

**PRELIMINARY DESIGN OF CHEMICAL PLANT OF
N-PROPANOL FROM ETHYLENE AND SYNGAS
WITH CAPACITY OF 60,000 TON/YEAR**

PLANT PRELIMINARY DESIGN

**Submitted as One of the Requirements for Obtaining the Bachelor's Degree
in Chemical Engineering**



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2025

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**PRELIMINARY DESIGN OF CHEMICAL PLANT OF
N-PROPANOL FROM ETHYLENE AND SYNGAS WITH
CAPACITY OF 60,000 TON/YEAR**

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N-PROPANOL FROM ETHYLENE AND SYNGAS WITH

CAPACITY OF 60,000 TON/YEAR

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Declare that all the results of this Factory Preliminary Design are my work. If in the future it is proven that some parts of this work are not my work, then I am ready to bear any risks and consequences. Thus, I have made this statement letter, hopefully, it can be used as it should.



A handwritten signature in blue ink, appearing to read 'Des Try'.

Des Try Ashilah

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FOREWORD

The author prays for the presence of Almighty God for all the blessings and guidance that are always bestowed upon so that the author can complete this research report well. This plant preliminary design was prepared and submitted as one of the requirements for obtaining the bachelor's degree in Chemical Engineering Study Program, Faculty of Industrial Engineering, Islamic University of Indonesia.

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The author realizes that this plant preliminary design is still far from perfect, therefore the author expects constructive criticism and suggestions. The author hopes that this report will be useful for the author, readers, and society in general.

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Des Try Ashilah

ABSTRACT

The preliminary design of the n-propanol plant with a capacity of 60,000 tons/year uses ethylene, synthesis gas, and hydrogen as raw materials to produce n-propanol with a purity of 99%. The n-propanol manufacturing process is carried out using the Oxo process using rhodium-silica catalyst in a fixed bed multitube reactor, the reaction takes place in the gas phase at a temperature of 130 °C and a pressure of 20 atm. The location of the plant is planned in Serang, Banten. Economic evaluation shows a return on investment (ROI) of 73.5 % before tax and 55 % after tax, and a Pay Out Time (POT) before tax of 1.2 years. Feasibility analysis shows that this plant is technically and economically feasible. Considering the increasing demand for domestic n-propanol and the potential for reducing dependence on imports, the establishment of an n-propanol plant is considered a strategic step in supporting the Indonesian economy.

Keywords: n-Propanol; Oxo process; Plant preliminary design; Econoy analysis

CHAPTER I

INTRODUCTION

1.1 Background

The chemical industry sector is one of the main driving industries for national economic development, because it can make a significant contribution to increasing employment and foreign exchange, and to make a major contribution to the formation of national competitiveness. Advanced industrial development can reduce dependence on imports and accelerate the transfer of technology, increase production efficiency and productivity, as well as export commodities that have potential.

Recently, the chemical industry has continued to develop in an integrated manner. The rapid development of the downstream industry and also the semi-finished materials industry has been a driving force for the development of upstream industries. In other words, the needs for raw materials or raw material providers in the industrial sector are interrelated. Therefore, the development of the chemical industry must be balanced between the upstream industry, which provides raw materials, and the downstream industry, which will process these raw materials into products.

The development of the chemical industry continues to increase due to the increase in need and use of chemicals in Indonesia. One of the chemicals needed in Indonesia is n-propanol. N-propanol is a primary alcohol with the formula C_3H_8O that has the characteristics of being a colorless liquid, strong

alcoholic odor, and flammable. N-propanol has other names, namely 1-propanol, propan-1-ol, propyl alcohol, and 1-hydroxypropane. N-propanol is used in making cosmetics, perfume, dye solutions, antifreeze, soap, making acetone, and other chemical products (Kirk & Othmer, 1996).

The need for n-propanol in Indonesia is met by exporting from other countries. Therefore, the construction of an n-propanol factory in Indonesia is very necessary. It is hoped that it can help meet the needs of society and industry, also able to compete internationally, and increase the value of Indonesia's exports. Apart from that, the establishment of the factory aims to provide new jobs and encourage the establishment of other factories, especially those using n-propanol.

1.2 Capacity Determination

In determining the pre-design capacity of the factory, several factors are to be considered such as product needs, raw material availability, and minimum design capacity.

1.2.1 N-Propanol Needs in Indonesia

The n-propanol needs in Indonesia are met through imports.

The amount of imports from 2014 to 2023 can be seen in Table 1.1.

Table 1.1 Import data of n-propanol in Indonesia (Badan Pusat Statistik, 2024)

Year	Amount (ton/year)
2014	26,307
2015	26,799
2016	29,610
2017	30,618
2018	32,978
2019	33,700

Table 1.1 Import data of n-propanol in Indonesia (Badan Pusat Statistika, 2024)
(continuation)

Year	Amount (ton/year)
2020	35,370
2021	36,282
2022	37,162
2023	38,967

Based on the data above, predictions of the need for n-propanol in 2034 can be calculated using linear regression and compound annual growth rate (CAGR).

The results of the linear regression of n-propanol requirements can be seen in Figure 1.1.

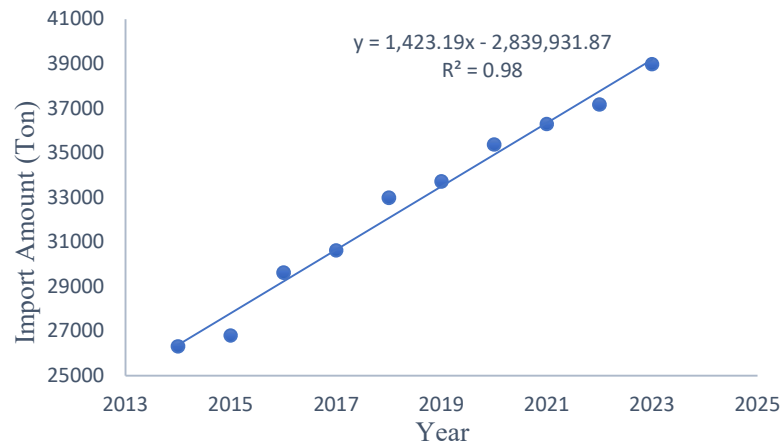


Figure 1.1 Graph of import data of n-propanol in Indonesia

Based on the graph of n-propanol needs in Indonesia above, it can be estimated that the need for n-propanol in Indonesia in 2034 is:

$$\begin{aligned}
 Y &= 1.423.19x - 2,839,931.87 \\
 &= 1.423.19 (2034) - 2,839,931.87 \\
 &= 54,836.590
 \end{aligned}$$

Using linear regression, the need for n-propanol in Indonesia in 2034 is estimated at 54,836.590 tons/year.

1.2.2 Raw Material Availability

Raw materials are a very important factor for the continuity of production in a factory. The main raw materials used are ethylene obtained from PT Chandra Asri Pacific Tbk (TPIA) which has a capacity of 900,000 tons/year, and syngas obtained from PT Krakatau Steel (Persero) Tbk. which has a capacity of 420,000 tons/year. Both companies are located in Cilegon, Banten, Indonesia.

