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**PRELIMINARY DESIGN OF POLYETHYLENE
TEREPHTHALATE FROM ETHYLENE GLYCOL
AND TEREPHTHALIC ACID WITH
60,000 TON/YEAR CAPACITY**

CHEMICAL PLANT DESIGN

Filed as One of the Requirements

To Obtain a Bachelor's Degree in Chemical Engineering



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**CHEMICAL ENGINEERING STUDY PROGRAM
FACULTY OF INDUSTRIAL TECHNOLOGY
UNIVERSITAS ISLAM INDONESIA
YOGYAKARTA
2025**

SUPERVISOR ENDORSEMENT SHEET

**PRELIMINARY DESIGN OF POLYETHYLENE TEREPHTHALATE
FROM ETHYLENE GLYCOL AND POLYTEREPHTHALIC ACID**

CHEMICAL PLANT DESIGN

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Yogyakarta, 2 June 2025

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الجامعة الإسلامية في اندونيسيا

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FROM ETHYLENE GLYCOL AND TEREPHTHALIC ACID WITH 60,000
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I hereby declare that this chemical plant design project report has been written in accordance with the applicable scientific guidelines. Should any violations be discovered in the future, I am prepared to take responsibility and accept the consequences in accordance with the prevailing regulations. This statement is made truthfully and is intended to be used as necessary.



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PRELIMINARY DESIGN OF POLYETHYLENE TEREPHTHALATE FROM ETHYLENE GLYCOL AND TEREPHTHALIC ACID WITH 60,000 TON/YEAR CAPACITY

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FOREWORD

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Assalamu'alaikum Warahmarullahi Wabarakatuh

Praise and gratitude to the Almighty God, who has bestowed His grace and blessings, enabling the authors to complete the Preliminary Chemical Plant Design titled **“Preliminary Design of Polyethylene Terephthalate from Ethylene Glycol and Poly Terephthalic Acid with 60,000 ton/year Capacity”** to fulfil part of the requirements for obtaining a Bachelor of Engineering degree in the Chemical Engineering program, Faculty of Industrial Technology, Universitas Islam Indonesia.

Various parties assisted us in compiling this Thesis Report. Therefore, on this occasion, we would like to express our gratitude to:

1. Allah SWT, for His grace and blessings that have enabled the authors to complete this thesis report.
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We realize that this research report still has many shortcomings. Therefore, constructive criticism and suggestions are highly expected to improve the writing of this thesis report. In conclusion, may this report be beneficial not only for the authors but also for the readers.

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Yogyakarta, 2 June 2025

Authors

DEDICATION PAGE

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Alhamdulillahirobbil'alamin

Prostrate and give thanks to Allah SWT. The sprinkling of Your love and affection has given me strength, equipped me with knowledge and introduced me to love. With the grace and ease that You have given, finally this Final Assignment Report can be completed on time. Blessings and greetings are always bestowed upon the blessings of the Prophet Muhammad SAW.

I dedicate this Final Assignment to the people I love and care about the most, namely:

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2. My family, my Brother and all the family member that always taking care in every step
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Rahmatan Amartya Ula

Chemical Engineering IP 2021

DEDICATION PAGE

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

Alhamdulillahirobbil'alamin

All praise and gratitude to Allah SWT. Your endless love and compassion have given me strength, equipped me with knowledge, and introduced me to the meaning of love. By Your grace and the ease, you have bestowed upon me, this Final Assignment Report has been completed on time. May peace and blessings always be upon the Prophet Muhammad SAW.

On this page, although I may not be good with words and may struggle to fully express my feelings, I dedicate this Final Assignment to the people I care about the most.

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Chemical Engineering IP 2021

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ABSTRACT

Indonesia's growing industrialization and rising demand for plastic-based products highlight the need to reduce reliance on imported polyethylene terephthalate (PET). This thesis outlines the preliminary design of a PET manufacturing plant with a planned capacity of 60,000 tons per year, utilizing ethylene glycol (EG) and purified terephthalic acid (PTA) through direct esterification and polycondensation processes. The plant is proposed to be built in Cilegon, West Java, Indonesia to serve the expanding domestic market, particularly in the packaging and textile sectors. Hazop analysis from several factors conclude in low risk and Economic analysis reveals a Fixed Capital Investment (FCI) of Rp 901,093,047,516, a payback period of 2.2 years (pre-tax), a Break-Even Point (BEP) of 56.87%, a Return on Investment (ROI) of 35.59% before tax, and a Discounted Cash Flow Rate of Return (DCFRR) of 10%. The results of the technical and financial evaluations confirm that the project is feasible and profitable. Establishing this PET facility is considered a strategic move to support national industry development, reduce import dependency, and enhance sustainable economic growth in Indonesia.

Keywords: Polyethylene Terephthalate, Ethylene Glycol, Terephthalic Acid, Plant Design, Economic Evaluation.

ABSTRAK

Industri yang berkembang di Indonesia dan meningkatnya permintaan produk berbasis plastik menyoroti perlunya mengurangi ketergantungan pada impor polyethylene terephthalate (PET). Tesis ini menguraikan desain awal dari pabrik manufaktur PET dengan kapasitas yang direncanakan sebesar 60.000 ton per tahun, menggunakan etilen glikol (EG) dan asam tereftalat murni (PTA) melalui proses esterifikasi langsung dan polikondensasi. Pabrik tersebut diusulkan untuk dibangun di Cilegon, Jawa Barat, Indonesia untuk melayani pasar domestik yang berkembang, terutama di sektor kemasan dan tekstil. Analisis Hazop dari beberapa faktor menyimpulkan bahwa risikonya rendah dan Analisis ekonomi mengungkapkan Investasi Modal Tetap (FCI) sebesar Rp 901.093.047.516, periode pengembalian modal selama 2,2 tahun (sebelum pajak), Titik Impas (BEP) sebesar 56,87%, Pengembalian Investasi (ROI) sebesar 35,59% sebelum pajak, dan Tingkat Pengembalian Arus Kas Diskontokan (DCFRR) sebesar 10%. Hasil evaluasi teknis dan finansial mengkonfirmasi bahwa proyek ini layak dan menguntungkan. Mendirikan fasilitas PET ini dianggap sebagai langkah strategis untuk mendukung pengembangan industri nasional, mengurangi ketergantungan impor, dan meningkatkan pertumbuhan ekonomi berkelanjutan di Indonesia.

Kata Kunci: Polietilen Tereftalat, Etilen Glikol, Asam Tereftalat, Perancangan Pabrik, Evaluasi Ekonomi.

CHAPTER I

INTRODUCTION

1.1 Background of Factory Establishment

As a developing country, Indonesia is undertaking development and progress in various sectors, one of which is the industrial sector. With advancements in the industrial sector, it is expected to improve the economy and the welfare of the Indonesian people. Its development has several stages and systematically enhances the relationship between the industrial sector and other industries.

The growth of Indonesia's chemical industry has been crucial to the nation's industrialization and economic development, as it supports various sectors like agriculture, manufacturing, healthcare, and infrastructure. With a vast supply of natural resources such as oil, gas, and minerals, Indonesia has a strong foundation for producing a wide range of chemical products, from basic chemicals to specialty chemicals used in high-value industries. Government initiatives, such as tax incentives and infrastructure improvements, have encouraged domestic and foreign investment in the sector. Additionally, increasing demand for industrial chemicals, agrochemicals, and consumer goods has driven companies to expand their local production capacities. However, building a robust chemical industry in Indonesia also faces challenges, including dependency on imported raw materials, environmental sustainability, and the need for skilled labour. To address these issues, the

industry is focusing on developing local supply chains, adopting eco-friendly technologies, and training a specialized workforce, positioning Indonesia as a competitive player in the global chemical market (Ministry of Finance Republic of Indonesia, 2020).

The development of the PET (polyethylene terephthalate) industry in Indonesia has been driven by rising demand in packaging, textiles, and consumer goods due to a growing population and increasing urbanization. As a versatile plastic known for its durability, recyclability, and clarity, PET is widely used in beverage bottles, food containers, and polyester fibres, which support Indonesia's expanding beverage, food processing, and textile sectors. The Indonesian government has encouraged local production through initiatives to reduce imports, support sustainable practices, and foster recycling programs to manage plastic waste effectively. As a result, major domestic companies have invested in PET production facilities, and foreign investors have partnered with local firms, enhancing the industry's capacity and technological advancement. Furthermore, increasing consumer awareness of sustainable packaging and recycling has pushed industry players to adopt eco-friendly manufacturing practices, aiming for a circular economy and aligning with global environmental standards (Abbas, 2015).

The most common type of polyester plastic is polyethylene terephthalate, or PET. Ethylene glycol (EG) and either dimethyl terephthalate (DMT) or terephthalic acid (TPA) are used to make it. It is frequently used in synthetic fibers, soft drink bottles, food containers, and films because of its exceptional

toughness, tensile and impact strength, wear resistance, and electrical insulating qualities. Over time, its annual production has grown to approximately 78 million tons. It is particularly crucial to take action to address PET waste because of its increasing consumption and the harm that results from its buildup after being discarded. The three primary traditional methods for disposing of PET waste are incineration, landfilling, and mechanical recycling. Among these, mechanical recycling is subject to strict specifications regarding the type and purity of plastic waste (Zhou, 2024)

1.2 Product Usage

Polyethylene terephthalate (PET) is a versatile polymer widely utilized across industries due to its exceptional physical and chemical characteristics. Its lightweight, durability, and adaptability make PET a preferred choice for manufacturing items like water bottles, food packaging, and textiles, establishing it as an indispensable material in modern applications (Joseph et al., 2024)

Figure 1.1 show that in 2019, water accounted for the largest share of PET packaging consumption globally at 34.6%, followed by carbonated soft drinks at 27.1%. Non-food products represented 12.1% of PET usage, while the food sector contributed 8.4%. Additionally, the thermoforming industry held a significant portion with 6.6%, and other beverages made up 11.2% of the total PET packaging demand worldwide (Bühning, 2023).

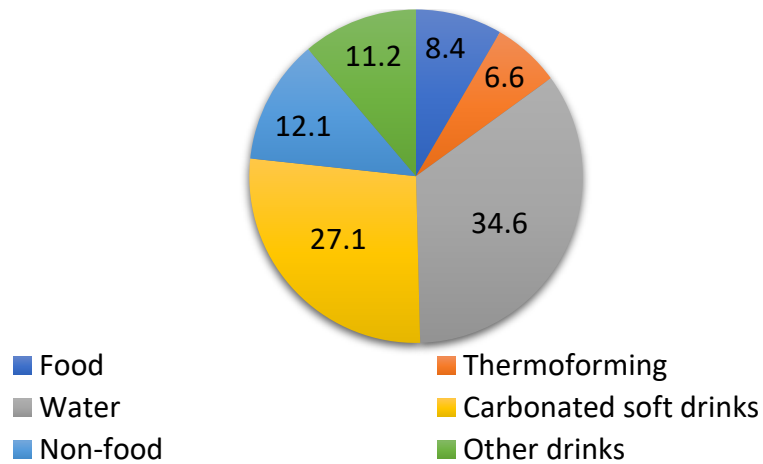


Figure 1.1 Distribution of PET Packaging Consumption Worldwide in 2019
(Bühning, 2023)

1.3 Design Capacity Determination

Determining the production capacity of an industry is considered based on the technical, financial, and economic opportunities, raw material availability, and minimum capacity aspects. From the technical aspects, the industry considers the high opportunity from the raw material availability and continuity. In addition, the determination of the pre-design factory capacity must be equivalent to the minimum or higher than the existing plant capacity. The factors that may be considered in determining the PET factory capacity include:

1.3.1 Estimation of PET Opportunities in Indonesia

Based on import statistics data from 2019-2023, the demand for Polyethylene Terephthalate (PET) in Indonesia is as follows:

Table 1.1 Import Data of PET in Indonesia

Year	Weight (ton/year)
2019	360,000.64
2020	456,037.18
2021	431,000.21
2022	380,194.18
2023	383,594.38

From the import data in Table 1.1, the linear regression value can be determined by making a graph of the import data in the table. This equation is utilized to predict the projected increase or decrease in PET imports in Indonesia over the coming years.

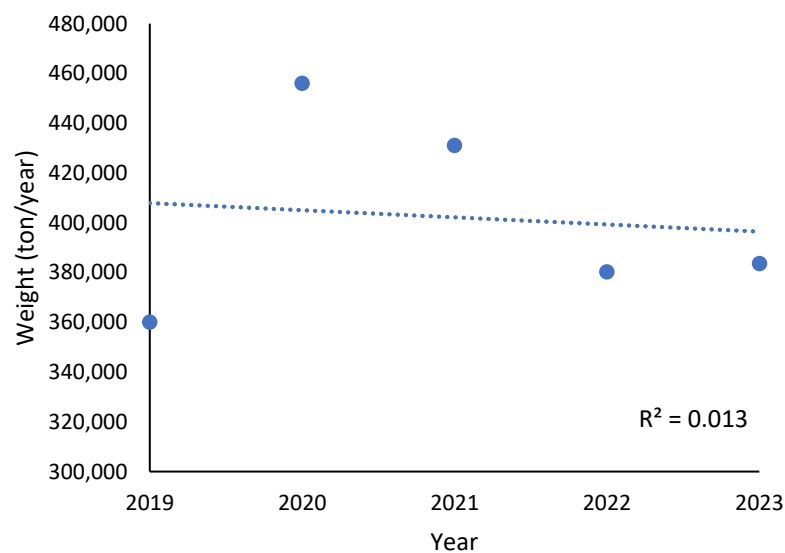


Figure 1.2 PET Import Graphic Data in Indonesia

From the PET import data in Indonesia in Figure 1 from 2019 to 2023, it is seen the PET import over the years is fluctuate which can be seen by the linear line equation that is $y = -2,866x + 6,193,447$. From this equation, it can be used to predict the import needs of PET in Indonesia for the coming year which is 2030. The calculation of the import prediction is as follows:

$$y = -2,866x + 6,193,447 \quad (1)$$

$$y = -2,866(2030) + 6,193,447$$

$$y = 375,467 \text{ tons/year}$$

The import of PET in Indonesia by 2030 is predicted to be 375,467 tons/year.

Based on the UN Data, the export of PET in Indonesia at Table 1.2 is as follows:

Table 1.2 Export Data of PET in Indonesia

Year	Weight (ton/year)
2019	30,650.78
2020	46,408.67
2021	125,770.37
2022	50,727.72
2023	62,376.81

The export data in Table 1.2 can be used to obtain is increase or decrease possibility of PET exports for the upcoming years in Indonesia by using the linear regression method.

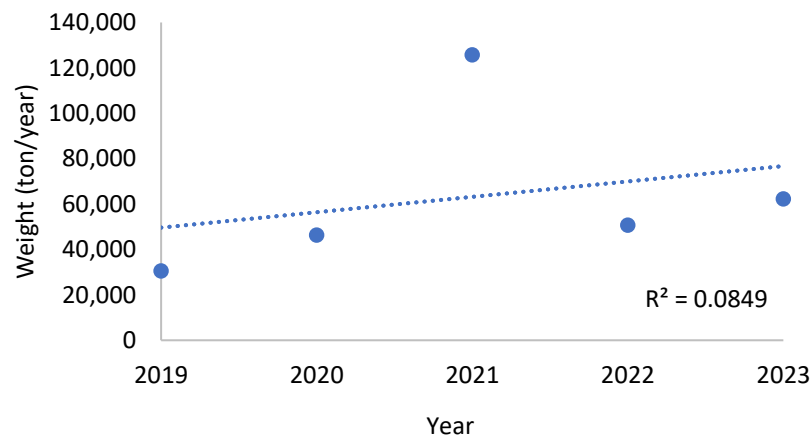


Figure 1.3 PET Export Graphic Data in Indonesia

From the PET export data in Indonesia in Figure 1.2 from 2019 to 2023, it is seen the PET export over the years fluctuates which can be seen by the linear line equation that is $y = 6,777x - 13,633,354$. From this equation, it can be used to predict the import needs of PET in Indonesia for the coming year which is 2030. The calculation of the export prediction is as follows:

$$y = 6,777x - 13,633,354 \quad (2)$$

$$y = 6,777(2030) - 13,633,354$$

$$y = 123,956 \text{ ton/year}$$

Characteristics PET bottles are more often used for mineral water containers, soft drinks, tea, sauces, and fruit drinks. PET is in high demand in Indonesia for the production of plastic bottles and other polymer-based products

(Fitriyano, 2019). It is predicted that PET consumption in Indonesia will increase by 13% per year where the consumption of PET in 2007 was 96,458 tons/year (Febriyanti, 2018). Thus, from this data, it is known that the consumption of PET by 2030 is 1,603,77 tons/year.

The opportunity in ton/year represents the highest production capacity the plant can reach when operating at full potential. This allows process engineers to evaluate how much market demand the plant can satisfy and whether the projected capacity aligns with future demand expectations. The opportunity of PET production is at 194,593 tons/year as follows:

$$\text{Opportunity} = \text{Demand} - \text{Supply} \quad (3)$$

$$\text{Opportunity} = (\text{Consumption} + \text{Export}) - (\text{Import} + \text{Production})$$

$$\text{Opportunity} = (1,603,771 + 123,956) - (375,467 + 609,350)$$

$$\text{Opportunity} = 742,850 \text{ tons/year}$$

1.3.2. Estimation of PET Opportunities in Indonesia

In the production of PET, raw materials needed are ethylene glycol (EG), and purified terephthalic acid (PTA). Moreover, this process uses Antimony trioxide (Sb_2O_3) catalyst to support the production process.

Currently, there are five existing companies in PTA production in Indonesia with a total capacity of 2,025,000 tons per year.

Table 1.3 Production of PTA (Lutfi Afifah, 2019)

Company Name	Location	Average capacity (Ton/year)
Pertamina	Plaju	225,000
PT Mitsubishi Chemical	Serang	650,000
PT Polysindo Eka Perkasa	Karawang	350,000
PT Amoco Mitsui PTA Indonesia	Merak	400,000
PT Polyprima Karyareksa	Serang	400,000
Total production capacity		2,025,000

To date, ethylene glycol production in Indonesia has only been produced by one company, namely PT. Polychem Indonesia Tbk., which produces 233,000 tons per year (PT. Polychem Indonesia Tbk., 2020)

1.3.3. Capacity of existing PET plant

The need for polyester derivative material in Indonesia is demanding. Therefore, there is a large domestic market potential for Polyethylene Terephthalate (PET). To establish a factory, the production capacity must be above or the same as the current minimum active factory. The current minimum capacity of the terephthalic acid plant is 12,500 tons/year. The data on PET production in Indonesia and internationally is the following.

Table 1.4 Production of PET in Indonesia (Anton et. al., 2018)

Company Name	Production Capacity (ton/year)
PT. Gajah Tunggal Petrochemical	61,760
PT. Teijin Indonesia Fiber Corporation	56,250
PT. Panasia Indosyntec	50,400
PT. Sulindafin	33,840
PT. Indorama Synthetics	64,800
PT. Indonesia Toray Synthetics	19,000
PT. Polysindo Eka Perkasa	64,800
PT. Texmaco Taman Synthetics	22,600
PT. Polyfin Canggih	39,600
PT. Vastex Prima Industries	12,500
PT. Sunkyong Keris	67,200
PT. KOHAP Indonesia	49,000
PT. Central Filament	38,000
PT. Polyfibre Industry	29,600
<u>Total Production</u>	<u>609,350</u>

The Polyethylene Terephthalate (PET) factory is planned to start operating in 2030, after 6 years of preparation, with a production capacity of 60,000 tons/year, or 8% of the PET opportunity in Indonesia. This decision is considering the following reasons:

1. The capacity considers the upper PET production capacity which is 67,200 tons/year.
2. The availability of raw materials in Indonesia, where the stoichiometry of the overall process is:



The ratio of EG:PTA to produce PET is 2:1, where EG acts as a limiting reagent of the process. Thus, to produce 60,000 tons/year PET requires around 120,000 tons/year of EG, where the domestic EG availability is 233,000 tons/year.

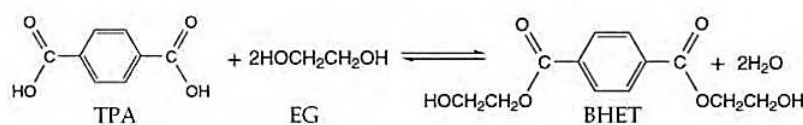
3. A 60,000 tons/year capacity is ideal for the PET plant because it matches the nearby supply of raw materials, reducing transportation costs and ensuring a steady supply. This size also helps avoid overproduction, keeping the plant efficient and cost-effective.
4. This capacity is determined to fulfil the PET domestic needs, which are predicted to be 500,000 tons/year in 2030 (Alba Blue Loan for Recycling Project, n.d.)

1.4 Literature review

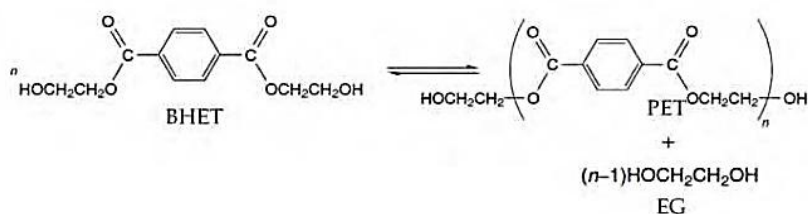
1.4.1 Direct Esterification

This method involves the direct reaction of terephthalic acid (PTA) and ethylene glycol (EG) as its raw material to form PET. It's one of the most common methods used in industrial production. This method is commonly used because of its simplicity and the availability of TPA and EG. The first reaction is the esterification of PTA and EG to produce BHET and water.

The esterification operating condition is 240 to 260°C and pressure 1 atm. The BHET follows a pre-polymerization process to obtain a degree of polymerization (DP) up to 30 at 250 to 280°C at 1 atm. It is then followed by a polycondensation process to increase DP to 100 at 290°C and 1 atm. The PET with a DP of 100 resulted from 99% conversion (Febriyanti, 2018; EP 2 003 159 B1).



(a)



(b)

Figure 1.4 PET synthesis reaction (a) esterification of TPA with EG and (b) polymerization

1.4.2 Transesterification

The trans-esterification reaction involves mixing dimethyl terephthalate (DMT) with ethylene glycol (EG) at temperatures between 150°C and 250°C and a pressure of 1 atm. This method is preferred because it allows for easier purification. The result of this reaction is bis(hydroxyethyl) terephthalate (BHET) and methanol. Followed by a polycondensation reaction at 205 to 305°C and 0.01-53 mbar with a

residence time of 1-4 hours to produce PET (US5898059A). The produced PET has a conversion of 95% (Febriyanti, 2018).

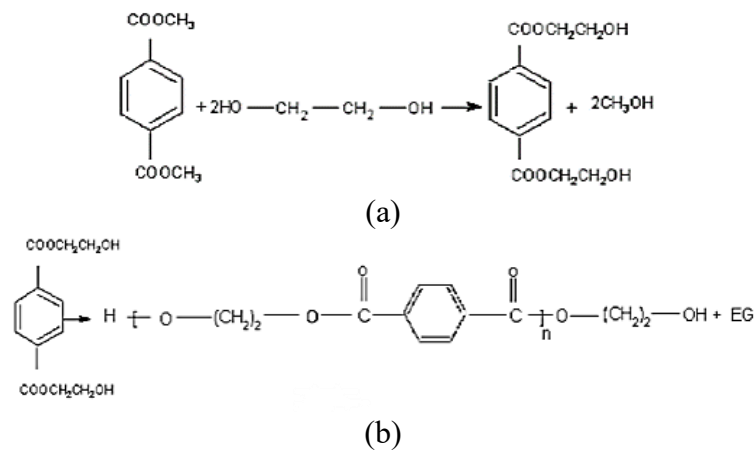


Figure 1.5 PET synthesis reaction (a) trans-esterification of DMT with EG and (b) polycondensation reaction (Firas and Dumitru, 2005).

