel from WCO emerges as a potential alternative to fossil fuels in the drive for greener energy alternatives. (Aditya, 2021).

1.3.2 Overview of Biodiesel Production Process

Waste cooking oil primarily consists of triglycerides, but also contains free fatty acids (FFAs), water, and various impurities resulting from the cooking process. The exact composition varies depending on the source and cooking conditions, presenting challenges for standardization in biodiesel production.

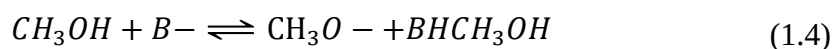
1. Homogeneous Catalyst

Homogeneous Catalysis remains the most widely used method in industrial biodiesel production. Alkaline catalysts such as sodium hydroxide (NaOH), potassium hydroxide (KOH), or sodium methoxide (CH₃ONa) are preferred for refined, low-FFA feedstocks, operating at 55–65°C and atmospheric pressure. Acid catalysts like sulfuric acid (H₂SO₄) are used when FFAs are high, typically in a two-step esterification–transesterification approach. The main advantages of homogeneous catalysis are low cost, high reactivity, and fast reaction times (1–2 hours). Alkaline-catalyzed processes can achieve conversions of 95–98%, while acid-catalyzed esterification steps can reduce FFAs to <1% before transesterification. However, homogeneous processes produce significant wastewater due to the need for neutralization and washing, and separating the catalyst from the product stream adds complexity. Moreover, soap formation in the presence of FFAs (>2%) reduces yield and increases purification costs.

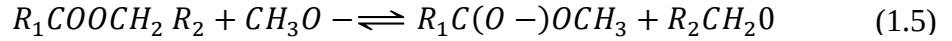
- Base catalysts (e.g., NaOH, KOH): Effective for low FFA content (<1%), fast reaction times.
- Acid catalysts (e.g., H₂SO₄): Suitable for high FFA content, but slower reaction rates.

The mechanism for base-catalyzed transesterification involves the following steps:

1. Formation of alkoxide ion:



2. Nucleophilic attack on the carbonyl carbon:



3. Rearrangement and formation of FAME:

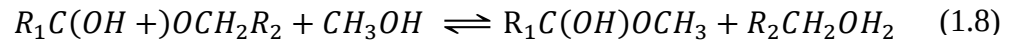


The mechanism for acid-catalyzed transesterification is as follows:

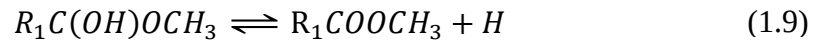
1. Protonation of the carbonyl group:



Nucleophilic attack by the alcohol:



2. Proton transfer and formation of FAME:



2. Non-Catalytic

Non-catalytic procedures for biodiesel generation from waste cooking oil (WCO) provide an alternative to classic catalytic methods by addressing some of the limitations of catalysts, particularly when dealing with feedstocks rich in free fatty acid (FFA). Supercritical transesterification is a well-known non-catalytic process that operates at high temperatures and pressures, allowing triglyceride esterification and transesterification to occur simultaneously without the need of a catalyst. This approach is useful since it eliminates the need for pretreatment procedures to lower FFA levels, as both reactions may take place simultaneously in a single reactor.

In supercritical transesterification, methanol is frequently utilized as the supercritical alcohol, which increases its reactivity and solubility with oils. Temperatures around 200 °C and pressures of roughly 20 MPa (200 bar) are common requirements for the process, which allows for fast reaction

kinetics. Studies have shown that under these circumstances, biodiesel may be created in minutes, which is substantially quicker than typical catalytic procedures. For example, research has shown that biodiesel synthesis may reach near-complete conversion within just four minutes under optimum circumstances of high temperature and pressure.

Another non-catalytic technique uses semicontinuous flow processes, in which WCO reacts with methanol in a regulated flow system. This approach allows for continuous input of reactants and disposal of products, potentially increasing overall efficiency and yield. The semicontinuous flow technique has been found as a promising alternative for manufacturing biodiesel from WCO due to its ability to accommodate a wide range of feedstock quality without considerable pretreatment. While non-catalytic processes have some advantages, such as decreased operational complexity and a lower environmental effect owing to the lack of chemical catalysts, they also have limitations. The demand for high temperatures and pressures might result in greater energy consumption and higher capital expenses for reactor construction and operation. Furthermore, non-catalytic procedures for separating and purifying biodiesel from glycerol and unreacted components might be more difficult than catalytic processes, which use solid catalysts that are easier. In conclusion, non-catalytic technologies for biodiesel generation from waste cooking oil offer an effective option that avoids some of the disadvantages of catalytic methods. These technologies, which use supercritical temperatures or semicontinuous flow systems, may successfully convert high-FFA feedstocks into biodiesel while reducing pre-

treatment needs. However, further study is needed to improve these technologies and solve difficulties like as energy efficiency and product separation.

3. Enzymatic Catalyst

Enzymatic catalysis is an increasingly significant approach for manufacturing biodiesel from waste cooking oil (WCO), taking advantage of enzymes' particular features to aid in the transesterification process. This method employs lipases, which are enzymes that catalyze the hydrolysis of triglycerides into free fatty acids and glycerol, resulting in the creation of fatty acid methyl esters (FAME), the major component of biodiesel. One of the primary benefits of enzymatic transesterification is its capacity to handle feedstocks with high free fatty acid (FFA) concentration, which is typically difficult in traditional alkaline or acid-catalyzed procedures. Enzymatic processes can work in milder settings and produce fewer by-products, simplifying downstream processing and lowering wastewater production, which is a major problem in chemical transesterification procedures.

Enzymatic biodiesel manufacturing normally consists of three stages: impurity removal from WCO, the transesterification process, and biodiesel product purification. Pretreatment removes any solid impurities or superfluous water to increase enzyme activity. The transesterification process happens when WCO is combined with an alcohol (often methanol or ethanol) in the presence of a lipase catalyst. This process may be carried out at mild settings, which allows for improved enzyme activity preservation while also lowering heating energy expenditures.

Despite its various advantages, enzymatic catalysis poses obstacles, most notably the cost of enzymes and their stability during protracted reactions. To address these challenges, researchers have concentrated on enzyme immobilization approaches, which improve enzyme stability and facilitate recovery and reuse following the process. Various lipases from diverse sources have been investigated for their efficacy in biodiesel synthesis; for example, lipases from *Mucor miehei*, *Pseudomonas cepacia*, and *Candida antarctica* have demonstrated promising results in reaching high conversion rates from WCO.

Furthermore, recent advances in biocatalysis technology, such as the use of whole-cell biocatalysts or the optimization of reaction parameters (e.g., the alcohol-to-oil ratio and reaction duration), have increased the efficiency of enzymatic biodiesel generation. Overall, enzymatic catalysis offers a sustainable and environmentally friendly alternative to traditional methods of converting waste cooking oil into biodiesel, helping to reduce waste and provide a renewable energy source while addressing environmental concerns associated with traditional biodiesel production processes.

4. Heterogenous Catalyst

Heterogeneous catalysis is critical in the manufacturing of biodiesel from waste cooking oil (WCO), enabling the transesterification process that transforms triglycerides into fatty acid methyl esters (FAME), biodiesel's principal component. This approach uses solid catalysts that work in a separate phase than the liquid reactants, making them ideal for industrial applications due to their ease of separation and reusability. Solid

heterogeneous catalysts, such as calcium oxide (CaO), have been thoroughly investigated for this purpose. CaO, which is generated from limestone by calcination, has a high basicity and is inexpensive in cost, making it an ideal catalyst for transesterification. The mechanism involves the adsorption of triglycerides onto the catalyst surface, followed by their interaction with methanol or ethanol to produce biodiesel and glycerin.

The solid form of these catalysts makes them easier to separate from the reaction mixture after completion, simplifying downstream processing and decreasing waste creation. Heterogeneous catalysts have various advantages in biodiesel production, including reusability, less corrosiveness when compared to homogeneous catalysts, and a lower environmental effect owing to reduced waste during the purification steps. Recent research has demonstrated that altering standard catalysts can greatly improve performance; for example, bifunctional catalysts with acidic and basic sites increase biodiesel yields by enabling both esterification and transesterification events at the same time. However, enhancing heterogeneous catalysis for biodiesel generation still presents obstacles, such as maintaining appropriate mass transfer between reactants and catalyst surfaces. Microbubble technology has been investigated to increase mass transfer rates and reaction kinetics. impact. Ongoing research into alternative catalyst materials, such as oil shale ash or modified metal oxides, is expanding the possibilities for more efficient and cost-effective biodiesel manufacturing. Overall, heterogeneous catalysis is essential for manufacturing biodiesel from waste cooking oil,

resulting in a sustainable method that maximizes waste resources while reducing environmental damage.

1.3.3 The Selection of Production Process

The selection of the production process is carried out by comparing the advantages and disadvantages of each method, as outlined in Table 1.3 below:

Table 1.3 Table Comparison Of Biodiesel Process

Criteria	Homogeneous Catalysis (Esterification + Transesterification)	Enzymatic Catalysis	Non-Catalytic (Supercritical Method)	Heterogeneous Catalysis
Process Temperature (°C)	60	30–50	240–350	60–80
Process Pressure (atm)	1	1	80–100	1–5
Reaction Time	60–180 minutes	8–72 hours	20–30 minutes	60–120 minutes
Catalysts Used	H ₂ SO ₄ (acid), NaOH or KOH (base)	Lipase enzyme (e.g. <i>Candida antarctica</i>)	None	CaO, MgO, ZnO, solid acid/base catalysts
Reaction Phase	Liquid–Liquid	Liquid–Liquid	Supercritical fluid	Solid–Liquid
Feedstock Compatibility	Suitable for high-FFA oils (esterification stage)	High FFA and moisture tolerance	Any type of oil, including waste	Can handle moderate FFA, some sensitive
Conversion Efficiency	96–98%	85–95%	>98%	90–96%
Selectivity	High toward FAME; soap formation risk in base stage	High; very specific to triglycerides/FFA	High, but risk of thermal degradation	High to moderate depending on catalyst quality
Advantages	- Simple and widely studied - High conversion efficiency - Cost-effective catalysts - Suitable for waste cooking oil after pre-treatment	- Mild conditions - Environmentally friendly - Tolerant to FFA and water - Minimal side reactions	- Catalyst-free - Fast reaction - No need for separation step - Suitable for low-quality feedstock	- Reusable and recoverable catalyst - Less wastewater - High product purity

Table 1.3 Table Comparison Of Biodiesel Process (Continued)

Disadvantages	- Requires two-step process - Soap formation if FFA is high - Neutralization and washing required - Catalyst disposal	- High cost of enzymes - Slow reaction rate - Enzyme inhibition by alcohol - Sensitive to temperature	- High energy consumption - Requires expensive high-pressure equipment - Complex safety concerns	- Lower activity than homogeneous - Sensitive to water and FFA - Mass transfer limitations - Catalyst deactivation over time
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The selection of homogeneous catalysis as the preferred method for biodiesel production in this plant is based on a comprehensive evaluation of technical, economic, and operational factors. Utilizing two separate reactors for esterification and transesterification—each employing a different homogeneous catalyst (H_2SO_4 for esterification and NaOH for transesterification)—offers distinct advantages for feedstock flexibility and high conversion rates.

This method is particularly well-suited for processing waste cooking oil, which typically contains a high free fatty acid (FFA) content. The initial esterification step using sulfuric acid effectively converts FFAs into esters, thereby preventing soap formation in the subsequent base-catalyzed transesterification stage. This ensures the stability and efficiency of the overall process.

1. **High Conversion and Yield Efficiency** The combination of acid and base catalysis allows for the near-complete conversion of both triglycerides and FFAs into methyl esters (biodiesel), achieving efficiencies up to 96–98% under controlled conditions.

2. **Compatibility with Low-Cost, High-FFA Feedstocks** The process can accommodate waste cooking oil, which is readily available and cost-effective, especially in areas like Indramayu where restaurants and food outlets generate a large volume of used oil.
3. **Mature and Well-Understood Technology** Homogeneous catalysis is a well-established and industrially proven method, supported by extensive literature, commercial scale data, and accessible design references, which simplifies scale-up and process modeling.
4. **Shorter Reaction Time Compared to Enzymatic or heterogeneous Catalysis** Reactions using homogeneous catalysts typically require only 1 hour, significantly shorter than enzymatic or some heterogeneous approaches, allowing higher throughput and reactor efficiency.
5. **Lower Operating Pressure and Temperature Requirements** Unlike supercritical methods, homogeneous catalysis can be conducted at atmospheric pressure and moderate temperatures (50–65°C), reducing equipment costs and energy consumption.

Considering the abundant availability of waste cooking oil, moderate capital investment, and proven technical feasibility, the homogeneous catalysis method with a two-reactor system is the most practical and economically viable choice for the biodiesel plant design. The method ensures high yield, utilizes local resources, and aligns with existing infrastructure and technological capabilities.

1.4 Overview of Thermodynamics and Kinetics

1.4.1 Thermodynamics Overview

The thermodynamic review is aimed at determining whether the reactions occurring in the production of biodiesel from waste cooking oil are exothermic or

endothermic, and whether they proceed spontaneously or non-spontaneously. This assessment is based on the enthalpy of formation values for each reactant and product, evaluated at a temperature of 298 K.

Main Reactions:

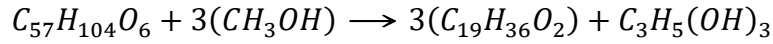


Table 1.4 Value ΔH_f° on Each Component

Name	BM	ΔH_f (kJ/mol.K)
$C_{57}H_{104}O_6$	885.432	-2015.00
$C_{51}H_{98}O_6$	852.378	-2067.70
$C_{18}H_{34}O_2$	282.46	-700.82
$C_{16}H_{32}O_2$	256.424	-745.42
$C_{17}H_{34}O_2$	270	-773.06
$C_{19}H_{36}O_2$	296.49	-532.38
CH_3OH	32.04	-202.48
H_2SO_4	98.079	-790.32
$C_3H_8O_3$	92.09	-559.44
H_2O	18.015	-283.16

Source: Aspen Plus

$$\Delta H_r^0 = \Delta H_r^0 \text{ Product} - \Delta H_r^0 \text{ Reactants} \quad (1.10)$$

From the calculation, it is obtained that:

$$\Delta H^{\circ}R \text{ 298K} = -87.76 \text{ kJ/mol}$$

A negative value of ΔH° indicates that the reaction is exothermic, meaning it releases heat to the surroundings during the course of the reaction. This characteristic is important in reactor design, as exothermic reactions require proper cooling systems to maintain stable process temperatures.

In addition to enthalpy, the spontaneity of the reaction must also be considered. A chemical reaction is said to be spontaneous if the change in Gibbs free energy (ΔG°) is negative. This value helps determine the natural direction of the reaction and its relationship with the chemical equilibrium. The relationship

between Gibbs free energy and the equilibrium constant is expressed by the following equation:

Table 1.5 Value of Standard Gibbs of Each Component

Name	BM	ΔH_g (298 K)
$C_{57}H_{104}O_6$	885.432	-224.811
$C_{51}H_{98}O_6$	852.378	-415.286
$C_{18}H_{34}O_2$	282.46	-216.724
$C_{16}H_{32}O_2$	256.424	-250.274
$C_{17}H_{34}O_2$	270	-220.470
$C_{19}H_{36}O_2$	296.49	-113.811
CH_3OH	32.04	-158.377
H_2SO_4	98.079	-679.163
$C_3H_8O_3$	92.09	-464.064
H_2O	18.015	-231.586

Source: Aspen Plus

The Gibbs free energy of the reaction at 298 K is calculated using the following equation:

$$\Delta G^\circ_{R\ 298K} = \sum \Delta G_F^\circ \text{ Products} - \sum \Delta G_F^\circ \text{ Reactants} \quad (1.11)$$

$$= 29.70 \text{ kJ/mol}$$

Based on the Gibbs free energy calculation, the reaction has a positive ΔG° value at 298 K. This indicates that the reaction is non-spontaneous under standard conditions. In other words, the formation of the desired product will not proceed naturally without the input of external energy. To drive the reaction forward, it may be necessary to apply heat, increase pressure, use a catalyst, or adjust the concentration of reactants and products. Therefore, process optimization is essential to ensure the feasibility and efficiency of the reaction in an industrial setting.

Equilibrium Constant of the Reaction at 298 K

$$\ln K_1 = \frac{-\Delta G_{298K}}{RT} \quad (1.12)$$

$$K_1 = 1.14 \times 10^{18}$$

Equilibrium Constant at Reaction Temperature

$$\frac{\ln K_2}{\ln K_1} = \frac{\Delta H_R}{R} \left[\frac{1}{T_2} - \frac{1}{T_1} \right] \quad (1.13)$$

$$\frac{K_2}{K_1} = 18,9578$$

$$K_2 = 2.27 \times 10^{16}$$

From the calculations above, indicating that the formation of product.

1.4.2 Kinetics Review

Before determining the type of reactor flow design, it is necessary to obtain the kinetic data of the reaction. The kinetic review is used to determine the reaction rate, which will serve as a basis for reactor design. The design equation expresses the dependence of the rate constant on temperature for an elementary process according to the Arrhenius equation. The reaction between WCO and methanol proceeds as a direct reaction with first-order kinetics (L.S Keong, 2016), and its rate equation can be expressed as:

$$-r_a = k C_a \quad (1.14)$$

Where:

$-r_A$ = Reaction Rate (kmol/m³.s)

k = Reaction Rate Constant (/s)

C_a = Concentration of Component A (kmol/m³)

The equation for the reaction rate constant is given by the Arrhenius equation:

$$k = A e^{-E/RT} \quad (1.15)$$

Where:

$$A = 74 \times 10^6 \text{ min}^{-1}$$

$$E = 57.82 \text{ kJ/mol}$$

(Pugazhendhi et al, 2020).

$$R = 0,008314 \text{ kJ/mol.k}$$

$$T = 60 \text{ }^{\circ}\text{C}$$

Thus the value is 0.06 min^{-1}

CHAPTER II.

PRODUCT DESIGN

To ensure that the product quality meets the specified targets, the design of the biodiesel production plant is based on several key variables: raw material specifications, product specifications, auxiliary material specifications, and quality control measures.

2.1 Material and Products Specification

Table 2.1 Raw Material and Products Specifications

Specifications	Raw Material		Supporting Material		Product	
	WCO	Methanol	Sodium Hydroxide	Sulfuric Acid	Biodiesel	Glycerol
Molecular Formula	Triglycerides	CH ₃ OH	NaOH	H ₂ SO ₄	RCOOCH ₃ (Methyl esters)	C ₃ H ₈ O ₃
Molecular Weight (g/mol)	~880–920	32.04	39.997	98.08	~292	92.094
Boiling Point (°C)	Decomposes	64.7	1.338	337	315–350	290
Melting Point (°C)	-5 to -10	-97.6	323	50.65	-11 to -15	17.8
Flash Point (°C)	~220	11	-	-	>120	180
Critical Pressure (atm)	-	-	-	-	~25	-
Density (kg/m ³)	~920 (20°C)	792 (20°C)	2.13	1.83	860–900 (at 15°C)	1.22 (at 20 °C)
Viscosity (cP)	~38 (40°C)	0.6 (20°C)	78	26.725	3.5–5.0 (at 40°C)	1.412 (at 20 °C)
Purity (%)	95–99	99	98	98	>99	-
Solubility	Insoluble in water	Soluble in water and organic solvents	Soluble in water and organic solvents	Soluble in water and organic solvents	Insoluble in water	Soluble in water and organic solvents
Specific Gravity	~0.92	0.79	2.13	-	0.86–0.90	-
Phase	Liquid	Liquid	Solid	Liquid	Liquid	Liquid

Table 2.2 WCO Composition

Component	Formula	%wt
Triolein	$C_{57}H_{104}O_6$	42.5
Tripalmitin	$C_{51}H_{98}O_6$	46.5
Oleic Acid	$C_{18}H_{34}O_2$	4.10
Palmitate Acid	$C_{16}H_{32}O_2$	5.90
Impurities		1.00

2.2 Quality Control

Ensuring product quality is paramount in biodiesel production from Waste Cooking Oil (WCO). Implementing rigorous quality control measures throughout the production process guarantees that the final product meets established standards and satisfies consumer expectations. This section outlines the quality control procedures applied to raw materials, supporting materials, production processes, and the final biodiesel product.

2.3.1 Raw Material Quality Control

Prior to production, thorough testing of raw materials is essential to confirm their suitability and compliance with specified standards. For WCO, key quality parameters include:

- a) Free Fatty Acid (FFA) Content: High FFA levels can lead to soap formation during transesterification, reducing biodiesel yield. It's crucial to measure and, if necessary, pre-treat WCO to lower FFA content.
- b) Water Content: Excessive water can cause incomplete reactions and soap formation. WCO should be dried to achieve a water content below 0.5%.

- c) Impurities: Physical contaminants such as food particles and sediments should be removed through filtration to prevent equipment damage and ensure a smooth production process.

2.3.2 Supporting Material Quality Control

Supporting materials, including methanol and catalysts (e.g., sodium hydroxide or potassium hydroxide), must meet purity standards to facilitate efficient reactions. Regular testing ensures:

- a) Methanol Purity: Should be $\geq 95\%$ to ensure effective transesterification.
- b) Catalyst Quality: Purity levels of $\geq 85\%$ for NaOH/KOH are recommended to prevent unwanted side reactions

2.3.3 Production Process Quality Control

Monitoring and controlling production parameters are vital to maintain consistent product quality. Key aspects include:

- a) Temperature Control: Maintaining the reaction temperature between 50–60°C ensures optimal reaction rates without decomposing the biodiesel product.
- b) Methanol-to-Oil Ratio: An appropriate molar ratio (commonly 6:1) is crucial for high conversion rates.
- c) Reaction Time: Sufficient reaction time must be allowed to achieve complete transesterification.

These parameters are monitored using control systems such as:

- a) Temperature Control (TC): Regulates the temperature within reactors to maintain optimal conditions.

b) Flow Control (FC): Manages the flow rates of reactants to ensure proper mixing and reaction efficiency.

c) Level Control (LC): Maintains appropriate levels of liquids in tanks and reactors to prevent overflow or equipment damage.

Pressure Control (PC): Ensures that system pressures remain within safe and specified limits.

2.3.4 Product Quality Control

Quality control extends to the final biodiesel product to ensure it meets industry standards such as ASTM D6751 or EN 14214. Critical parameters include:

- Density: Should be between 860–900 kg/m³ at 15°C.
- Viscosity: Measured at 40°C, typically ranging from 3.5–5.0 cP.
- Flash Point: Should exceed 120°C for safe handling and storage.
- Acid Value: Should be less than 0.5 mg KOH/g to prevent corrosion and engine deposits.
- Water and Sediment Content: Should be minimal to prevent microbial growth and fuel system issues.

Regular sampling and laboratory analysis are conducted to verify these parameters, ensuring the biodiesel produced is of high quality and safe for use.

2.3.5 Transportation Process Control

Ensuring the quality of biodiesel during transportation is crucial to maintain its integrity until it reaches the end user. Key measures include:

- Storage Tank Inspection: Before transfer, storage tanks are inspected to ensure they are clean and free from contaminants.

- Quality Verification: Samples are taken and analyzed to confirm that the biodiesel meets all specified quality parameters before transportation.

Monitoring During Transfer: The transfer process is monitored to prevent contamination or degradation, ensuring the biodiesel remains within quality specifications.