1.2.3 Minimum Design Capacity

Data on the capacity of plants operating to produce n-propanol outside the country can be seen in Table 1.2.

Table 1.2 Capacity of operating n-propanol plant in another country (ChemAnalyst, 2023)

Company	Location	Capacity (Ton/year)
Oxea	Bay City, Texas	100,000
Nanjing Rongxin Chemical	China	40,000
Sinochem Holdings	China	80,000
Ningbo Juhua Chemical	China	50,000

The minimum design capacity of an n-propanol manufacturing plant can be determined from the existing capacity data of similar factories on a commercial scale. From the data above, it can be known that the minimum capacity for n-propanol manufacturing plant is 40,000 tons/year.

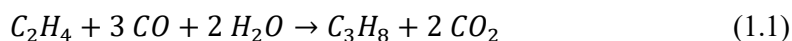
Based on several factors above that made into consideration, which include the amount of n-propanol needed in the future, raw materials availability, and the capacity of factories that have been established, the capacity of the n-propanol plant that will be established in 2034 is determined to be 60,000 tons/year.

1.3 Literature Review

N-Propanol is a colorless liquid at room temperature and atmospheric pressure, and can dissolve in alcohol and esters. N-Propanol can be made using several processes, such as Reppe process and Oxo process.

1.3.1 Reppe Process

The Reppe process is the synthesis of alcohol from olefins, carbon monoxide, and water. The technology for making n-propanol using this method was developed by Badische Anilin and Soda Factory A.G (BASF). Reaction that occurs:



The reaction was carried out at a temperature of 100 °C and a pressure of 15 atm with an Iron Hydrocarbonyl catalyst. The Reppe process has the advantages of lower reaction pressure and temperature, and high selectivity. However, its use is still small because the catalyst used is sensitive to the presence of water and CO₂. Apart from that, the process technology used is still more expensive. (McKetta, 1975)

1.3.2 Oxo Process

The Oxo process or hydroformylation was discovered by Otto Roelan in 1938. Roelan concluded that this reaction applies generally to all olefins, and this reaction was called the Oxo Process. Aldehydes are formed due to the addition of a formaldehyde group to the Olefin double bond, so this process is called hydroformylation.

With Oxo process, n-propanol is made through 2 stages. In the first stage is hydroformylation where ethylene is reacted with synthesis gas using metal from the transition group as catalyst. This process produces n-propanal. The catalysts used commercially are Co and Rh. However, Rh is preferred because it can operate at lower temperatures and pressures and has higher selectivity even though it is more expensive (McKetta, 1975). The reaction that occurs is:



(Kirk & Othmer, 1996)

In the second stage, n-propanal is reacted with hydrogen to become npropanol with a Ni (Nickel) or Rh (Rhodium) catalyst. The operation can take place in the liquid or gas phase. However, the liquid phase on a commercial scale is not widely used because it is less economical. The reaction that occurs is:



(Kirk & Othmer, 1996)

The overall comparison between both processes can be seen in Table

1.3.

Table 1.3 The comparison between Reppe process and Oxo process in several aspects

Parameter	Reppe Process	Oxo Process
Process	Synthesis of alcohol from olefin, carbon monoxide, and water.	Synthesis of alcohol by reacting hydrogen with aldehyde that synthesized from olefin and syngas.
Temperature	100 °C	90 – 170 °C
Pressure	15 atm	≤ 6.8 atm
Conversion	60%	98 – 99%
Catalyst	Not stable because of the presence of carbon dioxide and water.	Stable.
Product	Carbon dioxide as the by-product.	Ethane as the by-product.

From both Reppe process and Oxo process, the latter is chosen because of several advantages:

1. Higher conversion rate.
2. The catalyst is stable even with the presence of fluid in reaction.
3. The equipment is cheaper.
4. Majority of industry uses Oxo process.

1.4 Overview of Thermodynamics and Kinetics

1.4.1 Thermodynamics Overview

The overall reaction for this process is written in eq. 1.4.



The enthalpy of formation (ΔH_f) and the Gibbs free energy (ΔG_f) of the compound at 298 K that is involved in the process is presented in Table 1.4.

Table 1.4 The enthalpy formation and the Gibbs free energy of the compounds in the process at 298 K (Yaws, 1999)

Compound	ΔH_f (kJ/mol)	ΔG_f (kJ/mol)
C ₂ H ₄	52.30	68.12
CO	-110.54	-137.28
C ₃ H ₈ O	-257.53	-162.97
H ₂	0	0
C ₃ H ₆ O	-192.05	-130.46

The enthalpy of formation for other temperatures can be calculated with eq. 1.5.

$$\Delta H_f = A + BT + CT^2 \quad (1.5)$$

(Yaws, 1999)

Where A, B, and C are regression coefficients, and T is temperature.

The value of A, B, and C to calculate the enthalpy of formation for each component can be found in Table 1.5.

Table 1.5 Regression coefficient of the compounds in the process to calculate the enthalpy of formation (Yaws, 1999)

Compound	A	B	C
C ₂ H ₄	63.053	-4.1076E-02	1.6598E-05
CO	-112.190	8.1182E-03	-8.0425E-06
C ₃ H ₈ O	-233.953	-9.2123E-02	4.2848E-05
C ₃ H ₆ O	-175.519	-6.4417E-02	2.9498E-05

The Gibbs free energy for other temperatures can also be calculated with:

$$\Delta G_f = A + BT + CT^2 \quad (1.6)$$

(Yaws, 1999)

Where A, B, and C are regression coefficients, and T is temperature.

The value of A, B, and C to calculate Gibbs free energy for each component can be found in Table 1.6.

Table 1.6 Regression coefficient of the compounds in the process to calculate the Gibbs free energy (Yaws, 1999)

Compound	A	B	C
C ₂ H ₄	51.752	4.9338E-02	1.7284E-05
CO	-109.885	-9.2218E-02	1.4547E-06
C ₃ H ₈ O	-259.317	3.1232E-01	3.3063E-05
C ₃ H ₆ O	-193.326	2.0318E-01	2.3446E-05

The heat of reaction, $\Delta H_{\text{reaction}}$, and related heating and cooling requirements are all determined by the enthalpy of formation for individual compounds in chemical reactions. The chemical reaction is exothermic if $\Delta H_{\text{reaction}} < 0$, meaning cooling is required to keep the reaction temperature constant. If $\Delta H_{\text{reaction}} > 0$, the chemical reaction is endothermic, meaning that heating is necessary to carry it out (Yaws, 1999). The $\Delta H_{\text{reaction}}$ can be calculated with eq. 1.7.

$$\Delta H_{\text{reaction}} = \sum (n\Delta H_f)_{\text{products}} - \sum (n\Delta H_f)_{\text{reactants}} \quad (1.7)$$

(Yaws, 1999)

For hydroformylation reaction at 298 K, the $\Delta H_{\text{reaction}}$ can be calculated with ΔH_f from table 1.4.

$$\begin{aligned}
 \Delta H_{\text{reaction}} &= \Delta H_{f, \text{C}_3\text{H}_6\text{O}} - (\Delta H_{f, \text{C}_2\text{H}_4} + \Delta H_{f, \text{CO}} + \Delta H_{f, \text{H}_2}) \\
 &= -192.05 - (52.30 + (-110.54) + 0) \\
 &= -133.81 \text{ kJ/mol}
 \end{aligned}$$

The $\Delta H_{\text{reaction}}$ for hydroformylation at 298 K is -133.81 kJ/mol which means the process is exothermic and cooling is required to maintain the temperature.