Therefore, the comparison of esterification and transesterification are as follows:

Table 1.5 Comparison of PET Manufacturing Processes

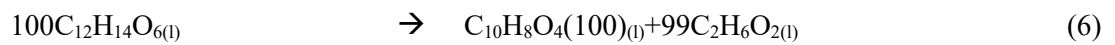
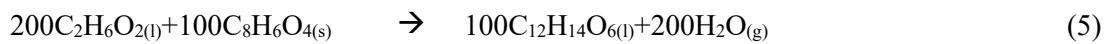
No.	Parameter	PET manufacturing process	
		Esterification of EG and PTA	Trans-esterification of DMT and EG
1	Raw material phase	Solid liquid	Solid liquid
2	Temperature, °C	250 to 270	150 to 305
3	Pressure, atm	1	0.05-1
4	Conversion	99%	95%
5	Byproducts	Water and ethylene glycol	Methanol

Based on the explanation of the two types of processes above, in designing PET manufacturing, the direct esterification process was chosen, and several considerations include the following:

1. The details provided in this Europe patent offer a more comprehensive explanation of the polyethylene terephthalate production process. They include specific data on operating conditions such as pressure in the evaporator, temperature ranges for both the reactor and evaporator, and pH levels during the reaction.
2. Direct esterification is preferred for PET production in Indonesia due to the local availability of purified terephthalic acid (PTA). This simplifies the process, lowers costs, and supports local industry, making it a more efficient and sustainable option.
3. The resulting conversion of direct esterification is larger, namely 99% compared to the trans-esterification process, namely 95% conversion.

1.5 Overview of Thermodynamics and Kinetics

The basic reaction of PET formation is the esterification reaction followed with polycondensation reaction with a Sb, Zn, and P compounds of catalyst. The reactions that occur are:



The first reaction is the esterification reaction between PTA and EG at a temperature between 240°C to 260°C which produces bis(hydroxyethyl) terephthalate (BHET). The following stage is the polycondensation of BHET to increase the DP to 100 at an operating condition of 280-290°C to produce PET (Elamri et.al, 2017)

1.5.1 Thermodynamics Review

The ΔH_f and ΔG° data for each component at a temperature of 240°C (513 K) for esterification and 270°C (543 K) for polycondensation are presented in the following table:

Table 1.6 Thermodynamic Properties of PET, Water, EG, BHET, and PTA

Compound	ΔH_f (kJ/mol)
$C_{10}H_8O_4$ (PET)	-38,500,000
H_2O (Water)	-269.65
$C_2H_6O_2$ (EG)	-400,000
$C_{12}H_{14}O_6$ (BHET)	-755,000
$C_8H_6O_4$ (PTA)	-530,000

(Ali et al., 2022; Yaws, 1999)

$$\Delta H_{f, \text{esterification}} = \sum \Delta H_{f, \text{esterification}} (\text{products}) - \sum \Delta H_{f, \text{esterification}} (\text{reactants}) \quad (7)$$

$$\Delta H_{f, 298} = ((-530,000) + 2(-400,000)) \text{ kJ/mol} - (2(-269.65) + (-755,000)) \text{ kJ/mol}$$

$$\Delta H_{f, 298} = 574,460.7 \text{ kJ/mol}$$

The value of $\Delta H_{f, \text{esterification}}$ is positive, thus the esterification reaction is an endothermic reaction.

$$\Delta H_{f, \text{polycondensation}} = \sum \Delta H_{f, \text{polycondensation}} (\text{products}) - \sum \Delta H_{f, \text{polycondensation}} (\text{reactants})$$

$$\Delta H_{f, \text{polycondensation}} = (100(-755,000)) \text{ kJ/mol} - ((-38,500,000) + 99(-400,000)) \text{ kJ/mol}$$

$$\Delta H_{f, 298} = -3,590,000 \text{ kJ/mol}$$

The value of $\Delta H_{f, \text{polycondensation}}$ is negative, thus the polycondensation reaction is an exothermic reaction.

The equilibrium constant of esterification and polycondensation is 1.25 and 0.5. Showing a reaction towards the product for the esterification. Polycondensation reaction have a possibility to be irreversible, however, the reaction can be move towards the products by decreasing the vapor flow rate or the ethylene glycol byproducts produced during the process (Kim, Kim, & Yeo, 2001)

1.5.2 Kinetics Potential Review

The primary input parameter in detailed reaction mechanisms is referred to as the reaction rate constant, representing the speed at which a chemical reaction occurs (Wang et.al., 2019). The temperature dependence of the kinetics of chemical reactions of simple chemicals is described very accurately by the Arrhenius equation. According to the Arrhenius equation, very small but non-zero reaction rates are observed at very low temperatures. The Arrhenius equation:

$$k = A. \exp \left(\frac{-E}{RT} \right) \quad (8)$$

(Kohout, 2021)

Where A is the pre-exponential factor and E is the activation energy of the chemical reaction. The chemical reaction in PET production consists of esterification and polycondensation reaction. Whereas the pre-exponential factor is 1.64×10^7 L.mol/min for esterification and the activation energy is 93,240 J/mol (Liu et.al., 2018). Therefore, the rate constant of esterification:

$$k_{esterification} = 1.64 \times 10^7 \text{ L.mol/min} \times \exp \left(\frac{-93,240 \text{ J/mol}}{(8.314 \frac{\text{J}}{\text{K} \cdot \text{mol}})(533 \text{ K})} \right)$$

$$k_{esterification} = 0.0119 \text{ L.mol/min}$$

Based on Zein (2010), the rate of polycondensation reaction is as bellow:

$$k_{polycondensation} = 6.0098 \times 10^{13} \cdot \exp - \left(\frac{16777}{T} \right) \text{ kg/gmole.min} \quad (9)$$

$$k_{polycondensation} = 2.29 \text{ kg/gmole.min or } 6.7 \text{ L/mol.min}$$

The rate constant of esterification and polycondensation process calculated shown a possibility of the completion of the reactions at the 533K.

The chemical reaction rate (r) is the speed at which a chemical reaction takes place, influenced by factors like the concentration of the reactants. It can be described by the rate at which products are formed, or reactants are consumed.

$$r = k[A]^a[B]^b \quad (10)$$

Where k is the reaction rate constant of each reaction which are dependent on temperature. The term [A] and [B] represents the concentrations of reactants A and B. The exponents a and b are the reaction order of each reactant showing the effect of the reaction rate in their concentrations (Henderson & Rettner, 2003)

The rate of reaction for esterification is:

$$r = k[\text{PTA}][\text{EG}] \quad (11)$$

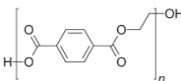
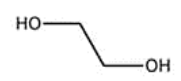
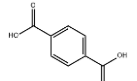
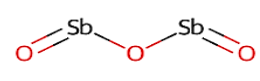
The rate of reaction for polymerization is:

$$r = k[\text{BHET}]^2 \quad (12)$$

CHAPTER II PRODUCT DESIGN

2.1 Product and Material Specification

Table 2.1 Product and Material Specification

	Product	Material		
Name:	Polyethylene Terephthalate	Ethylene Glycol	Purified Terephthalic Acid	Antimony Trioxide
Chemical Structure				
Chemical Formula	$(C_{10}H_8O_4)_n$	$C_6H_4(COOH)_2$	$C_8H_6O_4$	Sb_2O_3
Storage Temperature (°C)	30	30	30	15-30
Density at 25°C (g/mL)	1.68	1.113	1.58	5.3
Melting Point (°C)	240-265	-13	214.32	656
Boiling Point (°C)	> 350	195-198	>300	1,425
Solubility in Water:	Insoluble	Insoluble	Slight (0.017 g/L at 25°C)	Slight (0.00017g/L at 25°C)
Form	Pellets	Viscous liquid	Crystalline Powder	Powder
Purity	99.9% (2% as impurities, or residual by-products)	≥ 99.5 %	99.9%	≥ 99.9%

(“Ethylene Glycol | 107-21-1,” 2024, (“Terephthalic Acid” | ,100-21-0, 2016, Curbell, 2023; o poliester do Brasil, 2020; Polisan Hellas, 2017; Mwangi & Mokoena, 2019, Parchem - fine & specialty chemicals, 2014)

2.2 Quality Control

The PET production of this factory includes raw materials, products, catalysts, and process quality control.

2.2.1 Raw Material Quality Control

Effective quality control of purified terephthalic acid (PTA) and ethylene glycol (EG) is essential in PET production, as the quality of these raw materials directly impacts the performance of the final product. Ensuring PTA purity is critical, as impurities can lead to defects and advanced techniques like gas chromatography and mass spectrometry are used to verify it meets production standards (Pta Production, 2024). Similarly, EG must be free from contaminants that could interfere with polymerization, with regular testing for water content and volatile organic compounds (Fan, 2024). In short, rigorous purity testing, process monitoring, and compliance with standards are vital to producing high-quality PET for packaging and textile applications.

2.2.2 Product Quality Control

PET product quality control is essential to ensure safety and reliability in items like toys, food, collars, leashes, and bedding for pets. In a highly competitive industry, brands that neglect quality control face risks such as costly recalls and damage to their reputation. PET product quality control involves various testing methods, including chemical analysis, physical and mechanical tests, and performance and durability

evaluations, each tailored to address specific hazards associated with different products. Compliance with regulatory standards and clear labeling further enhances product safety and consumer trust. Companies provide expert, unbiased evaluation, performing factory audits and product inspections to prevent potential quality issues. For importers and manufacturers, working with third-party quality control services helps meet high standards, reduce risks, and ensure that PET products remain safe, durable, and compliant with market regulations (Bhuiyan, 2023).

2.2.3 Catalyst Quality Control

Quality control techniques in catalyst processing employ advanced methods to ensure high efficiency and reduce waste. Spectroscopic techniques, such as Attenuated Total Reflection Fourier Transform Infrared Spectroscopy (ATR-FTIR), are used to analyze catalyst inks and thin films, quantifying ionomer content in fuel cell catalysts to maintain efficiency (Jacobsen, Porter, Ulsh, & Przemyslaw Rupnowski, 2022). Gas Chromatography-Mass Spectrometry (GC-MS), combined with Inductively Coupled Plasma Mass Spectrometry (ICP-MS), detects contaminants in petrochemical processes, ensuring catalyst purity (Geiger, McCurdy, & Kelinske, 2023). Additionally, Six Sigma methodology is applied in the oil and gas sector, with predictive models to estimate coke content on catalysts, reducing downtime and optimizing operational efficiency (Cheng, Azman, Hamdan, & Mansa, 2014).

2.2.4 Processes Quality Control

In PET production, maintaining high-quality standards calls for a detailed and multi-faceted quality control approach. This process starts with a thorough inspection of raw materials to ensure they meet the required specifications for purity and composition, as any deviations can directly impact the quality of the final product. Continuous monitoring throughout the production process is essential, allowing for precise control over critical parameters such as temperature, pressure, and reaction conditions, which are important in achieving consistent results. Quality control also involves rigorous physical and chemical testing at various stages to detect any potential issues early on and to validate the PET's structural and performance characteristics. The final product is carefully evaluated to ensure it meets industry standards and application requirements, guaranteeing it is safe and effective for use. This comprehensive approach ensures that every batch of PET produced is of high quality, reliable, and suitable for its intended applications (Kalevi et.al., 2012).

CHAPTER III

PROCESS DESIGN

3.1 Process and Material Flow Diagram

3.1.1 Qualitative Process Flow Diagram

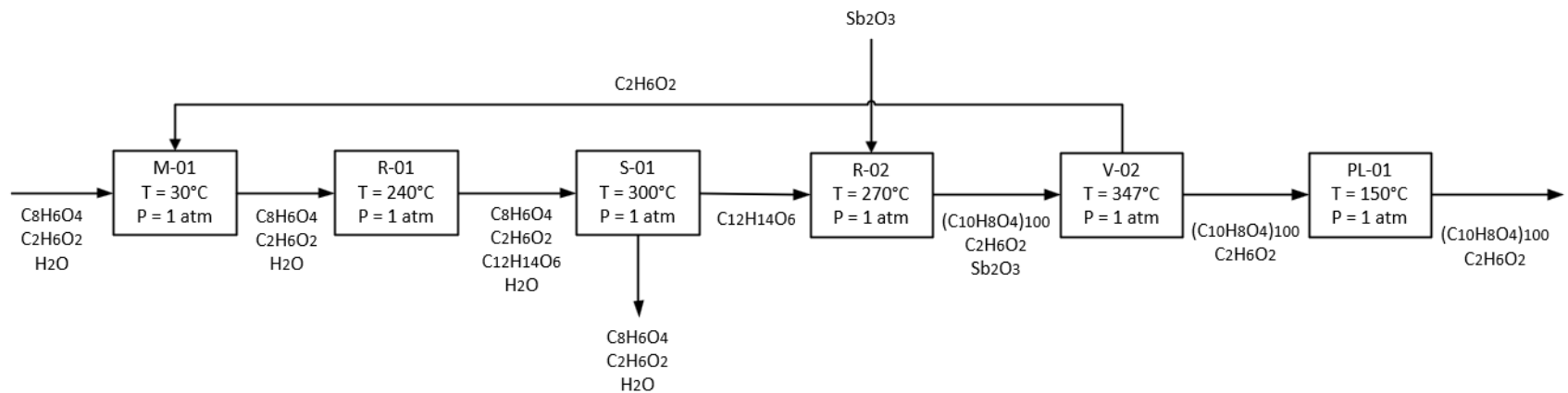
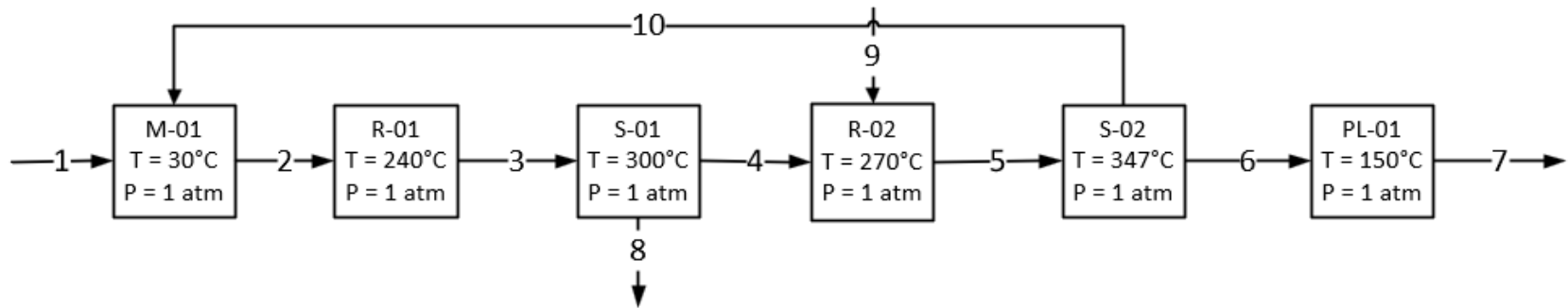


Figure 3.1 PET Production Qualitative Process Flow Diagram

3.1.2 Quantitative Process Flow Diagram



Component	Flow Rate (kg/h)									
	1	2	3	4	5	6	7	8	9	10
C ₈ H ₆ O ₄	6,556	6,556	656					656		
C ₂ H ₆ O ₂	2,716	4,899	490		2,182			490		2,182
C ₁₂ H ₁₄ O ₆		-	9,030	9,030						
H ₂ O	7	7	1,287					1,287		
Sb ₂ O ₃		-			0.1	0.1	0.1		0.1	
(C ₁₀ H ₈ O ₄) ₁₀₀		-			6,847	6,847	6,847			
Total	9,279	11,462	11,462	9,030	9,029	6,847	6,847	2,432	0.1	2,182

Figure 3.2 PET Production Quantitative Process Flow Diagram

3.2 Process Description

The PET production from PTA and EG in principle includes several stages, namely:

3.2.1 Raw material preparation stage

In the preliminary design of the PET production plant, terephthalic acid (PTA) in powder form is initially stored in the Storage Silo (S-01), where it is kept under optimal conditions to ensure quality and consistency. From the Silo, PTA is transported by screw conveyor (C-01) to the Mixing Tank (M-01), where it is introduced at ambient operating conditions. Simultaneously, ethylene glycol (EG) from the recycle and fresh feed (T-01) is pumped into M-01. The mixing process is carefully controlled to achieve the correct molar ratio of PTA to EG, which is maintained at 1:2. After thorough mixing, the combined stream is directed through a heat exchanger (HE-01), where it is heated to 270°C at ambient pressure. This precise thermal control is essential, as it allows the ethylene glycol to melt and integrate fully with the terephthalic acid forming a slurry. This preparation stage is critical, as the temperature and composition of the mixture directly influence the reaction kinetics and quality of the final PET product. By ensuring a fully homogeneous solution, the process conditions are optimized for the subsequent polymerization reaction, setting the foundation for efficient PET production with high-quality material properties.

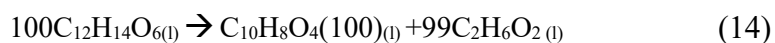
3.2.2 PET formation reaction stage

3.2.2.1 Esterification Process



The slurry mixture of terephthalic acid (PTA) and ethylene glycol (EG) enters the esterification continuous stirred tank reactor (R-01). The esterification reactor is operated under carefully controlled conditions at a temperature of 240°C and 1 atm pressure, which together enable a high conversion rate of 90%. In the Esterification reactor, PTA and EG undergo an esterification reaction, forming Bis(2-Hydroxyethyl) terephthalate (BHET) and water as intermediate products. The presence of water as a by-product requires removal to shift the reaction equilibrium towards BHET production. To separate unreacted raw materials from the desired intermediate, separator (S-01) is employed, operating at 487°C and 1 atm. This step selectively evaporates unreacted raw material and keeping BHET in its liquid form.

3.2.2.2 Polycondensation Process



The intermediate product, BHET, is then pumped into the polymerization continuous stirred tank reactor (R-02). Operating at a higher temperature of 270°C and pressure of 1 atm. Under these conditions, BHET is transformed into high-molecular-weight polyethylene terephthalate (PET) with a degree of polymerization (DP) reaching 100, achieving nearly complete conversion. The output is a

product stream containing PET100, and a by-product of ethylene glycol, which can be further recovered and recycled back into the process.

3.2.3 Product Treatment and Storage Stage

The outlet stream from the polymerization reactor contains PET with a degree of polymerization (DP) of 100, known as PET100, and EG as a by-product. The PET100 is separated from EG through separator (S-02) at 417°C and 1 atm which is critical for achieving a high-purity PET product. The evaporated EG from V-02 is condensed in a condenser (CD-01) and pumped into M-01 as a recycled stream.

The PET100 enters the final stage of solidification and pelletizing. The process uses pelletizer (PL-01), where the molten PET100 is carefully cooled and solidified into uniform pellets in 20 mm diameter and height. The pelletizer is controlled at 150°C. The beads are dried with the help of blower resulting in high-quality pellets suitable for commercial applications stored in Silo (S-03)

3.3 Equipment Specification

3.3.1 Reactor Specification

(i) Esterification Reactor (R-01)

General Specification:

Code	: R-01
Function	: Esterification reaction between PTA and EG, producing BHET and H ₂ O
Type	: Jacketed continuous stirred tank reactor
Operation mode	: Continuous
Quantity	: 1
Price	: Rp 813,599,480

Operating Condition:

Temperature	: 240°C
Pressure	: 1 atm
Process condition	: Endothermal

Construction and Material

Construction material	: Carbon Steel
Shell diameter (ID)	: 2.02 m
Shell thickness	: 0.27 in
Total height	: 2.37 m
Head type	: Torispherical

Insulator

Material : Stainless steel

Heat conductivity : 0.026 W/m.K

Insulator thickness : 0.05 m

Special specifications

Impeller type : Flat Blade Turbine (Semi Open)

Impeller size : Diameter: 27.67 in

Height: 5.51 in

Length: 27.57 in

Width: 6.89 in

Stirring speed : 1765.191 rpm

Power : 9 HP

Number of baffles : 1

Coolant type : Steam

Coolant requirements : 5328.04 kg/hour

Heat transfer mode : Jacket

U_D : 5.0 W/m²K

Heat transfer area : 0.71 m²

Jacket thickness : 0.75 m

(ii) Polycondensation Reactor (R-02)

General Specification:

Code	: R-02
Function	: Polymerization and condensation reaction of BHET with Sb_2O_3 catalysts
Type	: Jacketed continuous stirred tank reactor
Operation mode	: Continuous
Quantity	: 1
Price	: Rp 3,921,791,348

Operating Condition:

Temperature	: 270°C
Pressure	: 1 atm
Process condition	: Isothermal

Construction and Material

Construction material	: Carbon steel SA-182 F11
Shell diameter (ID)	: 3.2 m
Shell thickness	: 0.75 in
Total height	: 4.4 m
Head type	: Torispherical

Insulator

Material	: Stainless steel
----------	-------------------

Heat conductivity : 0.35 W/m.K

Insulator thickness : 0.03 m

Special specifications

Impeller type : Flat Blade Turbine (Semi Open)

Impeller size Diameter: 37.4 in

Length from base: 41.5 in

Width: 9.3 in

Height: 7.5 in

Stirring speed : 1804 rpm

Power : 553 HP

Number of baffles : 3

Coolant type : Water

Coolant requirements : 510 kg/hour

Heat transfer mode : Jacket

U_D : 7.2 W/m²K

Heat transfer area : 66 m²

Jacket thickness : 0.02 m

3.3.2 Separator and Supporting Operating Units Specification

(i) Separator (S-01)

Name and code	: Separator (S-01)
Function	: To separate vapor and liquid phase from HE-03
Type	: Vertical Separator
Material	: Carbon Steel 283 Grade A
Operating Condition	: 300°C and 1 atm
Specification	: Shell a. Height:35 ft b. Thickness:0.31 in c. Outside Diameter:31 in Head a. Height:13 in b. Thickness: 0.25 in
Amount	: 1

(ii) Separator (S-02)

Name and code	: Separator (S-02)
Function	: To separate vapor and liquid phase from HE-04
Type	: Vertical Separator
Material	: Carbon Steel 283 Grade A
Operating Condition	: 347°C and 1 atm
Specification	: Shell a. Height: 24 ft b. Thickness: 0.31 in c. Outside Diameter: 13 in Head c. Height: 13 in d. Thickness: 0.25 in
Amount	: 1

(iii) Mixing Tank (M-01)

Function	: Mixing EG and PTA
Operating Conditions	: Temperature: 30 °C Pressure: 1 atm
Type	: Cylindrical tank with torispherical head
Impeller Type	: Propeller
Specifications	: Volume: 0.8 m ³ Height: 2.4 m Diameter: 0.9 m
Materials	: Carbon steel SA-182 F11
Shell thickness	: 5/8 in
Head thickness	: 3/4 in
Quantity	: 1
Power	: 0.3 HP
Price	: Rp34,137,457

(iv) Pelletizer (PL-01)

Function	: To solidify and cut PET100 into pellets
Type	: Underwater pelletizer
Capacity	: 6847 kg/h
Beads	Diameter: 20 mm Height: 20 mm
Die specification	Temperature: 150°C Die diameter: 21mm

	Residence time: 1 s
	Number of holes: 554
Water bath specification	T inlet: 30°C
	T outlet: 40°C
	Water flowrate: 273 kg/h
	Pump power: 0.05 HP
Blower specification	Air rate: 18027 ft ³ /min
	Pressure: 14.7 psia
	Power: 4 HP
Dryer chamber	Height: 8 ft
	Diameter: 10 ft
	Thickness: 3/16 in
Knives design	Radius: 0.4 m
	Rate: 11 rpm
Price	: Rp1,887,600,547