CHAPTER III. PROCESS PLANNING

3.1 Process and Material Flow Diagram

3.1.1 Qualitative Flow Diagram

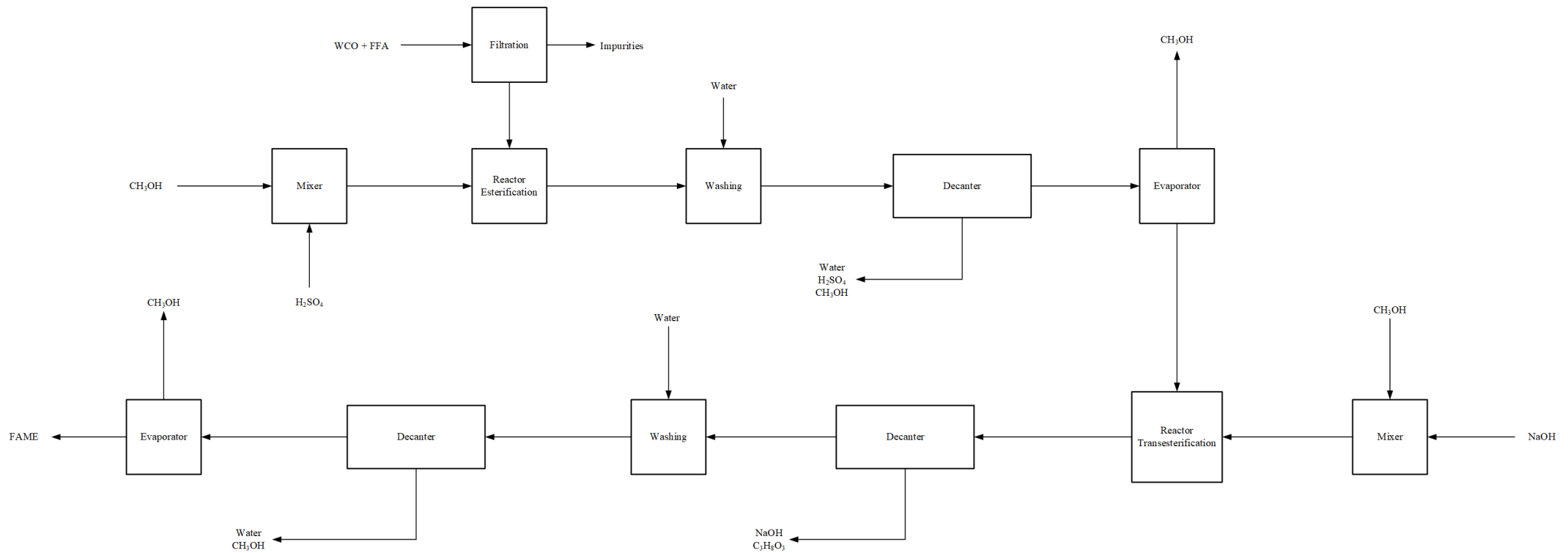


Figure 4. Qualitative Flow Diagram

3.1.2 Quantitative Flow Diagram

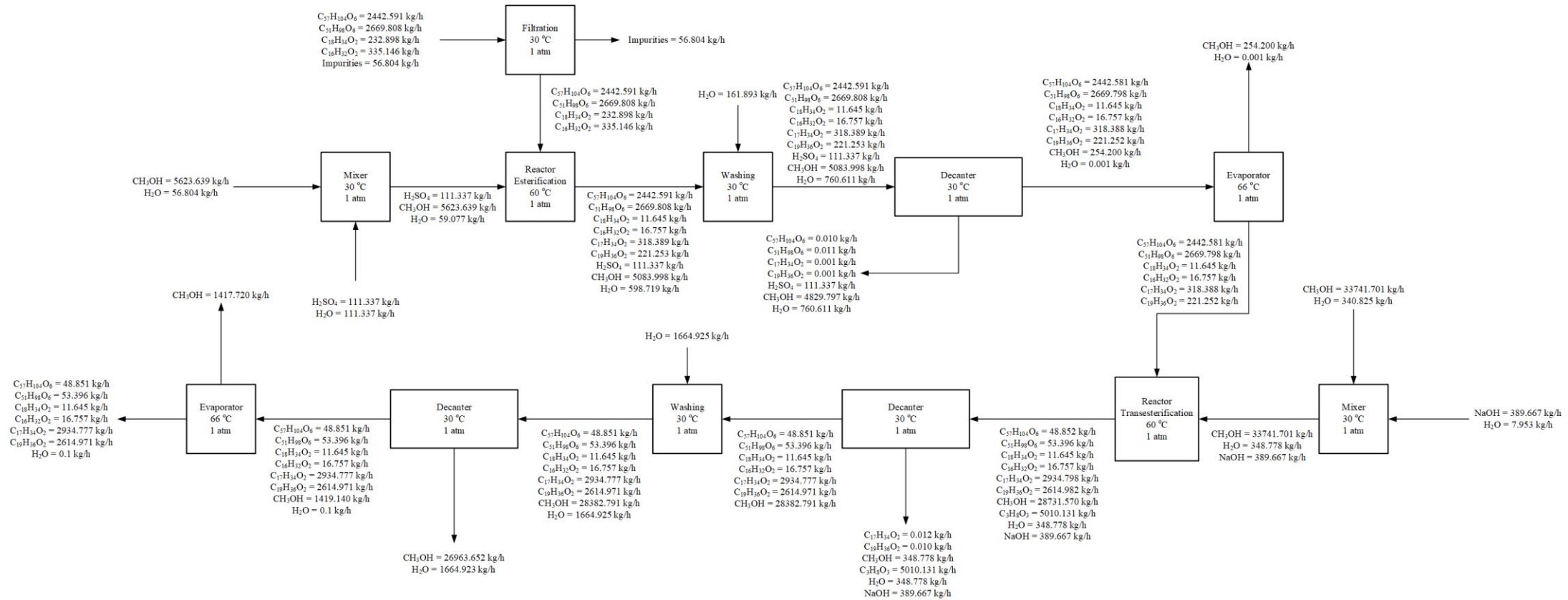


Figure 5. Quantitative Flow Diagram

3.2 Process Description

3.2.1 Raw Material Storage Unit

The storage unit is responsible for holding the primary raw materials: Waste Cooking Oil (WCO) and methanol.

- **WCO Storage:** Waste cooking oil, which is collected from different sites such as restaurants and food processing plants, frequently contains contaminants such as food particles, water, and other leftovers. The WCO is stored in a tank (Tank T-03) at ambient temperatures, where it remains stable and accessible. The storage solution also incorporates rudimentary filtration to keep solid particles from accumulating in the tank and blocking the transfer mechanism.
- **Methanol Storage:** To avoid evaporation, methanol, a flammable and volatile liquid, is stored in a specific, securely sealed tank (Tank T-01 & T-05). Because methanol is flammable, it must be stored at a low temperature (about 20°C) in a well-ventilated room with leak and spill protection. The methanol tank is connected to the manufacturing line by controlled flow pumps, which limit the quantity utilized in each batch, reducing waste and assuring safe handling.
- **Sulfuric Acid Storage:** Sulfuric acid (H_2SO_4) is used as a catalyst in this process and is supplied by PT. Petrokimia Gresik with a purity of 98%, containing water as an impurity. The sulfuric acid is stored in a storage tank (T-02) in the liquid phase at a temperature of 30 °C and a pressure of 1 atm, with a storage capacity sufficient for 30 days of production. The acid is pumped using a pump (P-02).

- **Sulfuric Acid Storage:** Sulfuric acid (H_2SO_4) is used as a catalyst in transesterification reactor process and is supplied by PT. Petrokimia Gresik with a purity of 98%, containing water as an impurity. The sulfuric acid is stored in a storage tank (T-04) in the liquid phase at a temperature of 30 °C and a pressure of 1 atm, with a storage capacity sufficient for 30 days of production. The base catalyst is pumped using a pump (P-14).

3.2.2 Filtration and Mixing Unit

This unit is essential for preparing the WCO by removing unwanted impurities and mixing it with methanol and a catalyst, creating a homogenous mixture for efficient reaction.

- **Filtration:** Because WCO may include particles, it is passed through a number of filters or mesh screens to eliminate solid impurities. This procedure guarantees that the oil is clean and clear of any particles that might clog pipelines, damage equipment, or limit reaction efficiency. In certain installations, centrifuges are also employed to remove tiny particles from the oil, improving the quality of the filtered WCO.
- **Mixing:** After filtering, the WCO enters a mixer and is blended with methanol and a catalyst. The catalyst, which is solid, is first dissolved in methanol to generate a homogeneous solution. The methanol-catalyst solution is next mixed with WCO to ensure that all components are uniformly distributed. Methanol serves as the alcohol in the reaction, while the catalyst begins and speeds the chemical process that finally yields

biodiesel. This thorough mixing is necessary for the subsequent processes to go smoothly and efficiently.

3.2.3 Esterification Unit

The esterification unit is designed to lower the Free Fatty Acid (FFA) content of WCO, a necessary step if FFA levels are high. High FFA levels can cause soap formation during the main reaction (transesterification), which reduces biodiesel yield.

- Esterification Reactor (R-01): The WCO-methanol mixture is added to an esterification reactor (R-01) using sulfuric acid (H_2SO_4) as a catalyst. The sulfuric acid stimulates the interaction between FFAs and methanol, turning them into methyl esters, a kind of biodiesel. The process happens at around 60°C for optimum FFA conversion.
- Decanter (D-01): After esterification, the mixture is transferred to a decanter, which separates the two different phases. The top layer treats WCO with considerably decreased FFA concentration, while the bottom layer includes water and contaminants from the esterification process. This water layer is removed as trash, and the refined oil is sent to the transesterification step.

3.2.4 Transesterification Unit

In this unit, the main biodiesel-producing reaction occurs. Transesterification converts triglycerides in WCO into biodiesel (methyl esters) and glycerol.

- Transesterification Reactor (R-02): The esterified WCO enters the transesterification reactor (R-02) along with more methanol and a base catalyst (NaOH or KOH). The reaction normally occurs at temperatures

about 60°C and atmospheric pressure, allowing the methanol and triglycerides in WCO to react. Transesterification breaks down each triglyceride molecule and replaces it with a methyl group from methanol, producing methyl esters (biodiesel) and glycerol.

- Evaporator (E-01): Following transesterification, surplus methanol that did not react is removed from the mixture with an evaporator. The evaporated methanol is condensed and collected, so it may be recycled back into the process. This recycling procedure eliminates waste, lowers costs, and increases process efficiency.

3.2.5 Separation and Washing Unit

After the transesterification reaction, the product mixture contains biodiesel, glycerol, unreacted methanol, and some residual catalyst.

- Decanter (D-02): The mixture is transported to a decanter, where it separates into biodiesel and glycerol owing to density differences. Biodiesel creates the lighter upper layer, whereas glycerol settles as the heavier bottom layer. This natural separation allows for the removal of glycerol from the bottom of the decanter. Glycerol, a valuable byproduct, can be sold and processed in other industries.
- Biodiesel Washing: The separated biodiesel contains leftover catalyst, methanol, and soap that must be removed. It goes through a washing procedure in which it is combined with warm water. Water absorbs and eliminates any leftover contaminants throughout the washing process. The mixture is allowed to settle before the water layer containing contaminants is drained away. Multiple washing stages can be done until the biodiesel

reaches the desired purity.

3.2.6 Biodiesel Purification and Drying Unit

To ensure the final biodiesel product meets industry standards, it undergoes additional purification and drying steps.

- Final Washing (Optional): If necessary, a final wash with deionized water can be performed to guarantee thorough removal of any trace contaminants, particularly if high-purity biodiesel is desired.
- Evaporator (E-02): After washing, the biodiesel passes through an evaporator to remove any remaining water and methanol. The evaporator warms the biodiesel, which causes water and methanol to evaporate. These vapors are condensed and collected separately, leaving the biodiesel dry and contamination-free. The removal of all traces of water and methanol assures biodiesel stability throughout storage and shipment.

3.2.7 Biodiesel Storage

The refined biodiesel is moved to a storage tank particularly constructed to preserve the fuel's purity. The tank is sealed to prevent moisture infiltration and contamination, and it is monitored to verify that the biodiesel meets fuel specifications until it is ready for distribution. Proper batch labeling and tracking provide quality control and traceability.

3.2.8 Glycerol Processing

Glycerol, the main by-product of biodiesel production, can be processed further or used directly depending on its purity.

- Glycerol Purification (Optional): The glycerol from Decanter D-02 may include quantities of methanol and other contaminants. It can be refined

further by filtering, neutralization, and potentially distillation. Purified glycerol is valuable in the pharmaceutical, cosmetic, and food sectors, providing an extra revenue source for the biodiesel manufacturing plant.

- **Waste Disposal:** Any water and methanol used in the washing and separating procedures are treated to meet environmental requirements before being disposed away. Proper waste treatment assures compliance with environmental requirements while reducing the environmental effect of biodiesel production.

3.3 Equipment Specification

3.3.1 Reactor

1. Reactor Esterification

Table 3.1 Reactor Esterification Specification

Code:	R-01			
Function:	Reacting free fatty acids with methanol to form fatty acid methyl esters with the addition of sulfuric acid as a catalyst			
Amount:	1			
Type:	Continuous Stirred Tank Reactor			
Operating Conditions				
Operating Temperature	1	atm	14.70	psi
Operating Pressure	60	°C	333.15	K
Specifications:				
Reactor Dimensions				
Reactor Materials:	Stainless Steel SA 167 Grade 11 type 316			
Diameter shell:	2.205	m		
Shell height:	4.410	m		
Volume shell:	16.833	m ³		
Volume head:	0.005	m ³		
Volume reactor:	16.838	m ³		
Reactor height:	5.602	m		
Head height:	0.596	m		
Thickness shell:	0.250	in		
Thick head:	0.250	in		
Flat Blade Turbines Impellers				
Impeller Type:	Turbin 6 blade			

Table 3.2 Reactor Esterification Specification (Continued)

Reactor diameter:	0.735	m
Reactor distance:	0.956	m
Reactor width:	0.184	m
Baffle width:	0.125	m
Number of Reactor:	1	
Agitator Speed (N):	125.829	rpm
Agitator Power (P):	15.569	hp
Jacket		
Jacket Material:	Stainless Steel SA 167 Grade 11 type 316	
UD:	152.402	W/ m ² .K
Area of Heat Transfer Area:	23.160	m ²
Jacket thickness:	0.006	m

2. Reactor Transesterification

Table 3.3 Reactor Transesterification Specification

Code:	R-02			
Function:	React Triolein and Methanol with Natrium Hydroxide as catalyst to produce Biodiesel and Glycerol			
Amount:	1			
Type:	Continuous Stirred Tank Reactor			
Operating Conditions:				
Operating Temperature	1	atm	14.70	psi
Operating Pressure	60	°C	333.15	K
Specifications:				
Reactor Dimensions				
Reactor Materials:	Stainless Steel SA 167 Grade 11 type 316			
Diameter shell:	3.403	m		
Shell height:	6.805	m		
Volume shell:	61.857	m ³		
Volume reactor:	0.011	m ³		
Reactor height:	61.868	m ³		
Head height:	8.596	m		
Thickness shell:	0.895	in		
Thick head:	0.250	in		
Flat Blade Turbines Impellers				
Impeller Type:	Turbin 6 blade			
Agitator diameter:	1.134	m		
Agitator Blade:	1.475	m		
Baffle width:	0.284	m		
Number of Reactor:	0.193			

Table 3.4 Reactor Transesterification Specification (Continued)

Agitator Speed (N):	1.179	rps
Agitator Power (P):	81.122	hp
Jacket		
Jacket Material:	Stainless Steel SA 167 Grade 11 type 316	
Ud:	130.031	W/m ² .K
Area of Heat Transfer Area:	9.7523	m ²
Jacket thickness:	0.00635	m

3.3.2 Separator and Supporting Equipment

1. Mixer – 01

Table 3.5 Mixer - 01 Specification

Code:	M-01			
Function:	For Mixing Methanol and Sulfuric Acid as cataylisy			
Amount:	1 alat			
Type:	Flanged and dished stirred tank			
Operating Conditions:				
Operating Pressure:	1	atm	29.39	psi
Operating Temperature:	30	°C	303	K
Specifications:				
Mixer Dimensions				
Mixer Material:	Stainless Steel SA 240 Grade M Type 316			
Diameter shell:	1.661	m		
Shell height:	3.322	m		
Volume shell:	7.198	m ³		
Volume head:	0.225	m ³		
Volume mixer:	7.422	m ³		
Mixer height:	3.335	m		
Head height (OA):	0.311	m		
Shell thickness:	0.250	in		
Thick head:	0.250	in		
Flat Blade Turbines Impellers				
Impeller Type:	Turbin 6 blade			
Mixer diameter:	0.498	m		
Mixer distance:	0.554	m		
Mixer width:	0.100	m		
Baffle width:	0.138	m		
Number of Mixers:	1	unit		
Agitator Speed (N):	1.947	rps		
Agitator Power (P):	5	hp		

2. Mixer – 02

Table 3.6 Mixer - 02 Specification

Code:	M-02			
Function:	Mix Water with the output of the esterification reactor so that bubling does not occur in the oil			
Amount:	1			
Type:	Flanged and dished lid stirred tank			
Operating Conditions:				
Operating Pressure:	1	atm	29.39	psi
Operating Temperature:	30	°C	303	K
Specifications:				
Mixer Dimensions				
Mixer Material:	Stainless Steel SA 240 Grade M Type 316			
Diameter shell:	2.047	m		
Shell height:	4.094	m		
Volume shell:	13.466	m ³		
Volume head:	0.343	m ³		
Volume mixer:	13.807	m ³		
Mixer height:	4.107	m		
Head height (OA):	0.379	m		
Shell thickness:	0.313	in		
Thick head:	0.250	in		
Flat Blade Turbines Impellers				
Impeller Type:	Turbin 6 blade			
Mixer diameter:	0.614	m		
Mixer distance:	0.682	m		
Mixer width:	0.123	m		
Baffle width:	0.171	m		
Number of Mixers:	1	unit		
Agitator Speed (N):	1.580	rps		
Agitator Power (P):	7	hp		

3. Mixer – 03

Table 3.7 Mixer - 03 Specification

Code:	M-03			
Function:	Mix methanol and natrium hydroxide as catalyst for reactor transesterification			
Amount:	1			
Type:	Flanged and dished lid stirred tank			
Operating Conditions:				
Operating Pressure:	1	atm	29.39	psi

Table 3.8 Mixer - 03 Specification (Continued)

Operating Temperature:	30	°C
Specifications:		
Mixer Dimensions		
Mixer Material:	Stainless Steel SA 240 Grade M Type 316	
Diameter shell:	3.020	m
Shell height:	6.039	m
Volume shell:	43.229	m ³
Volume head:	0.754	m ³
Volume mixer:	43.981	m ³
Mixer height:	6.058	m
Head height (OA):	0.544	m
Shell thickness:	0.375	in
Thick head:	0.375	in
Flat Blade Turbines Impellers		
Impeller Type:	Turbin 6 blade	
Mixer diameter:	0.906	m
Mixer distance:	1.007	m
Mixer width:	0.181	m
Baffle width:	0.252	m
Number of Mixers:	1	Unit
Agitator Speed (N):	1.071	rps
Agitator Power (P):	15	hp

4. Mixer – 04

Table 3.9 Mixer - 04 Specification

Code:	M-04			
Function:	Mix Water with the output of the transesterification reactor so that bubling does not occur in the oil			
Amount:	1			
Type:	Flanged and dished lid stirred tank			
Operating Conditions:				
Operating Pressure:	1	atm	29.39	psi
Operating Temperature:	30	°C	303	K
Specifications:				
Mixer Dimensions				
Mixer Material:	Stainless Steel SA 240 Grade M Type 316			
Diameter shell:	3.051	m		
Shell height:	6.101	m		
Volume shell:	44.578	m ³		
Volume head:	0.770	m ³		

Table 3.10 Mixer - 04 Specification (Continued)

Volume mixer:	45.345	m ³
Mixer height:	6.120	m
Head height (OA):	0.563	m
Shell thickness:	0.375	in
Thick head:	0.375	in
Flat Blade Turbines Impellers		
Impeller Type:	Turbin 6 blade	
Mixer diameter:	0.915	m
Mixer distance:	1.017	m
Mixer width:	0.183	m
Baffle width:	0.254	m
Number of Mixers:	1	unit
Agitator Speed (N):	1.060	rps
Agitator Power (P):	15	hp

5. Decanter – 01

Table 3.11 Decanter - 01 Specification

Code	DC-01	
Function	Separating Biodiesel from catalyst sulfuric acid	
Type	Horizontal Cylinder Vessel	
Operating Temperature	30	C
Operating Pressure	1	atm
Decanter Dimensions		
Decanter diameter/shell height	0.851	m
Total length of decanter	2.554	m
Thickness of the decanter wall (shell)	0.188	in
Thick head	0.188	Inch
Head height	10.881	Inch
Residence Time	10	minutees
Total volume of decanters	1.453	m ³
Volumetric Flow Rate of Light Phase (QL)	6.462	m ³ /h
Volumetric Flow Rate of Heavy Phase (QH)	0.805	m ³ /h
Pipe Diameter		
Feed Pipe	1.320	in
Heavy Phase Pipe	0.405	m
Light Phase Pipe	0.405	in
Position Height		
Feed Pipe	0.426	m
Heavy Phase Pipe	3.159	m
Light Phase Pipe	0.766	m
Construction Materials	Stainless Steel (316)	

6. Decanter – 02

Table 3.12 Decanter - 02 Specification

Code	DC-02	
Function	Separating Biodiesel from catalyst natrium hydroxide and glycerol	
Type	Horizontal Cylinder Vessel	
Operating Temperature	30	C
Operating Pressure	1	atm
Decanter Dimensions		
Decanter diameter/shell height	1.469	m
Total length of decanter	4.407	m
Thickness of the decanter wall (shell)	0.188	Inch
Thick head	0.188	Inch
Head height	10.901	Inch
Residence Time	10	minutees
Total volume of decanters	7.463	m ³
Volumetric Flow Rate of Light Phase (QL)	32.714	m ³ /h
Volumetric Flow Rate of Heavy Phase (QH)	4.603	m ³ /h
Pipe Diameter		
Feed Pipe	1.469	Inch
Heavy Phase Pipe	4.407	m
Light Phase Pipe	0.188	Inch
Position Height		
Feed Pipe	1.469	m
Heavy Phase Pipe	4.407	m
Light Phase Pipe	0.188	m
Construction Materials	Stainless Steel (316)	

7. Decanter – 03

Table 3.13 Decanter - 03 Specification

Code	DC-03	
Function	Separating Biodiesel from water	
Type	Horizontal Cylinder Vessel	
Operating Temperature	30	C
Operating Pressure	1	atm
Decanter Dimensions		
Decanter diameter/shell height	0.883	m
Total length of decanter	2.648	m

Table 3.14 Decanter - 03 Specification (Continued)

Thickness of the decanter wall (shell)	0.188	Inch
Thick head	0.188	Inch
Head height	11.816	Inch
Residence Time	10	minutees
Total volume of decanters	1.350	m ³
Volumetric Flow Rate of Light Phase (QL)	6.586	m ³ /h
Volumetric Flow Rate of Heavy Phase (QH)	1.516	m ³ /h
Pipe Diameter		
Feed Pipe	0.883	Inch
Heavy Phase Pipe	2.648	m
Light Phase Pipe	0.188	Inch
Position Height		
Feed Pipe	0.883	m
Heavy Phase Pipe	2.648	m
Light Phase Pipe	0.188	m
Construction Materials	Stainless Steel (316)	

8. Evaporator – 01

Table 3.15 Evaporator - 01 Specification

Code	EV – 01			
Function	Vaporize methanol and water			
Type	Long-tube vertical. natural circulation evaporator			
Amount	1			
Operating Condition	Pressure	1	atm	
	Temperature	66	°C	
Construction Material:	Stainless Steel SA -167 Grade 3 Type 304			
Dimension	Tube Thickness	0.1254	in	
	Tube Type	Triangular Pitch		
	Shell Side	Steam		
		IDs Steam	8	in
		Baffle space	2	in
	Tube Side	Light Organics		
		Passed (n)	6	
		Tube (Nt)	20	
		Area per Tube (A't)	0.185	in²
	Dirt Factor	0.00500		
	Pressure Drop	1.1606		

Table 3.16 Evaporator - 01 Specification

Separator Dimension Phase	Liquid Volume	1.2235	m ³	
	Time	7	min	
	Volume Vapor	12.6561	m ³	
	Volume Total	16.6556	m ³	
	Diameter	5.8996	m	
	Height	11.7992	m	
	Thickness	0.1875	In	
Separator	Head Thickness	0.25	In	

9. Evaporator – 02

Table 3.17 Evaporator - 02 Specification

Code	EV – 02			
Function	Vaporize methanol			
Type	Long-tube vertical. natural circulation evaporator			
Amount	1			
Operating Condition	Pressure	1	atm	
	Temperature	66	°C	
Construction Material:	Stainless Steel SA -167 Grade 3 Type 304			
Dimension	Tube Thickness	0.1254	in	
	Tube Type	Triangular Pitch		
	Shell Side	Steam		
		IDs Steam	8	in
		Baffle space	2	in
	Tube Side	Light Organics		
		Passed (n)	6	
		Tube (Nt)	20	
		Area per Tube (A't)	0.185	in²
	Dirt Factor	0.005		
	Pressure Drop	0.6633		
Separator Dimension Phase	Liquid Volume	1.071	m³	
	Time	8.016	min	
	Vapor Volume	73.168	m³	
	Volume Total	89.087	m³	
	Diameter	3.843	m	
	Height	7.685	m	
	Thickness	0.188	in	
Separator	Head Thickness	0.250	in	

3.3.3 Storage Tank Specification

Table 3.18 Storage Tank Specification

Tank	T-01	T-02	T-03	T-04	T-05	T-06
Function	Storing Raw Material CH ₄ O	Storing Raw Material H ₂ SO ₄	Storing Raw Material WCO	Storing Raw Material NaOH	Storing Raw Material CH ₄ O	Storing Raw Material Biodiesel
Storage Duration	14 Days	30 Days	7 Days	30 Days	14 Days	7 Days
Phase	liquid	liquid	liquid	solid	liquid	liquid
Amount of Vessel	1	1	1	1	1	1
Type of Vessel	Vertical Cylindrical Tank with Flat Bottom and Torispherical Roof	Vertical Cylindrical Tank with Flat Bottom and Conical Roof	Vertical Cylindrical Tank with Flat Bottom and Conical Roof	Vertical Cylindrical Tank with Flat Bottom and Conical Roof	Vertical Cylindrical Tank with Flat Bottom and Torispherical Roof	Vertical Cylindrical Tank with Flat Bottom and Torispherical Roof
Operating Conditions	30°C	30°C	30°C	30°C	30°C	30°C
Specifications						
Material Construction	Stainless Stell SA-240 type 316	Stainless Stell SA-240 type 316	Stainless Stell SA-240 type 316	Stainless Stell SA-240 type 316	Stainless Stell SA-240 type 316	Stainless Stell SA-240 type 316
Volume, m ³	55.2921	1444.2015	1293.3568	181.6671	8752.7374	1574.6882
Diameter,m	6.096	9.1440	15.2400	7.6200	9.1440	7.6200
Total Height,m	3.0480	6.0960	6.0960	3.6576	6.0960	3.6576
Number of Courses	3	3	8	4	3	4
Head & Bottom						
Head Type	Torispherical Head	Conical Head	Conical Head	Conical Head	Torispherical Head	Torispherical Head
Thickness Head (in)	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875
Bottom Type	Flat Bottom	Flat Bottom	Flat Bottom	Flat Bottom	Flat Bottom	Flat Bottom
Thickness Bottom (in)	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875