For hydrogenation reaction at 298 K, the $\Delta H_{\text{reaction}}$ can be calculated with ΔH_f from table 1.4.

$$\begin{aligned}\Delta H_{\text{reaction}} &= \Delta H_{f, C_3H_8O} - (\Delta H_{f, C_3H_6O} + \Delta H_{f, H_2}) \\ &= -162.97 - ((-130.46) + 0) \\ &= -32.51 \text{ kJ/mol}\end{aligned}$$

The $\Delta H_{\text{reaction}}$ for hydrogenation at 298 K is -32.51 kJ/mol which means the process is exothermic and cooling is required to maintain the temperature.

In the study of chemical reactions, Gibbs energy of formation is crucial. Calculating the change in Gibbs energy for the reaction requires values for each compound (reactant and product). Because of the reaction's related chemical equilibrium, this change is noteworthy. The reaction's thermodynamics are favorable if the change in Gibbs energy is negative. On the contrary, the reaction's thermodynamics are unfavorable if the change in Gibbs energy is highly positive. The $\Delta G_{\text{reaction}}$ can be calculated with eq. 1.8.

$$\Delta G_{\text{reaction}} = \sum (n\Delta G_f)_{\text{products}} - \sum (n\Delta G_f)_{\text{reactants}} \quad (1.8)$$

(Yaws, 1999)

For hydroformylation reaction at 298 K, the $\Delta G_{\text{reaction}}$ can be calculated with ΔG_f from table 1.4.

$$\begin{aligned}\Delta G_{\text{reaction}} &= \Delta G_{f, C_3H_6O} - (\Delta G_{f, C_2H_4} + \Delta G_{f, CO} + \Delta G_{f, H_2}) \\ &= -130.46 - (68.12 + (-137.28) + 0) \\ &= -61.3 \text{ kJ/mol}\end{aligned}$$

The $\Delta G_{\text{reaction}}$ for hydroformylation at 298 K is -61.3 kJ/mol which means the process is spontaneous.

For hydrogenation reaction at 298 K, the $\Delta G_{\text{reaction}}$ can be calculated with ΔG_f from table 1.4.

$$\begin{aligned}\Delta G_{\text{reaction}} &= \Delta G_{f, C_3H_8O} - (\Delta G_{f, C_3H_6O} + \Delta G_{f, H_2}) \\ &= -162.97 - ((-137.28) + 0) \\ &= -25.69 \text{ kJ/mol}\end{aligned}$$

The $\Delta G_{\text{reaction}}$ for hydrogenation at 298 K is -25.69 kJ/mol which means the process is spontaneous.

An equilibrium constant is a value that describes the ratio of concentrations or pressures at which two opposing chemical reactions reach equilibrium. It quantifies how much each reaction favors products over reactants and has units specific to the system being studied, such as moles per liter for concentrations or atmospheres for pressures (Laidler, 1990; Monazam et al., 2010). If the equilibrium constant is positive ($K > 1$) means that the reaction

is favorable towards the product. The equilibrium constant (K) can be calculated with eq. 1.9.

$$K = \exp\left(\frac{-\Delta G_{reaction}}{RT}\right) \quad (1.9)$$

(Van Ness et al., 2017)

Where R is the gas constant and T is the temperature.

The correlation between an equilibrium constant at one temperature and with equilibrium constant at another temperature can be calculated with eq. 1.10.

$$\ln \frac{K}{K'} = -\frac{\Delta H_{reaction}}{R} \left(\frac{1}{T} - \frac{1}{T'} \right) \quad (1.10)$$

(Van Ness et al., 2017)

For the equilibrium constant of hydroformylation at 298 K can be calculated by:

$$\begin{aligned} K &= \exp\left(\frac{-(-61.3)}{0.008314 \times 298}\right) \\ &= 5.56 \times 10^{10} \end{aligned}$$

For the equilibrium constant of hydrogenation at 298 K can be calculated by:

$$\begin{aligned} K &= \exp\left(\frac{-(-25.69)}{0.008314 \times 298}\right) \\ &= 3.07 \times 10^4 \end{aligned}$$

Both of the reactions has a large value of equilibrium constant. Large value of equilibrium constant means that the system prefers to

stay in its product state, making it less likely to revert back to starting materials (Atkins et al., 2018).

1.4.2 Kinetics Overview

The rate constant (k) is a crucial parameter in chemical kinetics that quantifies the relationship between the rate of a reaction and the concentrations of its reactants. The rate constant can be calculated with Arrhenius equation eq. 1.11

$$k = A \exp\left(\frac{-E}{RT}\right) \quad (1.11)$$

(Davis & Davis, 2003)

Where A is the frequency factor and E is the activation energy required for the reaction to occur. For the hydrogenation reaction, the E is 7.8 kJ/mol and the A is 175.915 (Oldenburg & Rase, 1957). The rate constant for the hydrogenation process at 423.15 K can be calculated by:

$$\begin{aligned} k &= 175.915 \exp\left(\frac{-7.8 \times 10^3}{82.05745 \times 423.15}\right) \\ &= 140.522 \frac{cm^3}{mol.h} \end{aligned}$$

The correlation between an equilibrium constant at one temperature with equilibrium constant at another temperature can be calculated with eq. 1.12

$$\frac{k_1}{k_2} = \exp\left[\left(-\frac{E}{R}\right)\left(\frac{T_1 T_2}{T_1 - T_2}\right)\right] \quad (1.12)$$

(Davis & Davis, 2003)

For hydroformylation process at 369 K, the value of E is 79.6 kJ/mol and the value of k is $3.02 \times 10^{-2} \text{ m}^3/\text{mol.s}$ (Siradze et al., 2021). The value of k for hydroformylation process at 393.15 K can be calculated by:

$$k_1 = 3.02 \times 10^{-2} \exp \left[\frac{-79.6}{8.2057 \times 10^{-5}} \left(\frac{393.15 \times 369}{393.15 - 369} \right) \right]$$

$$= 311,726 \frac{\text{m}^3}{\text{mol.s}}$$

The reaction rate (r) is a measure of the speed at which a chemical reaction occurs, defined as the change in concentration of reactants or products per unit time. The reaction rate can be calculated with eq. 1.13.

$$r = k[A]^a[B]^b[C]^c \quad (1.13)$$

(Davis & Davis, 2003)

Where a, b, and c are the reaction orders with respect to reactants A, B, and C, respectively.