3.3.3 Storage Material Specification

(i) Storage Silo

Table 3.1 Silo Specification

Code	SL-01	SL-02	SL-03
Function	Storing raw materials of Pure Terephthalic Acid for 1 week as much as 4,405,512 kg/7 days	Storing Catalyst Alumunium Trioxide 1 week as much as 60.6784889 kg/7 days	Storing products of Polyethylene Terephthalate for 1 week as much as 4,601,262 kg/7 days
Pressure (atm)	1	1	1
Temperature (°C)	30	30	30
Type	Vertical cylinder with conical bottom and flat head	Vertical cylinder with conical bottom and flat head	Vertical cylinder with conical bottom and flat head
Volume (m ³)	3,534	0.0140	790
Height (m)	8	0.195	5.6
Diameter (m)	6	0.249	4
Material	Carbon Steel	Carbon Steel	Carbon Steel
Shell thickness (in)	1/4	1/4	3/16
Head thickness (in)	3/16	3/16	3/16
Quantity	1	1	1
Price (Rp)	95,966,415	12,148,918	59,519,660
Total (Rp)	95,966,415	12,148,918	59,519,660

(ii) EG Storage Tank (T-01)

Function	: Storing raw materials of Ethylene Glycol
Storage Duration	: 7 days
Phase	: Liquid
Number of Tanks	: 1
Type of Tanks	: A vertical cylindrical tank with a flat bottom and a conical top.
Operating Conditions	: Temperature: 30 °C Pressure: 1 atm
Specifications	Construction material: Carbon Steel SA-283 Grade C Tank volume: 600 m ³ Diameter: 9.1 m Height: 9.1 m Number of course: 6 Shell thickness: 0.5 in
Head & Bottom	Head type: Torispherical Head thickness: 0.28 in Bottom type: Flat Bottom thickness: 0.5 in
Price	: Rp1,423,732,753

3.3.4 Material Transportation Specification

(i) Screw Conveyor (C-01)

Table 3.2 Conveyor Specification

Code	C-01	C-02	C-03	C-04
Function	Distribute the PTA into mixer	Distribute the Antimony Trioxide into reactor (R-02)	Transporting PET100 into storage silo (S-03)	Transporting PET100 into packaging equipment (PK-01)
Material transported	Pure Terephthalic Acid	Antimony Trioxide	Polyethylene Terephthalate	Polyethylene Terephthalate
Pressure (atm)	1	1	1	1
Temperature (°C)	30	30	30	30
Material form	Powder	Powder	Pellet	Pellet
Conveyor type	Horizontal Screw Conveyor	Horizontal Screw Conveyor	Horizontal Screw Conveyor	Horizontal Screw Conveyor
Capacity (kg/h)	13,754.14	10,835.44	11,135.34	11,135.34
Speed (m/min)	35.908	35.908	35.998	35.998
Motor power (Watt)	947.038	40.19	410.13	410.13
Height (m)	4.572	3.048	3.048	3.048
Driver pulley diameter (m)	0.304	0.226	0.228	0.228
Construction material	Carbon steel	Carbon Steel	Carbon Steel	Carbon Steel
Price (Rp)	18,052,690	18,052,690	18,650,188	18,650,188

(ii) Pump (P-01)

Table 3.3 Process Pump Specification

Code	P-01	P-02	P-03	P-04
Function	To pump Ethylene Glycol from Tank (T-01) to Mixer (M-01)	To flow EG, PTA and H ₂ O from M-01 to HE-01	To flow EG, PTA and H ₂ O from HE-01 to HE-02	To flow EG, PTA and H ₂ O from HE-02 to R-01
Material pumped	Ethylene Glycol	EG, PTA, and H ₂ O	EG, PTA, and H ₂ O	: EG, PTA, and H ₂ O
Viscosity (cP)	14.4	10.6	1.2	0.5
Capacity (m ³ /h)	5.3	8.9	9.5 m ³ /h	10.3
Pump head (m)	14	18.5	13.6	12.6
Fluid temperature (°C)	30	30	135	240
Installation	Horizontal	Horizontal	Horizontal	Horizontal
Submergibility	Dry	Immersed	Immersed	Immersed
Pump type	Centrifugal single stage	Multistage centrifugal pump with mixed flow impellers	Single stage centrifugal pump with mixed flow impellers	Single stage centrifugal pump with mixed flow impellers
Motor Power (Watt)	1491.4	5592.75	5592.75	3728.5
Construction material	Carbon steel	Carbon Steel	Carbon Steel	Carbon Steel
Price (Rp)	96,388,113	96,388,113	96,388,113	96,388,113

Table 3.3 Process Pump Specification (Continued)

Code	P-05	P-06	P-07	P-08
Function	To flow PTA, EG, H ₂ O, and BHET from R-01 to V-01	To flow BHET from CL-01 to R-02	To flow PET and EG from R-02 to V-02	To flow PET from D-02 to CL-03
Material pumped	PTA, EG, H ₂ O, and BHET	BHET	PET and EG	PET
Viscosity (cP)	2	3	2 cP	5.1
Capacity (m ³ /h)	11.3	2.1	3.4	2.8
Pump head (m)	8.5	1.3	1.3	1.3
Fluid temperature (°C)	240	270	271	417
Installation	Horizontal	Horizontal	Horizontal	Horizontal
Submergibility	Immersed	Dry	Immersed	Immersed
Pump type	Single stage centrifugal pump with mixed flow impellers	Single stage centrifugal pump with axial flow impellers	Single stage centrifugal pump with axial flow impellers	Single stage centrifugal pump with axial flow impellers
Motor Power (Watt)	1491.4	186.5	124.3	124.3
Construction material	Carbon steel	Carbon Steel	Carbon Steel	Carbon steel
Price (Rp)	96,388,113	96,388,113	96,388,113	96,388,113

Table 3.3 Process Pump Specification (Continued)

Code	P-09	P-10	P-11
Function	To flow PET from CL-03 to CL-04	To flow PET from CL-04 to PL-01	To pump Ethylene Glycol from CD-01 to M-01
Material pumped	PET	PET	EG
Viscosity (cP)	7.4	10	14.5
Capacity (m ³ /h)	2.6	2.4 m ³ /h	2.9 m ³ /h
Pump head (m)	1.3	1.3 m	14 m
Fluid temperature (°C)	283	150°C	30°C
Installation	Horizontal	Horizontal	Horizontal
Submergibility	Immersed	Immersed	Dry
Pump type	Single stage centrifugal pump with axial flow impellers	Single stage centrifugal pump with axial flow impellers	Single stage centrifugal pump with mixed flow impellers
Motor Power (Watt)	186.4 Watt	186.4 Watt	357.1 Watt
Construction material	Carbon steel	Carbon steel	Carbon steel
Price (Rp)	96,388,113	96,388,113	96,388,113

(iii) Blower (B-01)

Function	: Inhales EG and H ₂ O vapor to be fed to CD-01 Through CL- 05
Materials compressed	: EG
Suction pressure	: 0.2429 bar
Discharge pressure	: 0.02 bar
Suction temperature	: 30°C
Capacity	: 2.182 m ³ /h
Site elevation	: 3.5 m
Compressor type	: Backward curve blade centrifugal blower
Motor power	: 757.7 Watt
Material Construction	: Carbon steel
Price	: Rp174,703,455

(iv) Blower (B-02)

Function	: Inhales EG and H ₂ O vapor to be fed to CD-01
Material compressed	: EG
Suction pressure	: 0.2429 bar
Discharge pressure	: 0.02 bar
Suction temperature	: 30°C
Capacity	: 2.182 m ³ /h

Site Elevation	: 3.5 m
Blower type	: Backward curve blade centrifugal blower
Motor Power	: 757.7 Watt
Material construction	: Carbon steel
Price	: Rp174,703,455

(v) Expander (EX-01)

Function	: To decrease pressure of stream
Material transported	: PTA, EH, H ₂ O and BHET
Suction Pressure	: 9 bar
Discharge Pressure	: 1 bar
Temperature	: 300°C
Capacity	: 8.3 m ³ /jam
Material	: Carbon Steel
Stage	: Two stages
Minimum & Actual RPM	: 233 & 485
Motor Power	: 4647.3 Watt
Price	: Rp 283,821,050

(vi) Expander (EX-02)

Function	: To decrease pressure of stream
Material transported	: PET and EG
Suction Pressure	: 13 bar
Discharge Pressure	: 1 bar
Temperature	: 327°C
Capacity	: 16 m ³ /jam
Material	: Carbon Steel
Stage	: Two stages
Minimum & Actual RPM	: 919 & 950
Motor Power	: 15,271 Watt
Price	: Rp 324,363,300

3.3.5 Heat Exchanger Specification

Table 3.4 Heater Specification

Code	HE-01					Code	HE-02				
Function	Heating PTA and EG from M-01 to HE-02					Function	Heating PTA and EG from HE-01 to R-01				
Type	Double Pipe Heat Exchanger					Type	Double Pipe Heat Exchanger				
Price (Rp)	8,032,343					Price	20,080,857				
Operating Condition											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	Steam		Fluid	PTA and EG		Fluid	Steam		Fluid	PTA and EG	
Fluid Type	Hot		Fluid Type	Cold		Fluid Type	Hot		Fluid Type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate (kg/h)	-	-	Liquid flowrate (kg/h)	11,462	11,462	Liquid flowrate (kg/h)			Liquid flowrate (kg/h)	11,462	11,462
Vapor flowrate (kg/h)	794	794	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	794	794	Vapor flowrate (kg/h)		
Temperature (°C)	300	150	Temperature (°C)	30	135	Temperature (°C)	300	150	Temperature (°C)	135	240
Pressure (atm)	1	1	Pressure (atm)	1	1	Pressure (atm)	1	1	Pressure (atm)	1	1
Mechanical Design											
Length (ft)	15		Length (ft)	15		Length (ft)	16		Length (ft)	16	
Hairpin	1		Hairpin	1		Hairpin	1		Hairpin	1	
ID (in)	4		ID (in)	3		ID (in)	6.1		ID (in)	4	
			OD (in)	3.5					OD (in)	4.5	
			A (in ²)	7.38					A (in ²)	12.7	
			BWG	8					BWG	3	
ΔP _{cal} /ΔP _{allow}	0.001		ΔP _{cal} /ΔP _{allow}	0.001		ΔP _{cal} /ΔP _{allow}	0.0006		ΔP _{cal} /ΔP _{allow}	0.0005	
Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1	
Code	HE-03					Code	HE-04				
Function	Heating stream before S-01					Function	Heating steam before S-02				
Type	Double Pipe Heat Exchanger					Type	Double Pipe Heat Exchanger				
Price (Rp)	1,075,571,505					Price	1,819,196,586				
Operating Condition											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	Steam		Fluid	PTA, EG, and H ₂ O		Fluid	Steam		Fluid	PET, EG, and H ₂ O	
Fluid Type	Hot		Fluid Type	Cold		Fluid Type	Hot		Fluid Type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate (kg/h)	-	-	Liquid flowrate (kg/h)	11,461	11,461	Liquid flowrate (kg/h)	-	-	Liquid flowrate (kg/h)	9,031	9,031
Vapor flowrate (kg/h)	400	400	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	5,616	5,616	Vapor flowrate (kg/h)	-	-
Temperature (°C)	527	300	Temperature (°C)	240	300	Temperature (°C)	527	300	Temperature (°C)	271	327
Pressure (atm)	9	9	Pressure (atm)	9	9	Pressure (atm)	13	13	Pressure (atm)	13	13
Mechanical Design											
Length (ft)	7.5		Length (ft)	5.8		Length (ft)	10		Length (ft)	7.5	
Hairpin	1		Hairpin	1		Hairpin	1		Hairpin	1	
ID (in)	4.026		ID (in)	3.068		ID (in)	6.065		ID (in)	4.5	
			OD (in)	3.5					OD (in)	4.926	
			A (in ²)	7.38					A (in ²)	12.7	
			BWG	5					BWG	4	
ΔP _{cal} /ΔP _{allow}	0.001		ΔP _{cal} /ΔP _{allow}	0.4		ΔP _{cal} /ΔP _{allow}	0.4		ΔP _{cal} /ΔP _{allow}	0.09	
Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1		Rd _{cal} / Rd _{min}	1	

Table 3.5 Cooler Specification

Code	CL-01					Code	CL-02				
Function	Cooling BHET from S-01					Function	Cooling PET from S-02 to CL-03				
Type	Double Pipe Heat Exchanger					Type	Double Pipe Heat Exchanger				
Price (Rp)	481,940,565					Price	301,212,853				
Operating Condition											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	BHET		Fluid	Water		Fluid	Steam		Fluid	PTA and EG	
Fluid Type	Hot		Fluid Type	Cold		Fluid Type	Hot		Fluid Type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate (kg/h)	9,029	9,029	Liquid flowrate (kg/h)	84,649	84,649	Liquid flowrate (kg/h)	6,847	6,847	Liquid flowrate (kg/h)	454	454
Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)		
Temperature (°C)	300	270	Temperature (°C)	30	95	Temperature (°C)	417	238	Temperature (°C)	30	95
Pressure (atm)	1	1	Pressure (atm)	1	1	Pressure (atm)	1	1	Pressure (atm)	1	1
Mechanical Design											
Length (ft)	9		Length (ft)	5		Length (ft)	16		Length (ft)	16	
Hairpin	1		Hairpin	1		Hairpin	3		Hairpin	3	
ID (in)	2		ID (in)	1.38		ID (in)	2.067		ID (in)	1.66	
			OD (in)	1.66					OD (in)	1.38	
			A (in ²)	1.5					A (in ²)	1.5	
			BWG	9					BWG	9	
$\Delta P_{cal}/\Delta P_{allow}$	0.16		$\Delta P_{cal}/\Delta P_{allow}$	0.78		$\Delta P_{cal}/\Delta P_{allow}$	0.002		$\Delta P_{cal}/\Delta P_{allow}$	0.0000007	
Rd_{cal} / Rd_{min}	0.03		Rd_{cal} / Rd_{min}	0.03		Rd_{cal} / Rd_{min}	0.4		Rd_{cal} / Rd_{min}	0.4	
Code	CL-03					Code	CL-04				
Function	Cooling PET to PL-01					Function	Cooling EG from D-02 to CD-01				
Type	Double Pipe Heat Exchanger					Type	Double Pipe Heat Exchanger				
Price (Rp)	301,212,8531,075,571,505					Price	417,681,823				
Operating Condition											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	PET		Fluid	Water		Fluid	Water		Fluid	EG	
Fluid Type	Hot		Fluid Type	Cold		Fluid Type	Hot		Fluid Type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate (kg/h)	6,847	6,847	Liquid flowrate (kg/h)	11,461	11,461	Liquid flowrate (kg/h)	2,183	2,183-	Liquid flowrate (kg/h)	-	-
Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	-	-	Vapor flowrate (kg/h)	2,183	2,183
Temperature (°C)	378	270	Temperature (°C)	240	300	Temperature (°C)	30	95	Temperature (°C)	471	200
Pressure (atm)	1	1	Pressure (atm)	9	9	Pressure (atm)	1	1	Pressure (atm)	1	1
Mechanical Design											
Length (ft)	12		Length (ft)	12		Length (ft)	16		Length (ft)	16	
Hairpin	3		Hairpin	3		Passes	2		Passes	2	
ID (in)	2.38		ID (in)	1.38		ID (in)	73		OD (in)	0.5	
			OD (in)	1.66		Baffle Spaces (in)	7.2		Number of pipes	5,436	
			A (in ²)	1.5					A (in ²)	1,113	
			BWG	9					Pitch	0.94	
$\Delta P_{cal}/\Delta P_{allow}$	0.0002		$\Delta P_{cal}/\Delta P_{allow}$	0.0000007		$\Delta P_{cal}/\Delta P_{allow}$	0.22		$\Delta P_{cal}/\Delta P_{allow}$	0.22	
Rd_{cal} / Rd_{min}	0.4		Rd_{cal} / Rd_{min}	0.4		Rd_{cal} / Rd_{min}	1.9		Rd_{cal} / Rd_{min}	1.9	

(i) Condenser (CD-01)

Function : To condense EG from CL-05 to M-01

Price : Rp4,303,327,629

Operating Condition				
Position	Shell		Tube	
Fluid	EG		Water	
Fluid type	Hot		Cold	
	In	Out	In	Out
Liquid flowrate	2,183 kg/h	2,183 kg/h	-	-
Vapor flowrate	-	-	2,183 kg/h	2,183 kg/hr
Temperature	543 K	373 K	298 K	318 K
Pressure	1 atm	1 atm	1 atm	1 atm

Mechanical Design			
Shell		Tube	
Length	3.048 ft	Length	10 ft
Passes	1	Passes	0.3750.
ID	5 in	OD	0.375 in
Baffle spaces	1 in	Number	10
		A	8971.2 in ²
		BWG	8
		Pitch	1 in
$\Delta P_{cal} / \Delta P_{allow}$	0.586	$\Delta P_{cal} / \Delta P_{allow}$	0.0996
Rd_{cal} / Rd_{min}	0.21	Rd_{cal} / Rd_{min}	0.21

3.4 Process and Material Flow

3.4.1 Mass Balance

3.4.1.1 Total Mass Balance

Component	Input (kg/h)			Output (kg/h)	
	1	2	25	21	10
PTA		6556			656
EG	2716				490
Sb ₂ O ₃			0.1	0.1	
PET100				6847	
H ₂ O	7				1288
Total	9279			9279	

3.4.1.2 Equipment Mass Balance

(i) Mixing Tank (M-01) Mass Balance

Component	Input (kg/h)			Output (kg/h)
	1	2	24	3
PTA		6556		6556
EG	2716		2182	4898
H ₂ O	7			7
Total	11462			11462

(ii) Esterification Reactor (R-01) Mass Balance

Component	Input (kg/h)	Output (kg/h)
	5	6
PTA	6556	656
EG	4898	490
H ₂ O	7	1287
BHET		9030
Total	11462	11462

(iii) Polycondensation Reactor (R-02) Mass Balance

Component	Input (kg/h)		Output (kg/h)
	12	25	13
BHET	9030		
PET100			6847
EG			2182
Sb ₂ O ₃		0.1	0.1
Total	9030		9030

(iv) Separator (S-01) Mass Balance

Component	Input (kg/h)	Output (kg/h)	
	9	11	10
PTA	656		656
EG	490		490
H ₂ O	1287		1287
BHET	9030	9030	
Total	11463	11463	

(v) Separator (S-02) Mass Balance

Component	Input (kg/h)	Output (kg/h)	
	16	17	22
PET100	6847	6847	
EG	2183		2183
Sb ₂ O ₃	0.1	0.1	
Total	9031.1	9031.1	

3.5 Heat Balance

3.5.1 Polycondensation Reactor (R-01)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PTA	2,969,515.5	296,951.6
EG	5,090,598.0	509,059.8
H ₂ O	35,898.5	6,465,323.8
BHET		4,207,379.2
Reaction	574,460.7	
Steam heat	2,808,241.7	
Total	11,478,714.4	11,478,714.4

3.5.2 Polymerization Reactor (R-02)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
BHET	4,800,553.3	
Antimony Trioxide	9.7	9.7
PET100		44,551.0
EG		1,016,494.2
Reaction	-3,590,000	
Cooling heat		149,508.2
Total	1,210,563	1,210,563

3.5.3 Double Pipe Heat Exchanger (HE-01)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PTA	39,659.3	872,504.8
EG	67,085.4	1,475,878.8
H ₂ O	149.92	3,298.15
Steam heat	2,244,787.1	
Total	2,351,681.8	2,351,681.8

3.5.4 Double Pipe Heat Exchanger (HE-02)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PTA	872,504.8	1,705,350.3
EG	1,475,878.8	2,884,672.2
H ₂ O	3,298.2	6,446.4
Steam heat	2,244,787.1	
Total	4,596,468.9	4,596,468.9

3.5.5 Double Pipe Heat Exchanger (HE-03)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PTA	143.9	246.3
EG	192.7	279.9
H ₂ O	1,180.7	1,978.6
BHET	5,457.3	11,264.1
Evaporation heat		684,579.3
Steam heat	691,372.8	
Total	698,348.1	698,348.1

3.5.6 Double Pipe Heat Exchanger (HE-04)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
EG	854	1961
PET	20	61
Evaporation heat		1,848,128
Steam heat	1,849,276	
Total	1,850,150	1,850,150

3.5.7 Double pipe Cooler (CL-01)

Component	Inlet	Output
	H (kJ/h)	H (kJ/h)
BHET	2,063,721.3	1.838.588.0
Cooling heat		225,133.2
Total	2,063,721.3	2,063,721.3

3.5.8 Double Pipe Cooler (CL-02)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PET	24,740.3	13,297.1
Sb ₂ O ₃	4,368.0	2,347.7
Cooling heat		15,811.2
Total	29,108.3	29,108.3

3.5.9 Double Pipe Cooler (CL-03)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PET	24,740.3	7,671.4
Sb ₂ O ₃	4,368.0	1,354.4
Cooling heat		17,068.9
Total	24,740.3	24,740.3

3.5.10 Shell and Tube Cooler (CL-04)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
EG	1,751,709.1	781,451.4
Cooling heat		970,257.8
Total	1,751,709.1	1,751,709.1

3.5.11 Condenser (CD-01)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
EG	2,239,033.1	623.9
Cooling heat		2,238,409.3
Total	2,239,033.1	2,239,033.1

3.5.12 Pelletizer (PL-01)

Component	Inlet	Outlet
	H (kJ/h)	H (kJ/h)
PET	11,679.5	254.8
Sb ₂ O ₃	1	0.12
Cooling heat		11,425.6
Total		

CHAPTER IV

FACTORY DESIGN

4.1 Plant Location

The selection and determination of a factory's location in factory planning will affect the progress and sustainability of an industry, as it involves production factors and the magnitude of profits generated, as well as future expansion. There are several factors that need to be considered in determining the right location for a factory because it will make a significant contribution both technically and economically. Based on certain considerations, the PET factory is planned to be established in the area Cilegon, Banten.

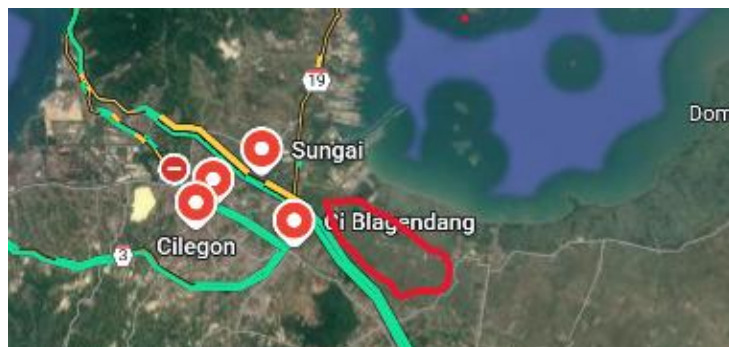


Figure 4.1 Plant Location PET

Selection of the factory location is based on several factors including

(i) Marketing

PET is a product that can be marketed directly to the public, in the form of pure PET or sold to other producers. The factory location should ideally be close to the marketing location. Here are the things to consider regarding marketing:

- Product marketing area
- The number of competitors present and their influence
- The ability of market absorption
- The marketing distance from the factory location
- marketing system used

(ii) Availability Raw Materials

Raw materials are the main capital for establishing a factory, with the factory location is quite close to the provincial capital, so it can be estimated that the available raw materials are quite abundant. A factory should be built in an area close to the source of raw materials to facilitate the procurement and transportation of raw materials. Here are the things to consider regarding the materials. is something to consider regarding the material.

- The distance of raw materials to the factory
- The capacity of the raw materials available at the source
- Handling of raw materials

(iii) Water Source

The chosen location is a vast area on the outskirts of the city, so there is still plenty of land available. In addition, there are also abundant water sources as well as transportation and electricity infrastructure. Water is a very important component for a chemical industry factory. The water needs are obtained from the water supply company, Cidanau River. Water is used as a cooling medium, boiler feed water, sanitation

water, and for other needs. The water needs in the factory can be obtained through two sources, namely:

- Direct sources, such as rivers or groundwater
- Water supply installation

Here are the things to consider in water supply:

- The capacity of the water source
- The quality of the water source
- The distance of the water source from the factory location

(iv) Source of Electricity

In the establishment of a factory, electricity and fuel are very important supporting factors. Here are the things that must be considered in the procurement of electricity and fuel for a factory:

- Possibilities and procurement of electricity and fuel at the factory location for now and in the future.
- Factory location for now and the future.
- Fuel prices that will be used.