3.3.4 Transportation Specification

Table 3.19 Pump Specification

Code	Amount	Diameter	Total Head	Power Efficiency (%)		Power (Hp)		Capacity (gallon)
		(in)	(m)	Pump	Motor	Pump	Motor	
P-01	2	2.067	5.564	80	80	0.252	1/2	38.136
P-02	2	0.269	14.137	80	80	0.017	1/2	0.332
P-03	2	2.469	5.021	80	80	0.232	1/2	37.934
P-04	2	2.469	4.450	80	80	0.202	1/2	33.392
P-05	2	2.469	4.450	80	80	0.202	1/2	33.392
P-06	2	3.068	4.412	80	80	0.500	1/2	72.349
P-07	2	0.622	3.264	80	80	0.004	1/2	0.837
P-08	2	3.068	4.412	80	80	0.500	1/2	72.349
P-09	2	2.059	3.770	80	80	0.123	1/2	29.731
P-10	2	2.047	3.802	80	80	0.116	1/2	29.984
P-11	2	1.992	4.120	80	80	0.112	1/2	27.882
P-12	2	0.618	4.120	80	80	0.012	1/2	1.849
P-13	2	0.474	4.804	80	80	1.395	1 1/2	0.926
P-14	2	4.636	3.688	80	80	0.649	1/2	189.366
P-15	2	4.672	7.376	80	80	1.175	1 1/2	192.280
P-16	2	4.690	7.350	80	80	1.194	1 1/2	193.090
P-17	2	4.650	12.287	80	80	1.946	2	189.912
P-18	2	0.780	7.287	80	80	0.039	1/2	3.178
P-19	2	4.690	5.963	80	80	1.276	1/2	193.090
P-20	2	4.690	9.520	80	80	1.582	2	197.081
P-21	2	4.650	8.265	80	80	0.353	2	34.807
P-22	2	0.780	9.013	80	80	0.312	1/2	29.005
P-23	2	4.650	5.570	80	80	0.046	1/2	5.803
P-24	2	4.650	8.265	80	80	0.353	2	35.238

3.3.5 Heat Exchanger Specification

1. Heater

Table 3.20 Heater – 01 & Heater – 02 Specification

Code	HEATER (H-01)	HEATER (H-02)
Function	Increase the outlet temperature of Mixer - 01 to Reactor - 01	Increase the temperature of the WCO output from Filter-01 to go to Reactor-01
Total Unit	1	1
Type	Double Pipe Heat Exchanger	Double Pipe Heat Exchanger
Material		
Number of Hairpins	1	1
Length Hairpins (ft)	12	12
Cold Fluid		
IPS (in)	2	2
Flow Area (in ²)	1.190	1.190
OD (in)	1.250	1.250
ID (in)	1.250	1.250
Surface Area (ft ² /ft)	0.498	0.498
Hot Fluid		
IPS (in)	1.250	1.250
Flow Area (in ²)	1.500	1.500
OD (in)	2	2
ID (in)	2	2
Surface Area (ft ² /ft)	0.622	0.622
A (ft ²)	1.458	1.254
Ud (Btu/h.ft ² .F)	68.653	4.912
Uc (Btu/h.ft ² .F)	1095.040	3189.107
Rd	0.014	0.203
Rd min	0.003	0.003

Table 3.21 Heater – 03 Specification

Code	Heater – 03 (H-03)			
Funtion	Increase the outlet temperature of Mixer – 03 to Reactor - 02			
Amount	1			
Type	Double Pipe Heat Exchanger			
Material				
Total Haripins	1			
Haripins Length	12	ft	3.6576	m
Cold Fluid Annulus (light Organics)				
IPS	2.000	in	0.0508	m
Flow Area	1.190	in ²	0.0008	m ²

Table 3.22 Heater – 03 Specification (Continued)

OD	1.250	in	0.03175	m
ID	1.250	in	0.03175	m
Surface Area	0.498	(ft ² /ft)		m
Hot Fluid Inner pipe (Steam)				
IPS	1.250	in	0.03175	m
Flow Area	1.500	in ²	0.0010	m ²
OD	2.000	in	0.0508	m
ID	2.000	in	0.0508	m
Surface Area	0.622	(ft ² /ft)		
A	1.381	ft ²		
Ud	108.207	Btu/hr. ft ² .°F		
Uc	3221.869	Btu/hr. ft ² .°F		
Rd	0.009			
Rd min	0.003			

2. Cooler

Table 3.23 Cooler – 01 & Cooler – 02 Specification

Code	COOLER (CL-01)	COOLER (CL-02)
Function	Decrease the temperature from Reactor-01 to Mixer-02	Decrease the temperature from Reactor-02 to Decanter-02
Total Unit	1	1
Type	Double Pipe Heat Exchanger	Double Pipe Heat Exchanger
Material		
Number of Hairpins	3	1
Length Hairpins (ft)	12	12
Cold Fluid		
IPS (in)	2	2
Flow Area (in ²)	1.190	1.190
OD (in)	2.380	2.380
ID (in)	2.067	2.067
Surface Area (ft ² /ft)	3.350	3.350
Hot Fluid		
IPS (in)	1.250	1.250
Flow Area (in ²)	1.500	1.500
OD (in)	1.660	1.660
ID (in)	1.380	1.380
Surface Area (ft ² /ft)	1.500	1.500
A (ft ²)	2.495	2.625
Ud (Btu/h.ft ² .F)	20.794	65.619
Uc (Btu/h.ft ² .F)	24.886	8.474
Rd	0.008	0.103
Rd min	0.003	0.003

Table 3.24 Cooler – 3 Specification

Code	COOLER (CL-03)
Function	Decrease the temperature Evaporator to Product Storage Tank
Total Unit	1
Type	Double Pipe Heat Exchanger
Material	
Number of Hairpins	1
Length Hairpins (ft)	12.0000
Cold Fluid	
IPS (in)	2.000
Flow Area (in ²)	1.190
OD (in)	2.380
ID (in)	2.067
Surface Area (ft ² /ft)	3.350
Hot Fluid	
IPS (in)	1.250
Flow Area (in ²)	1.500
OD (in)	1.660
ID (in)	1.380
Surface Area (ft ² /ft)	1.500
A (ft ²)	2.625
Ud (Btu/h.ft ² .F)	65.619
Uc (Btu/h.ft ² .F)	8.474
Rd	0.103
Rd min	0.003

3. Condensor

Table 3.25 Condensor – 01 & Condensor – 02 Specification

Code	COOLER (CL-01)	COOLER (CL-04)
Function	Condensing the distillate from Evaporator-01 to be recycled to mixer-01	Condensing the distillate from Evaporator-02 to be recycled to mixer-03
Total Unit	1	1
Type	Double Pipe Heat Exchanger	Double Pipe Heat Exchanger
Specification		
a" (In ²)	0.639	0.639
Pt (Triangular)	1.250	1.250
Passes	4	4
A (ft ²)	139.130	770.119
Uc (Btu/hr.ft ² .F)	94.808	163.069
Ud (Btu/hr.ft ² .F)	73.810	408.560
Rd calculated	0.003	0.004
Rd min	0.003	0.003
Hot Fluid		
IDs (in)	15.25	15.25
Passes	1.0000	1.0000
ΔP Calculated (psi)	0.0348	1.1025
ΔP Allowed (psi)	10	10
Cold Fluid		
Nt (unit)	27.000	27.000
L (ft)	20.000	20.000
OD (in)	1.000	1.000
ID (in)	0.902	0.902
BWG	18.000	18.000
ΔP Calculated (psi)	0.219	0.214
ΔP Allowed (psi)	10	10

3.4 Mass Balance

3.4.1 Mass Balance Total

Table 3.19 Mass Balance Total

Component	Mr	Input	Output
		Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2443.181	48.864
C ₅₁ H ₉₈ O ₆	852.378	2670.454	53.409
C ₁₈ H ₃₄ O ₂	282.46	232.954	11.648
C ₁₆ H ₃₂ O ₂	256.424	335.227	16.761
C ₁₇ H ₃₄ O ₂	270	0.000	2935.511
C ₁₉ H ₃₆ O ₂	296.49	0.000	2615.624
CH ₃ OH	32.04	5624.998	0.000
H ₂ SO ₄	98.079	111.364	111.364
NaOH	39.997	389.773	389.773
C ₃ H ₈ O ₃	92.09	0.000	5011.362
H ₂ O	18.015	598.863	1212.500
Total (Kg/h)		12406.815	12406.815

3.4.2 Mass Balance Mixer

Table 3.20 Mass Balance Mixer 1

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	0.000	0.000	0.000
C ₅₁ H ₉₈ O ₆	852.378	0.000	0.000	0.000
C ₁₈ H ₃₄ O ₂	282.46	0.000	0.000	0.000
C ₁₆ H ₃₂ O ₂	256.424	0.000	0.000	0.000
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	5623.639	5623.639
H ₂ SO ₄	98.079	111.337	0.000	111.337
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	2.272	56.804	59.077
Sub Total		113.105	5680.443	5794.052
Total (Kg/h)		5794.052		5794.052

3.4.3 Mass Balance Filter

Table 3.21 Mass Balance Filter

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2442.591	0.000	2442.591
C ₅₁ H ₉₈ O ₆	852.378	2669.808	0.000	2669.808
C ₁₈ H ₃₄ O ₂	282.46	232.898	0.000	232.898
C ₁₆ H ₃₂ O ₂	256.424	335.146	0.000	335.146
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	0.000	0.000
H ₂ SO ₄	98.079	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.000	0.000	0.000
Impurities		56.804	56.804	0.000
Sub Total		5737.248	56.804	5680.443
Total (Kg/h)		5737.248	5737.248	

3.4.4 Mass Balance Reactor Esterification

Table 3.26 Mass Balance Reactor Esterification

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	0.000	2442.591	2442.591
C ₅₁ H ₉₈ O ₆	852.378	0.000	2669.808	2669.808
C ₁₈ H ₃₄ O ₂	282.46	0.000	232.898	11.645
C ₁₆ H ₃₂ O ₂	256.424	0.000	335.146	16.757
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	318.389
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	221.253
CH ₃ OH	32.04	5623.639	0.000	5083.997
H ₂ SO ₄	98.079	111.337	0.000	111.337
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	59.077	0.000	598.719
Sub Total		5794.052	5680.443	11474.495
Total (Kg/h)		11474.495		11474.495

3.4.5 Mass Balance Mixer 2

Table 3.27 Mass Balance Mixer 2

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2442.591	0.000	2442.591
C ₅₁ H ₉₈ O ₆	852.378	2669.808	0.000	2669.808
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	318.389	0.000	318.389
C ₁₉ H ₃₆ O ₂	296.49	221.253	0.000	221.253
CH ₃ OH	32.04	5083.997	0.000	5083.997
H ₂ SO ₄	98.079	111.337	0.000	111.337
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	598.719	161.893	760.611
Sub Total		11474.495	161.893	11636.388
Total (Kg/h)		11636.388		11636.388

3.4.6 Mass Balance Decanter 1

Table 3.28 Mass Balance Decanter 1

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2442.591	0.010	2442.581
C ₅₁ H ₉₈ O ₆	852.378	2669.808	0.011	2669.798
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	318.389	0.001	318.388
C ₁₉ H ₃₆ O ₂	296.49	221.253	0.001	221.252
CH ₃ OH	32.04	5083.997	4829.797	254.200
H ₂ SO ₄	98.079	111.337	111.337	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	760.611	760.611	0.001
Sub Total		11636.388	5701.767	5934.621
Total (Kg/h)		11636.388	11636.388	

3.4.7 Mass Balance Evaporator 1

Table 3.29 Mass Balance Evaporator 1

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2442.581	0.000	2442.581
C ₅₁ H ₉₈ O ₆	852.378	2669.798	0.000	2669.798
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	318.388	0.000	318.388
C ₁₉ H ₃₆ O ₂	296.49	221.252	0.000	221.252
CH ₃ OH	32.04	254.200	254.200	0.000
H ₂ SO ₄	98.079	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.001	0.001	0.000
Sub Total		5934.621	254.200	5680.420
Total (Kg/h)		5934.621	5934.621	

3.4.8 Mass Balance Mixer 3

Table 3.30 Mass Balance Mixer 3

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	0.000	0.000	0.000
C ₅₁ H ₉₈ O ₆	852.378	0.000	0.000	0.000
C ₁₈ H ₃₄ O ₂	282.46	0.000	0.000	0.000
C ₁₆ H ₃₂ O ₂	256.424	0.000	0.000	0.000
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	33741.701	33741.701
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	389.677	0.000	389.677
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	7.953	340.825	348.778
Sub Total		397.629	34082.526	34480.155
Total (Kg/h)		34480.155		34480.155

3.4.9 Mass Balance Reactor Transesterifications

Table 3.31 Mass Balance Reactor Transesterification

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2442.581	0.000	48.852
C ₅₁ H ₉₈ O ₆	852.378	2669.798	0.000	53.396
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	318.388	0.000	2934.789
C ₁₉ H ₃₆ O ₂	296.49	221.252	0.000	2614.982
CH ₃ OH	32.04	0.000	33741.701	28731.570
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	389.677	389.677
C ₃ H ₈ O ₃	92.09	0.000	0.000	5010.131
H ₂ O	18.015	0.001	348.778	348.778
Sub Total		5680.421	34480.155	40160.576
Total (Kg/h)		40160.576		40160.576

3.4.10 Mass Balance Decanter 2

Table 3.32 Mass Balance Decanter 2

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	48.852	0.000	48.851
C ₅₁ H ₉₈ O ₆	852.378	53.396	0.000	53.396
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	2934.789	0.012	2934.777
C ₁₉ H ₃₆ O ₂	296.49	2614.982	0.010	2614.971
CH ₃ OH	32.04	28731.570	348.778	28382.791
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	389.677	389.677	0.000
C ₃ H ₈ O ₃	92.09	5010.131	5010.131	0.000
H ₂ O	18.015	348.778	348.778	0.000
Sub Total		40160.576	6097.387	34063.189
Total (Kg/h)		40160.576	40160.576	

3.4.11 Mass Balance Mixer 4

Table 3.33 Mass Balance Mixer 4

Component	Mr	Input		Output
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	48.851	0.000	48.851
C ₅₁ H ₉₈ O ₆	852.378	53.396	0.000	53.396
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	2934.777	0.000	2934.777
C ₁₉ H ₃₆ O ₂	296.49	2614.971	0.000	2614.971
CH ₃ OH	32.04	28382.791	0.000	28382.791
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.000	1664.925	1664.925
Sub Total		34063.189	1664.925	35728.114
Total (Kg/h)		35728.114		35728.114

3.4.12 Mass Balance Decanter 3

Table 3.34 Mass Balance Decanter 3

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	48.851	0.000	48.851
C ₅₁ H ₉₈ O ₆	852.378	53.396	0.000	53.396
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	2934.777	0.000	2934.777
C ₁₉ H ₃₆ O ₂	296.49	2614.971	0.000	2614.971
CH ₃ OH	32.04	1.419	26963.652	1419.140
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.001	1664.923	0.001
Sub Total		35728.114	28628.575	7099.539
Total (Kg/h)		35728.114	35728.114	

3.4.13 Mass Balance Evaporator 2

Table 3.35 Mass Balance Evaporator 2

Component	Mr	Input	Output	
		Mass (kg/h)	Mass (kg/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	48.851	0.000	48.851
C ₅₁ H ₉₈ O ₆	852.378	53.396	0.000	53.396
C ₁₈ H ₃₄ O ₂	282.46	11.645	0.000	11.645
C ₁₆ H ₃₂ O ₂	256.424	16.757	0.000	16.757
C ₁₇ H ₃₄ O ₂	270	2934.777	0.000	2934.777
C ₁₉ H ₃₆ O ₂	296.49	2614.971	0.000	2614.971
CH ₃ OH	32.04	1419.140	1417.720	1.419
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.001	0.000	0.001
Sub Total		7099.539	1417.721	5681.818
Total (Kg/h)		7099.539	7099.539	

3.5 Heat Balance

3.5.1 Heat Balance Total

Table 3.36 Heat Balance Total

Component	Mr	Input	Output
		Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4277.044	85.262
C ₅₁ H ₉₈ O ₆	852.378	4605.514	92.610
C ₁₈ H ₃₄ O ₂	282.46	2829.148	140.600
C ₁₆ H ₃₂ O ₂	256.424	4245.467	211.136
C ₁₇ H ₃₄ O ₂	270	0.000	5579.332
C ₁₉ H ₃₆ O ₂	296.49	0.000	28455.970
CH ₃ OH	32.04	102576.738	0.000
H ₂ SO ₄	98.079	796.382	796.382
NaOH	39.997	4244.690	4244.690
C ₃ H ₈ O ₃	92.09	0.000	71110.672
H ₂ O	18.015	12548.402	25406.730
Total (Kj/h)		136123.385	136123.385

3.5.2 Mixer 1

Table 3.37 Heat Balance Mixer 1

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	0.000	0.000	0.000
C ₅₁ H ₉₈ O ₆	852.378	0.000	0.000	0.000
C ₁₈ H ₃₄ O ₂	282.46	0.000	0.000	0.000
C ₁₆ H ₃₂ O ₂	256.424	0.000	0.000	0.000
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	70333.189	70333.189
H ₂ SO ₄	98.079	796.503	0.000	796.503
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	47.611	1190.280	1237.891
Sub Total		844.115	71523.470	72367.584
Total (Kj/h)		72367.584		72367.584

3.5.3 Filter

Table 3.38 Heat Balance Filter

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4276.491	0.000	4276.491
C ₅₁ H ₉₈ O ₆	852.378	4604.321	0.000	4604.321
C ₁₈ H ₃₄ O ₂	282.46	2827.553	0.000	2827.553
C ₁₆ H ₃₂ O ₂	256.424	4245.467	0.000	4245.467
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	0.000	0.000
H ₂ SO ₄	98.079	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.000	0.000	0.000
Total (Kj/h)		15953.832	15953.832	

3.5.4 Reactor 1

Table 3.39 Heat Balance Reactor 1

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4551.91	0.000	4551.915
C ₅₁ H ₉₈ O ₆	852.378	4897.39	0.000	4897.390
C ₁₈ H ₃₄ O ₂	282.46	581.14	0.000	29.057
C ₁₆ H ₃₂ O ₂	256.424	879.79	0.000	43.990
C ₁₇ H ₃₄ O ₂	270	0.00	0.000	639.515
C ₁₉ H ₃₆ O ₂	296.49	0.00	0.000	497.270
CH ₃ OH	32.04	0.00	14627.877	13224.192
H ₂ SO ₄	98.079	0.00	164.357	164.357
C ₃ H ₈ O ₃	92.09	0.00	0.000	0.000
H ₂ O	18.015	0.00	246.247	2495.620
Sub Total		10910.239	15038.481	26543.305
Enthalphy Pendingin		4906183.24		
Q Pendingin				4905588.65
Total (Kj/h)		4932131.955		4932131.955

3.5.5 Mixer 2

Table 3.40 Heat Balance Mixer – 2

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4276.491	0.000	4276.491
C ₅₁ H ₉₈ O ₆	852.378	4604.321	0.000	4604.321
C ₁₈ H ₃₄ O ₂	282.46	141.378	0.000	141.378
C ₁₆ H ₃₂ O ₂	256.424	212.273	0.000	212.273
C ₁₇ H ₃₄ O ₂	270	605.155	0.000	605.155
C ₁₉ H ₃₆ O ₂	296.49	2407.055	0.000	2407.055
CH ₃ OH	32.04	63584.045	0.000	63584.045
H ₂ SO ₄	98.079	796.503	0.000	796.503
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	12545.554	3392.299	15937.853
Sub Total		89172.775	3392.299	92565.074
Total (Kj/h)		92565.074		92565.074

3.5.6 Decanter 1

Table 3.41 Heat Balance Decanter 1

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4276.491	0.017	4276.473
C ₅₁ H ₉₈ O ₆	852.378	4604.321	0.018	4604.303
C ₁₈ H ₃₄ O ₂	282.46	141.378	0.001	141.377
C ₁₆ H ₃₂ O ₂	256.424	212.273	0.001	212.272
C ₁₇ H ₃₄ O ₂	270	605.155	0.002	605.153
C ₁₉ H ₃₆ O ₂	296.49	2407.055	0.010	2407.045
CH ₃ OH	32.04	63584.045	60404.843	3179.202
H ₂ SO ₄	98.079	796.503	796.503	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	15937.853	15937.841	0.012
Sub Total		92565.074	77139.236	15425.838
Total (Kj/h)		92565.074	92565.074	

3.5.7 Evaporator 1

Table 3.42 Heat Balance Evaporator 1

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	4276.473	0.000	4276.473
C ₅₁ H ₉₈ O ₆	852.378	4604.303	0.000	4604.303
C ₁₈ H ₃₄ O ₂	282.46	1177.195	0.000	1177.195
C ₁₆ H ₃₂ O ₂	256.424	1775.994	0.000	1775.994
C ₁₇ H ₃₄ O ₂	270	605.153	0.000	605.153
C ₁₉ H ₃₆ O ₂	296.49	20101.068	0.000	20101.068
CH ₃ OH	32.04	26631.468	26631.468	0.000
H ₂ SO ₄	98.079	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.098	0.098	0.000
Sub Total		59171.752	26631.566	32540.186
Total (Kj/h)		59171.752	59171.752	

3.5.8 Mixer 3

Table 3.43 Heat Balance Mixer 3

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	0.0000	0.000	0.000
C ₅₁ H ₉₈ O ₆	852.378	0.0000	0.000	0.000
C ₁₈ H ₃₄ O ₂	282.46	0.0000	0.000	0.000
C ₁₆ H ₃₂ O ₂	256.424	0.0000	0.000	0.000
C ₁₇ H ₃₄ O ₂	270	0.0000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.0000	0.000	0.000
CH ₃ OH	32.04	0.0000	421997.490	421997.490
H ₂ SO ₄	98.079	0.0000	0.000	0.000
NaOH	39.997	4243.6673	0.000	4243.667
C ₃ H ₈ O ₃	92.09	0.0000	0.000	0.000
H ₂ O	18.015	166.6386	7141.654	7308.292
Sub Total		4410.3059	429139.144	433549.450
Total (Kj/h)		433549.450		433549.450

3.5.9 Reactor 2

Table 3.44 Heat Balance Reactor 2

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
$C_{57}H_{104}O_6$	885.432	4551.90	0.000	91.038
$C_{51}H_{98}O_6$	852.378	4897.37	0.000	97.947
$C_{18}H_{34}O_2$	282.46	29.06	0.000	29.057
$C_{16}H_{32}O_2$	256.424	43.99	0.000	43.990
$C_{17}H_{34}O_2$	270	0.00	0.000	5894.809
$C_{19}H_{36}O_2$	296.49	1503.23	0.000	5877.205
CH_3OH	32.04	0\	87766.918	74734.861
H_2SO_4	98.079	0.00	0.000	0.000
$NaOH$	39.997	0.00	847.782	847.782
$C_3H_8O_3$	92.09	0.00	0.000	14490.037
H_2O	18.015	0.00	1453.799	1453.802
Sub Total		11025.540	90068.499	103560.528
Enthalphy Formation		46332546.66		
Q Pemanas				46330080.17
Total (Kj/h)		46433640.697		46433640.697

3.5.10 Decanter 2

Table 3.45 Heat Balance Decanter 2

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	85.529	0.000	85.529
C ₅₁ H ₉₈ O ₆	852.378	92.086	0.000	92.086
C ₁₈ H ₃₄ O ₂	282.46	1177.195	0.005	1177.191
C ₁₆ H ₃₂ O ₂	256.424	1775.994	0.007	1775.987
C ₁₇ H ₃₄ O ₂	270	5578.095	0.022	5578.073
C ₁₉ H ₃₆ O ₂	296.49	237574.494	0.950	237573.544
CH ₃ OH	32.04	3010088.122	36540.077	2973548.045
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	34776.634	34776.634	0.000
C ₃ H ₈ O ₃	92.09	589198.572	589198.572	0.000
H ₂ O	18.015	59721.017	59721.017	0.000
Sub Total		3940067.740	720237.286	3219830.454
Total (Kj/h)		3940067.740	3940067.740	

3.5.11 Mixer 4

Table 3.46 Heat Balance Mixer 4

Component	Mr	Input		Output
		Mass (Kj/h)	Mass (kg/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	85.529	0.000	85.529
C ₅₁ H ₉₈ O ₆	852.378	92.086	0.000	92.086
C ₁₈ H ₃₄ O ₂	282.46	141.377	0.000	141.377
C ₁₆ H ₃₂ O ₂	256.424	212.272	0.000	212.272
C ₁₇ H ₃₄ O ₂	270	5578.073	0.000	5578.073
C ₁₉ H ₃₆ O ₂	296.49	28448.750	0.000	28448.750
CH ₃ OH	32.04	354975.194	0.000	354975.194
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.000	34886.836	34886.836
Sub Total		389533.280	34886.836	424420.116
Total (Kj/h)		424420.116		424420.116

3.5.12 Decanter 3

Table 3.47 Heat Balance Decanter 3

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	85.529	0.000	85.529
C ₅₁ H ₉₈ O ₆	852.378	92.086	0.000	92.086
C ₁₈ H ₃₄ O ₂	282.46	141.377	0.000	141.377
C ₁₆ H ₃₂ O ₂	256.424	212.272	0.000	212.272
C ₁₇ H ₃₄ O ₂	270	5578.073	0.000	5578.073
C ₁₉ H ₃₆ O ₂	296.49	28448.750	0.000	28448.750
CH ₃ OH	32.04	354975.194	337226.435	17748.760
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	34886.836	34886.806	0.030
Sub Total		424420.116	372113.240	52306.876
Total (Kj/h)		424420.116	424420.116	

3.5.13 Evaporator 2

Table 3.48 Heat Balance Evaporator - 2

Component	Mr	Input	Output	
		Mass (Kj/h)	Mass (Kj/h)	Mass (Kj/h)
C ₅₇ H ₁₀₄ O ₆	885.432	85.529	0.000	85.529
C ₅₁ H ₉₈ O ₆	852.378	92.086	0.000	92.086
C ₁₈ H ₃₄ O ₂	282.46	141.377	0.000	141.377
C ₁₆ H ₃₂ O ₂	256.424	212.272	0.000	212.272
C ₁₇ H ₃₄ O ₂	270	5578.073	0.000	5578.073
C ₁₉ H ₃₆ O ₂	296.49	28448.750	0.000	28448.750
CH ₃ OH	32.04	17748.760	17731.011	17.749
H ₂ SO ₄	98.079	0.000	0.000	0.000
NaOH	39.997	0.000	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000
H ₂ O	18.015	0.030	0.002	0.029
Sub Total		52306.876	17731.012	34575.863
Total (Kj/h)		52306.876	52306.876	

CHAPTER IV.