CHAPTER II

PRODUCT DESIGN

2.1 Product Specification

2.1.1 N-Propanol

Chemical formula	: C ₃ H ₈ O
Molecular weight	: 60.09 g/mol
Form	: Liquid
Colour	: Colourless
Odour	: Alcohol-like
Freezing point	: -126.2 °C
Boiling point	: 97.20 °C
Flash point	: 28.9 °C
Vapour pressure	: 28.2 hPa (25 °C)
Density	: 0.80375 g/cm ³ (20 °C)
Vapour density	: 2.07 (20 °C)
Viscosity	: 2.3 mPa.s (20 °C)
Critical temperature	: 263.65 °C
Critical pressure	: 5169.60 kPa

(BASF, 2024; Kirk & Othmer, 1996)

Purity	: ≥ 99% w/w
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2.2 Raw Material Specification

2.2.1 Ethylene

Chemical formula	: C ₂ H ₄
Molecular weight	: 28.0536 g/mol
Form	: Gas at ambient conditions
Colour	: Colourless
Odour	: Gassy/aromatic
Solubility in water	: Negligible
Boiling point	: -103.77 °C
Flash point	: -136 °C
Relative density	: 0.5678 (104 °C)
Vapour density	: 0.975 (20 °C)
Viscosity	: 1.06 cSt (-170 °C)
Critical temperature	: 9.194 °C
Critical pressure	: 5040.8 kPa
Concentration	: ≥ 99.95 %vol

(Chandra Asri, 2023; Kirk & Othmer, 1996)

2.2.2 Syngas

Composition	: 60 % H ₂
	37 % CO
	2 % N ₂
	1 % CH ₄
Form	: Compressed gas

Colour	: Colourless
Melting point	: < -180 °C
Boiling point	: < -160 °C
Ignition temperature	: > 500 °C
Density	: < 1.25 g/L (0 °C)

(BASF, 2025)

2.2.3 Hydrogen

Chemical formula	: H ₂
Molecular weight	: 2.02 g/mol
Form	: Gas at ambient conditions
Colour	: Colourless
Solubility in water	: 0.00196 g/L (0 °C)
Boiling point	: -252.8 °C
Melting point	: -259.2 °C
Density	: 0.09 g/L (0 °C)
Relative vapor density	: 0.08
Concentration	: ≥ 99.99 %

(Sigma-Aldrich, 2024)

2.3 Catalyst Specification

2.3.1 Rhodium-Silica

Chemical formula	: Rh/SiO ₂
Molecular weight	: 102.91 g/mol
Density	: 12.41 g/cm ³

Appearance	: Gray pellets or powder
Melting point	: 1966 °C
Boiling point	: 3727 °C

(American Elements, 2024)

2.3.2 Nickel-Kieselguhr

Chemical formula	: Ni/Kieselguhr
Molecular weight	: 58.71 g/mol
Appearance	: Light gray powder

(Oakwood Chemical, 2025)

2.4 Quality Control

Quality control at this n-propanol factory includes raw material quality control, process quality control, and product quality control.

2.4.1 Raw Material Quality Control

Raw material quality control refers to the systematic processes and methodologies implemented to ensure that chemical raw materials meet specified standards for purity, composition, and performance before they are used in manufacturing. This involves several key components, such as supplier evaluation, testing, and compliance with standards. Effective quality control of chemical raw materials is crucial for preventing defects in final products, ensuring safety, and maintaining regulatory compliance in industries

such as pharmaceuticals, food production, and manufacturing (Li et al., 2022; Misra, 2015)

2.4.2 Process Quality Control

Control of this plant production process includes flow system control and control system tools.

a. Flow System Control

1. Sensors, which are used to identify process variables. The tools used are a manometer for fluid flow, pressure and level sensors, and a thermocouple for temperature sensors.
2. Controllers and Indicators, including level indicators and control, temperature indicator control, pressure control, and flow control.
3. Actuators, which are used to manipulate variables so that they are the same as the controller variables. The tools used are an automatic control valve and a manual hand valve.

b. Control System Tools

1. Pneumatic flow (compressed air flow) is used for the valve where it controls from the controller to the actuator.
2. Electric flow is used for temperature where it controls from the sensor to the controller.
3. Mechanical flow (movement flow/level transfer) is used for flow where it controls from the sensor to the controller.

2.4.3 Product Quality Control

Product quality control is a critical aspect of manufacturing and service industries, ensuring that products meet specified standards and consumer expectations. This process involves systematic measures to monitor and manage the quality of products throughout their production lifecycle (Wang et al., 2023).

The use of vision systems in quality control has gained traction, allowing for enhanced monitoring of manufacturing parameters. These systems employ imaging and image analysis to detect defects and ensure product quality, with advancements in resolution and imaging frequency contributing to their effectiveness (Sioma, 2023).