(v) Land Needed and The Development of the land

In the construction of a factory, the topology of the land will determine land preparation costs. The type and condition of the land will determine the cost of building construction. The area that will be designated for construction the factory is in an area with extensive land so it can be used the expansion of the factory in the future.

(vi) Transportation

For transportation facilities such as material transport, repair needs, maintenance, and work safety, a road is made between the processing areas to facilitate vehicle entry and exit, so that in the event of a disaster, there will be no difficulty in handling it. Transportation issues need to be addressed to ensure the smooth supply of raw material, and the marketing of products can be guaranteed and with the lowest possible operating cost in a short time. Some things to consider are:

- Highway that can be traversed by cars and highway that can be traversed by cars and other land transportation. other land transportation.
- River or sea that can be navigated by boats and ships. by boats and ships.
- Sea ports and airports that are close to the location Seaports and airports near factory locations.

(vii) Employee Availability

Labor is the main capital for establishing a factory, with the factory location is quite close to the provincial capital, so it can be estimated that the available workforce is quite large. The need labour, both unskilled and skilled, greatly influences towards the performance and smooth operation of the company. The level of education of society and the workforce can support the establishment of factories. Here are the things to consider: are the things that need to be considered:

- The possibility of obtaining the desired workforce.

- Education or skills of the available workforce.
- The income of the workforce around the factory location.
- The income of the workforce around the factory location.
- The existence of labour unions or labour regulations. The existence of labour unions or labour regulations.
- The existence of labour unions or labour regulations.
- The presence of training centres or institutions for the workforce. The presence of locations or institutions for workforce training.

(viii) Environment and Society around the Plant

The process area is the area used to place tools related to the production process. Where this process area placed in an area separate from the other parts. Here are the things that placed in an area separate from other parts. Here are the things to consider regarding the environment and society:

- The presence or absence of home, school, and worship facilities.
- Availability of housing, school, and worship facilities.
- Availability of recreational and health facilities.
- The presence or absence of recreational and health facilities.

(ix) National Regulation (Regional or National Regulation)

Here are the things to consider regarding the law. law and government regulations:

- Provisions regarding industrial zones.

- Provisions regarding public roads for industry in factory development area
- Taxation and insurance.

(x) Waste of Production

The proper flow of raw materials and waste will provide great economic benefits, as well as supporting the smoothness and safety production. Waste from the factory must be monitored carefully, especially impact on the health of the community around the factory location. Here are the things to consider regarding factory waste:

- How to handle waste so that it does not cause pollution How to manage waste to prevent pollution environment.
- The cost required to address pollution issues against environment.

(xi) Control of Natural Disaster

Around the process area, attention must be paid to avoid stagnation in a place that can lead to avoid stagnation in a place that can result in accumulation of hazardous chemicals, which can endanger worker safety. Here are the things you need to pay attention to.in controlling hazards:

- The factory location must be far from residential areas.
- The factory location should be far from residential areas.
- The factory location is aimed to not be in a flood-prone area.
- The factory location must have supporting tools to overcoming hazards.

- The factory location must have supporting tools to overcoming hazards.

Here are the basic considerations in selecting the location:

a. Raw Material

The raw material supplier from Cilegon Banten, near by the Plant location

b. Marketing and Distribution

The distribution by using truck to all around Javanese island, and from port Ratu to distribute all around Indonesia

c. Transportation

Plant location is nearby main road in the Cilegon, and easy access to capital city Jakarta. The Cilegon Road have an easy access to another city in west java

d. Source of Electricity Plant

Electricity is a very important supporting factor. The need for electrical power for factory operations is obtained from the State Electricity Company (PLN) Cilegon. In addition to the electricity supply from PLN, a power generator is also provided. backup from diesel generators whose fuel is obtained from Pertamina.

e. Water Needed

Water is the main component inside of Plant Design, the water source from Cidanau river in Cilegon. Water is used for utility, process, domestic needed in the Factory.

f. Employee Availability

Labor is the main capital for establishing a factory. Factory location which is quite close to the capital of East Java Province makes it easy to obtain enough labor. And provide job opportunities wide-ranging employment and improve the welfare of the surrounding community.

g. Climate, Weather, and Nature Conditions

Climate, Weather, and Natural Conditions The weather and climate conditions around the factory are relatively stable, allowing for support the sustainably factory that can operate optimally. Conditions in the surrounding area where the factory is established has never experienced a disaster natural condition that mean the factory can operate smoothly.

4.2 Plant Layout

The factory layout is a plan for the very effective arrangement of physical facilities and labour to produce products. In determining the factory layout, the placement of production equipment must be considered so that the safety, security, and comfort of employees can be ensured. Besides the equipment listed in the flow sheet processes, several other physical buildings such as offices, warehouses, laboratories, workshops, and so on must be in the most efficient parts, especially in terms of goods traffic, control, security, and economy. Additionally, what must be considered in determining the factory

layout is the placement of production equipment in such a way that it provides comfort during the production process.

The factory layout includes planning the space requirements for all factory activities, including offices, warehouses, rooms, and all other facilities related to the process of producing products. The layout of a factory plays an important role in determining construction costs, production costs, efficiency, and workplace safety. From the perspective of the relationships between different elements, the factory layout must be designed in such a way that the use of the factory area is efficient, and the production and distribution processes can be ensured to run smoothly. Therefore, the factory layout must be carefully arranged to avoid difficulties in the future. Here are the factors that must be considered in the factory layout:

- The factory that was established is an addition to the factory that was already in operation or is a completely new factory.
- Land reserves for future factory expansion.
- Ensuring the smooth distribution of raw materials, products, and utilities (water, steam, electricity, fuel).
- Weather or environmental climate.
- Issues related to safety such as the possibility of fire, accidents, and so on.
- Plant site must comply with local regulations.
- Waste disposal
- Efficient use of workspace.

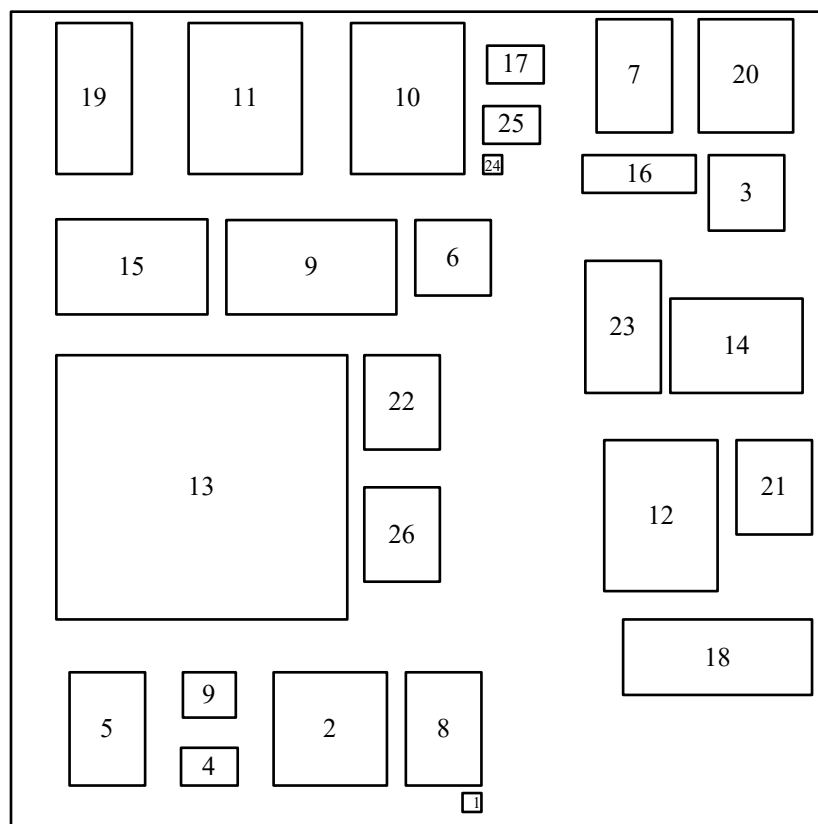
Plant layout is the overall arrangement of equipment and buildings, including the process area, storage area, and material handling area, so that the factory can operate effectively and efficiently. Here are the things to consider in the arrangement of equipment in the factory:

- The proper flow of raw materials and products will provide significant economic benefits, as well as support the smoothness and safety of production.
- The placement of pipes also needs to be considered, where above-ground pipes should be installed at a height of three meters or more, while surface piping should be arranged in such a way that it does not disrupt work traffic.
- The placement of pipes should also be considered, where above-ground pipes need to be installed at a height of three meters or more, while surface piping should be arranged in such a way that it does not interfere with work traffic. The placement of sufficient space between equipment to facilitate operation, inspection, maintenance, and to ensure the equipment functions according to its purpose and maintains continuity between tools.
- Safety against the possibility of fire, explosion, smoke, or toxic gas hazards must be thoroughly considered in determining the factory layout. For that reason, it must be done placement of safety equipment such as hydrants, sufficient water reservoirs, and blast barriers

PET company is established in the land 40,000 m². Here is the description of each land

Table 4.1 Detailed of Building and Land Area

No.	Location	Length (m)	Width (m)	Area (m ²)
1	Security post	5	5	25
2	Garden	30	30	900
3	Clinics	20	20	400
4	Fire and safety	10	15	150
5	Multipurpose hall	30	20	600
6	Mosque	20	20	400
7	Canteen	30	20	600
8	Training office	30	20	600
9	Main office	25	45	1125
10	Parking lot	40	30	1200
11	Truck parking lot	40	45	1800
12	Development area	40	30	1200
13	Process area	70	77	5390
14	Laboratory	25	35	875
15	Utility	25	40	1000
16	Canteen	10	30	300
17	Fire and safety	10	30	297
18	Warehouse	20	50	1000
19	Waste process area	40	20	800
20	Empty land	30	25	750
21	Storage	25	20	500
22	Control room	25	20	500
23	Maintenance workshop	35	20	700
24	Security post	5	5	25
25	Fire and safety	10	15	150
26	Engineering and production office	25	20	500
Total Building Area				21787
Total Land Area				22000



Description:

- | | |
|-----------------------|---------------------------------------|
| 1. Security Post | 14. Laboratory |
| 2. Garden | 15. Utility |
| 3. Clinics | 16. Canteen |
| 4. Fire and Safety | 17. Fire and Safety |
| 5. Multipurpose Hall | 18. Warehouse |
| 6. Mosque | 19. Waste Process Area |
| 7. Canteen | 20. Empty Land |
| 8. Training Office | 21. Storage |
| 9. Main Office | 22. Control Room |
| 10. Parking Lot | 23. Maintenance Workshop |
| 11. Truck Parking Lot | 24. Security Post |
| 12. Development Area | 25. Fire and Safety |
| 13. Process Area | 26. Engineering and Production Office |

1:2000

Figure 4.2 Plant Layout (1:2000)

4.3 Machines Layout

In the design of the process equipment layout in this PET plant has several things that need to be considered, namely:

a. Flow of Raw Materials and Products

Flow the right raw materials and products will provide great economic benefits, as well as supporting the smoothness and safety production. It is also important to consider the elevation of the pipes, where for pipes above the ground the ground surface needs to be installed at a height of three meters or more, while for the pipes on the ground, they are arranged in such a way that does not obstruct worker traffic

b. Airflow

Airflow in and around the process area needs to be monitored to ensure smooth process. There must be airflow and ventilation around the process area to prevent air stagnation in places where hazardous chemical accumulation could occur. The locations that need to be monitored are around the process flow that uses methanol, specifically around the Mixer, Reactor, and Distillation Tower. The smooth flow of air inside and around the process area needs to be monitored. This aims to avoid air stagnation in a certain area that can lead to the accumulation of hazardous chemicals, thereby posing a risk to workplace safety.

c. Lighting

The lighting throughout the factory must be adequate, and in places where processes are dangerous or highly risky, additional lighting must be provided.

d. Traffic Humans and Vehicles

In the design of process layout arrangements, it is necessary to pay attention so that workers can reach all process tools quickly and easily, allowing for immediate repairs in case of any disruptions to the process tools. In addition, if there is a malfunction in the process equipment, it can be repaired immediately. Additionally, the safety of workers while performing their duties needs to be prioritized. prioritized.

e. Considerations Economic Considerations

In placing process equipment in factories, efforts are made to reduce operational costs and ensure the smoothness and safety of factory production, thereby making it economically beneficial.

f. Maintenance

Maintenance is useful for maintaining the means or facilities of factory equipment through the maintenance and repair of tools so that production can run smoothly and productivity becomes high, thereby achieving the expected production targets and raw material specifications. Preventive maintenance is carried out daily to prevent equipment damage and maintain the cleanliness of the equipment

environment. Meanwhile, periodic maintenance is carried out on a scheduled basis according to the existing manual.

g. Distance Between Process Equipment

For process equipment that has high operating temperature and pressure, it is advisable to separate it from other process equipment. So that if an explosion or fire occurs in that equipment, it does not endanger other process equipment.

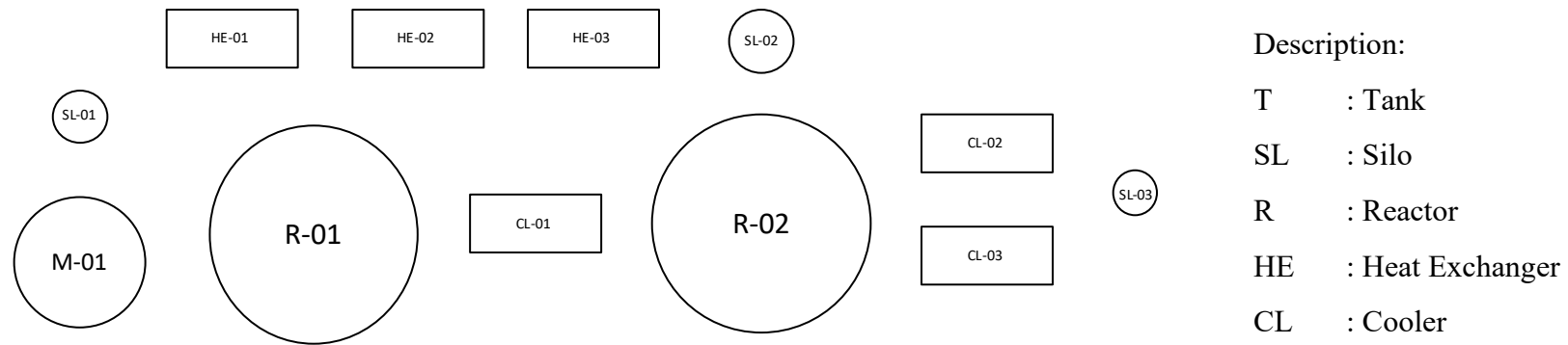


Figure 4.3 Layout of Equipment

4.4 Company Organisation

4.4.1 Type of Company Organisation

The Company will be established is planned to be in the form of limited Liability Company (LLC). Perseroan Terbatas (PT) is a form a company that obtains its capital from the sale of shares where each partner takes part with at least one share or more. In a Limited Liability Company (LLC), shareholders are only responsible for being responsible for fully paying the amount stated in each share.

For large-scale companies, they usually use the form of a Limited Liability Company (LLC/corporation). Limited Liability Company (LLC) is an association of shareholders created based on law and considered a legal entity. Several factors that become the reason for choosing a company in the form of a Limited Liability Company limited is as follows:

- a. The ease of obtaining capital by selling shares companies or originating from banks.
- b. From a legal standpoint, the company's assets are clearly separate from the personal wealth of the shareholders.
- c. The easiness of production can only be held by the leader the company because the responsibility of the shareholders is very limited.
- d. The owners and managers of the company are separate from each other, the owners the company is the shareholders and the company's management are the board of directors along with its staff who are

supervised by the board of commissioners so that the continuity of the company is more assured, because

not affected by the resignation of shareholders, directors along with its staff or company employees

e. The efficiency of management where shareholders can choose experts as the board of commissioners and directors main who is quite competent and experienced.

f. A broader field of business because a limited company can attract very large capital from the public so that with this capital, it can expand its business.

g. Can easily obtain credit from the bank with company guarantee.

h. The continuity of the company is more assured because the company does not dependent on one party because ownership can change.

Characteristics of a Limited Liability Company include, among others:

a. Established with a notarial deed based on the Commercial Code Commercial law.

b. The amount of capital is determined in the deed of establishment and consists of shares.

c. The owners of the company are the shareholders.

d. The factory is led by a director chosen by the shareholders.

- e. The management of personnel is fully entrusted to the Director with consideration of labour laws.

4.4.2 Structure Organisation

In running a company, what is needed is human resources and also a management system or organization that has a good division of tasks and authority. Structure the organization of a company can be adjusted to the form and the needs of each individual company. The formation of a structure a good organization can be achieved through good company management also good. The organizational structure helps the company to organize and divide sections, positions, tasks, roles, authority, and responsibilities of each part or division that is formed within the company. Sections or positions that will be formed in this company starting from the highest level where there are two good forms of organizational structure, namely the line and staff system. There are two types of groups of people—those who are influential in running the line and staff organization, which include the following:

- a. As lines or lines, that is, people who carry out the main tasks of the organization to achieve its goals.
- b. As staff, they are the people who perform their tasks with the expertise they possess, in this case, functioning to provide advice to operational units.

Shareholders, as the owners of the company, in the execution of daily tasks are represented by a Board of Commissioners, while the task of running the company is carried out by a President Director who is assisted

by the Production Director and the Administration, Finance, and General Director. Where the General Production Director. Where the Production Director oversees the fields of production, process, control, utilities, and maintenance. Meanwhile, the Director of Administration, maintenance. Meanwhile, the Director of Administration, Finance, and General Affairs oversees the fields of procurement, marketing, administration and finance, personnel, public relations, security, as well as research and development. The Director supervises several Heads of Departments who will be responsible for their subordinates as part of the delegation of authority and responsibility. Each Head of Department will oversee several sections, and each section will supervise and manage several company employees in their respective fields. Fields. The company's employees will be divided into several groups of teams that will be led by each group leader, where the team leaders will be responsible to the supervisors in each section. Meanwhile, to achieve smooth production, it is necessary form an expert staff consisting of people who are experts in their fields. Expert staff will provide intellectual assistance and advice to supervisory level, to achieve the company's goals. The benefit of having the organizational structure is as follows:

- a. Explaining the limitations of duties, responsibilities, and authority.
- b. As introductory material for officials.

- c. More appropriate placement of employees. More accurate placement of employees.
- d. Preparation of management development plans. Preparation of the management development plan.
- e. Rearranging the work steps and applicable work procedures if proven to be inefficient and not meeting the requirements

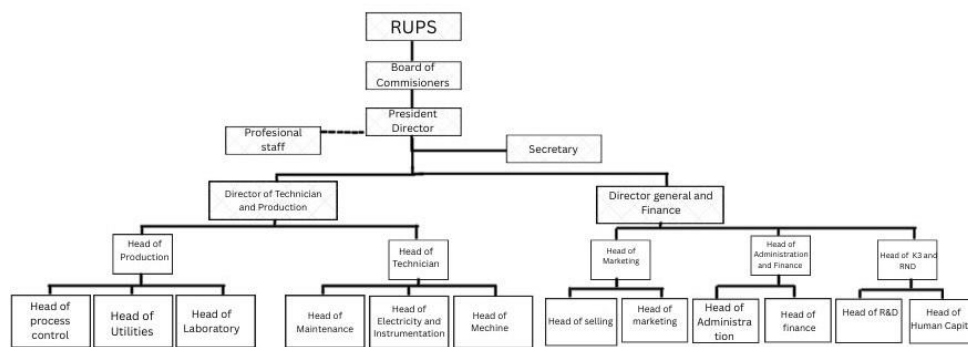


Figure 4.4 Organizational structure of PET factory company

4.4.3 Tasks and Authority

4.4.3.1 Rapat Umum Pemegang Saham (RUPS)

Holder of power highest in the line and staff organizational structure staff is the General Meeting of Shareholders (GMS). The General Meeting of Shareholders (GMS) is attended by the shareholders and the board of commissioners and held at least once a year to continuously monitor and evaluate the company's operations. However, if an urgent matter arises, the GMS can still be held in accordance with forum regulations. Rights and the authority of the GMS is as follows

1. Requesting accountability from the Board of Commissioners
2. Appoint and dismiss the Board of Commissioners and Directors and approve shareholders if resign in accordance with the deliberation
3. Ratifying the results of the work and the balance sheet calculations annual profit and loss of the company
4. Setting the number of annual profits earned to distributed, saved, or reinvested.

4.4.3.2 Board of Commissioners

Board Commissioners are elected by the GMS, which is the executor of shareholders, thus being accountable to the shareholders.

The duties of the Board of Commissioners include the following:

1. Evaluate and approve the board's plan regarding general policies general, company targets, allocation of funds, and guidance
2. Implement supervision over all activities and the execution of the director's tasks. Conducting supervision over all activities and the implementation of the director's tasks
3. Assisting the main director in important activities. Helping the main directors in important activities. important.

4.4.3.3 Vice Director

Director The main director holds the highest position in the company that fully responsible for the success of the company in accordance with the targets set by the GMS. The CEO as the highest leader in the company has responsibility for all actions and policies towards the board of commissioners. Tasks of the main director's duties include:

1. Leading and developing the company effectively and efficiently and efficient.
2. Formulating and implementing general policies Formulating and implementing general policies factory in accordance with the GMS policy.

3. Proposing collaboration with external parties for Proposing collaboration with external parties for the sake of the interests of the company.
4. Representing the company to establish relationships or representing the company to establish relationships or agreements with third parties.
5. Planning and supervising the execution of tasks for each people who work in the company.

In carrying out his duties, the President Director will be assisted by the Secretary of the Production and Technical Director, as well as the Finance and General Director and General. Here are the respective tasks:

1. Secretary

Appointed by the CEO to correspondence issues for the company, handling archiving and other tasks to assist in handling the company's administration.

2. Director of Engineering and Production

Director engineering and production are responsible directly to the CEO. The task of the technical and production director is to lead all production activities of the companies that are related to the field of production, operations, engineering, utilities, development, maintenance, procurement, and laboratory. Director of engineering and production assisted by two heads of department, namely:

a) Head of Production Department

Head of Production Department Task from the head of the production department is to organize and supervising all the implementation of company activities that related to the fields of production, process, control, and laboratory. In carrying out his duties, the head of the production department production will be assisted by several sections, namely, the process section control, utility section, and laboratory section.

b) Head of the Technical Department

Task from the head of the engineering department is to organize and supervising all the implementation of company activities that related to the field of engineering and maintenance. In carrying out his duties, the head of the technical department is assisted by 3 Section Heads, namely the maintenance section, the instrumentation & electrical section, and the machinery section instrumentation & electrical and mechanical sections

3. Director of Finance and General Affairs

Director finance and general affairs are directly responsible directly to the CEO. The duties of the finance director and general is to lead all company activities that related to the fields of administration, personnel, finance, marketing, public relations, security, and safety work. The finance and general director are assisted by several head of department, namely:

a) Head of Marketing Department

Head of Marketing Department Task the head of the marketing department is to organize and overseeing all the implementation of company activities related to the field of raw material procurement and product marketing. In carrying out his duties, the head the marketing department is assisted by two section heads, namely the purchasing section and the marketing section. purchasing and marketing sections.

b) Head of the Administration and Finance Department

Head of the Administration and Finance Department Task the head of the administration and finance department is organizing and supervising all operational activities company operations as well as bookkeeping and payroll management employees. In carrying out his duties, the head of the administration and finance department administration and finance are assisted by two section heads, namely the administration section and the finance section.

c) Head of General Affairs

The duty of the head of the general affairs department is to organize and supervise all the implementation of company activities that related to the fields of personnel, public relations, and security. In carrying out their duties, the head of the general affairs department is assisted by the section heads, namely the personnel section, public relations section, and security section

d) Head of the K3 and Research and Development Section

The task of the head of the K3 and research and development section are to manage R&D, which means organizing and supervise all company activities related to related to the fields of K3 and R&D. In carrying out their duties, the head of the K3 and research and development division is assisted by two section heads, covering the K3 section and the R&D section.

e) Expert Staff

Staff experts have the task of providing input, in the form of suggestions, advice, and views on all operational aspects that involved in the company.