FACTORY DESIGN

Plant design is an essential requirement for accurately estimating costs and other necessary aspects prior to the establishment of a manufacturing facility. It includes the design of piping systems, building infrastructure, equipment types and quantities, and electrical installations. This process specifically provides reliable information on construction and site costs, thereby enabling a detailed cost estimation before the plant is built.

4.1 Factory Location

The selection and determination of location is one of the most important parts for estimating costs accurately before establishing a factory in a factory design that includes building facilities, types and quantities of equipment, piping and electrical design. This will provide reliable information regarding building and land costs so that more detailed and specific cost calculations can be obtained before establishing a factory.

With this consideration, the biodiesel factory design with a capacity of 45.000 tons/year will be established in the Indramayu area, West Java, precisely at Jl. Pantai Song, Karangsong, Indramayu, Indramayu Regency, 45219

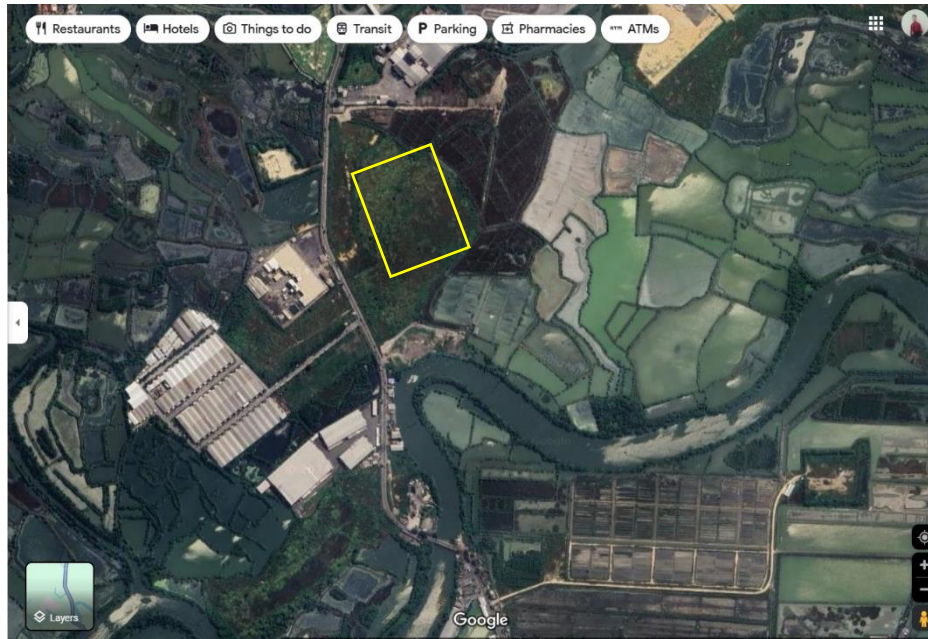


Figure 6. Factory Location

In the preliminary design of the biodiesel plant to be established in the area, several factors are considered based on the following considerations:

4.1.1 Availability of Raw Materials

The availability of raw materials is very much needed to ensure the continuity of production in a factory. The raw materials for the production of Biodiesel is waste cooking oil, as well as sulfuric acid and natrium hydroxide as a catalyst. The location was chosen because it is close to the sea and to the island of kalimantan as a distribution of main reaction ingredients, the products of methanol taken from PT. Kaltim Methanol Industry located in Samarinda, East Kalimantan. The Location was also chosen because it is close to the main road on java island which is usually used for distribution and transportaion for land routes, namely Jalan Pantai Utara. To obtain the main raw material, which is waste cooking oil that ingridient can be obtained in densely populated areas or in urban areas, because in these areas there

are still many small and large scale restaurants. Other materials such as sulfuric acid and sodium hydroxide are obtained from PT. Petrokimia Gresik

4.1.2 Adequate Utility Facilities

In order for a process in the factory to run smoothly, supporting facilities are needed such as utilities. Utilities themselves function as supporting facilities such as water, electricity, and fuel. In the establishment of this biodiesel factory, the most abundant raw material is the nearest water source that flows directly beside the factory, namely the Cimanuk River. Considering that this water source has a sufficiently large water discharge with relatively small fluctuations between the rainy season and the dry season. The source of electrical energy is obtained from the State Electricity Company (PLN) and the factory generator as a backup in case PLN experiences disruptions. The fuel for the generator itself is obtained from the nearest Pertamina, namely PT. Pertamina RU VI Balongan, which is only 11.7 km from the factory.

4.1.3 Smooth Transportation and Distribution

Indramayu is an industrial area that has been designated by the government, where this area has adequate infrastructure such as highways that will facilitate the distribution process of products through land routes. In addition, it is close to several ports that will ease access for importing raw materials and exporting products abroad via sea routes.

4.1.4 Potential Marketing

The market for biodiesel from used cooking oil in Indonesia is experiencing rapid growth, driven by increasing awareness of renewable energy and environmental sustainability. The target market for this biodiesel includes the

transportation sector, manufacturing industry, power generation, as well as households and commercial sectors that use diesel fuel. Biodiesel from used cooking oil has various applications, such as an environmentally friendly alternative fuel for motor vehicles, an energy source for industrial machinery and generators, and a fuel blend component (B20 to B100) to reduce dependence on fossil fuels. With advantages in reducing greenhouse gas emissions and utilizing waste cooking oil that could otherwise pollute the environment, this biodiesel presents a sustainable solution for Indonesia's energy industry.

4.1.5 Provision of Human Resources as Labor

For labor needs, specifications are required according to the company's criteria. Consideration is also needed for the local minimum wage, working hours, diversity of skills, education of the surrounding community, and other considerations. With this, the labor needs will be met, both from the surrounding area and outside the factory location. With the establishment of this factory, it is expected to reduce the unemployment rate and improve the existing human resources.

4.1.6 Stable Climate Conditions

Indramayu, West Java, shows an average temperature of 33.5°C (92.3°F) to 26.2°C (79.2°F), so the factory operations will run smoothly.

4.1.7 Environment and Community

With the establishment of this new factory, it will open up a wide range of job opportunities. The response from the surrounding community is also quite good due to the establishment of the new factory. In addition to improving the welfare of the surrounding community, the establishment of this factory also does not disturb

the safety and security of the surrounding community because the impacts have been considered beforehand.

4.2 Plant Layout

The plant layout is a crucial aspect in organizing the facilities within a factory to ensure a smooth production process. It encompasses all spatial planning required for various activities within a factory, including office operations, warehouses, workspaces, and other activities related to the production process. The plant layout is designed by considering multiple factors to ensure a sustainable production process and facilitate employee mobility in a safe, efficient, and convenient manner. Several factors must be considered when determining the plant (Peters, 2004):

- a. The sequence of the production process,
- b. Expansion of the plant site,
- c. Efficient distribution of raw materials, water supply, steam process, and electricity,
- d. Maintenance and repair of plant components,
- e. Safety and occupational health,
- f. Building area, structural conditions, and construction standards compliance,
- g. A flexible layout design that accommodates potential changes in processes or machinery, ensuring modifications can be implemented cost-effectively,
- h. Wastewater disposal management.
- i. Proper arrangement of service areas, such as prayer rooms, cafeterias, restrooms, and parking lots, to ensure accessibility without disrupting workflow

The key considerations in designing a plant layout include :

1) Plant Expansion

Plant expansion should be incorporated into the initial design to prevent future spatial constraints. Specific areas should be designated for future expansions, additional equipment, and increased production capacity.

2) Safety

Safety considerations should address potential hazards, including fire, explosions, and exposure to toxic gases. Protective measures, such as the installation of hydrants, adequate water reservoirs, and explosion barriers, must be implemented. Hazardous product storage tanks should be placed in designated areas with appropriate spacing between buildings to facilitate emergency response and provide evacuation routes for employees during critical situations.

3) Available Land Area

The cost of land is a limiting factor in determining the available space. The use of space must be optimized based on land availability. If land prices are too high, efficiency in space utilization becomes necessary, which may include placing certain equipment above others or designing floor layouts strategically to maximize space usage.

4) Buildings

The physical structures must meet established standards and be equipped with essential features such as ventilation, installations, and other necessary infrastructure that comply with regulatory requirements.

5) Installation and Utilities

Proper installation and distribution of gas, steam, and electricity facilitate efficient operations and maintenance. The arrangement of process equipment should allow easy access for employees, ensuring smooth operations and simplified maintenance.

6) Road Network

To support material transportation, maintenance, repairs, and workplace safety, sufficient roadways must be established within the plant area. These roads should enable the smooth movement of vehicles, ensuring accessibility during emergencies.

General Plant Layout:

a) Administrative, Laboratory, and Support Facilities Area

- The administrative area serves as the center for administrative and financial operations.
- The laboratory functions as the quality control center for raw materials and finished products.
- Employee facilities such as a clinic, cafeteria, and mosque are also included in this area.

b) Processing and Expansion Area

- This area houses processing equipment and serves as the primary location for production activities.
- The control room is positioned within this area to monitor and manage operations.

c) Warehousing, Workshop, Garage, and Loading Space

- This section is designated for storage, equipment maintenance, vehicle

parking, and logistics.

d) Utilities and Firefighting Area.

- This area accommodates essential utilities such as water supply, steam, cooling water, and electricity generation to support the production.
- It also includes firefighting units for emergency response.

e) Waste Treatment Area

- This area is designated for waste disposal and the treatment of byproducts from the production process.

A detailed breakdown of the land allocation for the factory buildings can be found in Table 4.1:

Table 4.1 Building Specification

NO	Location	Area (m ²)	Length (m)	Width (m)
1	Process Area	4260	60	71
2	Expansion Area	300	15	20
3	Utility Area	1564	34	46
NO	Location	Area (m ²)	Length (m)	Width (m)
1	Security Area	8	2	4
2	Main Parking	150	10	15
3	Mosque	8	2	4
4	Canteen	8	2	4
5	Laboratorium	144	12	12
6	Clinic	24	4	6
7	Main Office	63	7	9
8	Firefighting Area	60	10	6
9	Transport Truck	72	12	6
10	Warehouse	120	12	10
11	Process Control Area	45	9	5
12	Utility Process Control	45	9	5
13	Park	70	7	10
Building Area		42205	185	203
Surface Area		48290	207	233

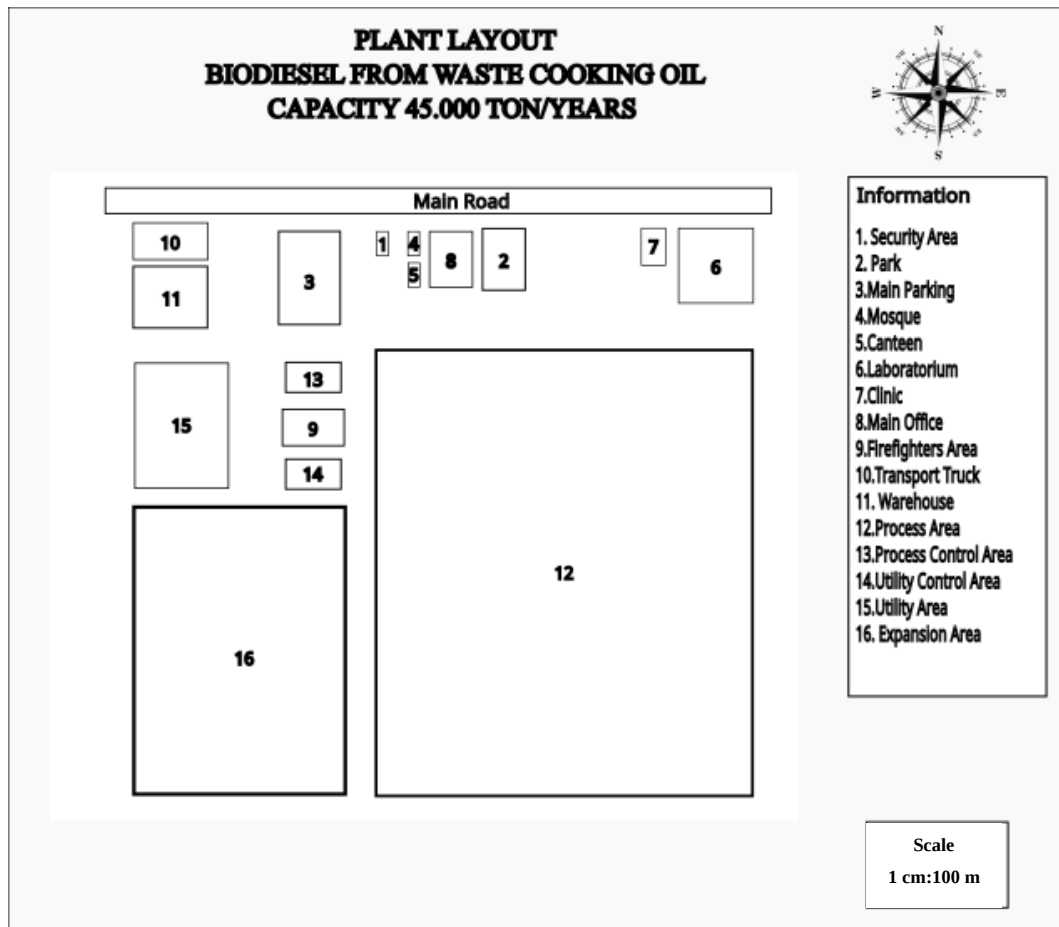


Figure 7. Plant Layout Biodiesel

4.3 Process Equipment Layout

In designing the layout of process equipment, several key factors must be considered to ensure efficiency, safety, and operational effectiveness. These factors include:

- Flow of Raw Materials and Products

An optimal flow of raw materials and products significantly enhances economic efficiency. The closer raw materials and finished products are placed to transportation routes, the lower the associated handling costs.

- Airflow

Proper airflow in and around the process equipment must be ensured to

maintain adequate ventilation and prevent the accumulation of hazardous gases.

- Lighting

Adequate lighting must be provided throughout the entire plant, with particular attention to high-risk areas to ensure safety and operational accuracy.

- Traffic Flow

The movement of materials and personnel must be carefully planned to prevent congestion, ensure smooth production processes, and maintain worker safety.

- Economic Considerations

The placement of production equipment should aim to minimize operational costs while ensuring efficiency and safety in plant operations, thereby increasing overall profitability.

- Spacing Between Process Equipment

Equipment operating under high temperature and pressure should be positioned separately from other process units. This precaution minimizes the risk of damage to adjacent equipment in the event of an explosion or fire.

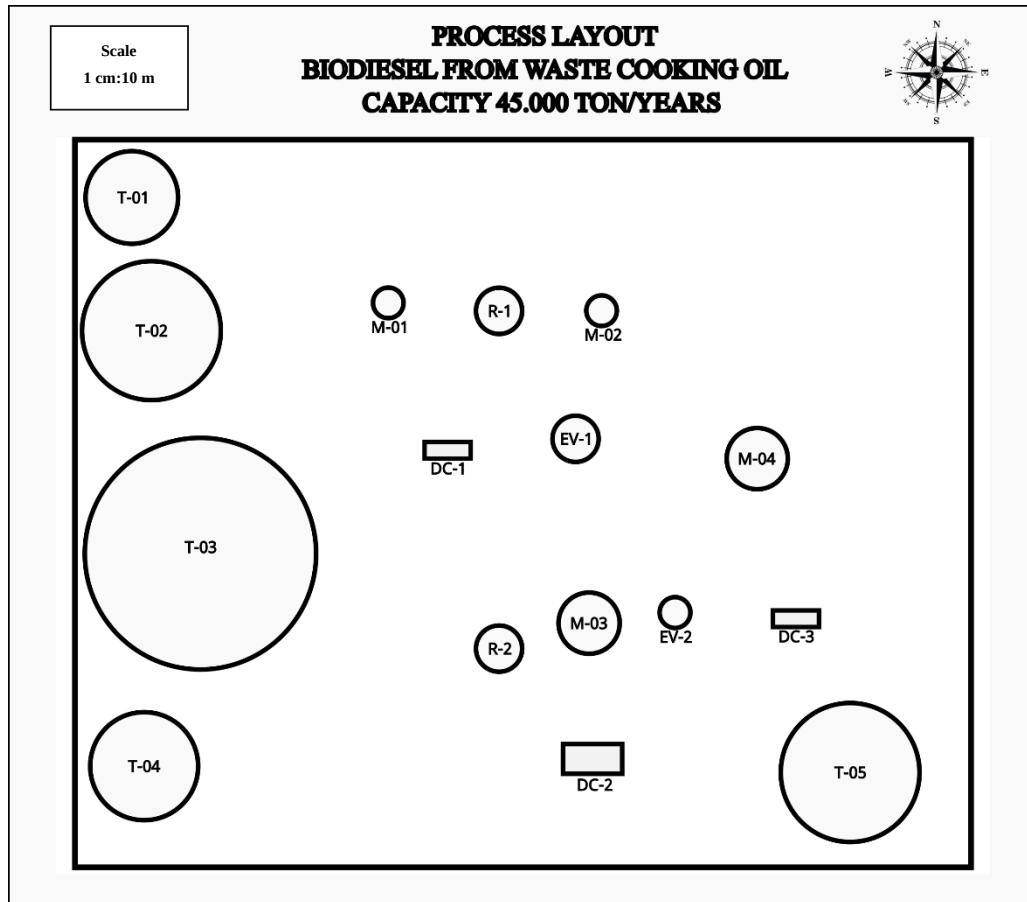


Figure 8. Process Layout

4.4 Company Organization

4.3.1 Organizational Structure

The preliminary design of this biodiesel plant will adopt a Limited Liability Company (PT) structure. The company's capital is obtained through the sale of shares, where each shareholder is entitled to own one or more shares.

Shareholders are only responsible for contributing the agreed amount for each share. For large-scale enterprises, the Limited Liability Company (PT) structure is a legal partnership treated as a corporate entity. The selection of this structure is based on the following considerations:

- a. Ease of Capital Acquisition – The company can raise funds by selling shares or securing financing from banks.

- b. Operational Continuity – The production process is managed by the company's leadership, with shareholders having limited liability.
- c. Separation of Ownership and Management – Shareholders own the company, while the executive management team oversees daily operations under the supervision of a board of commissioners. This separation ensures the company's sustainability, as it is not affected by changes in ownership, executive management, or employee turnover.
- d. Efficient Management – Shareholders can appoint experienced and competent individuals as the board of commissioners and directors.
- e. Expansion Opportunities – A Limited Liability Company (PT) can attract significant public investment, allowing for business growth and expansion.
- f. Access to Credit – The company can easily obtain bank loans using corporate assets as collateral

4.3.2 Organizational Structure

Effective company operations require human resources and a well-structured management system with clear divisions of tasks and authority. The organizational structure of a company is tailored to its size and operational needs. A well-designed structure enhances efficiency by defining roles, responsibilities, and hierarchical relationships within the organization. There are two fundamental organizational structures:

- 1. Line Organization – Consists of individuals performing core operational tasks to achieve the company's objectives.
- 2. Staff Organization – Consists of specialists who provide expert advice and recommendations to operational units

In this company, shareholders are the owners and are represented by a Board of Commissioners for day-to-day oversight. The President Director is responsible for company operations, assisted by:

- Production Manager – Oversees production, processes, control, supply chain, and maintenance.
- Director of Administration, Finance, and General Affairs – Manages procurement, marketing, administration, finance, human resources, public relations, security, and research & development.

The President Director supervises department heads, who in turn manage various operational units. Each department head is responsible for directing employees and ensuring smooth operations. Employees are grouped into specialized teams, each led by a team leader, who reports to the respective department manager.

Benefits of an Organizational Structure:

- 1) Clearly defines tasks, responsibilities, and authority.
- 2) Serves as an orientation guide for newly appointed officials.
- 3) Ensures proper employee placement based on expertise.
- 4) Facilitates management development planning.
- 5) Enables workflow and procedural improvements when inefficiencies arise.

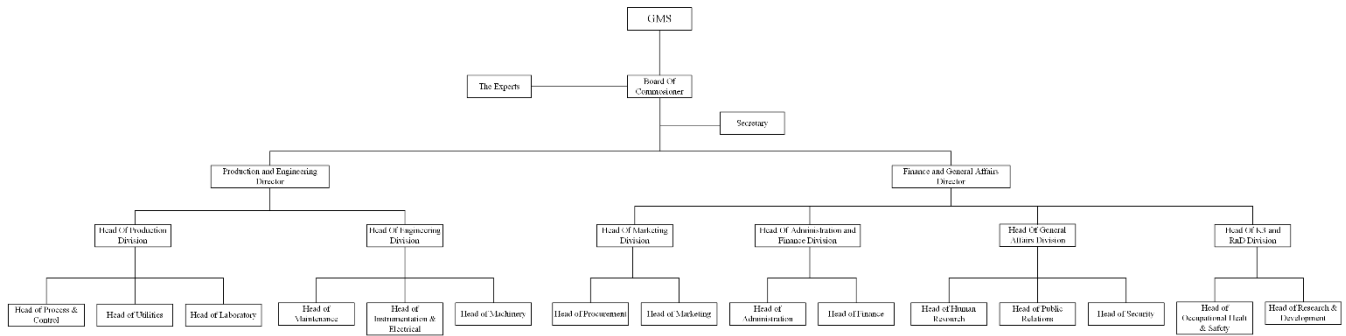


Figure 9. Organizational Structure

4.5 Duties and Authorities

4.4.1 General Meeting of Shareholders (GMS)

The highest authority in the line and staff organizational structure is the General Meeting of Shareholders (GMS). The GMS is attended by shareholders and the board of commissioners and is held at least once a year to monitor and evaluate the company's performance. However, in urgent situations, the GMS may be convened as per the forum regulations. The rights and authorities of the GMS include:

- Requesting accountability from the Board of Commissioners.
- Appointing and dismissing the Board of Commissioners and Directors and approving the resignation of shareholders through deliberation
- Approving the company's annual financial statements and profit and loss balance sheet
- Determining the allocation of annual profits for distribution, retention, or reinvestment

4.4.2 Board of Commissioners

The Board of Commissioners is elected by the GMS to act as representatives of the shareholders and is accountable to them. The duties of the Board of Commissioners include:

- a. Evaluating and approving the directors' plans regarding general policies, corporate targets, resource allocation, and marketing direction.
- b. Supervising all activities and responsibilities of the directors.
- c. Assisting the President Director in significant company matters.

4.4.3 President Director

The President Director holds the highest executive position in the company and is fully responsible for achieving the company's objectives as determined by the GMS. As the top leader, the President Director is accountable to the Board of Commissioners for all actions and policies. The duties of the President Director include:

- a. Leading and developing the company effectively and efficiently.
- b. Formulating and implementing general policies in line with GMS directives.
- c. Proposing collaborations with external parties for the company's benefit.
- d. Representing the company in establishing relationships and agreements with third parties.
- e. Planning and overseeing the execution of tasks performed by all employees.

In carrying out these responsibilities, the President Director is assisted by the Secretary, the Director of Production and Engineering, and the Director of Finance and General Affairs. Their respective roles are as follows:

1. Secretary

The Secretary is appointed by the President Director to manage corporate correspondence, handle document archiving, and assist with administrative tasks.