CHAPTER III
PROCESS DESIGN

3.1 Process and Material Flow Diagram

3.1.1 Qualitative Flow Diagram

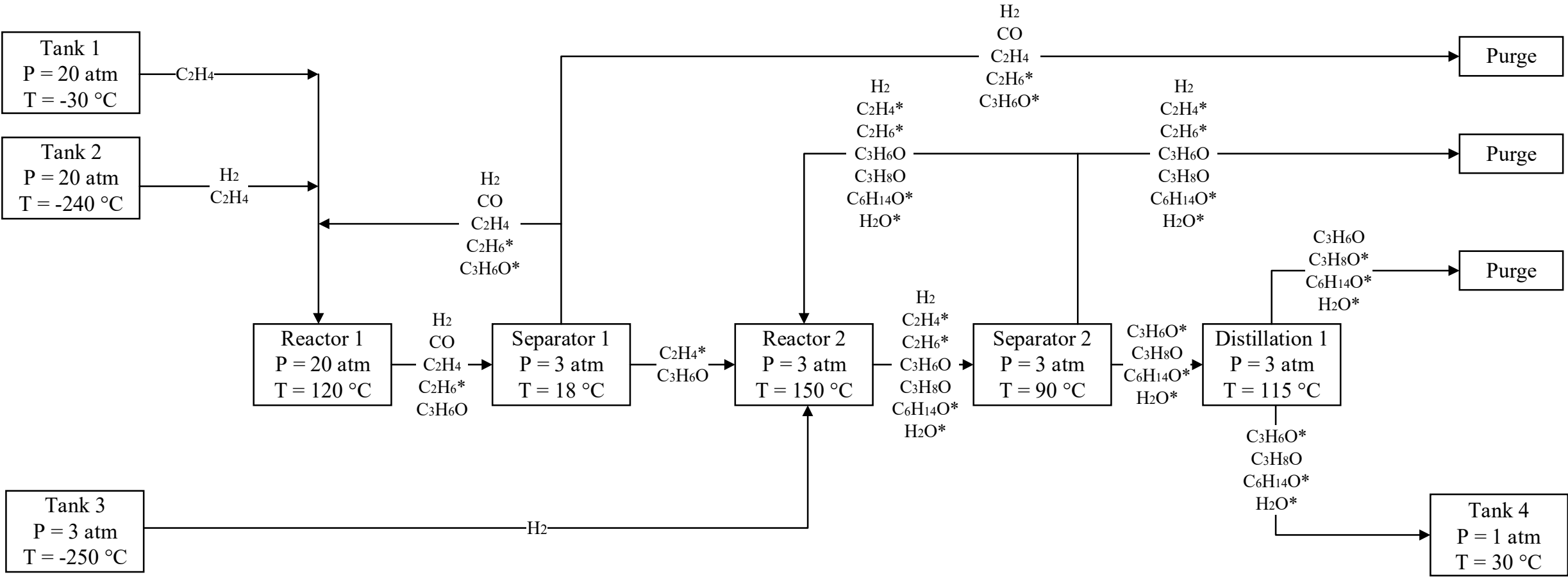
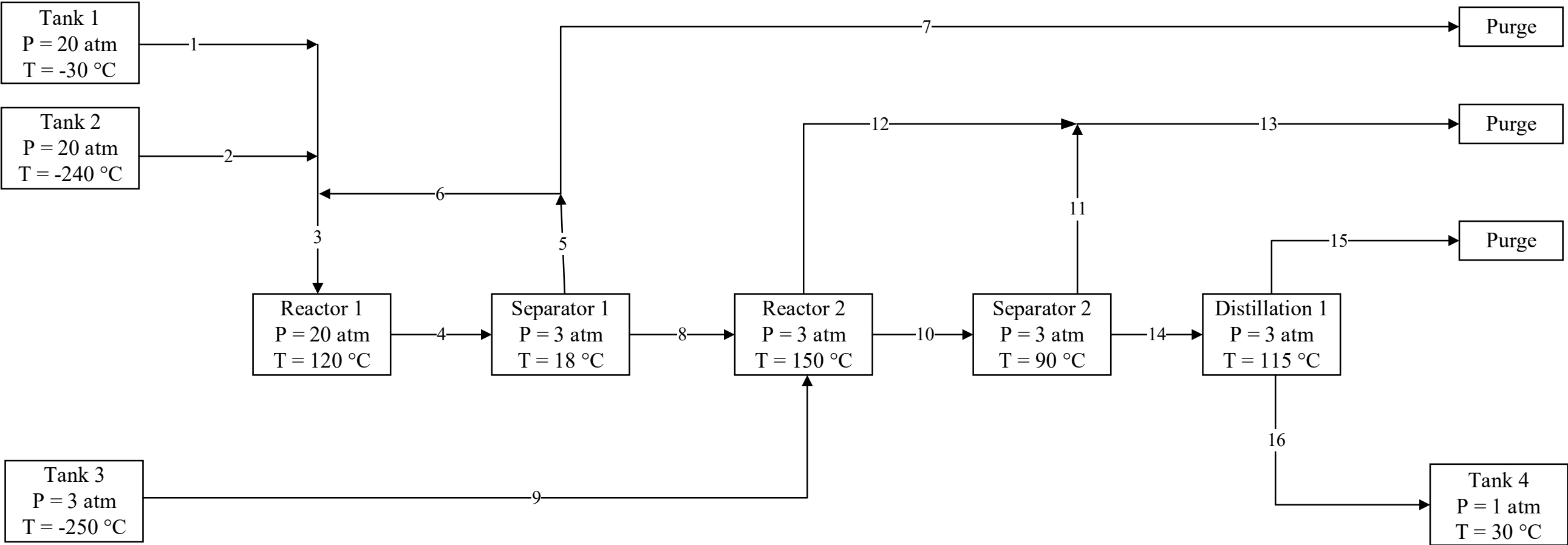


Figure 3.1 Qualitative flow diagram

3.2 Quantitative Flow Diagram



Component	Flow Rate (kg/h)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
H ₂	316		410	119	119	94	26		265	20	20	18	2			
CO	4,337		5,638	1,656	1,656	1,301	355									
C ₂ H ₄		4,127	4,343	291	276	217	59	15		16	13	12	2	3	3	
C ₂ H ₆			179	249	227	179	48	21		99	74	66	8	25	25	
C ₃ H ₆ O			506	8,762	644	506	138	8,118		593	30	27	3	562	561	2
C ₆ H ₁₄ O										67	1	1	0	66	19	47
C ₃ H ₈ O										7,785	55	50	5	7,730	155	7,576
H ₂ O										12	0	0	0	12		11
Total	4,653	4,127	11,077	11,077	2,923	2,297	626	8,154	265	8,592	194	173	21	8,399	763	7,636

Figure 3.2 Quantitative flow diagram

3.3 Process Description

The ethylene raw material is evaporated using E-101 and its temperature is raised using E-102 until the gas is at 100 °C as feed for R-101. The same treatment is also carried out on the liquid syngas raw material which is evaporated using E-103 and its temperature is raised using E-102 until the gas is at 100 °C as feed for R-101.

The reaction between ethylene-synthesis gas occurs in a fixed bed multitube reactor with Rh-Silica catalyst (5% Rh - 95% Silica). The reaction takes place in the gas phase isothermally and non-adiabatically. This reaction takes place endothermically so a coolant is needed. The coolant used is water at a pressure of 20 atm. The gas mixture coming out of R-01 has a temperature of 130 °C and a pressure of 20 atm.

The mixed gas product exiting R-101, its pressure and temperature are reduced, the initial pressure of 20 atm is reduced to 3 atm and the initial temperature of 120 °C is reduced to 18 °C using C-101. The product is separated in V-101. The gas exiting V-101 is partly recycled to R-101 and partly diverted to purge. The recycled gas was compressed using C-102 and experienced a temperature increase to 162 °C which was then cooled to 100 °C using E-105. The liquid product is evaporated using E-106 to change the liquid phase of propionaldehyde into the gas phase which will be used as feed for R-102. Before the feed enters R-02, the feed temperature is first increased from 18 °C to 100 °C using E-109.

The hydrogen raw material is evaporated using E-107 and its temperature is raised using E-108 until the gas is at 90 °C as feed for R-102. Before the feed enters R-02, the feed temperature is first increased from 18 °C to 100 °C using E-109.

The gas product coming out of R-102 has a pressure of 3 atm and a temperature of 150 °C. The product is condensed using E-110. The gas-liquid mixture coming out of E-110 is separated using V-102 at a pressure of 3 atm and a temperature of 90 °C. The gas coming out of V-102 is partly recycled to R-102 and partly diverted to purge. The recycled gas was then heated to 100 °C using E-109. The liquid is evaporated using E-111 to change the liquid phase of n-propanol into the gas phase which will be used as feed for T-101 that operates in 3 atm and the temperature of 133 °C for bottom part and 93 °C for top part.