4.4.4 Work Shift Arrangement

Polyethylene Terephthalate company is arranged to operate for 330 days a year continuously for 24 hours a day. The remaining days that are not holidays are used for repairs, maintenance, or shutdown According to the work schedule work, employees can be grouped into two categories, namely:

- a. Non-shift employees are those who work for 5 days with a total of 40 hours of work per week. Whereas Saturday, Sundays and holidays are designated as days off. Employees non-shift employees are those who do not handle the production process directly. Those included as non-shift employees are President Director, Secretary, Director of Engineering and Production, Director of Administration, Finance, and

General Affairs, Head of Department and subordinates who are in the office. Below are details of non-shift employee working hours as follows

Table 4.2 Schedule of staff non-shift

Working Group	Working Time	Rest Time
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

- b. Shift employees are divided into 4 groups (A/B/C/D) where in one workday only three groups work, and one group has a day off. Each group has a rotation of six working days and two days off each week. For holidays or major holidays determined by the government, the on-duty group must still report for work, but it will be counted as overtime and receive additional incentives. Each shift is headed by one shift leader. The work schedule for each group is as shown in table 4.3.

Table 4.3 Group Schedule

Group	Week 1							Week 2						
	S	M	T	W	TH	F	SA	S	M	T	W	TH	F	SA
A	1	1	2	2	3	3	0	1	1	2	2	2	3	0
B	1	2	2	3	2	0	1	1	2	2	3	3	0	1
C	2	2	3	1	0	1	2	2	2	3	1	0	1	2
D	3	3	1	0	1	2	3	3	3	1	0	1	2	3

Group	Week 3							Week 4						
	S	M	T	W	TH	F	SA	S	M	T	W	TH	F	SA
A	1	1	2	2	3	3	0	1	1	2	2	2	3	0
B	1	2	2	3	2	0	1	1	2	2	3	3	0	1
C	2	2	3	1	0	1	2	2	2	3	1	0	1	2
D	3	3	1	0	1	2	3	3	3	1	0	1	2	3

Description:

- 1 : Morning (07.00-15.00)
- 2 : Evening (15.00-23.00)
- 3 : Night (23.00-07.00)
- 0 : Holiday

Table 4.4 Total Staff and The Salary

No	Position	Amount	Salary per month (Rp)	Total salary (Rp)	Salary per year (Rp)
1	Vice Director	1	Rp40,000,000	Rp40,000,000	Rp480,000,000
2	Professional staff	1	Rp18,000,000	Rp18,000,000	Rp216,000,000
3	Secretary	1	Rp18,000,000	Rp18,000,000	Rp216,000,000
4	Director of Technician and Production	1	Rp30,000,000	Rp30,000,000	Rp360,000,000
5	Director of Finance and General	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
6	Head of Marketing	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
7	Head of Finance	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
8	Head of Technician	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
9	Head of Production	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
10	Head of R&D	1	Rp16,000,000	Rp16,000,000	Rp192,000,000
11	Head of Public Relation	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
12	Head of Security	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
13	Head of Selling	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
14	Head of Administration	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
15	Head of Budget	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
16	Head of Process	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
17	Head of Maintenance	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
18	Head of utility	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
19	Head of Development	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
20	Head of Electricity & Instruments	1	Rp15,000,000	Rp15,000,000	Rp180,000,000
21	Staff Public Relation	4	Rp8,000,000	Rp32,000,000	Rp96,000,000
22	Staff selling	4	Rp8,000,000	Rp32,000,000	Rp96,000,000
23	Staff Marketing	4	Rp8,000,000	Rp32,000,000	Rp96,000,000
24	Staff Admin & Finance	5	Rp8,000,000	Rp40,000,000	Rp96,000,000
25	Staff Process	11	Rp8,000,000	Rp88,000,000	Rp96,000,000
26	Staff control	3	Rp8,000,000	Rp24,000,000	Rp96,000,000
27	Staff Laboratory	3	Rp8,000,000	Rp24,000,000	Rp96,000,000

Table 4.4 Total Staff and Total Salary (Continued)

No	Position	Amount	Salary per month (Rp)	Total salary (Rp)	Salary per year (Rp)
28	Staff Maintenance	3	Rp8,000,000	Rp24,000,000	Rp96,000,000
29	Staff Utility	8	Rp8,000,000	Rp64,000,000	Rp96,000,000
30	Staff HSE	4	Rp8,000,000	Rp32,000,000	Rp96,000,000
31	Staff R&D	4	Rp8,000,000	Rp32,000,000	Rp96,000,000
32	Operator process	32	Rp8,000,000	Rp256,000,000	Rp96,000,000
33	Operator Utility	16	Rp8,000,000	Rp128,000,000	Rp96,000,000
34	Doctor	2	Rp8,000,000	Rp16,000,000	Rp96,000,000
35	Nurse	4	Rp5,000,000	Rp20,000,000	Rp60,000,000
36	Security	6	Rp5,000,000	Rp30,000,000	Rp60,000,000
37	Driver	6	Rp5,000,000	Rp30,000,000	Rp60,000,000
38	Cleaning Service	5	Rp5,000,000	Rp25,000,000	Rp60,000,000
Total		144	Rp484,000,000	Rp1,281,000,000	Rp15,372,000,000

4.4.5 Facility and Employee Rights

The following are the facilities and employee rights provided by the company to support employees' work activities, including the following:

a. Leave Entitlement

1. Annual Leave

Every employee in the company is entitled to a maximum of 12 days of leave per year. If the leave entitlement is not used within that one-year period, the leave entitlement will be forfeited and cannot be accumulated for the following year.

2. Mass Leave

Every year, mass leave is granted to employees coinciding with the Idul-Fitri holiday for 4 working days.

3. Maternity Leave

Women who are about to give birth are entitled to 3 months of leave, and during this leave, their salary will continue to be paid, provided that the interval between the birth of the first child and the second child is at least 2 years.

b. National Holidays

For daily employees (non-shift), national holidays are work holidays. As for shift employees, on national holidays, they still have to work, with the note that the day is counted as an overtime workday.

c. Overtime Work

Overtime work is carried out with the approval of the department head if there is urgent work that needs to be completed immediately.

d. Work Attire

To avoid disparities among employees, the company provides two sets of work clothes each year. Additionally, masks are provided as safety equipment for work.

e. Jamsostek

Jamsostek is a life insurance and accident insurance that aims to provide a sense of security to employees while they are performing their duties.

f. Provision of facilities for employees

1. Provision of transportation facilities/employee buses.
2. Provision of polyclinic facilities handled by doctors and nurses.

3. Provision of worship facilities equipped with water and electricity.
4. Provision of employee cooperative facilities.
5. Provision of cafeteria facilities

Giving a token of appreciation in the form of a souvenir to employees who have completed 10 consecutive years of service.

CHAPTER V

UTILITIES

The utility unit is a supporting unit that has an important role in the running of a process in the industry. Utility design is needed to ensure the sustainability of a factory. Some of the utility provisions needed by the factory include:

- a. Water Treatment System
- b. Steam Generation System
- c. Power Plant System
- d. Instrument Air System
- e. Fuel Supply Unit
- f. Waste Management Unit

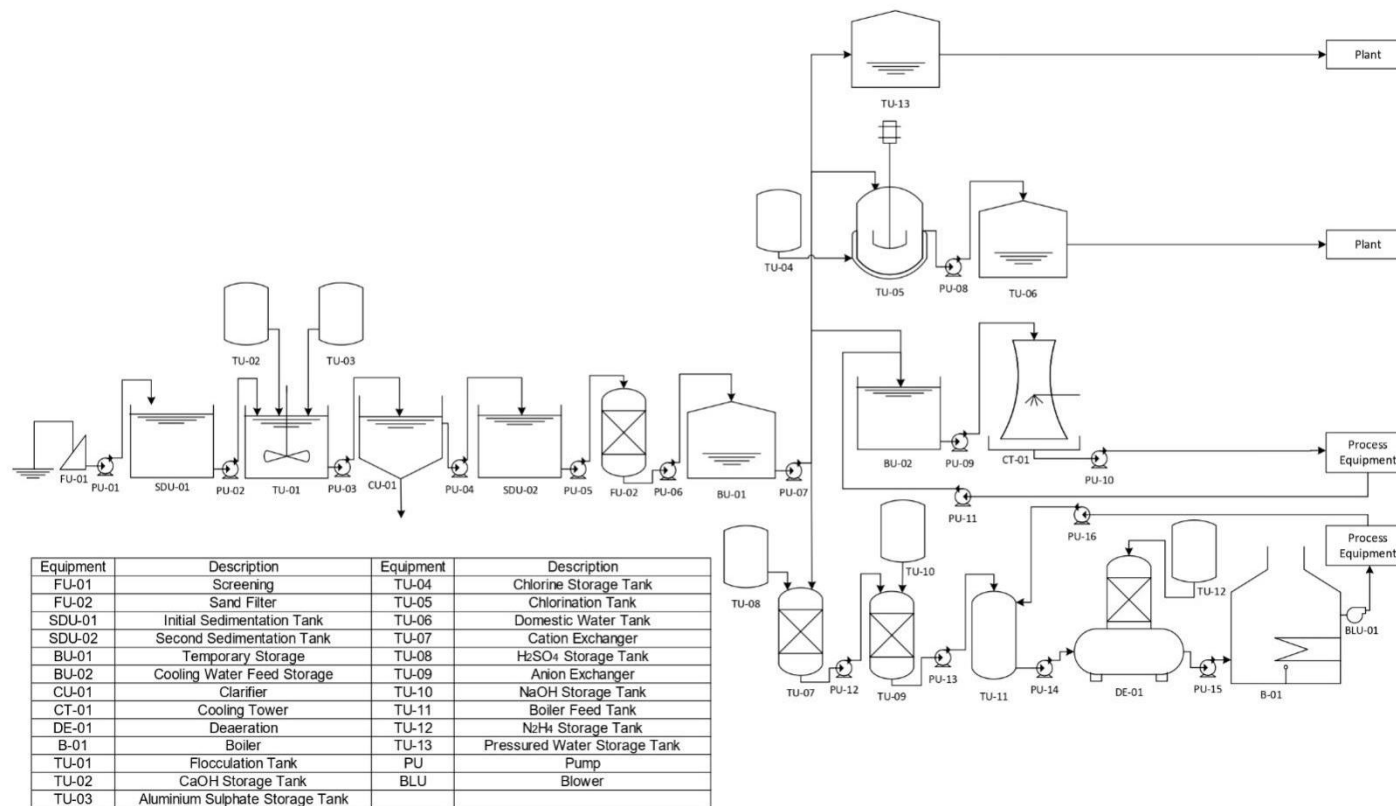


Figure 5.1 Utility Process Flow Diagram

5.1 Water Supply and Treatment Unit

5.1.1 Water Supply Unit

To meet the water needs of a factory generally uses well water, river water, lake water or sea water as its source. In the design of this PET factory, the water source used comes from the river. The use of river water as a water source with consideration. The water used in the design of this PET factory comes from the Cidanau River. River water will be used for needs in the factory environment as a source to obtain water as follows:

- a. River water is a water source with relatively high continuity, so it will always be available and will avoid the problem of water shortages.
- b. River water processing is relatively easier, simpler, and the processing costs are relatively cheap compared to the more complicated seawater processing process and the processing costs are higher because it requires relatively more expensive equipment.
- c. The amount of river water is greater than the amount of well water.
- d. The location of the river is not far from the factory construction site.

Overall, the water needs in this factory are used for:

- a. Domestic Water

Based on WHO standards, the water requirement per person ranges from 100-120 liters per day. For a factory or office, the water requirement for one person is 120 liters per day (Nur & Alfian Purnomo, 2024). The

number of employees in this factory is 144 people. Thus, the total domestic water requirement is 17,208 kg/day.

b. Water Service

Estimated water requirements for public service use such as workshops, laboratories, mosques, canteens, firefighters, and others are 32,351 kg/hour.

c. Cooling Water

Cooling water is used for equipment that requires a decrease in temperature. The cooling water requirement in this PET factory is attached in Table 5.1 below

Table 5.1 Cooling water requirements

Equipment	Water Required (kg/h)
R-02	509.6
CL-01	84,649.2
CL-02	50,542.4
CL-03	284.3
CL-04	306.9
CL-05	50,541.9
CD-01	109,443.0
PL-01	279.5
Total	296,556.9

The design was over designed by 20% to become 355,868.2 kg/hour.

During the process, the cooling water experienced blowdown in the cooling tower unit so that make-up water was needed. After the calculation, the make-up water requirement was 26,215.6 kg/hour.

d. Steam

Steam water in the factory is used as a heating medium. Steam water that can be used for the boiler must meet the requirements. If the boiler water does not meet the requirements, it can cause damage to the equipment so that prevention is carried out to prevent scaling, fouling and foaming. The steam requirements for equipment in this PET factory are attached in Table 5.2 below:

Table 5.2 Steam Requirements

Equipment	Steam Required (kg/h)
R-01	11,130.6
HE-01	826.9
HE-02	826.9
V-01	1,496.3
V-02	3,877.7
Total	18,158.3

The design was over designed by 20% to become 21,790.0 kg/hour. During the process, the steam generator water was 19.45 due to the blowdown in the boiler of 15 and the use of a steam trap of 5%, so that the amount of make-up water needed after the calculation was 2245.206 kg/hour.

5.2 Water Treatment Unit

River water cannot be used directly; it requires some processing to be used properly. Some stages in water processing are:

a. Suction

Water from the river is pumped and flowed to the screening device to remove large dirt particles. After the screening stage, the water will be collected in the initial reservoir.

b. Screening

This stage is carried out to separate large dirt such as leaves, twigs, and other waste without using chemicals. While small particles that are still carried will be processed in the next stage. On the suction side of the pump, a screen must be installed to minimize the screening equipment in the next process from becoming dirty and quickly damaged.

c. Coagulation

Coagulation is the process of destabilizing and aggregating colloidal particles through the addition of coagulant chemicals, allowing them to neutralize and settle under the influence of gravity. In this process, alum (aluminum sulfate, $\text{Al}_2(\text{SO}_4)_3$) is commonly used as the coagulant. As a salt derived from a strong acid and a weak base, alum readily hydrolyzes in alkaline water. To create the necessary alkaline conditions for effective coagulation and subsequent flocculation, calcium hydroxide ($\text{Ca}(\text{OH})_2$) is added. It helps reduce or eliminate carbonate hardness, thereby increasing the pH and promoting the formation of flocs. Flocculation then follows,

where the destabilized particles aggregate into larger flocs that can be more easily removed by sedimentation and filtration.

d. Sedimentation

This sedimentation process takes place in a sedimentation tank, which is designed to allow the flocs formed during the coagulation process to settle. These flocs will then accumulate at the bottom of the tank and can subsequently be removed through a blowdown process.

e. Sand Filter

The water from the sedimentation tank, which still contains suspended solids, then flows into a sand filter for further filtration. This filtration process aims to remove dissolved minerals such as Ca^{2+} , Mg^{2+} , Na^+ , and others using a resin medium. When the sand filter becomes saturated with impurities, it is cleaned through a backwash and rinse process.

f. Temporary Storage

Water that has passed through the filtration stage can be classified as clean water and is collected in a temporary storage tank. This water is then distributed for various purposes, including:

1. Domestic and service water
2. Process water
3. Cooling water
4. Boiler feed water (steam generation)

g. Chlorination

Water chlorination is the process of adding chlorine (Cl_2) or hypochlorite to water. The purpose of this process is to eliminate bacteria and microorganisms, ensuring that the water is safe for daily use.

h. Demineralization

The purpose of the demineralization process is to remove ions present in filtered water to prepare it for use as boiler feedwater. This process consists of two main stages: water softening and dealkalization. Water softening occurs in the cation exchanger, where hardness-causing minerals such as Ca^{2+} , Mg^{2+} , Na^+ , and other cations are removed from the water. These minerals are captured by a hydrogen zeolite resin, which has the capacity to bind positively charged ions. Over time, the resin becomes saturated and loses its effectiveness, at which point it must undergo regeneration using a strong acid, typically sulfuric acid (H_2SO_4). The water exiting the cation exchanger is essentially free of hardness ions, reducing its tendency to form scale.

Following softening, the water enters the anion exchanger for the dealkalization process. This stage removes negatively charged ions such as bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), sulfate (SO_4^{2-}), and chloride (Cl^-). These anions must be removed because, when the alkaline water is heated, they can produce carbon dioxide (CO_2), which may reduce the efficiency of boilers and other processing equipment. The mechanism of ion removal in the anion exchanger is similar to that in the cation exchanger. However, the

resin used in this stage is a weakly basic anion resin. When the resin reaches its ion-exchange capacity, it is regenerated with a strong base, typically sodium hydroxide (NaOH).

The water that exits the anion exchanger is considered demineralized and is suitable for use as process water. However, for applications requiring high-purity water—such as boiler feedwater—additional treatment steps may still be necessary to meet stringent quality standards.

i. Deaeration

The demineralized water intended for use as boiler feedwater must undergo a deaeration process to remove dissolved gases, particularly oxygen (O_2), which can cause corrosion in the boiler system. Corrosion inside boilers is highly detrimental—it not only shortens the equipment's lifespan but can also lead to dangerous failures. Internal erosion may cause structural weaknesses, and if the pressure exceeds the design limits due to gas expansion, it could result in boiler explosions.

To eliminate these dissolved gases, a chemical compound such as hydrazine (N_2H_4) is added to the water. Hydrazine acts as an oxygen scavenger, binding with O_2 and other residual gases to ensure their removal. Once the deaeration process is complete and the gas content is minimized, the treated water can be used directly as boiler feedwater and sent into the boiler unit. Inside the boiler, the water is converted into steam to support industrial processes or energy production.

To maintain system integrity and efficiency, a blowdown system is periodically employed to remove accumulated suspended solids from the boiler. This process involves discharging a portion of the boiler water to control the concentration of impurities. To compensate for the volume of water lost during blowdown, make-up water is added to ensure the system consistently meets the operational requirements.

5.3 Steam Generation Unit

The steam generation unit aims to meet the steam needs in the PET production process, namely by providing a steam boiler with the following specifications:

Capacity : 21,790 kg/h
Type : Water Tube Boiler
Amount : 1 equipment

The boiler system is equipped with an economizer unit, a safety valve system, and automatic safety mechanisms. Prior to use as boiler feedwater, water from the water treatment plant undergoes a treatment process to regulate the levels of impurities such as silica (SiO_2), oxygen (O_2), calcium (Ca), and magnesium (Mg), which may still be present. This is achieved by adding specific chemical agents to the boiler feedwater tank. Additionally, the pH of the feedwater is adjusted to a range of approximately 10.5 to 11.5. Maintaining this pH range is essential because excessively high pH levels can lead to increased corrosivity, which poses a risk to the system. As a result of this heat transfer, the water within the boiler absorbs thermal energy from the heated

surfaces and tubes, causing it to reach its boiling point. The generated steam accumulates at which point it is directed to the steam header for distribution to various units within the production process.

5.4 Power Generation Unit

The electricity demand of the PET plant is primarily supplied by the national electricity provider (PLN). In addition to this main source, a backup power supply is ensured through the use of an in-plant generator, which is activated in the event of a disruption in the PLN power supply. This arrangement is intended to maintain a continuous and uninterrupted electrical supply to support plant operations. The electrical energy produced by the generator is generated through the rotation of the crankshaft, which is driven by thermal energy derived from diesel fuel combustion. The generator specifications used in this factory are:

Capacity : 1.000 kW

Type : AC

Amount : 1 Generator

The following are details of the electricity requirements for a PET factory, including the following:

- a. Process equipment electricity requirements

Table 5.3 Process equipment electricity requirements

No.	Equipment Type	Equipment	Hp	kW
1	Mixing Tank	M-01	0.5	0.37
2	Reactor 1	R-01	2.0	1.46
3	Reactor 2	R-02	7.5	5.59
4	Pelletizer	PL-01	5.1	3.77
5	Conveyor 1	C-01	1.5	1.12
6	Conveyor 2	C-02	0.8	0.56
7	Conveyor 3	C-03	0.8	0.56
8	Pump 1	P-01	2.0	1.49
9	Pump 2	P-02	7.5	5.59
10	Pump 3	P-03	7.5	5.59
11	Pump 4	P-04	5.0	3.73
12	Pump 5	P-05	2.0	1.49
13	Pump 6	P-06	2.0	1.49
14	Pump 7	P-07	0.3	0.19
15	Pump 8	P-08	0.3	0.19
16	Pump 9	P-09	0.3	0.19
17	Pump 10	P-10	0.2	0.12
18	Pump 11	P-11	0.2	0.12
19	Blower 1	B-01	3.0	2.24
20	Blower 2	B-02	3.0	2.24
Total			52.5	39.2

b. Electricity requirements for utilities

Table 5.4 Utilities electricity requirements

No.	Equipment Type	Equipment	Hp	kW
1	Flocculation Tank	TU-01	0.1	0.1
2	Clarifier	CU-01	0.1	0.1
3	Cooling Tower	CT-01	10.0	7.5
4	Utility Blower 1	BLU-01	5.0	3.7
5	Utility Pump 1	PU-01	7.5	5.6
6	Utility Pump 2	PU-02	7.5	5.6
7	Utility Pump 3	PU-03	7.5	5.6
8	Utility Pump 4	PU-04	7.5	5.6
9	Utility Pump 5	PU-05	7.5	5.6
10	Utility Pump 6	PU-06	7.5	5.6
11	Utility Pump 7	PU-07	7.5	5.6
12	Utility Pump 8	PU-08	0.1	0.1
13	Utility Pump 9	PU-09	7.5	5.6
14	Utility Pump 10	PU-10	5.0	3.7
15	Utility Pump 11	PU-11	10.0	7.5
16	Utility Pump 12	PU-12	0.8	0.6
17	Utility Pump 13	PU-13	0.8	0.6
18	Utility Pump 14	PU-14	0.8	0.6
19	Utility Pump 15	PU-15	0.8	0.6
20	Utility Pump 16	PU-16	0.8	0.6
Total			94.0	70.1

Thus, the total electricity requirement for the process and utilities is 109.2 kW then over-designed by 10% = 120.2 kW.

c. Electricity requirements for lighting

The power required for lighting equipment is estimated to be 15% of the total electricity requirement.

$$P = 15\% \times 109.2 \text{ kW}$$

$$\text{kWP} = 16.4 \text{ kW}$$

$$\text{Overdesign 10\%} = 18.0 \text{ kW}$$

d. Electricity requirements of control devices

The power required for the control device is estimated at 25% of the total electricity requirement:

$$P = 25\% \times 109.2 \text{ kW}$$

$$\text{kWP} = 27.3 \text{ kW}$$

$$\text{Overdesign 10\%} = 30.0 \text{ kW}$$

e. Electricity requirements for office equipment

The power required for lighting equipment is estimated to be 15% of the total electricity requirement.

$$P = 15\% \times 109.2 \text{ kW}$$

$$\text{kWP} = 16.4 \text{ kW}$$

$$\text{Overdesign 10\%} = 16.4 \text{ kW}$$

f. Electricity requirements for workshops, laboratories, etc.

The power required for lighting equipment is estimated to be 15% of the total electricity requirement.

$$P = 15\% \times 109.2 \text{ kW}$$

$$\text{kWP} = 16.4 \text{ kW}$$

$$\text{Overdesign 10\%} = 18.0 \text{ kW}$$

Table 5.5 Total Electricity Requirements

No.	Electricity Requirement	kW
1	Process and Utility Electricity	120.2
2	Instrumentation Electricity	30.0
3	AC and Lighting Electricity	18.0
4	Maintenance and Laboratory Electricity	18.0
Total Electricity Required		204.3

5.5 Fuel Supply Unit

This unit is designed to supply fuel for the boiler, with diesel fuel being used at a rate of 3,227 kg per hour.