2. Director of Engineering and Production

The Director of Engineering and Production reports directly to the President Director and is responsible for overseeing all production, operations, technical, utility development, maintenance, procurement, and laboratory activities. The Director of Engineering and Production is supported by two division heads:

- a. Head of Production Division

Responsible for managing and supervising all company activities related to production, processes, control, and laboratory operations. The Head of Production Division is assisted by three sections: Process & Control, Utilities, and Laboratory.

- b. Head of Technical Division

Responsible for managing and supervising all company activities related to technical operations and maintenance. The Head of Technical Division is assisted by three section heads: Maintenance, Instrumentation & Electrical, and Machinery.

3. Director of Finance and General Affairs

The Director of Finance and General Affairs reports directly to the President Director and is responsible for overseeing company activities related to administration, human resources, finance, marketing, public relations, security, and occupational safety. This director is supported by several division heads:

- a. Head of Marketing Division

Responsible for managing and supervising all activities related to raw

material procurement and product marketing. The Head of Marketing Division is assisted by two sections: Procurement and Marketing.

b. Head of Administration and Finance Division

Responsible for managing and supervising company operations, bookkeeping, and employee payroll management. The Head of Administration and Finance Division is assisted by two sections: Administration and Finance.

c. Head of General Affairs Division

Responsible for managing and supervising activities related to human resources, public relations, and security. The Head of General Affairs Division is assisted by three sections: Human Resources, Public Relations, and Security.

d. Head of Occupational Health, Safety, and Research & Development Division (K3 & R&D)

Responsible for managing and supervising activities related to occupational health and safety (K3) and research & development. This division is supported by two sections: Occupational Health & Safety and Research & Development.

4.4.4 Expert Staf

Expert staff members provide input in the form of advice, recommendations, and insights regarding various operational aspects of the company.

4.4.5 Work Schedule Regulation

Biodiesel plant is planned to operate continuously for 330 days per year, 24 hours per day. The remaining days will be allocated for maintenance, repairs, or shutdowns. Based on work schedule regulations, employees are categorized into two groups:

1. Non-Shift Employees

Non-shift employees work five days a week, with a total of 40 working hours per week. Saturdays, Sundays, and public holidays are designated as off days. Non-shift employees are those who do not directly handle production processes, including the President Director, Secretary, Director of Engineering and Production, Director of Finance and General Affairs, Division Heads, and office staff. The detailed work schedule for non-shift employees is as follows

Table 4.2 Work Schedule Non-Shift Employees

Day	Work Time	Break
Monday - Thursday	07.00 – 16.00	12.00 – 13.00
Friday	07.00 – 16.00	12.00 – 13.00

2. Shift Employees

Shift employees are personnel directly involved in the production process or responsible for specific sections of the company related to maintaining security and ensuring smooth production operations 24 hours a day. This category includes production operators, technical staff, warehouse personnel, and other essential roles required to safeguard the safety and security of the plant:

Table 4.3 Work Schedule Shift Employee

Working Group	Work Time	Break
Shift 1	07.00 – 15.00	11.00 – 12.00
Shift 2	15.00 – 23.00	19.00 – 20.00
Shift 3	23.00 – 07.00	03.00 – 04.00

Employees work in shifts, divided into four groups (A/B/C/D), where only three groups are scheduled to work each day, while one group has a day off. Each group follows a schedule of six working days and two days off per week. On public holidays or other official holidays designated by the government, the assigned group is still required to work; however, these hours are counted as overtime and are compensated with additional incentives. Each shift is supervised by a shift leader. The work schedule for each group is as follows:

Table 4.4 Work Schedule Group

	1	2	3	4	5	6	7	8	9	10	11	12
A	D	D	D	D	D	H	A	A	A	A	A	H
B	N	N	N	N	H	D	D	D	D	D	H	A
C	A	A	A	H	N	N	N	N	N	H	D	D
D	H	H	H	A	A	A	H	H	H	N	N	N

Information:

D = Morning Shift (07.00 – 15.00) A = Afternoon Shift (15.00 – 23.00) N = Night Shift (23.00 – 07.00)

H = Holiday

4.4.6 Number of Employee and Salary System

The number of employees is adjusted according to operational needs to ensure that tasks are completed efficiently. Table 4.5 below provides a detailed breakdown of the workforce and the corresponding salary system.

Table 4.5 Number of Employee and Salary

No.	Position	Amount	Sallary	Total	Annual Sallary
			(Rp)	(Rp)	(Rp)
1	President Director	1	20,000,000.00	20,000,000.00	240,000,000.00
2	Production Director	1	15,000,000.00	15,000,000.00	180,000,000.00
3	Director of Finance and General Affairs	1	15,000,000.00	15,000,000.00	180,000,000.00
4	Production Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
5	RnD Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
6	Engineering Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
7	Administration Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
8	Marketing Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
9	General Manager	1	12,000,000.00	12,000,000.00	144,000,000.00
10	Process Section	1	8,000,000.00	8,000,000.00	96,000,000.00
11	Utility Section	1	8,000,000.00	8,000,000.00	96,000,000.00
12	Packaging and Warehouse Section	1	8,000,000.00	8,000,000.00	96,000,000.00
13	RnD Section	1	8,000,000.00	8,000,000.00	96,000,000.00
14	Laboratorium Section	1	8,000,000.00	8,000,000.00	96,000,000.00
15	Quality Control Section	1	8,000,000.00	8,000,000.00	96,000,000.00
16	Maintenance & Elektrikal Section	1	8,000,000.00	8,000,000.00	96,000,000.00
17	Workshop & Machine Section	1	8,000,000.00	8,000,000.00	96,000,000.00
18	Administration Section	1	8,000,000.00	8,000,000.00	96,000,000.00
19	Financial Section	1	8,000,000.00	8,000,000.00	96,000,000.00
20	Public Relations Section	1	8,000,000.00	8,000,000.00	96,000,000.00
21	Accountant Section	1	8,000,000.00	8,000,000.00	96,000,000.00
22	Purchasing and Procurement Section	1	8,000,000.00	8,000,000.00	96,000,000.00
23	Marketing Section	1	8,000,000.00	8,000,000.00	96,000,000.00
24	Medical Section	1	8,000,000.00	8,000,000.00	96,000,000.00
25	Human Resources Developmen Section	1	8,000,000.00	8,000,000.00	96,000,000.00
26	Security Section	1	8,000,000.00	8,000,000.00	96,000,000.00
27	Logistics Section	1	8,000,000.00	8,000,000.00	96,000,000.00
28	Workshop & Machine Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
29	RnD Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
30	Maintenance & Elektrikal Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
31	Workshop & Machine Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
32	Administration Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
33	Financial Staff	2	6,000,000.00	12,000,000.00	144,000,000.00
34	Public Relations Staff	1	6,000,000.00	6,000,000.00	72,000,000.00
35	Accountant Staff	1	6,000,000.00	6,000,000.00	72,000,000.00

Employee salaries are paid on the 1st of each month. If this date falls on a public holiday, salary payments will be made on the preceding day.

4.4.7 Employee Benefits and Entitlements

The company provides various benefits and entitlements to support employees in their work activities, including:

1. Leave Entitlements

a. Annual Leave

Each employee is entitled to a maximum of 12 days of annual leave per year. If the leave is not utilized within the year, it will be forfeited and cannot be carried forward to the following year.

b. Collective Leave

Employees are granted collective leave annually, coinciding with the Eid al-Fitr holiday for four working days.

Female employees who are expecting a child are entitled to three months of maternity leave. During this leave, salaries will continue to be paid, provided that there is a minimum two-year gap between the birth of the first and second child.

2. National Holiday

For non-shift employees, national holidays are designated as non-working days. For shift employees, work continues on national holidays, but these days are considered overtime (paid at an overtime rate).

3. Overtime Work

Overtime work is only permitted with the approval of the department

head when urgent tasks require immediate completion.

4. Work Attire

To maintain uniformity among employees, the company provides two sets of work attire per year. Additionally, masks are provided as part of workplace safety measures..

5. Social Security

Social Security includes life and accident insurance to ensure employee security while performing their duties..

6. Employee Facilities:

- a. Employee transportation services or company buses.
- b. A company-operated clinic with medical professionals, including doctors and nurses.
- c. A prayer facility equipped with water and electricity.
- d. An employee cooperative.
- e. A company canteen
- f. A service award in the form of a commemorative token for employees who have completed 10 consecutive years of service

CHAPTER V.

UTILITY

One of the essential supporting facilities for ensuring the smooth operation of a plant is the utility unit. The design of the utility unit plays a crucial role in maintaining the continuous operation of the plant. Several utility systems are required for a plant, including:

- A. Water Supply and Treatment Unit
- B. Steam Generation Unit
- C. Power Plant
- D. Fuel Supply Unit
- E. Waste Disposal Unit
- F. Compressed Air Unit

5.1 Water Supply and Treatment Unit

5.1.1 Water Supply Unit

In general, industrial water requirements are met using groundwater, lake water, river water, or seawater as sources. The design of this biodiesel plant utilizes water from the Cimanuk river as the primary source due to its proximity to the plant location. To prevent fouling in heat exchange equipment, river water treatment must be carried out both physically and chemically. The considerations for selecting river water as the primary source include:

- River water provides a relatively high level of continuity, ensuring a consistent supply and minimizing the risk of water shortages.
- River water treatment is relatively simpler, more straightforward, and cost-effective compared to seawater treatment, which is more complex

and requires higher processing costs due to the need for more expensive equipment.

- The volume of river water is significantly greater than that of groundwater.
- The river is located close to the plant site, reducing transportation and infrastructure costs.

The overall water demand in this plant is categorized into several uses, including

a. Sanitary Water

According to WHO standards, the daily water requirement per person ranges between 100–120 liters. For industrial or office environments, the water demand per person is set at 120 liters per day (Sularso, 2001). This plant employs 195 personnel, resulting in a total domestic water requirement of liters per day:

Table 5.1 Sanitary Water Requirement

No.	Information	Water Requirements (kg/h)
1	Employee	858
2	Laboratorium	17.74
3	Park	492.89
4	Pharmacy	1155
5	Canteen	360.42
6	Mosque	120.14
Total		3004

b. Cooling Water

Cooling water functions to assist in reducing the temperature of various equipment. The cooling water requirements for this plant are presented in Table 5.2 as follows Cooling water functions to assist in reducing the temperature of various

equipment. The cooling water requirements for this biodiesel plant are presented in Table 5.2 as follows:

Table 5.2 Cooling Water Requirement

Equipment	Code	Amount (kg/h)
Cooler 1	CL-01	51.652
Cooler 2	CL-02	11.429
Cooler 3	CL-03	66.550
Condensor 1	CD-01	2297.544
Condensor 2	CD-02	436.854
Reactor Cooling Water	R-01	3864.999
Total		2873.102

The total cooling water requirement is 2873,102 kg/hour, with a make-up water requirement of 20%, amounting to 574.62 kg/hour.

c. Steam Generation

Steam serves as a heating medium in the plant, playing a crucial role in increasing the temperature of various equipment. The water used for steam generation in boilers must meet specific quality standards to prevent issues such as scaling, fouling, and foaming. The steam requirements for each piece of equipment in this biodiesel plant design are detailed in the following table:

Table 5.3 Steam Requirement

Equipment	Code	Amount (kg/h)
Heater 1	H-01	165.8124
Heater 2	H-02	16.3792
Heater 3	H-03	1.2091
Steam Water Reactor	R-02	36502.5344
Evaporator 1	EV-01	2695.7944
Evaporator 2	EV-02	3734.1800
Total		43.127.439

The make-up water required for steam generation is 10% of the total steam demand, amounting to 43.127.439 kg/hour. Thus, the total water requirement for steam generation is 4887.364 kg/hour.

d. Service Water

Service water is used for general facility needs such as mosques, cafeterias, laboratories, and other utilities. It is set at 10% of the sanitary water demand, amounting to 222 Kg/h.

e. Fire Hydrant Water

According to NFPA 15 standards, fire hydrant water is required for 12 hours at a rate of 260 L/min, resulting in a total hydrant water demand of 2.306.71 Kg/h.

5.1.2 Water Treatment Unit

The water used to meet the requirements of the biodiesel plant is sourced from river water, which undergoes treatment before use to ensure it meets the necessary quality standards for industrial processes. The following are the stages of river water treatment:

a. Filtration

Before the treatment process begins, the river water undergoes an initial cleaning process by passing through filters designed to remove large impurities such as wood, branches, leaves, and other debris. The filtered water is then directed to the initial sedimentation tank.

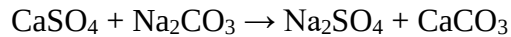
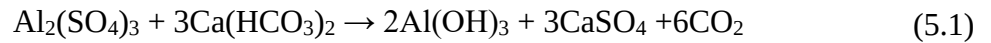
b. Initial Sedimentation Tank

The pre-filtered river water is collected in the initial sedimentation tank, where suspended solids such as silt and other particles that were not removed during

filtration are allowed to settle. The clarified water is then transferred to the coagulation tank.

c. Coagulant/Flucculation Tank

The coagulation tank is designed to facilitate the aggregation of suspended colloidal particles that do not settle in the sedimentation tank. This is achieved by adding chemical agents, commonly alum ($\text{Al}_2(\text{SO}_4)_3$) and sodium carbonate (Na_2CO_3). The chemical reactions occurring in the coagulation tank are as follows:



d. Clarifier

The water from the coagulation tank is then directed to the clarifier, where flocculated particles are separated and settled. The clarifier controls the water flow and is equipped with an agitator to aid in the separation process. The clarified water exits through an overflow system, while the settled sludge (floc) accumulates at the bottom and is periodically removed via blowdown.

e. Sand Filter

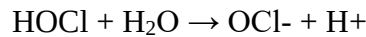
The water from the clarifier then flows into a sand filter, which removes any remaining fine particles that have not settled. The filtration media typically consists of anthracite, sand, and gravel.

f. Temporary Storage Tank

After passing through the sand filter, the treated water is collected in a temporary storage tank, from which it is distributed for various uses, including residential, boiler, cooling and process.

g. Chlorinator Tank

The treated water is then directed to the chlorinator tank, where chlorine (Cl_2) or calcium hypochlorite ($\text{Ca}(\text{OCl})_2$) is added to eliminate bacteria and microorganisms such as amoebas, making the water safe for consumption. Chlorine is widely used due to its affordability and its sustained disinfectant properties. The chemical reactions involved in chlorine disinfection are as follows:



h. Clean Water Tank

After chlorination, the water is stored in the clean water tank, where it is reserved for drinking water and office use.

i. Cooling Water Tank

The cooling water tank is used to store water designated for cooling processes within the plant. The cooling water used in daily operations is recycled by cooling it in a cooling tower. Water losses due to evaporation, air carryover, and blowdown from the cooling tower are replenished using water from the temporary storage tank.

Cooling water must have non-corrosive properties, minimal scaling potential, and no microbial contamination that could lead to algae growth. To maintain water quality, the following chemical additives are injected into the cooling water:

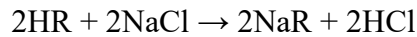
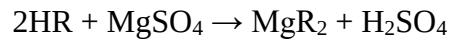
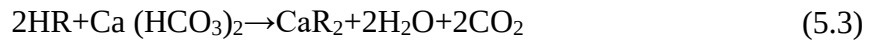
- 1) Phosphate to prevent scaling
- 2) Chlorine to eliminate microorganisms
- 3) Dispersants to prevent coagulation and sludge formation

j. Cooling tower

The cooling tower functions to cool the water used as cooling water in the plant's processes.

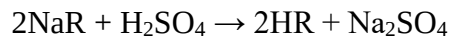
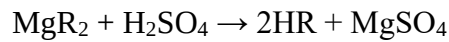
k. Kation Exchanger Tank

Water from the temporary storage tank, serving as boiler make-up water, is then fed into the cation exchanger tank. The cation exchanger functions to bind alkali metals and reduce the hardness of the water. This process involves the exchange of dissolved cations such as Ca^{2+} and Mg^{2+} with hydrogen ions (H^+) from the resin. The chemical reactions occurring in the cation exchanger are:

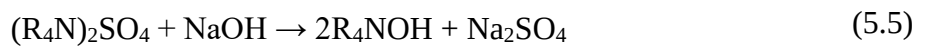


l. Anion Exchanger Tank

Over time, the resin becomes saturated and needs to be regenerated using hydrochloric acid (HCl). The regeneration reactions are as follows:



After a certain period, the anion resin becomes saturated and must be regenerated using sodium hydroxide (NaOH). The regeneration reaction is as follows:



m. Boiler Feedwater Tank

The boiler feedwater tank stores water that has passed through the anion exchanger and collects circulating condensate from the boiler. The water is then pumped to the deaerator, where it is mixed with the circulating condensate.

n. Deaerator

Deaeration is the process of removing dissolved gases from boiler feedwater, specifically oxygen (O₂) and carbon dioxide (CO₂), which can cause corrosion in the boiler system. The demineralized water (from the cation and anion exchanger units) is pumped into the deaerator. In boiler water treatment, it is crucial to remove dissolved gases and solids to prevent corrosion. The deaeration process is conducted both mechanically and chemically:

- Mechanical Process: Boiler feedwater is brought into contact with low-pressure steam, causing most of the dissolved gases to escape and be vented into the atmosphere.
- Chemical Process: A chemical scavenger, hydrazine (N₂H₄), is added to further remove oxygen through the following reaction:



o. Boiler

From the boiler feedwater tank, the water is pumped into the boiler, where it is converted into saturated steam. The boiler's function is to generate steam for industrial processes

5.2 Utility Equipment Specification

Table 5.4 Filter Specification

Equipment	Filtration
Function	Remove both small and large impurities from the water
Material	Alumunium
Type	Course bar screen
Area	150 m ²
Length	15 m
Width	10 m

Table 5.5 Initial Sedimentation Tank Specification

Equipment	Initial Sedimentation Tank
Function	Facilitates the settling of suspended solids and sludge carried by river water
Material	Reinforced Concrete
Type	Rectangular tank reinforced with concrete
Volume (m3)	352.574
Width	7.0645
Length	7.0645
Height	7.0645

Table 5.6 Coagulation Tank Specification

Equipment	Coagulation Tank
Function	Facilitates the precipitation of dispersed colloidal impurities in water through the addition of a coagulant
Material	Concrete
Type	Cylindrical tank equipped with an agitator
Volume (m3)	4708.580
Diameter (m)	18.169
Height (m)	18.169
Agitator Type	Marine propeller with four baffles inside the tank
Width Agitator (m)	1.090
Length Agitator (m)	1.363
Putaran Agitator	50 rpm
Power Agitator (Hp)	7 Hp

Table 5.7 Clarifier Specification

Equipment	Clarifier
Function	Separates and settles coagulated impurities from the coagulation tank
Material	Concrete
Type	Circular Clarifiers
Volume	113005.93
Diameter	52.410

Height	5.000
Type Agitator	Marine propeller without baffle
Width Agitator	4.193
Length Agitator	5.241
Putaran Agitator	1.2 rpm
Power Agitator	3 Hp

Table 5.8 Sand Filter Specification

Equipment	Sand Filter
Function	Removes residual impurities that remain in the water after clarification
Material	Beton
Type	Gravity sand filter
Diameter	70.396
Stack Height	1.630
Cross Sectional Area	3890.116

Table 5.9 Temporary Storage Tank Specification

Equipment	Temporary Storage Tank
Function	Temporarily stores water after passing through the sand filter before further processing or distribution
Material	Concrete
Type	Rectangular tank reinforced with concrete
Volume	9509.283
Width	33.6307
Length	33.6307
Height	8.407675

Table 5.10 Chlorination Tank Specification

Equipment	Chlorination Tank
Function	Mixes chlorine, typically in the form of calcium hypochlorite, into the water for sanitation purposes
Type	Cylindrical tank equipped with an agitator
Volume	0.9045 m ³
Diameter	0.4644 m
Height	0.6966 m
Type Agitator	Marine propeller 3 blade

Table 5.11 Clean Water Tank Specification

Equipment	Clean Water Tank
Function	Reserved for drinking water and office
Type	Vertical Cylindrical
Material	Carbon steel SA 283 grade C
Volume	3.6180 m ³
Diameter	2.4369 m
Height	0.6092 m

Table 5.12 Cooling Water Tank Specification

Equipment	Cooling Water Tank
Function	Stores circulated cooling water before being recovered in the cooling tower
Material	Reinforced Concrete
Type	Rectangular tank reinforced with concrete
Volume	0.6644 m ³
Length	1.3851 m
Width	1.3851 m
Height	0.3462 m

Table 5.13 Cooling Tower Specification

Equipment	Cooling tower
Function	Cools down the process cooling water from 50°C to 30°C by contacting water with air before recirculation
Material	Carbon steel SA 283 grade C
Type	Mechanical induced draft counterflow cooling tower
Cooling Tower Dimension	
Width	0.4011 m
Length	0.4011 m
Height	12.2 m
Packing Height	4.5613 m
Design Dimension	
Width	0.66 m
Length	0.66 m
Height	0.5268 m
Motor Power	0.05

Table 5.14 Kation Exchanger Tank Specification

Equipment	Cation Exchanger Tank
Function	Removes water hardness caused by cations such as Ca^{2+} and Mg^{2+}
Material	Carbon steel SA 283 grade C
Type	Down flow kation exchanger
Resin	Natural greensand zeolite
Volume	0.0879 m^3
Diameter	0.3195 m
Height	1.5971 m

Table 5.15 Anion Exchanger Tank Specification

Equipment	Anion Exchanger Tank
Function	Removes water hardness caused by anions such as Cl^- , SO_4^{2-} , and NO_3^-
Material	Carbon steel SA 283 grade C
Type	Down flow anion exchanger
Resin	Weakly basic anion exchanger
Volume	0.0346 m^3
Diameter	0.2475 m
Height	1.2199 m

Table 5.16 Deaerator Specification

Equipment	Daerator
Function	Removes dissolved gases in water, primarily O_2 , CO_2 , NH_3 , and H_2S
Material	Carbon steel SA 283 grade C
Type	Cold water vacuum
Volume packing	1.1762 m^3
Area	0.2406 m^2
Diameter	0.5536 m
Height	5.3889 m

Table 5.17 Boiler Feed Tank Specification

Equipment	Boiler Feed Tank
Function	Mixes recirculated condensate and boiler make-up feedwater before being converted into steam in the boiler
Type	Rectangular Tank
Volume	2.941 m^3
Length	2.274 m
Width	2.274 m
Height	0.569 m

Table 5.18 Natrium Hydroxide Storage Tank Specification

Equipment	Natrium Hydroxide Storage tank
Function	Prepares and stores NaOH solution for regenerating the anion exchanger
Material	Carbon steel SA 283 grade C
Type	Silinder vertical
Volume	0.0153 m ³
Diameter	0.2349 m
Height	0.3524 m

Table 5.19 Blower Specification

Equipment	Blower
Function	Supplies fresh air to the boiler
Type	Centrifugal blower
Material	Carbon steel SA 283 grade C
Capacity	44.008 kg/h
Total of air	40.007 kg/h
Inlet Pressure	1 atm
Inlet Temperature	35 °C
Motor Power	0.05 Hp

Table 5.20 Sodium Carbonate Storage Tank

Equipment	Sodium Carbonate Storage Tank
Function	Stores sodium carbonate as a coagulant for a duration of 7 days
Material	Carbon steel SA 283 grade C
Type	Silinder vertical
Volume	1.2328 m ³
Diameter	0.9225 m
Height	0.4612 m

Table 5.21 Hydrazine Storage Tank

Equipment	Hydrazine Storage Tank
Function	Stores and dissolves hydrazine (N ₂ H ₄)
Material	Carbon steel SA 283 grade C
Type	Silinder vertical
Volume	0.1369 m ³
Diameter	0.4913 m
Height	0.7369 m

Table 5.22 Utility Pump Specification

Equipment	Function	Type	Material	Amount	Impeller	Cappacity	BHP Teoritical	BHP Actual	Motor Power
P-01	Transfers river water to the initial sedimentation tank.	Centrifugal single stage	Commercial material	1	mixed flow impeller	26.2232	0.11629	3.30536	0.33333
P-02	Transfers water from the initial sedimentation tank to the coagulation tank.	Centrifugal single stage	Commercial material	1	mixed flow impeller	26.2232	0.11629	0.92723	0.25
P-03	Transfers water from the coagulation tank to the clarifier.	Centrifugal single stage	Commercial material	1	radial flow impeller	26.2232	0.11629	56.4422	3
P-04	Transfers water from the clarifier to the filtration tank.	Centrifugal single stage	Commercial material	1	mixed flow impeller	26.2232	0.11629	0.38631	0.16667
P-05	Transfers water from the temporary storage tank to the chlorination tank. cooling water tank. and cation exchanger tank.	Centrifugal single stage	Commercial material	1	radial flow impeller	26.2232	0.11629	12.9309	0.75
P-06	Transfers cooling water from the cooling water tank to the cooling tower.	Centrifugal single stage	Commercial material	1	radial flow impeller	5.87011	0.04287	7.00658	0.125

Table 5.23 Utility Pump Specification

P-07	Transfers cooling water from the cooling tower back to the cooling water tank	centrifugal single stage	commercial material	1	radial flow impeller	5.87011	0.04287	6.88467	0.125
P-08	Transfers water from the cation exchanger tank to the anion exchanger tank.	centrifugal single stage	commercial material	1	radial flow impeller	2.5981	0.53646	11.1462	0.53646
P-09	Transfers water from the anion exchanger tank to the deaerator.	centrifugal single stage	commercial material	1	radial flow impeller	2.5981	0.53646	11.8625	0.125
P-10	Transfers water from the deaerator to the boiler feedwater storage tank.	centrifugal single stage	commercial material	1	radial flow impeller	2.5981	0.53646	2.25512	0.05
P-11	Transfers water from the boiler feedwater storage tank to the boiler	centrifugal single stage	commercial material	1	radial flow impeller	2.5981	0.53646	21.7931	0.25

5.3 Steam Generation Unit

The produced steam is utilized as a heating medium in heat exchangers and reboilers. To meet the steam demand, a single boiler is required. The steam generated by the boiler is saturated steam at a temperature of 154°C and a pressure of 4 atm. Saturated steam is chosen because it provides latent heat, which facilitates phase change without temperature variation, ensuring stable heat transfer and energy efficiency:

1. Demineralitation Unit

This unit removes dissolved minerals such as Ca^{2+} , Mg^{2+} , Na^+ , HCO_3^- , SO_4^{2-} , Cl^- , and others using ion-exchange resins before the water is fed into the boiler. The following conditions must be met:

- a. The generated steam should not cause scale formation in heat exchanger tubes, as this would reduce efficiency or even halt operations.
- b. The water must be free of gases that can cause corrosion, especially O_2 and CO_2 . The process involves passing water through a cation exchanger to remove cationic minerals, followed by an anion exchanger to remove anionic contaminants.