The top product of T-101 at a pressure of 3 atm and 93 °C will be condensed in E-112 and will partially re-enter T-101 and the rest will go into purge. The bottom product of T-101 at a pressure of 3 atm and 133 °C will be reboiled in E-113 and will partially re-enter T-101 and the rest will go to P-101 A/B to decrease its pressure to 1 atm and then cooled to 30 °C with E-114 which then will be stored in TK-104 in ambient temperature and condition

3.4 Equipment Specification

3.4.1 Reactor 01

General Specification

Code : R-101

Function : Place to react ethylene and syngas t

to become propionaldehyde

Type	: Fixed bed multitube
Operating mode	: Continuous
No. of equipment	: 1 reactor
Price, Rp	: Rp 1,596,566,662

Operating Conditions

Temperature, °C	: 120 °C
Pressure, atm	: 20 atm
Process condition	: Non-adiabatic and non-isothermal

Construction and Materials

Construction materials	: Carbon Steel SA-212 Grade B
Shell diameter (ID), m	: 2.769 m
Shell thickness, in.	: 1.5 in.
Total height, m	: 9.049 m
Head type	: Elliptical dished head

Insulation

Material	: Asbestos
Heat conductivity, W/m.K	: 0.192 W/m.K
Insulation thickness, m	: 0.065 m

Special Specifications

Types of catalysts	: Rhodium-Silica
Catalyst shape	: Sphere
Catalyst size, mm	: 4.3 mm

Stack height, m	: 7.455 m
Porosity of the pile	: 0.954
WHSV, /hour	: 1.017/h
Pressure drop, atm	: 0.015 atm

Tube dimensions

Construction material : Stainless steel

Outside diameter, in : 1.9 in.

Inside diameter, in : 1.61 in.

Length, m : 7.455 m

Quantity : 1940 pcs

Pitch type : Triangle pitch

Pitch size, in. : 2.375 in.

Coolant type : Water

Coolant needs : 31,339 kg/h

3.4.2 Reactor 02

General Specification

Code	: R-102
Function	: Place to react propionaldehyde and hydrogen to become n-propanol
Type	: Fixed bed multitube
Operating mode	: Continuous
No. of equipment	: 1 reactor
Price, Rp	: Rp 1,289,534,611

Operating Conditions

Temperature, °C	: 150 °C
Pressure, atm	: 3 atm
Process condition	: Non-adiabatic and non-isothermal

Construction and Materials

Construction materials	: Carbon Steel SA-283 Grade A
Shell diameter (ID), m	: 2.718 m
Shell thickness, in.	: 0.5 in.
Total height, m	: 33.657 m
Head type	: Elliptical dished head

Insulation

Material	: Asbestos
Heat conductivity, W/m.K	: 0.192 W/m.K
Insulation thickness, m	: 0.093 m

Special Specifications

Types of catalysts	: Nieckel-Kieselguhr
Catalyst shape	: Sphere
Catalyst size, mm	: 4.55 mm
Stack height, m	: 32.120 m
Porosity of the pile	: 0.923
WHSV, /hour	: 1.389/h
Pressure drop, atm	: 0.200 atm
Tube dimensions	

Construction material : Carbon Steel

Outside diameter, in : 1.66 in.

Inside diameter, in : 1.38 in.

Length, m : 32.120 m

Quantity : 2400 pcs

Pitch type : Triangle pitch

Pitch size, in. : 2.075 in.

Coolant type : Water

Coolant needs : 21,358 kg/h

3.4.3 Distillation Tower 01

General Specification

Code : T-101

Function : Place to separate n-propanol from
other component and syngas to

Type : Multistage distillation

Operating type : Tray distillation column

Material : Carbon Steel SA-283 Grade A

No. of equipment : 1

Price, Rp : Rp 25,997,938,868

Operating Conditions

Feed

Temperature, °C : 116.568 °C

Pressure, atm : 3 atm

Condition : Saturated liquid

Distillate

Temperature, °C : 93.4 °C

Pressure, atm : 3.136 atm

Bottom

Temperature, °C : 133 °C

Pressure, atm : 3.340 atm

Specification

Shell

Diameter, m : 1.067 m

Height, m : 20.515 m

Thickness, in. : 0.25 in.

Material : Carbon Steel SA-283 Grade A

Head

Type : Elliptical dished

Thickness, in. : 0.25 in.

Material : Carbon Steel SA-283 Grade A

Tray

Tray type : Sieve plate

Total of actual plates : 23 stages

Hole arrangement : Triangular pattern

Hole diameter, mm : 5 mm

Tray spacing, m : 0.6 m

Total of holes : 3460 pcs

3.4.4 Separator 01

General Specification

Code : V-101

Function : Separate propionaldehyde from
other components

Type : Vertical drum

Material : Carbon Steel SA-283 Grade A

No. of equipment : 1

Price, Rp : Rp 241,787,740

Operating Conditions

Temperature, °C : 11 °C

Pressure, atm : 3 atm

Specification

Shell

Height, m : 3.210 m

Thickness, in. : 0.25 in.

Outside diameter, m : 0.914v m

Head

Height, m : 0.205 m

Thickness, in. : 0.25 in.

3.4.5 Separator 02

General Specification

Code	: V-02
Function	: Separate n-propanol from other components
Type	: Vertical drum
Material	: Carbon Steel SA-283 Grade A
No. of equipment	: 1
Price, Rp	: Rp 216,841,386

Operating Conditions

Temperature, °C	: 90 °C
Pressure, atm	: 3 atm

Specification

Shell

Height, m	: 3.590 m
Thickness, in.	: 0.25 in.
Outside diameter, m	: 0.914 m

Head

Height	: 0.271 m
Thickness, in.	: 0.25 in.

3.4.6 Storage Tank 01

General Specification

Code	: TK-101
------	----------

Function	: Place to store ethylene as the raw material
Storage time	: 7 days
Phase	: Liquid
Type	: Sphere
No. of equipment	: 1
Price, Rp	: Rp 3,837,900,630

Operating Conditions

Temperature, °C	: -30 °C
Pressure, atm	: 20 atm

Specification

Material	: Alloy Steel SA-203 Grade E
Volume, m ³	: 3202.561 m ³
Diameter, m	: 18.288 m
Thickness, in.	: 4.5 in.

3.4.7 Storage Tank 02

General Specification

Code	: TK-102
Function	: Place to store syngas as the final product
Storage time	: 7 days
Phase	: Liquid
Type	: Sphere

No. of equipment	: 1
Price, Rp	: Rp 3,837,900,630

Operating Conditions

Temperature, °C	: -240 °C
Pressure, atm	: 20 atm

Specification

Material	: Alloy Steel SA-353
Volume, m ³	: 3202.561 m ³
Diameter, m	: 18.288 m
Thickness, in.	: 3.5 in.

3.4.8 Storage Tank 03

General Specification

Code	: TK-103
Function	: Place to store hydrogen as the raw material
Storage time	: 7 days
Phase	: Liquid
Type	: Cylinder
No. of equipment	: 1
Price, Rp	: Rp 8,165,133,590

Operating Conditions

Temperature, °C	: -250 °C
Pressure, atm	: 3 atm

Specification

Material	: Stainless steel AISI type 304
Volume, m ³	: 1639.711 m ³
Diameter, m	: 14.630 m
Thickness, in.	: 0.5 in.