5.6 Waste Treatment Unit

Waste generated from PET factories can be classified into three:

- a. Liquid Waste Material
 1. Domestic water waste
 2. Blowdown cooling water
 3. Back wash the oily water filter from the pump

Domestic wastewater generated from toilets located within the plant and office areas is collected and treated in a stabilization unit that employs activated sludge, aeration, and chlorine gas injection processes.

Wastewater originating from the laboratory undergoes additional treatment prior to discharge due to the presence of various chemical substances. The treatment process for this laboratory wastewater involves a combination of physical treatment (filtration), chemical treatment (chemical dosing and pH control), and biological treatment

methods, ensuring that the effluent meets environmental safety standards before being released into the environment.

b. Slurry Waste Material

Slurry waste from PTA and EG processing can be treated using an incinerator, which burns the waste at high temperatures to significantly reduce its volume and destroy harmful organic compounds. However, when liquid wastes containing slurry are fed using the spraying method, nozzle clogging can occur immediately. To address this, a specialized feed mechanism has been developed that allows slurries and concentrated liquid wastes to be introduced into the incinerator without the need for atomization, ensuring continuous operation and effective waste destruction under controlled conditions.

5.7 Utility Equipment Specification

Table 5.6 Utility Pump Specification

Code	PU-01	PU-02	PU-03	PU-04	PU-05
Function	To flow water from Screening (FU-01) to Sedimentation Tank 1 (SDU-01)	To flow water from Sedimentation Tank 1 (SDU-01) to Flocculation Tank (TU-01)	To flow water from Flocculation Tank (TU-01) to Clarifier (CU-01)	To flow water from Clarifier (CU-01) to Sedimentation Tank 2 (SDU-02)	To flow water from Sedimentation Tank 2 (SDU-02) to Sand Filter (FU-02)
Type	Single Stage Centrifugal Pump				
Material	Commercial Steel				
Capacity (gpm)	1961.1	1961.1	1961.1	1961.1	1961.1
Pipe Size					
IPS (in)	14	14	14	14	14
No. Sch	30	30	30	30	30
OD (in)	12.75	12.75	12.75	12.75	12.75
ID (in)	12.09	12.09	12.09	12.09	12.09
Pump Efficiency	0.85	0.85	0.85	0.85	0.85
Pump Power (Hp)	7.4	7.4	7.4	7.4	7.4
Motor Power (Hp)	7.5	7.5	7.5	7.5	7.5

Table 5.6 Utility Pump Specification (Continued)

Code	PU-06	PU-07	PU-08	PU-09	PU-10
Function	To flow water from Sand Filter (FU-02) to Temporary Storage Tank (SDU-03)	To flow water from Temporary Storage Tank (SDU-03) to water treatment of domestic water, cooling water, and steam	To flow water from Chlorination Tank (TU-05) to Domestic Water Storage Tank (TU-06)	To flow water from cooling water feed storage (SDU-04) to Cooling Tower (CT-01)	To flow water from Cooling Tower (CT-01) to Process Equipment
Type	Single Stage Centrifugal Pump				
Material	Commercial Steel				
Capacity (gpm)	1961.1	1961.1	10.7	1838.0	1838.0
Pipe Size					
IPS	14	14	1.25	14	14
No. Sch	30	30	40	30	30
OD (in)	12.75	12.75	1.66	12.75	12.75
ID (in)	12.09	12.09	1.38	12.09	12.09
Pump Efficiency	0.85	0.85	0.85	0.85	0.85
Pump Power (Hp)	7.4	7.4	0.06	5.7	4.2
Motor Power (Hp)	7.5	7.5	0.08	7.5	5

Table 5.6 Utility Pump Specification (Continued)

Code	PU-11	PU-12	PU-13	PU-14	PU-15	PU-16
Function	To flow spent cooling water from Process Equipment to cooling water feed storage (SDU-04)	To flow water from Cation Exchanger (TU-07) to Anion Exchanger (TU-09)	To flow water from Anion Exchanger (TU-09) to Boiler Feed Tank (TU-11)	To flow water from Boiler Feed Tank (TU-11) to Deaeration Tank (DE-01)	To flow water from Deaeration Tank (DE-01) to Boiler (B-01)	To flow condensate from Process Equipment to Boiler Feed Tank (TU-11)
Type	Single Stage Centrifugal Pump					
Material	Commercial Steel					
Capacity (gpm)	1957.0	112.5	112.5	112.5	112.5	112.5
Pipe Size						
IPS	14	4	4	4	4	4
No. Sch	30	40	40	40	40	40
OD (in)	12.75	4.5	4.5	4.5	4.5	4.5
ID (in)	12.09	4.026	4.026	4.026	4.026	4.026
Pump Efficiency	0.85	0.85	0.85	0.85	0.85	0.85
Pump Power (Hp)	8.3	0.6	0.6	0.6	0.6	0.6
Motor Power (Hp)	10	0.8	0.8	0.8	0.8	0.8

Table 5.7 Utility Blower Specification

Code	BLU-01
Function	To transfer superheated steam from Boiler (TU-11) to Process Equipment
Type	Centrifugal Blower
Material	Carbon Steel
Specification	
Capacity (ft ³ /min)	51,446
Blower Efficiency	0.8
Power	5

Table 5.8 Utility Basin Specification

Basin	SDU-01	SDU-02	BU-01	BU-02
Function	To sediment dirt from the river water	To sediment floc from flocculation process	To temporarily store water after sand filtration	To temporarily store water before going into the Cooling tower
Type	Rectangular Basin			
Construction Material	Concrete			
Specification				
Capacity (m³/h)	911.7	760.3	455.8	296.6
Length (m)	9	9	10	9
Width (m)	9	9	10	9
Height (m)	11	10	5	4

Table 5.9 Utility Tank Specification

Tank	TU-01	TU-02	TU-03	TU-04	TU-05	TU-06
Function	Coagulate and precipitate the dirt in the form of dispersion by adding coagulant	To store 5% Aluminium Sulphate (Al_2SO_4) for 2 weeks of operation	To store 5% Carbon Hydroxide (CaOH) for 1 week of operation	To store Chlorine for 2 weeks for operation	Mixing chlorine in the form of bleach into water for household needs	To store domestic water for plant usage
Type	Stirred Cylindrical Tank	Cylindrical Tank	Cylindrical Tank	Cylindrical Tank	Vertical Cylindrical Tank	Vertical Cylindrical Tank
Construction Material	Stainless Steel	Stainless Steel	Carbon Steel	Carbon Steel	Carbon Steel	Carbon Steel
Specification						
Height (m)	8	3	5	0.1	1	3
Diameter (m)	8	2	2	0.1	1	3
Volume (m^3)	456	8	22	0.001	1	25
Impeller Type	Propeller 3 blade	-	-	-	-	-
Number of impellers	1	-	-	-	-	-
Power moto (Hp)r	0.08	-	-	-	-	-
Number of equipment	1	1	1	1	1	1

Table 5.9 Utility Tank Specification (Continued)

Tank	TU-07	TU-08	TU-09	TU-10	TU-11	TU-12
Function	To remove minerals contained in the water through Cation exchange	To store H ₂ SO ₄ for 1 week of operation	To store NaOH for 1 week of operation	To remove negative ions through Anion exchange	To mix circulating condensate and boiler feed water	To store N ₂ H ₄
Type	Vertical cylindrical tank	Vertical cylindrical tank	Vertical cylindrical tank	Vertical cylindrical tank	Vertical cylindrical tank	Vertical cylindrical tank
Construction Material	Stainless Steel	Stainless Steel	Stainless Steel	Carbon Steel	Carbon Steel	Carbon Steel
Specification						
Height (m)	2	2	1	2	3	2
Diameter (m)	1	2	1	1	3	2
Volume (m ³)	2	5	0.7	2	26	7
Impeller Type	-	-	-	-	-	-
Number of impellers	-	-	-	-	-	-
Power motor	-	-	-	-	-	-
Number of equipment	1	1	1	1	1	1

Table 5.10 Utility Clarifier Specification

Code	Clarifier
Function	Coagulates and settles colloidal dirt carried by water from the initial settling tank
Type	Conical Bottom Tank
Specification	
Diameter (m)	12
Height (m)	14
Volume (m ³)	13676
Number of impellers	1
Motor power	0.08 Hp

Table 5.11 Utility Screening Specification

Code	FU-01
Function	Filtering large dirt such as leaves, twigs and other rubbish.
Type	Aluminium
Specification	
Capacity (kg/h)	379,723
Diameter (m)	1.5
Height (m)	1.5
Volume (m ³)	3

Table 5.12 Utility Sand Filter Specification

Code	FU-02
Function	Filtering fine particles in river water.
Type	Cylindrical tank
Construction Material	Carbon Steel
Mesh size	28
Specification	
Capacity (kg/h)	379,836
Diameter (m)	4
Height (m)	8
Volume (m ³)	47

Table 5.13 Utility Cooling Tower Specification

Code	Cooling Tower (CT-01)
Function	To cool the water after use by the process equipment with air cooling media
Construction Material	Cooling Tower Force Draft
Specification	
Length (m)	3
Width (m)	3
Height (m)	11

Table 5.14 Utility Deaeration Specification

Code	De-01
Function	Removes CO ₂ and O ₂ gas bound in feed water which causes crust on the reboiler
Type	Vertical cylindrical tank
Specification	
Capacity (kg/h)	21,790
Diameter (m)	3
Height (m)	3
Volume (m ³)	26

Table 5.15 Utility Blower Cooling Tower

Code	Blower Cooling Tower
Function	To flow surrounding air to be contacted with the water to be cooled.
Type	Centrifugal Blower
Construction Material	Carbon Steel
Specification	
Capacity (m ³ /h)	254,480
Efficiency	0.86
Power (Hp)	10

Table 5.16 Utility Boiler Specification

Code	Boiler
Function	To produce superheated steam
Type	Field Lab Oil Fired Boiler
Construction Material	Carbon Steel
Specification	
Capacity (kg/h)	21,790
Diesel Fuel (kg/h)	3,134
Heat (kJ/h)	114,638,388

CHAPTER VI

ECONOMIC EVALUTION

To determine whether the established factory can be profitable or not from an economic standpoint, an evaluation is needed. the economics. the price of the equipment that will be used for the factory's needs, because the price used as the basis for estimating the economic evaluation of the feasibility capital investment in a production activity of a factory by reviewing the investment capital can be recouped and the break-even point occurs. For in the design of this biodiesel plant, there are several factors considered in calculating economic evaluation include:

- A. Modal Capital Investment
 - 1. Fixed Capital Cost
 - 2. Working Capital Investment
- B. Manufacturing Cost
 - 1. Direct Manufacturing Cost
 - 2. Indirect Manufacturing Cost
 - 3. Fixed Manufacturing Cost
- C. General Cost
- D. Economic Feasibility Analysis
 - 1. Percent return on investment (POI)
 - 2. Pay Out Time (POT)
 - 3. Break Event Point (BEP)

4. Discontinued CasH Flow (DCF)

6.1 Equipment Price Estimation

Process equipment on each device is influenced by the economic conditions that is currently happening. The price of equipment will vary each year, the price can experience increases or decreases depending on economic conditions, so it will be difficult to determine the exact price of the equipment. To estimating the price of equipment can be done by knowing the price the index of operational equipment in that year. The price analysis of the equipment was conducted in 2014 for the purchase of the equipment. in the construction year, which is 2030. In the economic analysis, the prices tools and the prices of other factory necessities are calculated for the year analysis. Here is the price index that in chemical engineering is called the CEP index or Chemical Engineering Plant Cost Index (CEPCI)

Table 6.1 Index Price of Equipment

Xi	Indeks (Yi)
1996	381.7
1997	386.5
1998	389.5
1999	390.6
2000	394.1
2000	394.1
2001	394.3
2002	395.6
2003	402.0
2004	444.2
2005	468.2
2006	499.6

Table 6.1 Index Price of Equipment (Continued)

2007	525.4
2008	575.4
2009	521.9
2010	550.8
2011	585.7
2012	584.6
2013	567.3
2014	576.1
2015	556.8
2016	541.7
2017	567.5
2018	603.1
2019	607.5
2020	596.2
2021	776.3
2022	648.9
2023	658.6
2024	655.4

To estimate the price of the tool, there are two approximation equations that can be used. The price of the equipment in the year the factory was established can be determined based on the price in the reference year multiplied by the price index ratio. (Aries & Newton, 1955)

$$Ex = Ey^{Nx} \quad (15)$$

Where:

Ex : Purchased price in 2030

Ey : Purchased price in the reference year 2014

Nx : Index price in 2030

Ny : Index price in the reference year 2014

From that equation, got an information from graph that $y=11.655x-22901$, by using this equation can decide the CEP index in the reference year, thus the number of CEP reference in 2014 572.2. In another side the CEP Index in the year 2030 is 758.7 by this CEP index can decided the price of equipment process and Equipment utility as below in this table:

Table 6.2 Index Price of Equipment

Name of Equipment	Ey (2014)	Ey (2030)
Conveyor 1	\$899.00	\$1,111.21
Conveyor 2	\$899.00	\$1,111.21
Conveyor 3	\$899.00	\$1,111.21
Cooler 1	\$24,000.00	\$29,665.18
Cooler 2	\$42,000.00	\$51,914.07
Cooler 3	\$15,000.00	\$18,540.75
Cooler 4	\$15,000.00	\$18,540.75
Cooler 5	\$20,800.00	\$25,709.83
Packaging	\$118,700.00	\$146,719.05
Tank Ethylene Glycol	\$70,900.00	\$87,635.90
Silo 1	\$4,779.00	\$5,907.08
Silo 2	\$605.00	\$747.81
Silo 3	\$2,964.00	\$3,663.65
Pump 1	\$4,800.00	\$5,933.04
Pump 2	\$4,800.00	\$5,933.04
Pump 3	\$4,800.00	\$5,933.04
Pump 4	\$4,800.00	\$5,933.04
Pump 5	\$4,800.00	\$5,933.04
Pump 6	\$4,800.00	\$5,933.04
Pump 7	\$4,800.00	\$5,933.04
Pump 8	\$4,800.00	\$5,933.04
Pump 9	\$4,800.00	\$5,933.04
Pump 10	\$4,800.00	\$5,933.04

Table 6.2 Index Price of Equipment (Continued)

Pump 11	\$4,800.00	\$5,933.04
Blower 1	\$4,800.00	\$10,753.63
Blower 2	\$4,800.00	\$10,753.63
Mixing Tank 1	\$4,800.00	\$2,101.28
Heat Exchanger 1	\$4,800.00	\$494.42
Heat Exchanger 2	\$4,800.00	\$1,236.05
Reactor Tank 1	\$4,800.00	\$632,610.03
Reactor Tank 2	\$4,800.00	\$241,400.43
Vaporizer 1	\$4,800.00	\$41,160.44
Vaporizer 2	\$4,800.00	\$47,006.95
Condensor 1	\$4,800.00	\$264,885.36
Pelletizer	\$4,800.00	\$116,188.63

Table 6.3 Price Index of Utilities Equipment

Name of Equipment	EY (2014)	EX (2030)
Screening	\$16,200	\$20,024
Bak Pengendapan Al	\$120,500	\$148,944
Alumunium Storage Tank	\$19,200	\$23,732
Caoh Storage Tank	\$35,000	\$43,262
Flocculation Tank	\$100,900	\$124,717
Clarifier	\$119,500	\$147,708
Sedimentation Tank 2	\$151,700	\$187,509
Tank Filter Sand	\$45,900	\$56,735
Primary Storage Tank	\$116,900	\$144,494
Clorine Tank	\$5,200	\$6,427
Pressure Water Tank	\$49,900	\$61,679
Cooling Batch	\$93,300	\$115,323
Cooling Tower	\$570,100	\$704,672
Blower Cooling Tower	\$598	\$739
H2So4 Tank	\$21,500	\$26,575
Cation Exchanger Tank	\$15,900	\$19,653

Table 6.3 Price Index of Utilities Equipment (Continued)

Naoh Tank	\$10,400	\$12,855
Anion Exchanger Tank	\$14,700	\$18,170
Boiler Feed Tank	\$37,400	\$46,228
N2H4 Tank	\$37,600	\$46,475
Boiler	\$212,800	\$263,031
Blower Utility	\$598	\$739
Pump 1	\$5,500	\$6,798
Pump 2	\$5,500	\$6,798
Pump 3	\$5,500	\$6,798
Pump 4	\$5,500	\$6,798
Pump 5	\$5,500	\$6,798
Pump 6	\$5,500	\$6,798
Pump 7	\$5,500	\$6,798
Pump 8	\$3,900	\$4,821
Pump 9	\$5,500	\$6,798
Pump 10	\$5,500	\$6,798
Pump 11	\$3,900	\$4,821

6.2 Fundamental of Calculation

Production Capacity : 60,000 Ton/Year

Plant Operational : 330 working days

Age of Equipment : 10 years

Currency : \$1 = Rp 16,242 (In May 2025)

Established : 2030

UMR Cilegon : Rp 5,128,084.48

6.3 Fund Component

6.3.1 Capital Investment

Capital investment is the total cost of establishing factory facilities along with their equipment and operating the factory. Capital investment consists of:

A. Fixed Capital Investment

Fixed Capital Investment is the cost required to establish factory facilities.

Table 6.4 Physical Plant Cost

No	Equipment	Price (Rp)
1	Equipment Process	Rp56,487,463,704
2	Equipment Utility	Rp120,995,789,111
3	Building Prices	Rp 98,942,108,753
4	Land Prices	Rp108,900,000,000
Total		Rp384,425,361,568

Table 6.5 Direct Plant Cost (DPC)

No	Component	Price (Rp)
1	Purchasing Equipment Cost	Rp 31,557,242,293
2	Installation	Rp 3,471,296,652
3	Instrumentation and Control	Rp 4,733,586,344
4	Piping	Rp 9,467,172,688
5	Electricity	Rp 4,733,586,344
6	Isolation	Rp 2,542,579,383
Total		Rp 56,487,463,704

Table 6.6 Fixed Capital Investment (FCI)

No	Component	Price (Rp)
1	Direct Plant Cost	Rp 461,310,433,882
2	Engineering and Construction	Rp 384,425,361,568
3	Contractor Fee	Rp 9,226,208,678
4	Contingency Cost	Rp 46,131,043
Total		Rp 901,093,047,516

B. Working Capital Investment

Working capital investment refers to the costs required to run a business, or the capital needed to operate a factory over a specific period. There are several sources of capital that can be obtained in the establishment of a factory, such as bank loans, personal funds, or from investors. The goal of investing capital is to gain profits from the invested capital; some characteristics of a good investment are:

- a) Can generate maximum profit
- b) Quick return on investment
- c) Adhering to good laws, adequate technology, safety, and others

Table 6.7 Working Capital Investment

No	Component	Price (Rp)
1	Raw Material Inventory	Rp39,381,832,074
2	In Process Inventory	Rp11,807,429,726
3	Product Inventory	Rp65,596,831,809
4	Available Cash	Rp65,596,831,809
5	Extended Credit	Rp1,574,323,963,428
Total		Rp1,756,706,888,846

6.3.2 Manufacturing Cost

Manufacturing cost is the cost required to produce a product; Manufacturing cost is the sum of Direct Cost. Indirect Cost, Fixed Cost that are always related to the production of a product. Manufacturing Cost includes:

A. Direct Manufacturing Cost (DMC)

Direct Manufacturing cost or direct cost is an expense that is directly related to the production of a product associated with manufacturing a product in a factory.

Table 6.8 Direct Manufacturing Cost (DMC)

No	Component	Price (Rp)
1	Raw Material Inventory	Rp 496,322,187,782
2	Utility Material	Rp 3,259,195,027
3	Worker Salary	Rp 15,372,000,000
4	Supervisor	Rp 1,537,200,000
5	Maintenance	Rp 81,098,374,276
6	Plant supplies	Rp 12,164,756,141
7	Royalty	Rp 608,237,807
Total		Rp 583,362,553,111

B. Indirect Manufacturing Cost (IMC)

Indirect Manufacturing Cost is a cost that not directly linked to the production unit inside of the plant

Table 6.9 Indirect Manufacturing Cost

No	Component	Price (Rp)
1	Payroll overhead	Rp 3,074,400,000
2	Laboratory	Rp 3,074,400,000
3	Plant overhead	Rp 15,372,000,000
4	Packaging and Shipping	Rp 38,103,741,000
Total		Rp 59,624,541,000

C. Fixed Manufacturing Cost (FMC)

Fixed Manufacturing cost is a cost that paid for either during operating condition or shut down. This cost characteristics is constant and not depend on time or level of production.

Table 6.10 Fixed Manufacturing Cost

No	Component	Price (Rp)
1	Depreciation	Rp 90,109,304,752
2	Property Tax	Rp 36,043,721,901
3	Insurance	Rp 18,021,860,950
Total		Rp 144,174,887,603

Table 6.11 Total manufacturing cost

No	Component	Price (Rp)
1	Direct Manufacturing Cost	Rp 583,362,553,111
2	Indirect Manufacturing Cost	Rp 59,624,541,000
3	Fixed Manufacturing Cost	Rp 144,174,887,603
Total		Rp 787,161,981,714

6.3.3 General Expense

General Expenses, also known as general expenditures, consist of expenses related to the functions of the company that are not included in Manufacturing cost. Expenses that must be incurred for the benefit of the smooth operation of the company.

Table 6.12 General expense (GE)

No	Component	Price (Rp)
1	Administration	Rp 79,733,998,091
2	Sales	Rp 398,669,990,454
3	Finance	Rp 106,311,997,455
4	Research	Rp 212,623,994,909
Total		Rp 797,339,980,909

Table 6.13 Total Production Cost

No	Component	Price (Rp)
1	Manufacturing cost	Rp 787,161,981,714
2	General Expenses	Rp 797,339,980,909
Total		Rp 1,584,501,962,623

6.4 Revenue Analysis

a. Revenue before tax

Total sales = Rp 1,905,187,050,000

Total Production cost = Rp 1,584,501,962,623

Revenue = Rp 320,685,087,377

b. Revenue After Tax

Tax 25% from the revenue

Revenue = Revenue before tax – Tax

= Rp 240,513,815,533

6.5 Factory Risk Analysis

Factory risk analysis is conducted to determine the level of risk of a factory (high risk or low risk) by considering the possibilities that may occur and then finding solutions for each of those risks. Based on the risk analysis conducted, it is known that the biodiesel plant falls into the low-risk category with the following considerations:

a. Operating Condition

The preliminary design of the biodiesel plant operates at temperatures ranging from 30 °C to 571 °C with an operating pressure of 1 atm. Thus, the preliminary design of the plant is considered quite safe based on its relatively low operating conditions.

b. Hazard Identification

Hazard Identification is used to identify risk factors from various materials used in the design of polyethylene terephthalic plant.