2. Boiler Feedwater Unit

After demineralization, the water enters the deaerator to eliminate residual dissolved gases, particularly oxygen, which can cause corrosion. In the deaerator, a chemical reagent (hydrazine, N_2H_4) is injected to react with and bind the remaining oxygen. Stripping with low-pressure steam ensures the removal of nitrogen and other dissolved gases.

Table 5.24 Boiler Specification

Equipment	Boiler
Amount Of Steam	
Temperature	154 °C
Pressure	4 atm
Function	Make Saturated steam
Type	Fire tube boiler
Material	Carbon steel SA 283 grade C
Amount	1
Boiler Cappacity	22,864.054 kJ/jam
Boiler Cross Section	7.912 m ²
Fuel	Natural gas
Natural Gas Requirement	48.009 kg/day
Efficiency	80%

5.4 Power Supply Unit

The power supply unit is responsible for providing electricity to meet the demands of both the plant and office facilities. The electricity required for the biodiesel plant is supplied by the State Electricity Company (PLN), with a generator serving as a backup source. This setup ensures a continuous power supply, even in the event of disruptions from PLN. The generator used is an alternating current (AC) generator, selected based on the following considerations:

- The generated electrical power is sufficiently high.
- Voltage levels can be adjusted (increased or decreased) as required.

The electricity within the plant is utilized for various purposes, including:

- Process and utility operations
- Lighting
- Air conditioning (AC)
- Laboratory, workshop, and other facility operations
- Instrumentation and control equipment

The estimated electricity demand for each of these functions is outlined in the

following table

a. Electricity for Process and Utility Requirements

The electricity demand for process requirements can be seen in the following table:

Table 5.25 Electricity for Process and Utility Requirements

Equipment Proses	Power, Hp	Amount	Σ power, Hp
Reactor-1	10	1	10
Reactor-2	7,5	1	7,5
Mixer-1	5	1	5
Mixer-2	7	1	7
Mixer-3	15	1	15
Mixer-4	15	1	15
Pump-01	1/2	2	1
Pump-02	1/2	2	1
Pump-03	1/2	2	1
Pump-04	1/2	2	1
Pump-05	1/2	2	1
Pump-06	1/2	2	1
Pump-07	1/2	2	1
Pump-08	1/2	2	1
Pump-09	1/2	2	1
Pump-10	1/2	2	1
Pump-11	1/2	2	1
Pump-12	1/2	2	1
Pump-13	1 1/2	2	3
Pump-14	1/2	2	1
Pump-15	1 1/2	2	3
Pump-16	1 1/2	2	3
Pump-17	2	2	4
Pump-18	1/2	2	1
Pump-19	1/2	2	1
Pump-20	2	2	4
Pump-21	2	2	4
Pump-22	1/2	2	1
Pump-23	1/2	2	1
Pump-24	2	2	4
Total			97.5

Conversion factor: 1 Hp = 0.7457 kW

Required power for process operations: 72.71 kW

The electricity demand for utility requirements is detailed in the table below.

Table 5.26 Utility Electrical Requirements

Equipment Proses	Power. Hp	Amount	Σ power. Hp
Air Compressor	25	1	25
Boiler	200	1	200
Fan Cooling Tower	0.75	1	0.75
Clarifier Impeller	3	1	3
Coagulation Tank Impeller	7	1	7
Chlorinator Tank Impeller	0.05	1	0.05
Pump 01	5	2	10
Pump 02	5	2	10
Pump 03	5	2	10
Pump 04	5	2	10
Pump 05	5	2	10
Pump 06	15	2	30
Pump 07	0.125	2	0.25
Pump 08	0.75	2	1.5
Pump 09	0.75	2	1.5
Pump 10	0.33	2	0.67
Pump 11	0.33	2	0.67
Pump 12	0.75	2	1.5
Total			321.883

Conversion factor: 1 Hp = 0.7457 kW

Required power for utility operations: 240.028 kW

a. Electricity for Lightning

The estimated power requirement for control equipment is 10% of the total electricity demand for motor operation, which amounts to 461.322 Kw.

b. Electricity for Laboratories, Workshops and Other Facilities

The estimated electricity demand for laboratories, office facilities, and miscellaneous needs is 25% of the total electricity demand for process and utility equipment, which amounts to 104.846 Kw.

c. Electricity for Instrument and Control Equipment

The estimated electricity demand for instrumentation and control systems is 5% of the total electricity demand for process and utility equipment, which also amounts to 20.969 Kw.

d. Generator

The generator functions as a backup power source for process operations, utility systems, and general plant needs in the event of a power outage from the national electricity provider (PLN). The selected type of generator is a diesel generator powered by fuel oil with a capacity of 600 kW. The combustion efficiency is assumed to be 80%. It is further assumed that power outages from PLN occur for approximately 6 hours per week. Therefore:

$$\text{Fuel Requirement} = \frac{Q}{\text{Heating value} \cdot \text{Efficiency}} \quad (5.7)$$

The fuel requirement = 2.459 Kg/h

5.5 Compressed Air Supply Unit

Compressed air is required to operate pneumatic equipment, such as valve actuation for opening and closing mechanisms. It is also used for instrumentation systems to ensure accurate and reliable operation. The air processing system ensures that the compressed air is moisture-free, dry, oil-free, and free from solid particles to maintain system efficiency and prevent contamination. For the preliminary design of the biodiesel plant, the estimated compressed air requirements are:

- Flow rate: 50.976 m³/h
- Pressure: 7.8231 atm
- Temperature: 35°C

The compressed air supply system consists of a compressor equipped with a dryer containing silica gel, which absorbs moisture to a maximum level of 84 ppm.

Table 0.27 Compressor Specification

Equipment	Compressor
Function	Compressed air supply system
Type	Single stage reciprocating compressor
Amount	1
Capacity	50.976 m ³ /jam
Pressure suction	1 atm
Pressure discharge	7.823 atm
Air Temperature	35 °C
Efficiency	80%
Compressor Power	25 Hp

5.6 Fuel Supply Unit

The fuel supply unit is responsible for meeting the fuel demands of boilers and generators. The fuel used in the system is natural gas (NG), sourced from Pertamina Gas and its distributors. Natural gas is selected based on the following considerations:

1. Availability – Easily accessible
2. Cost-effectiveness – More economical
3. Affordability – Relatively cheaper

Fuel Consumption Requirement:

1. Boiler
 - Boiler capacity = 21,670.94 Btu/h
 - Fuel consumption = 1,274.328438 L/h
2. Generator
 - Generator capacity = 5,119,453.925 Btu/h
 - Fuel consumption = 301,042.0843 L/h



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CHAPTER VI.

ECONOMIC EVALUATION

In the pre-design of this factory, an economic analysis is needed to get an estimate of the feasibility of capital investment in a factory production activity, by reviewing the need for investment capital, the amount of profit obtained, the length of time the investment capital can be returned and the break-even point occurs where the total cost of production is equal to the profit obtained. In addition, economic analysis is intended to find out whether the factory to be established can be profitable and feasible or not to be established. In this economic evaluation, the factors reviewed are:

1. Return On Investment (ROI)
2. Pay Out Time (POT)
3. Discounted Cash Flow Rate (DFCR)
4. Break Even Point (BEP)
5. Shut Down Point (SDP)

Before analyzing these five factors, it is necessary to make estimates of the following things:

1. Determination of industrial capital (Total Capital Investment) Include:
 - a. Fixed capital (Fixed Capital Investment)
 - b. Working capital (Working Capital Investment)
2. Determination of total production cost (Total Production Cost) include:
 - a. Manufacturing costs (Manufacturing Cost)
 - b. General expense costs (General Expenses)
3. Capital income

To find out the break-even point, it is necessary to make an estimate of:

- a. Fixed costs (Fixed Cost)
- b. Variable costs (Variable Cost)
- c. Floating fees (Regulated Cost)

6.1 Total Price Estimation

The price of equipment will change at any time depending on the economic conditions that affect it. To know the exact price of equipment every year is very difficult, so a method or way is needed to estimate the price of the equipment in a certain year and it is necessary to know in advance the index price of operating equipment in that year.

The Biodiesel plant operates for one production year of 330 days and an evaluation year in 2028. In economic analysis, the prices of tools and other prices are taken into account in the year of analysis. To find the price in the year of analysis, the index is searched for in the year of analysis. The index price in 2028 is estimated broadly with index data from 1995 to 2020 and determined by linear regression equations. To estimate the price of a tool, there are two approximation equations that can be used. the price at the mill can be determined based on the price in the reference year multiplied by the price index ratio.

$$E_x = E_y \cdot \frac{N_x}{N_y} \quad (6.1)$$

Where:

E_x : Purchase price in year

E_y : Purchase price in reference year

N_x : Price index in the year

N_y : Price index in reference year

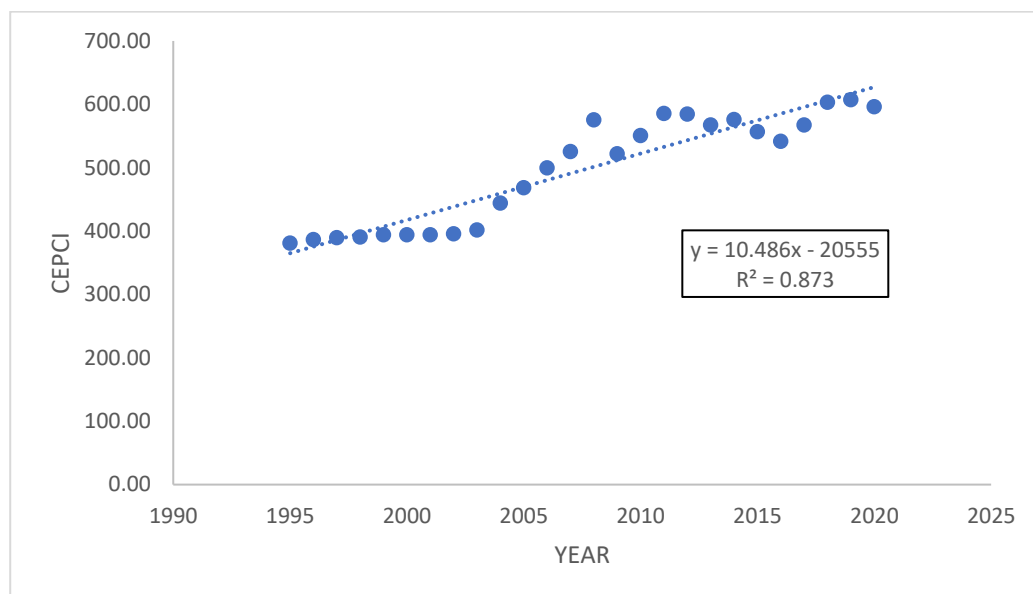


Figure 11.Total Price Index Chart

The equations obtained from the graph listed are:

$$y = 10.456x - 202555$$

Using the equation above, the CEP value of the index in the reference year and design can be found, so that the CEP value of the index in the reference year 2014 is 576.100. While the CEP value in the 2028 design year is 721.09. Based on the CEP value of the index index, the price of process tools and utility tools can be determined as follows

Table 6.1 Process Equipment Price

Name	Amount	Ey	Ex	Ny	Nx
		2014	2028	2014	2028
Natrium Hydroxide Storage Tank	1	\$ 12,400	\$ 15,521	576.10	721.09
Methanol Storage Tank	2	\$ 50,800	\$ 63,585	576.10	721.09
Sulfuric Acid Storage Tank	1	\$ 8,900	\$ 11,140	576.10	721.09
WCO Storage Tank	1	\$ 32,800	\$ 41,055	576.10	721.09
Biodiesel Storage Tank	1	\$ 31,700	\$ 39,678	576.10	721.09
Mixer – 1	1	\$ 2,850	\$ 3,567	576.10	721.09

Table 6.2 Process Equipment Price (Continued)

Mixer – 2	1	\$ 3,370	\$ 4,218	576.10	721.09
Mixer – 3	1	\$ 2,850	\$ 3,567	576.10	721.09
Mixer – 4	1	\$ 3,370	\$ 4,218	576.10	721.09
Reactor – 1	1	\$ 33,350	\$ 41,743	576.10	721.09
Reactor – 2	1	\$ 33,350	\$ 41,743	576.10	721.09
Decanter – 1	1	\$ 1,600	\$ 2,003	576.10	721.09
Decanter – 2	1	\$ 1,600	\$ 2,003	576.10	721.09
Decanter – 3	1	\$ 1,700	\$ 2,128	576.10	721.09
Evaporator – 1	1	\$ 43,400	\$ 54,323	576.10	721.09
Evaporator – 2	1	\$ 43,400	\$ 54,323	576.10	721.09
Condensor – 1	1	\$ 1,300	\$ 1,627	576.10	721.09
Condensor - 2	1	\$ 1,300	\$ 1,627	576.10	721.09
Heater	1	\$ 1,600	\$ 2,003	576.10	721.09
Heater	1	\$ 1,000	\$ 1,252	576.10	721.09
Heater	1	\$ 1,600	\$ 2,003	576.10	721.09
Cooler	1	\$ 2,300	\$ 2,879	576.10	721.09
Cooler	1	\$ 2,400	\$ 3,004	576.10	721.09
Cooler	1	\$ 2,400	\$ 3,008	576.10	722.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 3,200	\$ 4,005	576.10	721.09
Pump	2	\$ 2,800	\$ 3,505	576.10	721.09
Total		\$ 412,454	\$ 515,020		

Table 6.3 Utility Equipment Price

Name	Amount	Ey	Ex	Ny	Nx
		2014	2028	2014	2028
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 3.300,00	\$ 4.130,53	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Pump	2	\$ 2.800,00	\$ 3.504,69	576.10	721.09
Initial Sendimentation Tank	1	\$10,150.00	\$12,704.50	576.10	721.09
Hydrazin Tank	1	\$1,500.00	\$1,877.51	576.10	721.09
Sodium Carbonate Tank	1	\$1,200.00	\$1,502.01	576.10	721.09
Anion Tank	1	\$1,000.00	\$1,251.68	576.10	721.09
Kation Tank	1	\$1,000.00	\$1,251.68	576.10	721.09
Natrium Hydroxide Tank	1	\$1,200.00	\$1,502.01	576.10	721.09
Aluminium Tank	1	\$1,000.00	\$1,251.68	576.10	721.09
Mixing Tank	1	\$1,800.00	\$2,253.02	576.10	721.09
Clarifier	1	\$15,900.00	\$19,901.63	576.10	721.09
Sand Filter	1	\$1,000.00	\$1,251.68	576.10	721.09
Cooling Water Tank	1	\$10,000.00	\$12,516.75	576.10	721.09
Cooling Tower	1	\$35,600.00	\$44,559.63	576.10	721.09
Chlorinator Tank	1	\$1,100.00	\$1,376.84	576.10	721.09
Clean Water Tank	1	\$1,200.00	\$1,502.01	576.10	721.09
Compressor	1	\$1,500.00	\$1,877.51	576.10	721.09
Boiler	1	\$3,800.00	\$4,756.37	576.10	721.09
Daerator	1	\$1,000.00	\$1,251.68	576.10	721.09
Condensor	1	\$1,000.00	\$1,251.68	576.10	721.09
Total		\$ 114,350.00	\$ 145,632.39		

6.2 Basic of Calculation

Biodiesel product capacity	= 45.000 ton/Years
One year of operation	= 330 DAYS
Factory life	= 10 Years
The factory was established in 1999	= 2028
Currency exchange rate in 2028	= 1 US\$ = Rp 16,197

6.3 Cost Calculation

1. Capital Investment

Capital Investment is the amount of expenditure required to establish and operate a factory. Capital Investment consists of:

a. Fixed Capital Investment

Fixed Capital Investment is the cost required to set up plant facilities.

b. Working Capital Investment

Working Capital Investment is the cost required to run a business or capital to run the operations of a factory for a certain period of time.

2. Manufacturing Cost

Manufacturing Cost is the amount of Direct, Indirect and Fixed Manufacturing Cost, which is involved in manufacturing products. According to Aries & Newton 's table 23, Manufacturing Cost includes:

a. Direct Cost

Direct Cost is an expense that is directly related to the manufacture of a product.

b. Indirect Cost

Indirect Cost is an indirect result of factory operations.

c. Fixed Cost

Fixed Cost is certain costs that are always incurred either when the factory is operating or not or expenses that are fixed regardless of time and level of production.

3. General Expense

General Expense or general expense includes expenses related to the company's functions that do not include Manufacturing Cost.

6.4 Feasibility Analysis

To be able to find out whether the profits obtained are large or not, so that it can be categorized whether the factory has potential or not, an analysis or feasibility evaluation is carried out. Some of the ways used to declare eligibility are:

1. Percent Return On Investment (ROI)

Return On Investment is the level of profit that can be generated from the level of investment spent.

$$\%ROI = \frac{\text{Profit}}{\text{Fixed Capital Investment}} \quad (6.2)$$

Profit is calculated based on Annual Sales (Sa) and total Manufacturing Cost. Finance will be counted as a component that contains debt repayment during the construction of the plant. Finance will contribute to the cash flow of the factory. Factories with low risk tend to have a minimum ROI before tax of 11% while factories with high risk have a minimum ROI before tax value of 44%.

2. Pay Out Time (POT)

Pay Out Time (POT):

- a. The number of years that have elapsed, before an income exceeded the initial investment or the number of years required for the return of Capital Investment with profit before depreciation.
- b. The theoretical minimum time required for a fixed return on capital invested on a profit basis each year plus depreciation.
- c. The time of return on capital generated based on the profits earned. This calculation is necessary to know in what years the investment that has been made will return.
- d. Low-risk factories have a maximum POT value of 5 years, while high-risk factories have a maximum POT value of 2 years.

$$POT = \frac{\text{Fixed Capital Investment}}{(\text{Profit} + \text{Depresiasi})} \quad (6.3)$$

3. Break Even Point (BEP)

Break Even Point (BEP) are Production break-even point (a condition where the factory does not gain profits or losses).

- a. The point indicates at what level the cost and income amount to the same.
With BEP we can determine the selling price and the number of units sold in a minimum and how much price and sales units must be achieved in order to make a profit.
- b. The production capacity at the time of sales is equal to the total cost.
Factories will lose if they operate under BEP and will profit if they operate under BEP.
- c. BEP values generally have values ranging from 40% - 60%

$$BEP = \frac{(Fa + 0,3Ra)}{(Sa - Va - 0,7Ra)} \quad (6.4)$$

In this case:

Fa : Annual Fixed Manufacturing Cost at maximum production

Ra : Annual Regulated Expenses at maximum production

Va : Annual Variable Value at maximum production

Sa : Annual Sales Value at maximum production

4. Shut Down Point (SDP)

Shut Down Points (SDP) are:

- a. point or time when the determination of a production activity is stopped.
The causes include Variable Costs that are too high, or it can also be due to management decisions due to the uneconomical nature of a production activity (not making a profit).
- b. The minimum percent capacity of a factory can reach the expected product capacity in a year. If it is unable to reach the minimum percentage of capacity in one year, the factory must stop operating or close.
- c. The level of production at which the cost of continuing plant operations will be more expensive than the cost of closing the plant and paying the Fixed Cost.
- d. It is a production point where the factory goes bankrupt so the factory has to stop or close.

$$SDP = \frac{(0,3 Ra)}{(Sa - Va - 0,7 Ra)} 100\% \quad (6.5)$$

5. Discounted Cash Flow Rate Of Return (DCFR)

Discounted Cash Flow Rate of Return (DCFR) are:

1. The economic feasibility analysis using DCFR is made using the value of money that changes over time and is perceived or investments that do not return at the end of the year during the life of the plant.
2. The maximum interest rate at which a project can repay the loan along with its interest to the bank over the life of the plant.
3. It is the estimated amount of profit earned each year, based on investments that do not return at the end of each year during the life of the plant.

Equations to determine DCFR:

$$\frac{(WC + FCI) \cdot (1 + i)^{10}}{CF} = ((1 + i)^9 + (1 + i)^8 + \dots + (1 + i)^1) \frac{WC + SV}{CV} \quad (6.6)$$

Where:

FC : Fixed capital

SV : Salvage value

C : Cash flow: profit after taxes + depresiasi + finance

I : DCFR Value

WC : Working capital

N : Factory life = 10 years

6.5 Calculation Result

The establishment of this acrylic acid factory requires good financial planning and analysis to review whether or not it is feasible to establish this factory. The results of the calculation are presented in Table:

Table 6.4 Physical Plant Cost

No	Type of Capital Investment	Price (\$)	Price (Rp)
1	PEC	\$658,535.43	Rp6,397,119.70
2	PEI	\$283,170.23	Rp4,586,550,761.47
3	Instrumen and Control	\$98,780.31	Rp1,599,959,567.95
4	Piping	\$566,340.47	Rp9,173,101,522.94
5	Electrical Equipment and Material	\$98,780.31	Rp1,599,959,567.95
6	Insulation	\$52,682.83	Rp853,311,769.58
7	Building cost	\$2,201,900.21	Rp35,664,508,000.00
8	Land & Yard	\$951,612.07	Rp15,413,403,500.00
Physical Plant Cost (PPC)		\$4,911,801.88	Rp79,557,191,809.59

Table 6.5 Direct Plant Cost

No	Type of Capital Investment	Price (\$)	Price (Rp)
1	Engineering and Constructions	\$515,020.00	Rp10,912,381,312.98
2	Direct Plan Cost (DPC)	\$143,515.43	Rp2,431,966,711.99
Total (DPC + PPC)		\$ 658,535.43	Rp13,344,348,024.97

Table 6.6 Capital Investement (FCI)

No	Type of Capital Investment	Price (Rp)	Price (\$)
1	Direct Plant Cost	Rp 95.468.630.171,51	\$ 5.894.162,26
2	Cotractor's fee	Rp 3.818.745.206,86	\$ 235.766,49
3	Contingency	Rp 9.546.863.017,15	\$ 589.416,23
Fixed Capital Investment (FCI)		Rp 108.834.238.395,52	\$ 6.719.344,97

Table 6.7 Working Capital Investement (WCI)

No	Type of Expenses	Price (\$)	Price (Rp)
1	Raw Material Inventory	\$ 149,838.14	Rp 2,426,950,783.34
2	Inproses Onventory	\$ 209,681.77	Rp 3,396,247,005.59
3	Product Inventory	\$ 97,851.49	Rp 1,584,915,269.27
4	Extended Credit	\$ 623,462.67	Rp 10,098,318,406.81
5	Available Cash	\$ 419,363.53	Rp 6,792,494,011.17
Working Capital (WC)		\$ 1,500,197.60	Rp 24,298,925,476.19

Table 6.8 Direct Manufacturing Cost (DMC)

No	Type of Expense	Price (\$)	Price (Rp)
1	Raw Material	\$ 1,648,219.51	Rp 26,696,458,616.74
2	Laboratorium	\$ 703,383.00	Rp 11,392,800,000.00
3	Supervision	\$ 70,338.30	Rp 1,139,280,000.00
4	Maintenance	\$ 403,160.70	Rp 6,530,054,303.73
5	Plant Supplies	\$ 60,474.10	Rp 979,508,145.56
6	Royalty and Patents	\$ 68,580.89	Rp 1,110,815,024.75
7	Utilities	\$ 116,466.11	Rp 1,886,419,068.84
Direct Manufacturing Cost (DMC)		\$ 3,070,622.62	Rp 49,735,335,159.62

Table 6.9 Indirect Manufacturing Cost (IMC).