3.4.9 Storage Tank 04**General Specification**

Code	: TK-104
Function	: Place to store n-propanol as the final product
Storage time	: 7 days
Phase	: Liquid
Type	: Cylinder (vertical)
No. of equipment	: 1
Price, Rp	: Rp 3,354,325,151

Operating Conditions

Temperature, °C	: 30 °C
Pressure, atm	: 1 atm

Specification

Material	: Carbon Steel SA-283 Grade A
Volume, m ³	: 2132.330 m ³
Diameter, m	: 15.24 m
Height, m	: 13.133 m

Total course : 36

Thickness, in. : 0.75 in.

3.4.10 Expander 01

Code : C-101

Function : Decrease the pressure of product of R-01

Capacity, m³/h : 32.155 m³/h

Site elevation, m : 0 m

Price, Rp : Rp 47,973,758

Operating Conditions

Temperature in, °C : 120 °C

Temperature out, °C : 20 °C

Pressure in, bar : 21.277 bar

Pressure out, bar : 4.052 bar

Specification

Expansion ratio : 5.250

Stage : Multi-stage (2 stages)

Volumetric efficiency : 76%

Type : Positive displacement

Minimum RPM : 281 RPM

Actual RPM : 485 RPM

Motor power, W : 2044.055 W

Material : Carbon Steel SA-212 Grade B

3.4.11 Compressor 01

General Specification

Code	: C-102
Function	: Increase the pressure of recycle to R-01
Capacity, m ³ /h	: 32.155 m ³ /h
Site elevation, m	: 0 m
Price, Rp	: Rp 47,973,758

Operating Conditions

Temperature in, °C	: 18 °C
Temperature out, °C	: 162.080 °C
Pressure in, bar	: 4.052 bar
Pressure out, bar	: 21.277 bar

Specification

Compression ratio	: 5.250
Stage	: Multi-stage (2 stages)
Volumetric efficiency	: 77%
Type	: Positive displacement
Minimum RPM	: 590 RPM
Actual RPM	: 690 RPM
Motor power, W	: 2991.633 W
Material	: Carbon Steel SA-212 Grade B

3.4.12 Pump 01**General Specification**

Code	: P-101 A/B
Function	: Decrease the pressure of n-propanol from T-101
Viscosity, mPa.s	: 0.010 mPa.s
Capacity, m ³ /h	: 13.305 m ³ /h
Pump head, m	: 34.903 m
Temperature, °C	: 133.268 °C
Motor power, W	: 2237.1 W
Material	: Carbon steel SA-283 Grade A
Price, Rp	: Rp 145,840,224

Table 3.1 Heat exchanger design specification

Code	E-101					Code	E-102				
Function	To vaporize ethylene from TK-101					Function	To heat ethylene from E-101				
Type	Double pipe					Type	Double pipe				
Price	Rp 34,541,106					Price	Rp 28,784,255				
Operating Conditions											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	Air		Fluid	Ethylene		Fluid	Water		Fluid	Ethylene	
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	10,335	2,067	Liquid flowrate, kg/h	2,462	2,462	Liquid flowrate, kg/h	-	-
Vapor flowrate, kg/h	22,919	22,919	Vapor flowrate, kg/h	-	8,268	Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	4,650	4,650
Temperature, °C	30	150	Temperature, °C	-30	-28	Temperature, °C	213	30	Temperature, °C	-28	100
Pressure, atm	20	20	Pressure, atm	20	20	Pressure, atm	20	20	Pressure, atm	20	20
Mechanical Design											
Length, ft	16		Length, ft	16		Length, ft	12		Length, ft	12	
Hairpin	3		Hairpin	3		Hairpin	2		Hairpin	2	
ID, in.	12.09		ID, in.	4.026		ID, in.	6.065		ID, in.	4.026	
			OD, in.	4.5					OD, in.	4.5	
			A, in. ²	12.730					A, in. ²	12.730	
			BWG	16					BWG	16	
ΔP _{cal} /ΔP _{allow}	0.453		ΔP _{cal} /ΔP _{allow}	0.048		ΔP _{cal} /ΔP _{allow}	0.001		ΔP _{cal} /ΔP _{allow}	0.164	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	
Code	E-103					Code	E-104				
Function	To vaporize syngas from TK-101					Function	To heat syngas from E-102				
Type	Double pipe					Type	Double pipe				
Price	Rp 28,784,255					Price	Rp 34,541,106				
Operating Conditions											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	Air		Fluid	Syngas		Fluid	Water		Fluid	Syngas	
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	6,532	1,306	Liquid flowrate, kg/h	5,748	5,748	Liquid flowrate, kg/h	-	-
Vapor flowrate, kg/h	17,672	17,672	Vapor flowrate, kg/h	-	5,226	Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	5,226	5,226
Temperature, °C	30	150	Temperature, °C	-240	-231	Temperature, °C	213	30	Temperature, °C	-231	100
Pressure, atm	20	20	Pressure, atm	20	20	Pressure, atm	20	20	Pressure, atm	20	20
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	16		Length, ft	16	
Hairpin	2		Hairpin	2		Hairpin	3		Hairpin	3	
ID, in.	10.02		ID, in.	3.068		ID, in.	6.065		ID, in.	4.026	
			OD, in.	3.5					OD, in.	4.5	
			A, in. ²	7.40					A, in. ²	12.730	
			BWG	16					BWG	16	
ΔP _{cal} /ΔP _{allow}	0.393		ΔP _{cal} /ΔP _{allow}	0.069		ΔP _{cal} /ΔP _{allow}	0.006		ΔP _{cal} /ΔP _{allow}	0.059	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	

Table 3.1 Heat exchanger design specification (continuation)