Table 6.14 Hazard Identification

Component	Hazard							Description	Management
	Explosive	Flammable	Toxic	Corrosive	Irritant	Oxidizing	Radioactive		
Raw Material									
Terephtalic Acid					√			Dust can form flammable Combustion will produce irritant	Keep the material inside package Keep in room temperature Keep distance from water

Table 6.14 Hazard Identification (Continued)

Component	Hazard							Description	Management
	Explosive	Flammable	Toxic	Corrosive	Irritant	Oxidizing	Radioactive		
Raw Material									
Ethylene Glycol			√			√		Toxic, do not inhale	Keep the material inside package Keep in room temperature Use Personal Body Protection during handle this material
Intermediate Product									
Bis(2-hydroxyethyl) Terephthalate					√			Irritation may occur if direct contact to skin	Keep the material inside package Keep in room temperature Use Personal Body Protection during handle this material

Table 6.14 Hazard Identification (Continued)

Component	Hazard							Description	Management
	Explosive	Flammable	Toxic	Corrosive	Irritant	Oxidizing	Radioactive		
Supporting Material									
Antimony Trioxide					√			May cause irritation through direct contact	Wash thoroughly after handling. Store in a cool dry place in a tightly sealed container. Do not use tobacco or food in work area.
Product									
Polyethylene Terephthalate					√				Keep the material dry Keep in room temperature Do not direct contact with environment to protect hygiene

c. Raw Material

Based on the hazard identification from table 6.14 regarding hazard analysis

- i. Terephthalic Acid as the raw material is caused an irritation of respiration when its scattered, to handle this issue, all the workers are mandatory to use personal body protection and keep storing material in the package
- ii. Ethylene Glycol is toxic when its breath cause loss of consciousness when its eaten and oxidizing, to protect this issue, the area of production is sterile area, always use body protection, keep in the room temperature while store

d. Product

- i. Bis(2-hydroxyethyl) terephthalate is intermediate product from esterification process the issue can cause irritation when its direct contact with skin, to prevent the accident the area of production is a clear area and all the workers are mandatory to use personal body protection.
- ii. Polyethylene Terephthalate is a safe material, to protect the hygiene keep store inside of packaging.

e. Waste Management

Process production waste is containing some materials that effected to human, organism and environment such as

- i. Terephthalic Acid Waste can cause water and soil pollution, when

freely thrown away in the environment. The solution is to depolymerization process or store it in a certain tank

- ii. Ethylene Glycol waste can cause air pollution and affect irritation if directly contacted the skin, the solution is washing the area that contacts the material with water combustion using incinerator
- iii. Water containing some impurities can cause water pollution, the solution is storing waste in certain tanks or remove the impurities by process

d. Raw Material Availability

The raw material availability of this plant design is obtained from various plants in Indonesia. The availability of Ethylene glycol can be obtained from PT. Polychem Indonesia Tbk with 233,000 tons per year production (PT. Polychem Indonesia Tbk., 2020). The Terephthalic Acid in Indonesia also shows a promising availability as shown in table 1.3. From these aspects it shows an ease for obtaining the raw material from the supplier to the designated plant design.

e. Product Sales

It is expected that the demand for Polyethylene Terephthalate at Indonesia in 2030 to be 1,727,727 tons/year which indicates a favorable sale of this plant design product during the operating years.

6.6 Feasibility Analysis

Feasibility analysis serves to determine the profit obtained to achieve maximum profit and to see whether the profit is small or large, so that the factory can be categorized as potential or non-potential from an economic perspective. There are several methods used to assess the feasibility of a factory, including:

A. Return on Investment (ROI)

Return On Investment (ROI) is the rate of profit obtained each year from the level of investment made. Factories with low risk have a minimum ROI before tax of 11%, while factories with high risk have a minimum ROI before tax of 44%. The amount of money received or lost is called profit/loss or interest.

$$\%ROI = \frac{\text{Profit}}{\text{Fixed Capital Investment}} \times 100\% \quad (16)$$

1. ROI before tax (ROI b)

$$ROI\ b = 35.59\ \%$$

2. ROI after tax (ROI a)

$$ROI\ a = 20.24\ \%$$

B. Pay Out Time (POT)

Pay Out Time is the duration of capital return based on the profits earned. The factory with low risk has a maximum POT of 5 years, while factories with high risk have a maximum POT of 2 years. This calculation is necessary for knowing in how many years the investment has been recouped

$$POT = \frac{\text{Fixed Capital Investment (FCI)}}{\text{Keuntungan + Depresant}} \quad (17)$$

1. POT before Tax (POTb)

POT for chemical plant with the risk lower than 5 years

POT a = 2.2 year

2. POT after tax (POTa)

POT a = 2.7 years

C. Break Even Point (BEP)

Break Event Point is a point that indicates a level where costs and revenues are equal. With the break-even point, we can determine the minimum selling price, and the minimum number of units sold, as well as the selling price per unit to achieve profit.

$$BEP = \frac{(Fa + 0.3Ra)}{Sa - Va - 0.3Ra} \quad (18)$$

$$BEP = 56.87\%$$

D. Shut Down Point (SDP)

Shut Down Point is the point or condition when the determination of a production activity must stop. The causes include excessively high variable costs, or it could also be due to management decisions resulting from the unprofitability of a production activity. This is caused by the fact that the cost of continuing factory operations will be higher than the cost of shutting down the factory and paying the fixed costs.

$$SDP = \frac{0.3 Ra}{Sa - Va - 0.3Ra} \quad (19)$$

thus SDP = 37.49%

E. Discounted Cash Flow Rate (DCFR)

Discounted cash flow rate of return is the estimated amount of profit obtained each year. Based on the investment that does not return at the end of each year over the life of the factory. DCFR limit is 1.5 times the bank interest

$$\frac{(WC+FCI) \times (1+i)^{10}}{CF} = ((1+i)^9 + 1 + i)^8 + \dots + (1+i)1) \frac{WC+SV}{CV} \quad (20)$$

Where:

FCI = Fixed Capital Investment

WC = Working Capital Investment

SV = Salvage value = depreciation

n = Age of Plant for 10 years

I = DCFR

Based on calculation:

FCI = Rp 901,093,047,516

WCI = Rp 1,756,706,888,846

SV = Rp 90,109,304,752

n = 10 years

Based on calculation, trial error and goal seek, the DCFR is:

DCFR = 10 %

Indonesian bank taxes in 2027 = 5.70%

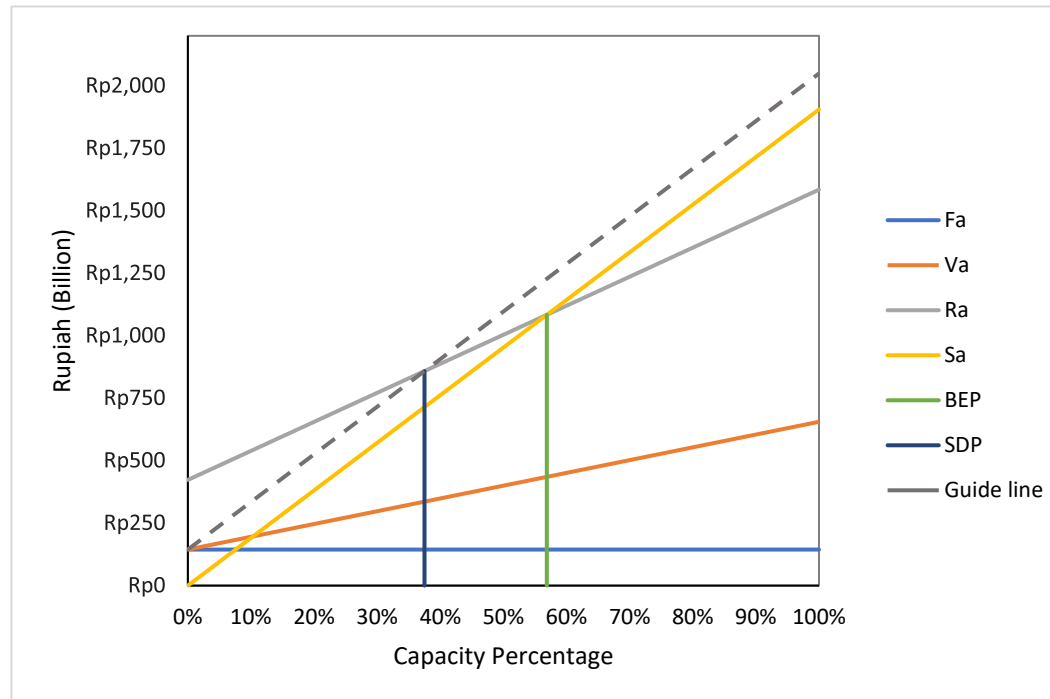
1.5 times from Indonesian bank taxes in 2030 = 8.5%

Therefore, the economy analysis graphic can be seen from Figure 6.1, and be concluded as the following:

Table 6.15 Economy analysis

Component	Parameter	Evaluation	Results
ROI	Minimum 11% before taxes	35.59%	Feasible
POT	Maximum 5 years before taxes	2.2 years	Feasible
BEP	40%-60% of capacity	56.87%	Feasible
SDP		37.49%	Feasible
DCFRR	Minimum 1.5 of bank deposit interest	10%	Feasible

The PET plant from terephthalic acid and ethylene glycol is classified as low risk due to easy material handling, stable product sales, favorable process conditions, and raw material availability. Economic indicators (POT, ROI, DCFR) also confirm its feasibility.



Where:

Fa : Annual Fixed Manufacturing Cost

Va : Annual Variable Value

Ra : Regulated Cost

Sa : Annual Sales Value

BEP: Break Even Point

SDP: Shut Down Point

BEP: Break Even Point

Figure 6.1 Economic Analysis Graphic

CHAPTER VII

CONCLUSION AND SUGGESTIONS

7.1 Conclusion

Based on the calculation of Preliminary plant Polyethylene Terephthalate from Terephthalic Acid and Ethylene Glycol with capacity 60,000 ton/year reviewed from technical or economical concluded as:

- a. The establishment of this plant by capacity 60,000 ton/year to full fill needed of Polyethylene Terephthalate from local and decreasing dependence on Import supplier.
- b. Plant is form as a Persroan Terbatas (PT), Establish in Cilegon, West Java by total area of the land is 2200 m² and total of employee 144.
- c. From identification of HAZOP material, conclude that the raw material, side product, and catalyst is low risk
- d. The operating condition is in normal temperature and pressure
- e. From economic evaluation point of view, the feasibility of this plant is interesting to build by some parameters, such as:

1. Return of Investment (ROI)

- a) ROI before tax = 35.44 %

- b) ROI after tax = 25.49 %

Minimum for low-risk chemical industrial chemical is 11%

2. Pay Out Time (POT)

- a) POT before tax = 4 year

- b) POT after tax = 4.7 year

maximum for industrial chemical is 5 years

3. Break Event Point (BEP) = 57 %

4. Shut Down Point (SDP) = 37%

5. Discounted Cash Flow Rate (DCFR) = 10%

Minimum requirement of DCFR from the Investment bank
is 1.5 times than bank interest rate.

Based on that justification this PET plant is feasible to establish.

7.2 Suggestion

The design of a chemical plant requires an understanding of basic concepts that can enhance the feasibility of establishing the plant, including the following:

- a. It is necessary to optimize the selection of main and supporting equipment as well as raw materials to maximize the profits obtained.
- b. In the design of a chemical plant, knowledge and understanding supported by and other reasoning related to the basic concepts of establishing a plant are required. Studying these concepts in depth is expected to enable the realization of PET products to meet domestic needs and export to foreign countries in the future, where demand is increasingly rising.

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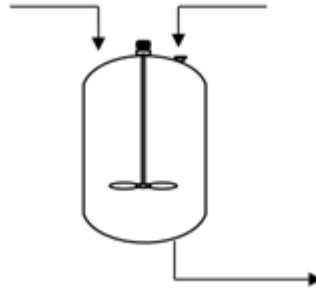
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ATTACHMENT A
REACTOR DESIGN

A.1 Reactor Design (R-01)



Code : R-01

Type : Stirred reactor equipped with heating jacket

Material : Carbon Steel (SA-182 F11)

Function : The reaction on the formation of bis(2-hydroxyethyl)
terephthalate

Operating Condition : Temperature = 240°C

Pressure = 1 atm

1. Mass Balance

Reactor Inlet

Stream 2

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
PTA	39.46	1	166.13	6555.82	1
Total	39.46	1	166.13	6555.82	1

Stream 1

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
EG	78.92	1	62.07	4898.812	1
H2O	0.40	1	18.01	7.14	1
Total	79.32	1	80.08	4905.95	1

Reactor Outlet

Stream 6

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
BHET	35.51	0.60	254.24	9029.53	0.78
H2O	71.43	0.30	18.01	1286.79	0.11
PTA	3.94	0.03	166.13	655.58	0.05
EG	7.89	0.06	62.07	489.88	0.04
Total	35.5	1.00	118.78	11461.79	1

Total Reactor Mass Balance

Component	In		Out
	Stream 4	Stream 11	Stream 5
PTA	6555		655
EG	4898		489
H2O		7.14	1286
BHET			9029
TOTAL	11461		11461

2. Calculating Density and Flow Rate

- Calculating the volumetric flow rate (F_v)

$$F_v = \frac{11461 \frac{kg}{m^3}}{2770 \frac{kg}{h}} = 4.13 \frac{m^3}{h} = 4137 \frac{L}{h}$$

- Calculating Initial Feed Concentration

$$C_{ao} = \frac{\text{Feed mole}}{\text{Volumetric flow rate}} = \frac{n_a}{F_v}$$

$$C_{ao} = \frac{39.46 \frac{kmol}{h}}{4137.82 \frac{L}{h}} = 0.009 \frac{kmol}{l} = 9.52 \frac{mol}{L}$$

$$C_{bo} = \frac{\text{Feed mole}}{\text{Volumetric flow rate}} = \frac{n_b}{F_v}$$

$$C_{bo} = \frac{78.92 \frac{kmol}{h}}{4137.82 \frac{L}{h}} = 0.019 \frac{kmol}{l} = 19.07 \frac{mol}{L}$$

3. Calculating Final Feed Concentration

$$C_a = C_{ao}(1 - X) = 9.53(1 - 90\%) = 0.95 \frac{mol}{L}$$

$$C_b = C_{bo}(1 - X) = 19.07(1 - 90\%) = 1.90 \frac{mol}{L}$$

4. Calculating Reaction Kinetics

The reaction kinetics of Esterification is:

$$k = A_o e^{-\left(\frac{E}{RT}\right)}$$

$$k = 1.64 \times 10^7 \times e^{-\left(\frac{93.24}{T}\right)}$$

$$k = 1.64 \times 10^7 \times e^{-\left(\frac{93.24}{543}\right)} = 0.0119 \frac{L}{mol \cdot min} \text{ or } 0.714 \frac{L}{mol \cdot h}$$

5. Determining Residence Time

$$\tau = \frac{X \times (C_{bo}) \times C_{ao}}{K}$$

$$\tau = \frac{90\% \times \left(\frac{1.90 \text{ mol}^2}{l}\right) \times \left(\frac{0.95}{mol}\right)}{0.714 \frac{mol}{h}}$$

Where:

$$\tau = 2.3 \text{ h}$$

6. Calculating Reactor Volume

$$V = \frac{(Fv \times C_{a1}) - (Fv \times C_{a2})}{kC_{a1}C_{b1}}$$

$$V = \frac{(Fv \times C_{a1}) - (Fv \times C_{a2})}{kC_{ao}(1-X)C_{bo}(1-2.C_{ao}C_{bo})}$$

$$V = \frac{657.7 \text{ mol/min} - 92.1 \text{ mol/min}}{0.02L/mol \cdot min \times 1.3 \text{ mol/L} \times 2.7 \text{ mol/L}}$$

$$V = 6496.6 \text{ L} = 6.5 \text{ m}^3 = 1,715 \text{ gal}$$

Following ASME standardization, thus it is 1,715 gal

7. Reactor Optimization

No. of reactors	t (min)	k (L.mol/min)	X	V of each reactor (m ³)	Price each reactor (\$)	Total price reactor (\$)
1	138	0.02	0.9	6.5	50,000	50,000

No. of reactors	t (min)	k (L.mol/min)	X	V of each reactor (m ³)	Price each reactor (\$)	Total price reactor (\$)
1	138	0.02	0.76	2	26,900	53,800
2			0.9			

Therefore, by considering the reactor cost the optimum number reactor is one.

8. Calculating Shell Diameter and Height

The ideal ratio for the liquid level in a stirred-tank reactor is equal to the tank's diameter (Walas, 1988). Therefore, H:D is 1:1

$$H = D = \sqrt[3]{\frac{4V}{\pi}} = \sqrt[3]{\frac{4(6.4 \text{ m}^3)}{\pi}} = 2 \text{ m} = 81 \text{ inches}$$

Following ASME standardization, the diameter and height of shell are 81 in and 7 ft consequently.

9. Calculating Shell Thickness

The shell is designed with Carbon Steel (SA-182 F11)

$$t_s = \frac{P_d r_i}{fE - 0.6P_d} + C$$

(Eq. 13.1, Brownell & young, 1959; p. 254)

Where in this equation:

t_s = shell thickness (inch)

r_i = radius

$$= D/2 = 816/2 = 40.5 \text{ inch}$$

$$\begin{aligned} E &= \text{Welded-joint efficiency} \\ &= 80\% \end{aligned}$$

$$\begin{aligned} C &= \text{Corrosion allowance (inch)} \\ &= 0.125 \end{aligned}$$

Calculating pressure:

$$\begin{aligned} P_{\text{hydrostatic}} &= \rho_{\text{mixture}} \times g \times h \\ &= 2770 \times 9.18 \times 2 \\ &= 51,106 \text{ Pa} = 7.4 \text{ psi} \end{aligned}$$

$$P_{\text{reaction}} = 1 \text{ atm} = 14.7 \text{ psi}$$

$$\begin{aligned} P_{\text{operation}} &= P_{\text{hydrostatic}} + P_{\text{reaction}} \\ &= 7.4 \text{ psi} + 14.7 \text{ psi} \\ &= 22.1 \text{ psi} \end{aligned}$$

$$\begin{aligned} P_{\text{design}} &= 1.2 \times P_{\text{operation}} \\ &= 1.2 \times 22.1 \text{ psi} = 26.5 \text{ psi} \end{aligned}$$

$$\begin{aligned} P_{\text{abs}} &= P_{\text{operation}} + P_{\text{hydrostatic}} = 22.1 \text{ psi} + 7.4 \text{ psi} \\ &= 29.5 \text{ psi} \end{aligned}$$

Therefore, the shell thickness is:

$$t_s = \frac{(26.5)(1)}{(18750 \times 80\%) - (0.6 \times 26.5)} + 0.125 = 0.127 \text{ inch}$$

It is standardized according to Brownell Table 5.7 into 0.75 inch (0.019 m)

10. Determine Head Thickness and Bottom Thickness

Outside reactor diameter is:

$$OD = ID + 2t_s$$

$$OD = 2 \text{ m} + (2 \times 0.003 \text{ m}) = 2.02 \text{ m} = 79.9 \text{ in}$$

It is standardized according to Brownell Table 5.7 into 84 inches.

$$icr = 4.375 \text{ inch}$$

$$r = 72 \text{ inch}$$

$$w = \frac{1}{4} \left(3 + \sqrt{\frac{r}{icr}} \right)$$

$$w = \frac{1}{4} \left(3 + \sqrt{\frac{78}{4.75}} \right) = 1.76 \text{ inches}$$

Therefore, for the head thickness

$$th = \frac{P \cdot r \cdot c \cdot w}{2fE - 0.2P} + C$$

(Eq. 7.77, Brownell & young, 1959; p. 138)

$$th = \frac{25.47 \times 78 \times 1.76}{(2 \times 18750 \times 80\%) - (0.2 \times 26.5)} + 0.125$$

$$th = 0.25 \text{ inch}$$

The head thickness is chosen according to the standard on Brownell & young (1959), that is 0.25 in. The dimensions are taken one size bigger that is:

Head thickness (hd) = 0.25 inch

Standard Straight Flange (sf) = 2 inches

Inside corner radius (icr) = 0.75 inches

11. Determining the Total Reactor Height

$$OA = t_h + b + sf$$

Where the inside depth of dish (b) is:

$$b = rc - \sqrt{(rc - icr)^2 - \left(\frac{ID}{2} - icr\right)^2}$$
$$b = 78 - \sqrt{(78 - 0.75)^2 - \left(\frac{81}{2} - 0.65\right)^2} = 11.7 \text{ inches}$$

Therefore:

$$OA = 0.25 + 11.7 + 2 = 14 \text{ inches or } 0.4 \text{ m}$$

From the calculations, the reactor specifications are as follows:

Shell diameter = 2.1 m

Shell height = 2.02 m

Shell head and bottom height = 0.35 m

Reactor volume = 6.5 m³

Reactor height = 2.1 m

12. Reactor Impeller Design

Determination based on:

T operation	= 240°C
μ	= 0.73 cP
Liquid height (h)	= 1.1 m
Diameter (Dt)	= 2.1 m
Maximum level	= $h/Dt = 0.5$

In the Walas (1998) book, page 288, for viscosity <25,000 cP with maximum level of 1.4 uses one impeller. Based on Table 3.4.1 Geonkoplis, the geometric proportions for a standard agitation system are:

Propeller diameter (Da)	= $0.3 \times Dt$	= 0.70 m
Propeller length from base (E)	= $h / 3$	= 0.70 m
Propeller width (L)	= $Da / 4$	= 0.17 m
Baffle width (L)	= $Dt / 12$	= 0.17 m
Propeller height (W)	= $Da / 5$	= 0.14 m
Liquid height (H)	= $1.1 \times Dt$	= 2.3 m
Number of Baffle	= 4	

13. Calculating Power of Impeller

$$N = \frac{600}{\pi Di(ft)} \sqrt{\frac{WELH}{2Di(in)}}$$

$$WELH = H_{liquid} \times Sg$$

$$Sg = \frac{\rho_{fluid}}{\rho_{water}}$$

Where:

N = Stirrer rotation speed, rpm

ρ_{liquid}	= 2770 kg/m ³
ρ_{water}	= 1000 kg/m ³
Sg = Specific gravity	= 2770/1000 = 2.82
h liquid = Liquid height in tank	= 1.08 m
Di = Stirrer diameter	= 2.30 m = 90.49 in = 1.09 ft
WELH = Water Equivalent liquid height	= h liquid x sg = 1.08 m x 2.82 = 3.07 m

$$N = \frac{600}{\pi(2.29)} \sqrt{\frac{3.08}{2(27.58)}} = 1765 \text{ rpm} = 29.42 \text{ rps}$$

$$Re = \frac{\rho N D i^2}{\mu} = \frac{2.77 \frac{g}{cm^3} \times 29.42 \text{ rps} \times 229.8 \text{ cm}}{0.02 \frac{g}{cm \cdot s}} = 6.7 \times 10^6$$

$$Pa = \frac{\rho(Np)N^3 D^5}{gc} = \frac{2.77 \frac{g}{cm^3} \times 6 \times (29.42 \text{ rps})^3 \times (229.84 \text{ cm})^5}{981 \frac{cm}{s^2}}$$

With a motor efficiency of 90% based on figure 4.2 of Ulrich (1984). The impeller power needed is $Pa_{motor} = Pa / \eta$, that is 9 Hp.