No	Type of Expense	Price (\$)	Price (Rp)
1	Payroll Overhead	\$ 105,507.45	Rp 1,708,920,000.00
2	Laboratory	\$ 70,338.30	Rp 1,139,280,000.00
3	Plant Overhead	\$ 351,691.50	Rp 5,696,400,000.00
4	Packaging and Shipping	\$ 342,904.47	Rp 5,554,075,123.75
Indirect Manufacturing Cost (IMC)		\$ 870,441.72	Rp 14,098,675,123.75

Table 6.10 Fixed Manufacturing Cost (FMC)

No	Type of Expense	Price (\$)	Price (Rp)
1	Depreciation	\$ 537,547.60	Rp 8,706,739,071.64
2	Property taxes	\$ 67,193.45	Rp 1,088,342,383.96
3	Insurance	\$ 67,193.45	Rp 1,088,342,383.96
Fixed Manufacturing Cost (FMC)		\$ 671,934.50	Rp 10,883,423,839.55

Table 6.11 General Expense (GE)

No	Type of Expense	Price (\$)	Price (Rp)
1	Administration	\$ 138,389.97	Rp 2,241,523,023.69
2	Sales Expense	\$ 230,649.94	Rp 3,735,871,706.15
3	Research	\$ 161,454.96	Rp 2,615,110,194.30
4	Finance	\$ 164,390.85	Rp 2,662,663,277.43
General Expenses (GE)		\$ 694,885.72	Rp 11,255,168,201.57

Table 6.12 Feasibility Analysis

No	Type of Expense	Price (Rp)
1	Total Sales	Rp 111,081,502,474.91
2	Total Production Cost	Rp 85,972,602,324.49
3	Profit Before Tax	Rp 25,108,900,150.42
4	Profit After Tax	Rp 20,087,120,120.33

6.6 Feasibility Analysis Result

Biodiesel

- Production = 45,000 Kg/Year
- Selling price = Rp 20,000/Liter (www.alibaba.com)
- Total sales = Rp 111,081,502,474.91 /Years
- Tax = 20%
- Tax costs = Rp 5,021,780,030.08
- After-tax profits = Rp 20,087,120,120.33

The tax is determined at 20% of the government regulations on income tax.

<http://perpajakan.ddtc.co.id/peraturan-pajak>.

A. Return on Investment (ROI)

$$\%ROI = \frac{\text{Profit}}{\text{Fixed Capital Investment}}$$

ROI before tax = 23.07 %

ROI after tax = 18.46 %

B. Pay Out Time (POT)

$$POT = \frac{\text{Fixed Capital Investment}}{(\text{Annual Profit} + \text{Depresiasi})} 100\%$$

POT Before taxes = 3.22 Years

POT After Tax = 3.78 Years

C. Break Event Point (BEP)

Fa : \$ 671,934.50

Ra : \$ 2,459,779.08

Sa : \$ 6,858,089.38

Va : \$ 2,176,170.98

$$BEP = \frac{(Fa + 0,3Ra)}{(Sa - Va - 0,7Ra)} 100\%$$

$$BEP = 47,63\%$$

D. Shut Down Point (SDP)

$$SDP = \frac{(Fa+0,3Ra)}{(Sa-Va-0,7Ra)} 100\%$$

$$SDP = 24.93\%$$

E. Discounted Cash Flow Rate (DCFR)

Factory life = 10 Years

FCI = Rp 108,834,238,396

Working Capital = Rp 24,298,925,476

Salvage Value (SV) = Rp 8,706,739,072

Cash Flow (CF) = Annual Profit + Depresiasi + Finance
= Rp 31,456,522,469

$$\frac{(WC + FCI) \cdot (1 + i)^{10}}{CF} = ((1 + i)^9 + (1 + i)^8 + \dots + (1 + i)^1) \frac{WC + SV}{CV}$$

R = S With trial & error, the value i = 22.87% was obtained Bank Indonesia's interest rate for March is 10.50%.

Table 6.13 Economic Analysis

Parameter	Uncountable	Statement	Criterion
ROI before tax	23.07 %	High Risk Minimum 44% Low Risk Minimum 11%	Complies (Because the established factory is Low Risk. also reviewed from the operating conditions used)
ROI after tax	18.46 %		
POT before tax	3.22 Years	High Risk Maximal 2 Years Low Risk Maximal 5 Years	
POT after tax	3.78 Years		
BEP	47.64 %	40 - 60 %	Complies
SDP	24.93 %	20 - 30 %	Complies
DCFR	22.87 %	Interest = 1.5 bank deposit interest 10.50 %)	Complies

The results of the calculation of the economic feasibility of the establishment of Biodiesel Plants from WCO and Methanol can be understood through the following Break Point graph:

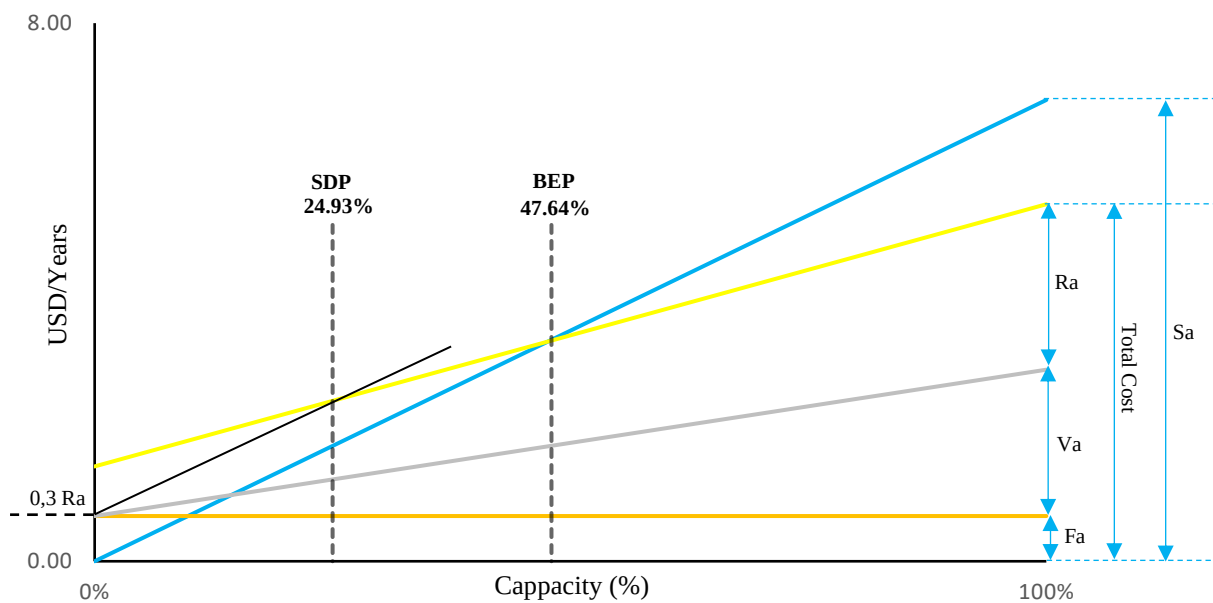


Figure 12. Break Even Point Graphics

CHAPTER VII.

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The proposed biodiesel plant, with a production capacity of 45,000 tons per year, utilizes the hydration process of waste cooking oil homogen catalyst. Based on the utility calculations, the total water requirement is approximately 16,210.324 kg/h, which will be used for process water, cooling water, steam generation, and domestic needs.

A risk analysis was conducted to compare the potential hazards of high-risk and low-risk scenarios within the plant. This analysis also aimed to identify appropriate mitigation strategies for the identified risks. Risk control measures were applied to all potential hazards, with consideration of their risk levels to determine the priority and required investment for mitigation.

In addition to technical assessments, an economic evaluation was also performed in this preliminary plant design. The results of the feasibility analysis are as follows:

1. Profitability

The profit before and after tax is Rp, 111,081,502,474.91/year and Rp, 20,087,120,120.33/year, respectively.

2. Return On Investment (ROI)

The ROI percentage before and after tax is 23.07% and 18.46%, respectively.

3. Pay Out Time (POT)

The pay out time before and after tax is 3.22 years and 3.78 years, respectively.

4. Break Even Point (BEP) and Shut Down Point (SDP)

The Break Even Point is achieved at 47.63% of capacity, while the Shut Down Point is at 24.93%.

5. Discounted Cash Flow Rate (DCFR)

The obtained DCFR value is 10.50%.

Considering the results of the economic evaluation above, the biodiesel plant with a production capacity of 45,000 tons/year is considered feasible for further development and meets the criteria for establishment.

4.2 Recommendations

The design of a chemical plant requires a comprehensive understanding of fundamental concepts that can enhance the feasibility of its establishment. Several important considerations include:

1. Optimization in the Selection of Process Equipment, Supporting Facilities, and Raw Materials. Careful selection and optimization of process equipment, auxiliary systems, and raw materials are essential to maximize profitability and operational efficiency.
2. Environmental Considerations in Chemical Plant Design. It is crucial to take into account the generation of waste during the design phase. This encourages the development of more environmentally friendly chemical plants, contributing to sustainable industrial growth.

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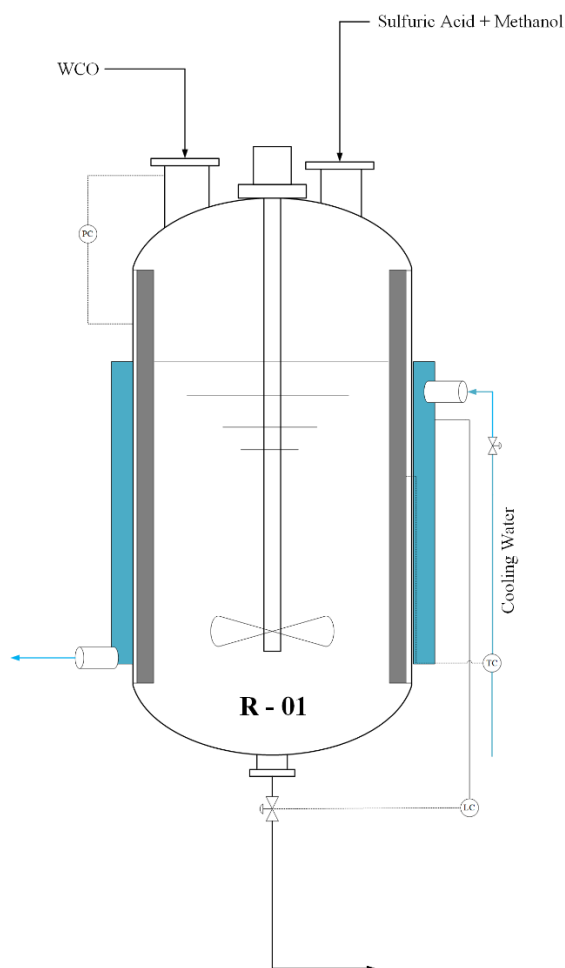
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APPENDIX A

Part 6 : Reactor Design



Function : Reacting free fatty acids with methanol to form fatty acid methyl esters with the addition of sulfuric acid as a catalyst

Type : Continuous Stirred Tank Reactor

Operating Condition : Temperature = 60 °C

Pressure = 1 atm

Reaction Time = 1 hours

Objective :

1. Determine the type of reactor
2. Calculate the reaction rate constant and reactor volume

3. Determine the dimensions of the reactor

4. Determine the type of cooler

1. Determination of Reactor Type

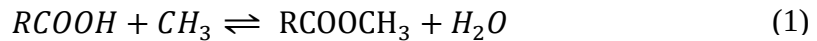
The selected reactor is a Continuous Stirred Tank Reactor (CSTR) due to the following reasons:

- The feed phase to be reacted is in liquid form
- The catalyst phase used is also in liquid form
- Relatively more cost-effective
- More effective for the specifications of the materials used

2. Calculation of Reaction Rate Constant and Reactor Volume

➤ The reaction occurring in the reactor:

Main Reaction:



The reaction conversion is 99%. Free fatty acids (FFA), comprising oleic acid and palmitic acid, are converted into fatty acid methyl esters with the addition of sulfuric acid as a catalyst, amounting to 1% of the total feed weight to the reactor.

➤ Determining the density of the mixture

The Relationship between density as a function of temperature can be expressed as:

$$\rho = A B^{-\left(1 - \frac{T}{T_c}\right)^n} \quad (2)$$

Where, value A, B, dan n as a regression coefficients for chemical component

T = Operation Temperature (K)

T_c = Critical Temperatur (K)

Tabel A. Data for calculating the density of each component

No	Name	Component	MW	Density	
			g/mol	Kg/m3	g/cm3
1	Triolen	C ₅₇ H ₁₀₄ O ₆	885.432	888.6844	0.889
2	Tripalmitin	C ₅₁ H ₉₈ O ₆	852.378	878.7984	0.879
3	Oleic Acid	C ₁₈ H ₃₄ O ₂	282.46	860.8979	0.861
4	Palmitate Acid	C ₁₆ H ₃₂ O ₂	256.424	855.2857	0.855
5	Methyl Palmitate	C ₁₇ H ₃₄ O ₂	270	835.7825	0.836
6	Methyl Oleate	C ₁₉ H ₃₆ O ₂	296.49	846.6684	0.847
7	Methanol	CH ₃ OH	32.04	754.5681	0.755
8	Sulphuric Acid	H ₂ SO ₄	98.079	1795.0610	1.795
9	Water	H ₂ O	18.015	979.6811	0.980
10	Glycerol	C ₃ H ₈ O ₃	92.09	1235.0780	1.235
11	Natrium Hydroxide	NaOH	39.997	1898.1040	1.898

The data was obtained using Aspen Plus at a temperature of 60° C

Tabel B. Calculating of mixture density

Component	kg/h	Mass Fraction	ρ (kg/m3)	ρ Mixed(kg/m3)
C ₅₇ H ₁₀₄ O ₆	2442.591	0.209	888.684	185.695
C ₅₁ H ₉₈ O ₆	2669.808	0.234	878.798	205.490
C ₁₈ H ₃₄ O ₂	11.645	0.020	860.898	17.561
C ₁₆ H ₃₂ O ₂	16.757	0.029	855.286	25.105
C ₁₇ H ₃₄ O ₂	318.389	0.000	835.783	0.000
C ₁₉ H ₃₆ O ₂	221.253	0.000	846.668	0.000
CH ₃ OH	5083.997	0.493	754.568	371.653
H ₂ SO ₄	111.337	0.010	1795.061	17.504
C ₃ H ₈ O ₃	0.000	0.000	1235.078	0.000
H ₂ O	598.719	0.005	979.681	5.069
Total	11474.495	1.0000	9930.5055	828.0774

➤ Determining the viscosity of the mixture

Relationship between liquid viscosity as a function of temperature

$$\log_{10} \eta_{liq} = A = \frac{B}{T} + C \cdot T + C \cdot T^2 \quad (3)$$

Where, the value of η liquid = Viscosity of the liquid (Centipoise)

A, B, and C = Regression coefficients for each compound

T = Temperature (K)

Tabel C. Data for calculating the viscosity of each component

No	Name	Molecul	MW	Density
			g/mol	Centipoise
1	Triolen	C ₅₇ H ₁₀₄ O ₆	885.432	14.538
2	Tripalmitin	C ₅₁ H ₉₈ O ₆	852.378	15.203
3	Oleic Acid	C ₁₈ H ₃₄ O ₂	282.46	8.021
4	Palmitate Acid	C ₁₆ H ₃₂ O ₂	256.424	7.626
5	Methyl Palmitate	C ₁₇ H ₃₄ O ₂	270	2.248
6	Methyl Oleate	C ₁₉ H ₃₆ O ₂	296.49	2.220
7	Methanol	CH ₃ OH	32.04	0.327
8	Sulphuric Acid	H ₂ SO ₄	98.079	6.849
9	Water	H ₂ O	18.015	0.408
10	Glycerol	C ₃ H ₈ O ₃	92.09	52.079
11	Natrium Hydroxide	NaOH	39.997	100.451

The data was obtained using Aspen Plus at a temperature of 60° C

Tabel D. Calculating of mixture viscosity

Component	Stream (kg/h)	Mass Fraction (%)	μ(Cp)	μ mix(Cp)
C ₅₇ H ₁₀₄ O ₆	2442.591	0.209	19.067	3.984
C ₅₁ H ₉₈ O ₆	2669.808	0.234	19.755	4.619
C ₁₈ H ₃₄ O ₂	11.645	0.020	10.320	0.211
C ₁₆ H ₃₂ O ₂	16.757	0.029	9.590	0.282
C ₁₇ H ₃₄ O ₂	318.389	0.000	2.654	0.000
C ₁₉ H ₃₆ O ₂	221.253	0.000	2.664	0.000
CH ₃ OH	5083.997	0.493	0.360	0.177
H ₂ SO ₄	111.337	0.010	0.395	0.004
C ₃ H ₈ O ₃	0.000	0.000	86.194	0.000
H ₂ O	598.719	0.005	0.474	0.002
Total	11474.495	1	151.473	9.279

➤ Determining the reaction rate equation

The formation reaction of Free Fatty Acid (FFA) and Methanol is a direct reaction with first order kinetic, the equation is:

$$-r_a = k C_a \quad (4)$$

Where =

-r_A = Reaction rate

k = Reaction rate constant (/s)

C_A = Concentration of component A (kmol/m³)

$$k = A e^{-E/RT} \quad (5)$$

Where:

$$A = 74 \times 10^6 \text{ min}^{-1}$$

$$E = 57.82 \text{ kJ/mol}$$

(Pugazhendhi et al, 2020).

$$R = 0,008314 \text{ kJ/mol.k}$$

$$T = 60 \text{ }^\circ\text{C}$$

$$K = 0.06 \text{ min}^{-1}$$

Thus the value is 0.06 min⁻¹

➤ Mass Balance in Reactor

Component	Mr	Input					
		WCO		Catalyst (H2SO4)		Metanol	
		Mol (kmol/h)	Mass (kg/h)	Mol (kmol/h)	Mass (kg/h)	Mol (kmol/h)	Mass (kg/h)
C ₅₇ H ₁₀₄ O ₆	885.432	2.759	2442.591	0.000	0.000	0.000	0.000
C ₅₁ H ₉₈ O ₆	852.378	3.132	2669.808	0.000	0.000	0.000	0.000
C ₁₈ H ₃₄ O ₂	282.46	0.825	232.898	0.000	0.000	0.000	0.000
C ₁₆ H ₃₂ O ₂	256.424	1.307	335.146	0.000	0.000	0.000	0.000
C ₁₇ H ₃₄ O ₂	270	0.000	0.000	0.000	0.000	0.000	0.000
C ₁₉ H ₃₆ O ₂	296.49	0.000	0.000	0.000	0.000	0.000	0.000
CH ₃ OH	32.04	0.000	0.000	0.000	0.000	175.519	5623.639
H ₂ SO ₄	98.079	0.000	0.000	1.135	111.337	0.000	0.000
C ₃ H ₈ O ₃	92.09	0.000	0.000	0.000	0.000	0.000	0.000
H ₂ O	18.015	0.000	0.000	0.126	2.272	3.153	56.804
Sub Total		8.022	5680.443	1.261	113.609	178.672	5680.443
Total (kg/h)		11474.495					

Output	
Flow 4	
Mol (kmol/h)	Mass (kg/h)
2.759	2442.591
3.132	2669.808
0.041	11.645
0.065	16.757
1.179	318.389
0.746	221.253
158.677	5083.997
1.135	111.337
0.000	0.000
33.234	598.719
200.969	11474.495
11474.495	

➤ Determining Reactor Volume

$$\text{Accumulation} = \text{in} - \text{out} + \text{Generation} \quad (6)$$

$$F_V \cdot C_{A \text{ in}} - F_V \cdot C_{A \text{ out}} + (-r_A) V = 0$$

$$F_V \cdot C_{A \text{ in}} - F_V \cdot C_{A \text{ out}} = (-r_A) V$$

$$F_V (C_{A \text{ in}} - C_{A \text{ out}}) = (-r_A) V$$

$$V = \frac{F_V (C_{A \text{ in}} - C_{A \text{ out}})}{(-r_A)}$$

$$V = \frac{F_V (C_{A0} - C_{A0}(1-Xa))}{(-r_A)}$$

$$V = \frac{F_V (C_{A0} \cdot Xa)}{(-r_A)}$$

$$V = \frac{F_V (C_{A0} \cdot Xa)}{k \cdot C_A}$$

$$V = \frac{F_V (C_{A0} \cdot Xa)}{k \cdot (C_{A0} (1-Xa))}$$

$$V = \frac{F_V \cdot Xa}{k \cdot ((1-Xa))}$$

$$V = \frac{F_V \cdot Xa}{k \cdot C_A}$$

Where:

$$F_v = 0.825 \text{ kmol/h}$$

$$x = 99\%$$

$$k = 0.06 \text{ min}^{-1}$$

$$= 2.869 \text{ h}^{-1}$$

$$C_a = 0.0005888 \text{ kmol/m}^3$$

Thus the value of V

$$V = 483.989 \text{ m}^3 \text{ atau } 483988.618 \text{ L}$$

➤ Reactor optimation

$$V = \frac{F_b(x_{An} - x_1)}{k(1 - x)} \quad (7)$$

1 Reactor	
V	483.989
X0	0.000
X1	0.990

2 Reactor	
V	160.232
X0	0
X1	0.895
X2	0.990

3 Reactor	
V	71.941
X0	0
X1	0.765
X2	0.947
X3	0.990

4 Reactor	
V	48.109
X0	0
X1	0.647
X2	0.880
X3	0.961
X4	0.990

5 Reactor	
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V	37.833
X0	0
X1	0.550
X2	0.804
X3	0.917
X4	0.968
X5	0.990

Cost and volume calculation of reactor:

n	V (gallon)	Price (\$)	Price Total (\$)
1	127856.2412	2093400	2093400
2	42328.8889	1161800	2323600
3	15832.1118	699800	2099400
4	10586.9061	557300	2229200
5	8326.4669	490700	2453500
Lower Price			2093400

The price of a stainless steel type 304 reactor is obtained from Matche.com, leading to the selection of one RATB reactor with a volume of 127856.2412 gallons. Volume Overdesign = 20% (Petters and Timmerhause, 1980)

➤ Determining Reactor Dimension

$$D = \sqrt[3]{\frac{4 V_{shell}}{\pi}} \quad (8)$$

$$D = 2.778 \text{ m}$$

$$D = 109.378 \text{ in}$$

$$D = 9.690 \text{ ft}$$

$$H = D$$

The value is

$$H = 2.778 \text{ m}$$

$$H = 109.378 \text{ in}$$

With an operating pressure of 1 atm, a torispherical dished head is selected (Brownell, p. 88).

$$V_{dish} = 0.000076 \text{ dt}^3$$

Where,

$$V_{dish} = 119.489 \text{ in}^3$$

$$V_{dish} = 0.00196 \text{ m}^3$$

Volume Straight Flange

$$V_{sf} = \frac{\pi}{4} \cdot ID \cdot sf \quad (9)$$

The value of the shape factor (sf) is taken from the standard, 0.625, based on the thickness above it. According to Table 5.8 in Brownell, for diameters above 180 inches, the value is determined.

$$Sf = 1,5 \text{ in}$$

Thus, the volume of the straight flange is:

$$V_{sf} = 136.92 \text{ in}^3$$

$$V_{sf} = 0.00224 \text{ m}^3$$

Volume Head

$$V_{head} = V_{dish} \cdot V_{sf} \quad (10)$$

$$V_{head} = 512.816 \text{ in}^3$$

$$V_{head} = 0.0084 \text{ m}^3$$

Volume Reactor

$$V_{reaktor} = V_{shell} \cdot V_{head} \quad (11)$$

$$V_{reaktor} = 1234636.62 \text{ in}^3$$

$$V_{reaktor} = 20.233 \text{ m}^3$$

Volume Bottom

$$V_{sbottom} = 0,5 \cdot V_{head} \quad (12)$$

$$V_{bottom} = 256,408 \text{ in}^3$$

$$V_{bottom} = 0.0042 \text{ m}^3$$

Volume Liquid

$$V_{cairan} = V_{shell} \cdot V_{bottom} \quad (13)$$

$$V_{liquid} = 1233867,396 \text{ in}^3$$

$$V_{liquid} = 20,221 \text{ m}^3$$

Liquid Height

$$148 \quad (14)$$

$$H_l = \frac{4 V}{\pi \cdot D^2}$$

$$H_l = 2.953 \text{ m}$$

$$H_l = 9,688 \text{ ft}$$

➤ Determining Hidrostatic Pressure

$$\rho_{hidrostatic} = \frac{\rho \cdot g \cdot h}{gc} \quad (15)$$

$$P = 1 \text{ atm} = 14,696 \text{ psi}$$

$$g = gc = 32,174 \text{ g cm/gf s}^2$$

$$H_l = 2,584 \text{ m}$$

$$\rho_{mix} = 837.8975$$

$$\text{Thus, the value } \rho_{hidrostatic} = 25,7786 \text{ kg/m}^2$$

$$\rho_{hidrostatic} = 0.0366 \text{ psi}$$

➤ Determine Total Pressure

$$P_{total} = P_{hidrostatic} \cdot P_{operasi} \quad (16)$$

Then, the value P_{total} is 14.737 psi

Calculating Reactor Wall Thickness

- Selected Material = Stainless steel SA 167 grade 11 type 36
- Allowable stress (f) = 18854,94 psia
- Selected joint = double welded butt joint
- Joint efficiency (E) = 0.85
- Corrosion allowance (c) = 0.125 in
- Reactor radius (r) = 58,1399 in
- Thus, the value of ts is = 0.189 in

From the above data, the value of ts is obtained as 0.189 in. Thus, the standard value of ts is 0,25 in (Table 5.6, Brownell, 1959, pp. 89-81). From the same data, the following values are also obtained: Value OD = 104.787

- OD Standart = 120 (table 5.7 brownell, hal 90)
- Icr = 7,25 in
- Rc = 114 in

Determine the head size

$$t_h = \frac{P \cdot d \cdot V}{2FE - 0,2 P} + C$$

From the data, the head thickness is obtained as 0,189 in

The standard head thickness is 0,25 in

➤ Calculating Agitator Specifications

Agitator specifications are selected based on the comparison between tank volume and liquid viscosity. From Figure 10.57 of the book *Unit Operations*, a turbine type agitator with 6 flat blades is selected, resulting in the following data:

Dt/Di	3	
Zl/Di	3,9	range 2,7 – 3,9
Zi/Di	1.3	range 0,75 – 1,3
wb/Di	0.17	
L/Di	0.25	
Baffle Total	4	Baffle to prevent vortex formation

Using this data, calculations are performed to determine the agitator dimensions.

Name	Symbol	Equation
Agitator Diameter	Di	$\frac{D_t}{3}$
Distance of the agitator from the bottom of the tank	Zi	$D_i \cdot 1,3$
Agitator Height	Zl	$D_i \cdot 3,9$
Baffle Wide	Wb	$D_i \cdot 0,17$
Agitator Wide	L	$D_i \cdot 0,25$

The result obtained are as follows

Di	0,985 m	3,230 ft
Zi	1,280 m	4,199 ft
Zl	3,840 m	12,597 ft
Wb	0,167 m	0,549 ft
L	0,246 m	0,808 ft

➤ Determine Agitation Speed

$$N = \frac{600}{\pi \cdot d} \sqrt{\frac{WELH}{2 \cdot d}} \quad (18)$$

Where:

N = Agitation speed (rpm)

WELH = Water Equivalent Liquid Height, to calculating WELH there need:

$$WELH = \text{Liquid Height (Zl)} \times \text{specific gravity (sg)}$$

Thus, the value of sg:

$$sg = \frac{\rho_{\text{liquid}}}{\rho_{\text{water}}} \quad (19)$$

$$\rho_{\text{liquid}} = 837,897 \text{ kg/m}^3$$

$$\rho_{\text{water}} = 997 \text{ kg/m}^3$$

$$Sg = 0,840 \text{ kg/m}^3$$

The result of WELH = 8.322 ft

$$N = 66,415 \text{ rpm}$$

$$N = 1,107 \text{ rps}$$

From the data, the number of agitators can be calculated using the formula:

$$\text{Number of agitators} = \frac{WELH}{D} \quad (20)$$

Number of agitators = 1 unit

➤ Calculate motor power

$$Re = \frac{N_p \cdot D_i^2}{\mu_{\text{mix}}} \quad (21)$$

Gc	32.174	ft.lbm/s2.lbf
ρ mix	978.5071	kg/m3
	61.08796808	lbm/ft3
Di	0.861798712	m
	2.827423599	ft
μ mix	3.72E-01	cP
	2.50E-04	lb/ft.s
N	1.366392871	rps
Re	2.67E+06	

From the data, the value of Np is obtained from Figure 447 in Brown's book, page 507.

The obtained Np value is 7. The agitator power can be calculated using the formula:

$$P = \frac{N_p \cdot \rho \cdot N^3 \cdot d^5}{550 \text{ gc}} \quad (22)$$

The calculated agitator power is:

$$P = 9,867 \text{ hp}$$

After obtaining the agitator power data, the motor power can be calculated using the formula:

$$daya\ motor = \frac{P}{n} \quad (23)$$

Where n is the motor efficiency value taken from Figure 14.38 in Peter's book, page 521, with a value of 87%. The obtained motor power is:

$$P = 11,139\ hp$$

With a standard value of 15 hp (NEMA Standard)

➤ Heat Capacity Reactor

Input Reactor

Component	kmol/h	kg/h	T (k)	T ref (K)	Cp. Dt (kJ/Kmol.K)
C ₅₇ H ₁₀₄ O ₆	2.759	2442.591	333.150	298.15	1650.06
C ₅₁ H ₉₈ O ₆	3.132	2669.808			1563.57
C ₁₈ H ₃₄ O ₂	0.825	232.898			704.81
C ₁₆ H ₃₂ O ₂	1.307	335.146			673.14
C ₁₇ H ₃₄ O ₂	0.000	0.000			542.32
C ₁₉ H ₃₆ O ₂	0.000	0.000			666.37
CH ₃ OH	175.519	5623.639			83.34
H ₂ SO ₄	1.135	111.337			144.79
C ₃ H ₈ O ₃	0.000	0.000			266.34
H ₂ O	3.279	59.077			75.09
Total	187.956	11474.495			

ΔH1 (Kj/h)	Mass Fraction	CP Reactor (kJ/Kg)	Cp Mix (kJ/Kg)
5367.725	0.209	1.864	0.389
5912.620	0.234	1.834	0.429
701.610	0.020	2.495	0.051
1062.176	0.029	2.625	0.077
0.000	0.000	2.009	0.000
0.000	0.000	2.248	0.000
17660.238	0.493	2.601	1.281
198.429	0.010	1.476	0.014
0.000	0.000	2.892	0.000
297.294	0.005	4.168	0.022
31200.092	1.000		

Output Reactor

Component	kmol/h	kg/h	T (k)	T ref (K)	Cp. Dt (kJ/Kmol.K)
C ₅₇ H ₁₀₄ O ₆	2.759	2442.591	333.150	298.15	1650.06
C ₅₁ H ₉₈ O ₆	3.132	2669.808			1563.57
C ₁₈ H ₃₄ O ₂	0.825	232.898			704.81
C ₁₆ H ₃₂ O ₂	1.307	335.146			673.14
C ₁₇ H ₃₄ O ₂	0.000	0.000			542.32
C ₁₉ H ₃₆ O ₂	0.000	0.000			666.37
CH ₃ OH	175.519	5623.639			83.34
H ₂ SO ₄	1.135	111.337			144.79
C ₃ H ₈ O ₃	0.000	0.000			266.34
H ₂ O	3.279	59.077			75.09
Total	187.956	11474.495			
ΔH1 (Kj/h)	Mass Fraction		CP Reactor (kJ/Kg)		Cp Mix (kJ/Kg)
5367.725	0.209		1.864		0.389
5912.620	0.234		1.834		0.429
35.081	0.001		2.495		0.003
53.109	0.001		2.625		0.004
772.086	0.028		2.009		0.056
600.354	0.019		2.248		0.044
15965.569	0.445		2.601		1.158
198.429	0.010		1.476		0.014
0.000	0.000		2.892		0.000
3012.962	0.052		4.168		0.219
31917.934	1.000				

➤ Enthalpy of Formation

Reaction 1 Oleic Acid as FFA to Oleic acid methyl ester. Reactor Input

Component	kmol/h	kg/h	T (k)	T ref (K)	ΔHf (Kj/mol)	ΔHf (Kj/kmol)	ΔHf (Kj/h) Reactan
C ₅₇ H ₁₀₄ O ₆	0.000	0.000	333.150	298.150	0.00	-2015000.000	0.000
C ₅₁ H ₉₈ O ₆	0.000	0.000			0.00	-2067700.000	0.000
C ₁₈ H ₃₄ O ₂	0.825	232.898			-582.75	-582748.000	-580103.084
C ₁₆ H ₃₂ O ₂	0.000	0.000			-745.42	-745416.625	0.000
C ₁₇ H ₃₄ O ₂	0.000	0.000			0.00	-773060.000	0.000
C ₁₉ H ₃₆ O ₂	0.000	0.000			-532.38	-532381.000	0.000
CH ₃ OH	175.519	5623.639			-202.48	-202478.962	-42906202.015
H ₂ SO ₄	1.135	111.337			0.00	-790320.000	-1083129.777
C ₃ H ₈ O ₃	0.000	0.000			-559.44	-559438.000	0.000
H ₂ O	0.000	0.000			0.00	-283160.000	0.000
Total	177.479	5967.874				-8551702.587	-44569434.876

Reactor output

Component	kmol/h	kg/h	T (k)	T ref (K)	ΔH_f (Kj/mol)	ΔH_f (Kj/kmol)	ΔH_f (Kj/h) Reactan
C ₅₇ H ₁₀₄ O ₆	0.000	0.000	333.150	298.150	0.00	-2015000.000	0.000
C ₅₁ H ₉₈ O ₆	0.000	0.000			0.00	-2067700.000	0.000
C ₁₈ H ₃₄ O ₂	0.041	11.645			-582.75	-582748.000	-29005.154
C ₁₆ H ₃₂ O ₂	0.000	0.000			-745.42	-745416.625	0.000
C ₁₇ H ₃₄ O ₂	0.000	0.000			0.00	-773060.000	0.000
C ₁₉ H ₃₆ O ₂	0.746	221.253			-532.38	-532381.000	-479642.260
CH ₃ OH	168.614	5402.385			-202.48	-202478.962	-41218124.673
H ₂ SO ₄	1.135	111.337			0.00	-790320.000	-1083129.777
C ₃ H ₈ O ₃	0.000	0.000			-559.44	-559438.000	0.000
H ₂ O	12.282	221.253			0.00	-283160.000	-4198581.424
Total	182.818	5967.874				-8551702.587	-47008483.288

The Result of enthalpy formation from oleic acid to methyl oleate is

$$\Delta H_{R1(298\text{ K})}^{\circ} = \Sigma \Delta H_{f\text{ produk}}^{\circ} - \Sigma \Delta H_{f\text{ reaktan}}^{\circ} \quad (24)$$

ΔH_f (Kj/h)	
Product	-47008483.288
Reactan	-44569434.876
Total	-2439048.41

Reaction 2 Palmitate acid as FFA to Palmitate acid methyl ester

Reactor Input

Component	kmol/h	kg/h	T (k)	T ref (K)	ΔH_f (Kj/mol)	ΔH_f (Kj/kmol)	ΔH_f (Kj/h) Reactan
C ₅₇ H ₁₀₄ O ₆	0.000	0.000	333.150	298.150	0.00	-2015000.000	0.000
C ₅₁ H ₉₈ O ₆	0.000	0.000			0.00	-2067700.000	0.000
C ₁₈ H ₃₄ O ₂	0.000	0.000			-582.75	-582748.000	0.000
C ₁₆ H ₃₂ O ₂	1.578	404.622			-745.42	-745416.625	-1176223.620
C ₁₇ H ₃₄ O ₂	0.000	0.000			0.00	-773060.000	0.000
C ₁₉ H ₃₆ O ₂	0.000	0.000			-532.38	-532381.000	0.000
CH ₃ OH	203.567	6522.301			-202.48	-202478.962	-41218124.673
H ₂ SO ₄	1.370	134.417			0.00	-790320.000	-1083129.777
C ₃ H ₈ O ₃	0.000	0.000			-559.44	-559438.000	0.000
H ₂ O	0.000	0.000			0.00	-283160.000	0.000
Total	206.516	7061.340				-8551702.587	-43477478.070

Reactor output

Component	kmol/h	kg/h	T (k)	T ref (K)	ΔH_f (Kj/mol)	ΔH_f (Kj/kmol)	ΔH_f (Kj/h) Reactan
C ₅₇ H ₁₀₄ O ₆	0.000	0.000	333.150	298.150	0.00	-2015000.000	0.000
C ₅₁ H ₉₈ O ₆	0.000	0.000			0.00	-2067700.000	0.000
C ₁₈ H ₃₄ O ₂	0.000	0.000			-582.75	-582748.000	0.000
C ₁₆ H ₃₂ O ₂	0.079	20.231			-745.42	-745416.625	-58811.181
C ₁₇ H ₃₄ O ₂	1.424	384.391			0.00	-773060.000	-1100582.330
C ₁₉ H ₃₆ O ₂	0.000	0.000			-532.38	-532381.000	0.000
CH ₃ OH	191.570	6137.910			-202.48	-202478.962	-38788940.206
H ₂ SO ₄	1.370	134.417			0.00	-790320.000	-1083129.777
C ₃ H ₈ O ₃	0.000	0.000			-559.44	-559438.000	0.000
H ₂ O	21.337	384.391			0.00	-283160.000	-6041861.074
Total	215.781	7061.340				-8551702.587	-47073324.567

The Result of enthalpy formation from palmitate acid to Methyl palmitate is:

$$\Delta H_{R1(298 K^\circ)}^\circ = \Sigma \Delta H_{f \text{ produk}}^\circ - \Sigma \Delta H_{f \text{ reaktan}}^\circ \quad (25)$$

ΔH_f (Kj/h)	
Product	-38990572.002
Reactan	-36012152.419
Total	-2978419.58

➤ Heat Balance

	Input (kJoule/h)	Output (kJoule/h)
ΔH_1 (in)	31200.09	0.00
$\Delta H^\circ R$ 1	6034894.91	0.00
ΔH_2 (out)	0.00	31917.93
Q Cooler	0.00	6034177.07
TOTAL	6066095.00	6066095.00

➤ Calculating of cooling water

$$m = \frac{Q}{\Delta H} \quad (26)$$

$$\begin{aligned}
 Q &= 6034177.07 \text{ kj/h} \\
 &= 1441238,432 \text{ kcal/h} \\
 m &= 4753.038 \text{ kg/h}
 \end{aligned}$$

After getting the required amount of cooling water, continue to calculate the volume of water

$$Qv = \frac{m}{\text{Density of Water}} \quad (27)$$

$$\begin{aligned} Qv &= 4753.038 \text{ m}^3/\text{h} \\ &= 1,320 \text{ m}^3/\text{s} \end{aligned}$$

Then looking for value of ΔT_{LMTD}

$$\Delta T_{LMTD} = \frac{(T_2 - t_1) - (T_1 - t_2)}{\ln \frac{(T_2 - t_1)}{(T_1 - t_2)}} \quad (28)$$

The result of ΔT_{LMTD} is 38,953 °F, by obtaining the ΔT_{LMTD} value calculate the value of A

$$A = \frac{Q}{U_D \cdot \Delta T_{LMTD}} \quad (29)$$

If the viscosity is greater than 0.5 cp, then UD for light organic with a range of 200-300 is selected. The selected UD is 200 Btu/ft² °F h.

$$\begin{aligned} A &= 0,610 \text{ ft}^2 \\ &= 0,057 \text{ m}^2 \end{aligned}$$

➤ Determine Using Coil or Jacket

Calculating the reactor shell

$$A = OD \cdot H + \left(\frac{\pi}{4} \cdot OD^2\right) \quad (30)$$

The value of reactor shell is

$$\begin{aligned} A &= 534,470 \text{ ft}^2 \\ &= 49,654 \text{ m}^2 \end{aligned}$$

If the reactor area is greater than or equal to the heat transfer area (AA), then a heating or cooling jacket is selected. If the reactor area is less than or equal to the heat transfer area (A), then a heating or cooling coil is selected. As the calculated heat transfer area is less than the heat transfer area of the reactor shell, a cooling jacket is selected.

➤ Calculate the size of cooling jacket

The distance between the outer tank wall and the inner jacket wall is taken from the inner diameter (ID) of the jacket

ID	= 124 in
H	= 186 in
Ts	= 0,20 in
Ts Standar	= 0,25 in
OD	= 124,5 in
OD standard	= 126 in
Icr	= 7,625 in
Rc	= 120 in
Th	= 0,073 in
Th Standar	= 0,1875 in
Sf	= 2 in
OA	= 33,1875 in
	= 0,843 m

After obtaining the data from the jacket calculations, the heat transfer area of the jacket is determined using the formula.

$$diameter = OD + \frac{OD}{24} + 2sf + \frac{2}{3}icr + t \quad (31)$$

De	= 140,333 in
	= 3,564 m
	= 11,694 ft

$$A = OD \times H + \left(\frac{\pi}{4} \times OD^2\right) \quad (32)$$

A	= 35898,66 in ²
	= 23,160 m ²
	= 249,297 ft ²

➤ Determining the heat transfer coefficient between the reactor and jacket

$$\frac{hi \cdot Di}{k} = 0.36 \left(\frac{L^2 N p}{\mu} \right)^{2/3} \left(\frac{Cp \cdot \mu}{k} \right)^{1/3} \left(\frac{\mu}{\mu_w} \right)^{0.14} \quad (33)$$

Di/k	= 29,122
0,36 (L ² .N. ρ/μ) ^{2/3}	= 7,59 x 10 ²
(Cp.μ/k) ^{1/3}	= 72,0298
(μ/ μw) ^{0,14}	= 1

$$Hi = 1878,203 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

$$hi_0 = hi \frac{ID}{OD} \quad (34)$$

$$Hio = 1761,271 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

$$\text{Ret} = \frac{ID \cdot Gt}{\mu} \quad (35)$$

$$Gt = 1802,006 \text{ kg/h m}^2$$

$$Gt = 369,0796 \text{ lb/h ft}^2$$

$$\text{Ret} = 3,05$$

$$\text{Re} = 3,04587$$

Using the data from Fig. 24 in Kern's book, the result obtained is that Jh 1,2

$$h_0 = j_h \frac{k}{De} \left(\frac{C_p \mu}{k} \right)^{1/3} \left(\frac{\mu}{\mu_w} \right)^{-0.14} \quad (36)$$

$$Ho = 28,760 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

$$Uc = \frac{hi_0 h_0}{hi_0 + h_0} \quad (37)$$

$$Uc = 28,298 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

Using the data from Table 12 in Kern's book page 845, the result obtained is that Rd 0,002 Btu/h ft² °F

$$hD = 1/Rd = 500$$

$$U_D = \frac{U_C \cdot hD}{U_C + hD} \quad (38)$$

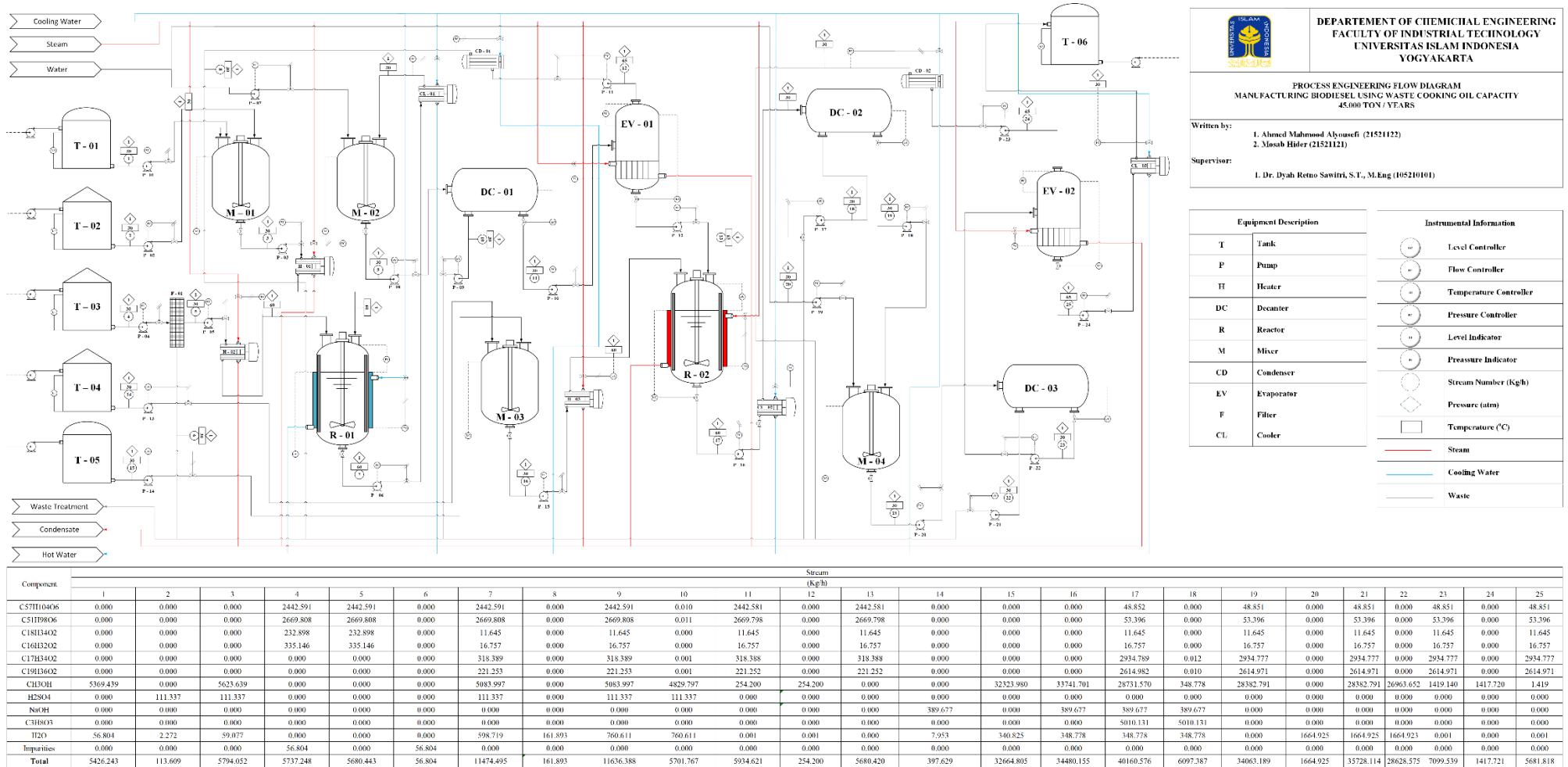
$$Ud = 26.782 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

$$= 152.077 \text{ W/m}^2 \text{ } ^\circ\text{K}$$

Summary				
Code	R-01			
Function	Reacting free fatty acids with methanol to form fatty acid methyl esters with the addition of sulfuric acid as a catalyst			
Total	1 Unit			
Type	Continuous Stirred Tank Reactor			
Operational Condition:				
Operation Pressure	1	atm	14.70	psi
Operation Temperature	60	°C	333.15	K
Specification:				
Reactor Dimension				
Material	Stainless Steel SA 167 Grade 11 type 316			
Shell Diameter	2.205	m		
Shell Height	4.410	m		
Shell Volume	16.833	m ³		
Head Volume	0.005	m ³		
Reactor Volume	16.838	m ³		
Reactor Height	5.602	m		
Head Height	0.596	m		
Thickness Shell	0.250	in		
Thickness Head	0.250	in		
Flat Blade Turbines Impellers				
Impeller Type	Turbin 6 blade			
Agitator Diameter	0.9260	m		
Agitator Distance	1.2038	m		
Agitator Wide	0.2315	m		
Baffle Wide	0.1574	m		
Numbers of Agitator	1	pcs		
Speed of Agitator	70.622	rpm		
Power	8.7351	hp		
Jaket				
Jaket Material	Stainless Steel SA 167 Grade 11 type 316			
U _D :	152.402	W/m2.K		
Heat Transfer Area	23.160	m2		
Thickness Jacket	0.006	m		

APPENDIX B

PROCESS ENGINEERING FLOW DIAGRAM (PEFD)



APPENDIX C

PLANT DESIGN SUPERVISION CONSULTATION CARD

1. Name : Ahmed Mahmood Alyousefi

NIM 21521122

2. Name : Mosab Hider

NIM 21521121

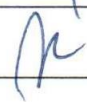
Plant Design Title : **MANUFACTURING BIODIESEL USING WASTE COOKING**

OIL CAPACITY 45,000 TON/YEAR

Start of Supervision Period : **14 September 2024**

End of Supervision Period : **13 September 2025**

No	Date	Consultation Topic	Supervisor's Signature
1	11/ October/ 2024	We had a discussion about choosing the title we will use for the design and we agreed that will be the preliminary design of biodiesel from waste cooking oil (WCO)	
2	30/ October/ 2024	We discussed the stage 1 which is the design capacity determination	
3	30/ October/ 2024	We discussed the stage 2 which is the process selection	
4	6/ November/ 2024	We discussed the stage 3 which is the determination of material specifications	
5	15/ November/ 2024	We discussed the stage 4 which is the creation of a qualitative flow chart	
6	24/ December/ 2024	We discussed the stage 5 which is the mass balance calculations	
7	17/ March/ 2025	We discussed the stage 6 which is the Reactor design	
8	19/ March/ 2025	We discussed the stage 7 which is the design of separators and supporting operating units	
9	19/ March/ 2025	We discussed the stage 8 which is the process flow diagram PFD	
10	19/ March/ 2025	We discussed the stage 9 which is the material storage equipment design	
11	19/ March/ 2025	We discussed the stage 10 which is the design of material transportation equipment	
12	19/ March/ 2025	We discussed the stage 11 which is the heat exchanger design	

13	19/ March/ 2025	We discussed the stage 12 which is the heat balance calculations	
14	19/ March/ 2025	We discussed the stage 13 which is the determination of the location, plant layout, and organizational structure of the company	
15	14/ April/ 2025	We discussed the stage 14 which is the designing the utility unit	
16	14/ April/ 2025	We discussed the stage 15 which is the economic evaluation calculations	
17	22/ April/ 2025	We discussed the stage 16 which is final script	

Approved for Draft Submission:

Yogyakarta, 22 / April / 2025

Supervisor,



Dr. Dyah Retno Sawitri, S.T., M.Eng