14. Jacket Cooler Design

i. Reactor heat balance

Component	Input	Output
	kJ/hr	kJ/hr
PTA	296951.55	-
EG	509059.8	-
BHET	-	42207379.247
H2O	-	6292
Heat absorbed	-	1344266.05
Heat Reaction	574460.7	-
Total	1380472.05	1380472.05

ii. Calculating cooling fluid

The coolant used is water with an inlet temperature of 30°C and an outlet temperature of 90°C.

$$m = Q / \Delta H$$

Where:

$$Q \text{ cooling water} = H_{in} - H_{out} + \Delta H_R = 149,508 \text{ kJ.hr}$$

$$\Delta H = C_p (\Delta T) = 4,205 \times (90-30) = 252.3 \text{ kJ/kg}$$

$$m = Q/\Delta H = 5328.04 \text{ kg/hr}$$

$$\text{Reactor hot fluid temperature} = 240^\circ\text{C} = 464^\circ\text{F}$$

$$\text{Cooling media inlet temperature (water)} = 30^\circ\text{C} = 86^\circ\text{F}$$

$$\text{Cooling media outlet temperature (water)} = 90^\circ\text{C} = 194^\circ\text{F}$$

iii. Calculating LMTD

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)}$$

$$\Delta T_{LMTD} = 369^{\circ}\text{F}$$

iv. Jacket Design

$$\text{The } U_d \text{ values for organic and water media are} = 20\text{-}75 \text{ Btu/hr.ft}^2 \cdot ^{\circ}\text{F}$$

$$\text{In this calculation, the } U_d \text{ value is taken as} = 50 \text{ Btu/hr.ft}^2 \cdot ^{\circ}\text{F}$$

$$\text{The heat absorbed by the cooling medium} = 130 \text{ Btu/hr}$$

$$\begin{aligned} \text{Heat transfer area} &= Q/U_d \cdot \Delta T_{LMTD} \\ &= 262 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Reactor shell surface area} &= \pi \cdot D \cdot H + \left(\frac{1}{4}\right) \cdot D^2 \\ &= 24.3 \text{ ft}^2 \end{aligned}$$

$$\text{Shell outer diameter (Shell OD)} = 71.3 \text{ in}$$

$$\text{Jacket pressure design (20\% over)} = 17.63 \text{ psi}$$

$$\begin{aligned} \text{Distance between outer shell and jacket inner} \\ \text{wall (TJ)} &= 2 \text{ in} \end{aligned}$$

$$\begin{aligned} \text{Jacket inner diameter (Jacket ID)} &= \text{Shell OD} + 2 \cdot \text{TJ} \\ &= 75 \text{ in} \\ &= 78 \text{ in (standardized)} \end{aligned}$$

$$\text{Standardized Jacket thickness (ts)} = 0.75$$

$$\begin{aligned} \text{Jacket outer diameter (Jacket OD)} &= \text{Jacket ID} + 2 \cdot \text{ts} \\ &= 79.5 \\ &= 84 \text{ in (standardized)} \end{aligned}$$

$$\text{Total jacket height} = H_{\text{liquid}} + H_{\text{head}}$$

$$= 2.21 \text{ m} + 0.54 \text{ m}$$

$$= 2.75 \text{ m}$$

Total jacket area

$$= A_{\text{shell}} + A_{\text{head}}$$

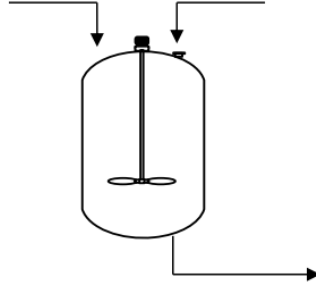
$$= 28,584.1 \text{ in}^2 + 13,336.7$$

$$\text{in}^2 = 41,920.8 \text{ in}^2$$

14. Conclusion

Reactor material	Carbon Steel (SA-182 F11)
Pressure operating condition	1 atm
Temperature operating condition	240°C
Shell diameter	112 in
Total tank height	90.6 in
Impeller type	Flat Blade Turbine (Semi Open)
Motor type	Standard AC induction Motor
Motor power	5.8 kW
Shell thickness	0.127 in
Shell head	9.8 in
Shell material	Carbon steel (SA-182 F11)
Jacket height	108.3 in
Jacket thickness	0.75 in
Heating System	Steam

A.2 Reactor Design (R-02)



Code	: R-02
Type	: Stirred reactor equipped with cooling jacket
Material	: Carbon Steel (SA-182 F11)
Function	: The reaction on the formation of Polyethylene Terephthalate and Ethylene Glycol
Operating Condition	: Temperature = 2770°C Pressure = 1 atm

1. Mass Balance

Reaction: 100BHET $\rightarrow$ PET100 + 99EG

Reactor Inlet:

Stream 11

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
BHET	35.5	1	254.2	9029.5	1
Total	35.5	1	254.2	9029.5	1

Stream 22

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
Sb ₂ O ₃	0.0003	1	275.5	0.1	1
Total	0.0003	1	275.5	0.1	1

Reactor Outlet

Stream 12

Component	kmol/hr	Mol fraction	Molecular Weight	kg/hr	Mass fraction
PET100	0.4	0.01	19279.1	6840.3	0.76
EG	35.1	0.99	62.1	2180.2	0.24
Sb ₂ O ₃	0.0003	trace	275.5	0.1	trace
Total	35.5	1.00			

Total Reactor Mass Balance

Component	In		Out
	Stream 6	Stream 13	Stream 7
BHET	9030		
PET100			2182
EG			6847
Sb ₂ O ₃		0.1	0.1
Total	9030		9030

2. Calculating Density and Volumetric Flow Rate at 270°C

- Calculating Feed Density at 270°C

Component	Density (kg/m ³)	Kg/hr	Mass fraction	Mixture Density (ρ _L) (kg/m ³)
BHET	1225	9030	0.99999	1224.9
Sb ₂ O ₃	4150	0.1	0.00001	0.04
Total	5375	9030.1	1	1225.03

- Calculating the volumetric flow rate (F_v)

$$F_v = \frac{\text{Feed mass}}{\text{Mixture density}} = \frac{m_a}{\rho_L}$$

$$F_v = \frac{1225 \frac{\text{kg}}{\text{m}^3}}{9030 \frac{\text{kg}}{\text{h}}} = 7.37 \frac{\text{m}^3}{\text{h}} = 7370.9 \frac{\text{L}}{\text{h}}$$

- Calculating Initial Feed Concentration

$$C_{ao} = \frac{\text{Feed mole}}{\text{Volumetric flow rate}} = \frac{n_a}{F_v}$$

$$C_{ao} = \frac{35.52 \frac{\text{kmol}}{\text{h}}}{7370.9 \frac{\text{L}}{\text{h}}} = 0.0048 \frac{\text{kmol}}{\text{h}}$$

3. Calculating Final Feed Concentration

$$C_a = C_{ao} (1 - X) = 0.0048 (1 - 100\%) = 0 \frac{kmol}{h}$$

4. Calculating Reaction Kinetics

Based on Zein, R (2010) the reaction kinetics of polymerization is:

$$k = A_o e^{-\left(\frac{E}{RT}\right)}$$

$$k = 6.0098 \times 10^{13} \times e^{-\left(\frac{16777}{T}\right)}$$

$$k = 6.0098 \times 10^{13} \times e^{-\left(\frac{16777}{543}\right)} = 2.29 \frac{kg}{gmole.min}$$

5. Determining Residence Time

Residence time is calculated with p-d analysis (Tomita, 1973)

$$n = \frac{1}{1 + pt} + dt$$

$$t = \frac{-(d - pn) \pm \sqrt{(d - pn)^2 - 4(pd)(1 - n)}}{2pd}$$

Where:

$$n = \frac{192}{\text{molecular weight of formed polymer}}$$

At 270°C

$$p = 36.3 \text{ mol}^{-1}h^{-1}, d = 3.7 \times 10^{-4} \text{ mol } h^{-1}$$

Therefore:

$$n = \frac{192}{19217} = 0.00999$$

$$t = \frac{-(-0.362267) \pm \sqrt{0.131237 - 0.05319}}{0.026862}$$

$$t = 3.1 \text{ h}$$

6. Calculating Reactor Volume

$$V = F_v \times t$$

$$V = 7370.9 \frac{L}{h} \times 3.1 \text{ h}$$

$$V = 22840.3 \text{ L} = 22.8 \text{ m}^3 = 6,033.8 \text{ gal}$$

Following ASME standardization, thus it is 6,477 gal or 24.5 m³

7. Reactor Optimization

No. of reactors	t (min)	k (L.mol/min)	X	V of each reactor (m ³)	Price each reactor (\$)	Total price reactor (\$)
1	186	6.7	0.99	23	97,300	99,500

No. of reactors	t (min)	k (L.mol/min)	X	V of each reactor (m ³)	Price each reactor (\$)	Total price reactor (\$)
1	186	6.7	0.89	8.7	97,300	114,600
2			0.99			

Therefore, by considering the reactor cost the optimum number reactor is one.

8. Calculating Shell Diameter and Height

The ideal ratio for the liquid level in a stirred-tank reactor is equal to the tank's diameter (Walas, 1988). Therefore, H:D is 1:1

$$H = D = \sqrt[3]{\frac{4V}{\pi}} = \sqrt[3]{\frac{4 \cdot (22.8 \text{ m}^3)}{\pi}} = 3.1 \text{ m} = 121 \text{ inches} = 10.1 \text{ ft}$$

Following ASME standardization, the diameter and height of shell are 126 in and 10 ft consequently.

9. Calculating Shell Thickness

The shell is designed with Carbon Steel (SA-182 F11)

$$t_s = \frac{P_d r_i}{fE - 0.6P_d} + C$$

(Eq. 13.1, Brownell & young, 1959; p. 254)

Where in this equation:

t_s = shell thickness (inch)

r_i = radius

$$= D/2 = 121.1/2 = 60.5 \text{ inch}$$

E = Welded-joint efficiency

$$= 80\%$$

C = Corrosion allowance (inch)

$$= 0.6$$

Calculating pressure:

$P_{\text{hydrostatic}} = \rho_{\text{mixture}} \times g \times h$

$$= 1225 \times 9.18 \times 2.9$$

$$= 32216 \text{ Pa} = 4.7 \text{ psi}$$

$P_{\text{reaction}} = 1 \text{ atm} = 14.7 \text{ psi}$

$P_{\text{operation}} = P_{\text{hydrostatic}} + P_{\text{reaction}}$

$$= 4.7 \text{ psi} + 14.7 \text{ psi}$$

$$= 19.4 \text{ psi}$$

$P_{\text{design}} = 1.2 \times P_{\text{operation}}$

$$= 1.2 \times 19.4 \text{ psi} = 23.2 \text{ psi}$$

$P_{\text{abs}} = P_{\text{operation}} + P_{\text{hydrostatic}} = 19.4 \text{ psi} + 4.7 \text{ psi}$

$$= 24.1 \text{ psi}$$

Therefore, the shell thickness is:

$$t_s = \frac{(23.2)(60.5)}{(17500 \times 80\%) - (0.6 \times 23.2)} + 0.6 = 0.7 \text{ inch}$$

It is standardized according to Brownell Table 5.7 into 0.75 inch (0.019 m)

10. Determine Head Thickness and Bottom Thickness

Outside reactor diameter is:

$$\text{OD} = \text{ID} + 2t_s$$

$$OD = 3.1 \text{ m} + (2 \times 0.019 \text{ m}) = 3.1 \text{ m} = 123 \text{ inch}$$

It is standardized according to Brownell Table 5.7 into 126 inches. From Brownell's table 5-7, p. 90 for OD = 126 in.

$$icr = 7.6 \text{ inch}$$

$$r = 120 \text{ inch}$$

$$w = \frac{1}{4} \left(3 + \sqrt{\frac{r}{icr}} \right)$$

$$w = \frac{1}{4} \left(3 + \sqrt{\frac{120}{7.6}} \right) = 1.74 \text{ inch}$$

Therefore, for the head thickness

$$th = \frac{P \cdot rc \cdot w}{2fE - 0.2P} + C$$

(Eq. 7.77, Brownell & young, 1959; p. 138)

$$th = \frac{23.2 \times 120 \times 1.74}{(2 \times 17500 \times 80\%) - (0.2 \times 23.2)} + 0.59$$

$$th = 0.76 \text{ inch}$$

The head thickness is chosen according to the standard on Brownell & young (1959), that is 0.875. The dimensions are taken one size bigger that is:

$$\text{Head thickness (hd)} = 1 \text{ inch}$$

$$\text{Standard Straight Flange (sf)} = 2.75 \text{ inch}$$

$$\text{Inside corner radius (icr)} = 3 \text{ inches}$$

11. Calculating Head and Bottom Height

$$OA = t_h + b + sf$$

Where the inside depth of dish (b) is:

$$b = rc - \sqrt{(rc - icr)^2 - \left(\frac{ID}{2} - icr\right)^2} b$$

$$= 120 - \sqrt{(120 - 7.6)^2 - \left(\frac{124.5}{2} - 7.6\right)^2} = 21.8 \text{ inches}$$

Therefore:

$$OA = 0.76 + 21.8 + 2.75 = 25.3 \text{ inch or } 0.64 \text{ m}$$

Therefore, the total height of reactor is:

Total Height = Head height + Shell height + Bottom height

$$\text{Total Height} = 0.64 \text{ m} + 3.07 \text{ m} + 0.64 \text{ m} = 4.36 \text{ m}$$

From the calculations, the reactor specifications are as follows:

Shell diameter	= 3.1 m
Shell height	= 3.1 m
Shell head and bottom height	= 0.64 m
Reactor volume	= 22.8 m ³
Reactor height	= 4.36 m = 171.65 inches

12. Reactor Impeller Design

Determination based on:

T operation	= 270°C
μ	= 2 cP
Liquid height (h)	= 2.6 m
Diameter (Dt)	= 3.1 m
Maximum level	= h/Dt = 0.8

In the Walas (1998) book, page 288, for viscosity <25,000 with maximum level of

0.8 uses one impeller. Based on Table 3.4.1 Geonkoplis, the geometric proportions

for a standard agitation system are:

Propeller diameter (Da)	= 0.3 x Dt	= 0.95 m
Propeller length from base (E)	= Dt / 3	= 1.05 m
Propeller width (L)	= Da / 4	= 0.24 m
Baffle width (L)	= Dt / 12	= 0.26 m
Propeller height (W)	= Da / 5	= 0.19 m
Liquid height (H)	= 1.1 x Dt	= 3.48 m
Number of Baffle	= 3	

13. Calculating Power of Impeller

$$N = \frac{600}{\pi Di(ft)} \sqrt{\frac{WELH}{2Di(in)}}$$

$$WELH = H \text{ liquid} \times Sg$$

$$Sg = \frac{\rho \text{ fluid}}{\rho \text{ water}}$$

Where:

N = Stirrer rotation speed, rpm

ρ liquid	= 1225 kg/m ³
ρ water	= 1000 kg/m ³
Sg = Specific gravity	= 1220/1000 = 1.23
h liquid = Liquid height in tank	= 2.57 m
Di = Stirrer diameter	= 0.95 m = 37.35 in = 3.11 ft
WELH = Water Equivalent liquid height	= h liquid x sg = 2.57 m x 1.23 = 3.15 m

$$N = \frac{600}{\pi(3.11)} \sqrt{\frac{3.15}{2(37.35)}} = 1803 \text{ rpm} = 30.1 \text{ rps}$$

$$Re = \frac{\rho N D i^2}{\mu} = \frac{1.2 \frac{g}{cm^3} \times 30.1 \text{ rps} \times (94.9 \text{ cm})}{0.02 \frac{g}{cm \cdot s}} = 1.7 \times 10^7$$

$$Pa = \frac{\rho(Np)N^3D^5}{gc} = \frac{1.23 \frac{g}{cm^3} \times 0.15 \times (30.1 \text{ rps})^3 \times (94.9 \text{ cm})^5}{10 \frac{m}{s^2}}$$

$$= 3.8 \times 10^{12} \frac{g \cdot cm^2}{s^3} Pa = 384 \text{ kW} = 514 \text{ HP}$$

With a motor efficiency of 93% based on figure 4.2 of Ulrich (1984). The impeller power needed is $Pa_{\text{motor}} = Pa / \eta$, that is 553 Hp.

14. Jacket Cooler Design

i. Reactor heat balance

Component	Input	Output
	kJ/hr	kJ/hr
BHET	4,800,553	-
PET100	-	44,551
EG	-	1,016,494
Sb2O3	9.7	9.7
Sub Total	4,800,563	1,061,055
Heat of reaction	-3,590,000	
Heat absorbed	-	149,508
Total	1,210,563	1,210,563

ii. Calculating cooling fluid

The coolant used is water with an inlet temperature of 30°C and an outlet temperature of 90°C.

$$m = Q / \Delta H$$

Where:

$$Q_{\text{cooling water}} = H_{\text{in}} - H_{\text{out}} + \Delta H R = 149,508 \text{ kJ.hr}$$

$$\Delta H = C_p (\Delta T) = 4,192 (90-30) = 293.4 \text{ kJ/kg}$$

$$m = Q/\Delta H = 510 \text{ kg/hr}$$

$$\text{Reactor hot fluid temperature} = 270^\circ\text{C} = 518^\circ\text{F}$$

$$\text{Cooling media inlet temperature (water)} = 30^\circ\text{C} = 86^\circ\text{F}$$

$$\text{Cooling media outlet temperature (water)} = 90^\circ\text{C} = 194^\circ\text{F}$$

iii. Calculating LMTD

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

$$\Delta LMTD = 369^\circ\text{F}$$

iv. Jacket Design

$$\text{The } U_d \text{ values for organic and water media are} = 20-75 \text{ Btu/hr.ft}^2 \cdot ^\circ\text{F}$$

$$\text{In this calculation, the } U_d \text{ value is taken as} = 50 \text{ Btu/hr.ft}^2 \cdot ^\circ\text{F}$$

$$\text{The heat absorbed by the cooling medium} = 141,707 \text{ Btu/hr}$$

$$\text{Heat transfer area} = Q/U_d \cdot \Delta LMTD$$

$$= 7.7 \text{ ft}^2$$

$$\text{Reactor shell surface area} = \pi \cdot D \cdot H + (1/4) \cdot D^2$$

$$= 345 \text{ ft}^2$$

Shell outer diameter (Shell OD)	= 126 in
Jacket pressure design (20% over)	= 17.6 psi
Distance between outer shell and jacket inner wall (TJ)	= 2 in
Jacket inner diameter (Jacket ID)	= Shell OD + 2.TJ
	= 130 in
	= 130.5 in (standardized)
Standardized Jacket thickness (ts)	= 0.75 in
Jacket outer diameter (Jacket OD)	= Jacket ID + 2.ts
	= 131.5
	= 132 in (standardized)
Total jacket height	= H liquid + H head
	= 3.5 m + 0.8 m
	= 4.3 m = 171.65 in
Total jacket area	= A shell + A head
	= 69619 in ² + 32771 in ²
	= 102390 in ²

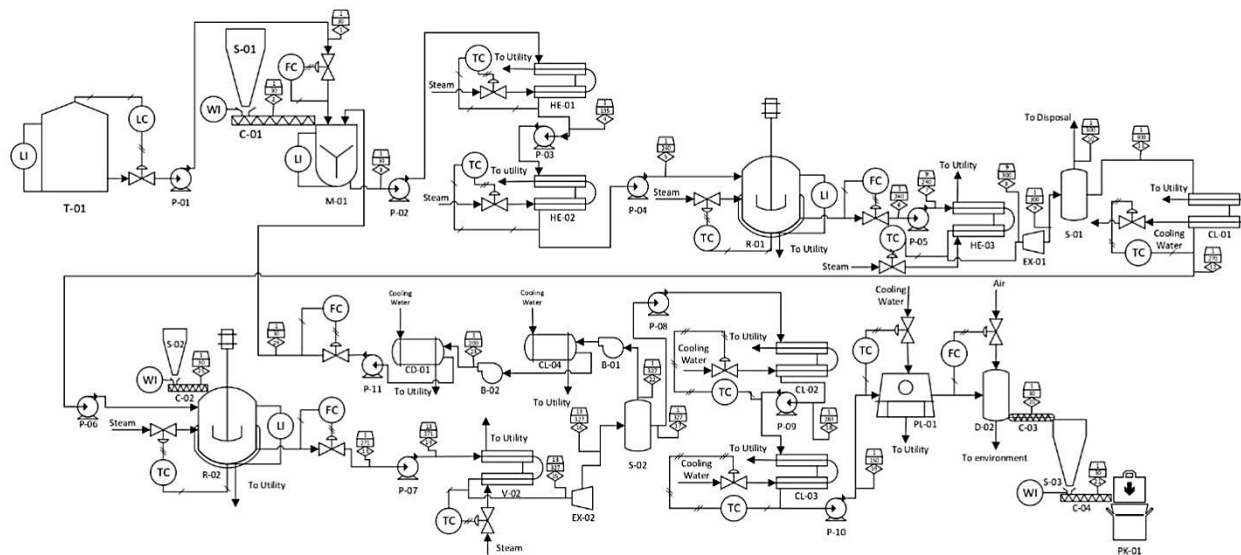
14. Conclusion

Reactor material	Carbon Steel (SA-182 F11)
Pressure operating condition	1 atm
Temperature operating condition	240°C
Shell diameter	126 in
Total tank height	171.65 in
Impeller type	Flat Blade Turbine (Semi Open)
Motor type	Standard AC induction Motor
Motor power	384 kW
Shell thickness	0.75 in
Shell head	1 in
Shell material	Carbon steel (SA-182 F11)
Jacket height	171.65 in
Jacket thickness	0.75 in
Cooling System	Water

ATTACHMENT B

PROCESS FLOW DIAGRAM (PFD)

PROCESS FLOW DIAGRAM
PRELIMINARY PLANT DESIGN OF POLYETHYLENE TEREPHTHALATE FROM ETHYLENE GLYCOL AND POLY
TEREPHTHALIC ACID WITH 60,000 TON/YEAR CAPACITY



Component	Flow Rate (kg/hr)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PTA		6,556	6,556	6,556	6,556	656	656	656	656	656															
EG	2,716		4,859	4,859	4,859	490	490	490	490	490		2,182	2,182	2,182	2,182							2,182	2,182	2,182	
BHET						9,030	9,030	9,030	9,030	9,030	9,030														
H ₂ O		7	7	7	7	1,287	1,287	1,287	1,287	1,287															
Sh203												0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1				0.1
PET100												6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847	6,847
Total	2,716	6,563	11,462	11,462	11,462	11,462	11,462	11,462	11,462	2,432	9,030	9,030	9,030	9,030	9,030	9,030	9,030	9,030	9,030	9,030	9,030	2,182	2,182	2,182	0.1

Equipment	Description	Symbol
T	Tank	(Circle)
C	Conveyor	(Diamond)
M	Mixing Tank	(Circle with cross)
HE	Heat Exchanger	(Square with X)
R	Reactor	(Circle with dot)
CL	Cooler	(Circle with dot)
S	Separator	(Circle with dot)
CD	Condenser	(Circle with dot)
PL	Pelletizer	(Circle with dot)
PK	Packaging	(Circle with dot)
EX	Expander	(Circle with dot)
P	Pump	(Circle with dot)
B	Blower	(Circle with dot)

Symbol	Description
(TC)	Temperature Controller
(WI)	Weight Indicator
(U)	Utility
(LC)	Level Controller
(FC)	Flow Controller
(S)	Signal
(C)	Connection
(P)	Pneumatic
(V)	Valve
(D)	Disposal
(A)	Air
(E)	Environment

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PROCESS FLOW DIAGRAM
PRELIMINARY PLANT DESIGN OF POLYETHYLENE
TEREPHTHALATE FROM ETHYLENE GLYCOL AND
TEREPHTHALIC ACID WITH 60,000 TON/YEAR CAPACITY

By:
1. Mita Dian Cahyani (21521041)
2. Rahmatan Amartya Uta (21521117)

Supervisor: Dr. Kramdan Cahyani S.T., M.Sc.

ATTACHMENT C

FACTORY PRE-DESIGN GUIDANCE

CONSULTATION CARD

CONSULTATION ADVISORY FORM

1. Name of Student : Mita Dian Cahyani
Student ID : 21521041
2. Name of Student : Rahmatan Amartya Ula
Student ID : 21521117

Title of Project : Preliminary Plant Design of Polyethylene Terephthalate from Terephthalic Acid and Ethylene Glycol with Capacity 60,000 ton/year

Starting Advisory date : 16 October 2024

Last Advisory date : 2 June 2025

No	Date	Advisory Topic	Sign
1	16 October 2024	Selecting the Title	
2	13 November 2024	Define the capacity and process	
3	24 December 2024	PFD process selection	
4	20 January 2025	Mass Balance equation	
5	29 January 2025	Reactor Calculation	
6	3 February 2025	Heat Exchanger and Cooling calculation	
7	20 February 2025	Separator equation	
8	21 March 2025	Storage Equation	
9	25 March 2025	PFD Approval	
10	30 March 2025	Transportation Equipment	
11	2 April 2025	Define the Place and The Layout	
12	5 May 2025	Define the Organisation Structure	
13	8 May 2025	Approval Organisation	
14	15 May 2025	Layout of Machine	

15	19 May 2025	PFD of utility	JK
16	20 May 2025	Water needed of utility	JK
17	23 May 2025	Process Utility	JK
18	25 May 2025	Utility Approval	JK
19	2 June	Economy and Approval SCRIPT	JK

Approve by Advisor,
Yogyakarta, 2 June 2025



Dr. Khamdan Cahyari, S.T., M.Sc.