Code	E-105					Code	E-106				
Function	To cool down recycle to R-101					Function	To vaporize propionaldehyde from V-101				
Type	Double pipe					Type	Shell and tube				
Price	Rp 30,703,205					Price	Rp 506,602,883				
Operating Conditions											
Position	Annulus		Position	Tube		Position	Shell		Position	Tube	
Fluid	Water		Fluid	Syngas		Fluid	Propionaldehyde		Fluid	Steam	
Fluid type	Cold		Fluid type	Hot		Fluid type	Cold		Fluid type	Hot	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate, kg/h	2,689	2,689	Liquid flowrate, kg/h	-	-	Liquid flowrate, kg/h	10,296	2,059	Liquid flowrate, kg/h	-	2,834
Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	4,573	4,573	Vapor flowrate, kg/h	-	8,237	Vapor flowrate, kg/h	2,834	-
Temperature, °C	30	140	Temperature, °C	162	-28	Temperature, °C	18	90	Temperature, °C	134	134
Pressure, atm	20	20	Pressure, atm	20	20	Pressure, atm	3	3	Pressure, atm	3	3
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	8		Length, ft	8	
Hairpin	2		Hairpin	2		Passes	2		Passes	2	
ID, in.	7.981		ID, in.	6.065		ID, in.	29		OD, in.	1.5	
			OD, in.	6.625		Baffle spaces, in.	4		Number	127	
			A, in. ²	50.027					BWG	16	
			BWG	16					Pitch, in.	1.875	
ΔP _{cal} /ΔP _{allow}	0.001		ΔP _{cal} /ΔP _{allow}	0.019		ΔP _{cal} /ΔP _{allow}	0.141		ΔP _{cal} /ΔP _{allow}	0.004	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	
Code	E-107					Code	E-108				
Function	To vaporize hydrogen from TK-103					Function	To heat hydrogen from E-107				
Type	Double pipe					Type	Double pipe				
Price	Rp 21,108,453					Price	Rp 28,784,255				
Operating Conditions											
Position	Annulus		Position	Tube		Position	Annulus		Position	Tube	
Fluid	Steam		Fluid	Hydrogen		Fluid	Water		Fluid	Hydrogen	
Fluid type	Hot		Fluid type	Cold		Fluid type	Hot		Fluid type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate, kg/h	-	76	Liquid flowrate, kg/h	364	73	Liquid flowrate, kg/h	4,850	4,850	Liquid flowrate, kg/h	-	-
Vapor flowrate, kg/h	76	-	Vapor flowrate, kg/h	-	291	Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	291	291
Temperature, °C	134	134	Temperature, °C	-250	-248	Temperature, °C	134	134	Temperature, °C	-248	90
Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	12		Length, ft	12	
Hairpin	2		Hairpin	2		Hairpin	2		Hairpin	2	
ID, in.	2.067		ID, in.	1.38		ID, in.	4.026		ID, in.	3.068	
			OD, in.	1.66					OD, in.	3.5	
			A, in. ²	1.495					A, in. ²	7.40	
			BWG	16					BWG	16	
ΔP _{cal} /ΔP _{allow}	0.849		ΔP _{cal} /ΔP _{allow}	0.083		ΔP _{cal} /ΔP _{allow}	0.091		ΔP _{cal} /ΔP _{allow}	0.32	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	

Table 3.1 Heat exchanger design specification (continuation)

Code	E-109					Code	E-110				
Function	To heat material of R-102					Function	To condense product of R-102				
Type	Double pipe					Type	Shell and tube				
Price	Rp 24,946,354					Price	Rp 1,510,213,898				
Operating Conditions											
Position	Annulus		Position	Tube		Position	Shell		Position	Tube	
Fluid	Water		Fluid	Propionaldehyde Hydrogen		Fluid	n-Propanol		Fluid	Water	
Fluid type	Hot		Fluid type	Cold		Fluid type	Hot		Fluid type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate, kg/h	6,335	6,335	Liquid flowrate, kg/h	-	-	Liquid flowrate, kg/h	-	8,859	Liquid flowrate, kg/h	4,936	4,936
Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	10,742	10,742	Vapor flowrate, kg/h	11,074	2,215	Vapor flowrate, kg/h	-	-
Temperature, °C	134	110	Temperature, °C	90	100	Temperature, °C	150	90	Temperature, °C	30	120
Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	24		Length, ft	24	
Hairpin	2		Hairpin	2		Passes	2		Passes	2	
ID, in.	4.026		ID, in.	3.068		ID, in.	37		OD, in.	1.5	
			OD, in.	3.5		Baffle spaces, in.	4		Number	220	
			A, in. ²	7.40					BWG	16	
			BWG	16					Pitch, in.	1.875	
ΔP _{cal} /ΔP _{allow}	0.108		ΔP _{cal} /ΔP _{allow}	0.203		ΔP _{cal} /ΔP _{allow}	0.308		ΔP _{cal} /ΔP _{allow}	0.011	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	
Code	E-111					Code	E-112				
Function	To vaporize n-propanol as feed to T-101					Function	To condense distillate of T-101				
Type	Shell and tube					Type	Shell and tube				
Price	Rp 385,709,013					Price	Rp 483,575,479				
Operating Conditions											
Position	Shell		Position	Tube		Position	Shell		Position	Tube	
Fluid	n-Propanol		Fluid	Water		Fluid	n-Propanol Propionaldehyde		Fluid	Air	
Fluid type	Cold		Fluid type	Hot		Fluid type	Hot		Fluid type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate, kg/h	10,583	2,117	Liquid flowrate, kg/h	2,584	2,584	Liquid flowrate, kg/h	-	811	Liquid flowrate, kg/h	-	-
Vapor flowrate, kg/h	-	8,466	Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	1,014	203	Vapor flowrate, kg/h	640	640
Temperature, °C	90	115	Temperature, °C	134	60	Temperature, °C	89	133	Temperature, °C	30	50
Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	8		Length, ft	8	
Passes	2		Passes	2		Passes	2		Passes	2	
ID, in.	27		OD, in.	1.5		ID, in.	27		OD, in.	1.5	
Baffle spaces, in.	4		Number	108		Baffle spaces, in.	4		Number	108	
			BWG	16					BWG	16	
			Pitch, in.	1.875					Pitch, in.	1.875	
ΔP _{cal} /ΔP _{allow}	0.165		ΔP _{cal} /ΔP _{allow}	0.004		ΔP _{cal} /ΔP _{allow}	0.003		ΔP _{cal} /ΔP _{allow}	0.0003	
Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1		Rd _{cal} /Rd _{allow}	1	

Table 3.1 Heat exchanger design specification (continuation)

Code	E-113					Code	E-114				
Function	To reboil reflux to T-101					Function	To cool down final product to TK-104				
Type	Shell and tube					Type	Shell and tube				
Price	Rp 470,142,827					Price	Rp 683,146,312				
Operating Conditions											
Position	Shell		Position	Tube		Position	Shell		Position	Tube	
Fluid	n-Propanol Propionaldehyde		Fluid	Steam		Fluid	n-Propanol		Fluid	Water	
Fluid type	Cold		Fluid type	Hot		Fluid type	Hot		Fluid type	Cold	
	In	Out		In	Out		In	Out		In	Out
Liquid flowrate, kg/h	9,534	9,534	Liquid flowrate, kg/h	-	-	Liquid flowrate, kg/h	7,655	7,655	Liquid flowrate, kg/h	10,019	10,019
Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	3,739	3,739	Vapor flowrate, kg/h	-	-	Vapor flowrate, kg/h	-	-
Temperature, °C	89	133	Temperature, °C	260	150	Temperature, °C	133	30	Temperature, °C	20	90
Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3	Pressure, atm	3	3
Mechanical Design											
Length, ft	8		Length, ft	8		Length, ft	12		Length, ft	12	
Passes	2		Passes	2		Passes	2		Passes	2	
ID, in.	23.25		OD, in.	1.5		ID, in.	21.25		OD, in.	1	
Baffle spaces, in.	4		Number	74		Baffle spaces, in.	4		Number	270	
			BWG	16					BWG	16	
			Pitch, in.	1.875					Pitch, in.	1.25	
$\Delta P_{cal}/\Delta P_{allow}$	Negligible		$\Delta P_{cal}/\Delta P_{allow}$	0.017		$\Delta P_{cal}/\Delta P_{allow}$	0.177		$\Delta P_{cal}/\Delta P_{allow}$	0.0002	
Rd_{cal}/Rd_{allow}	1		Rd_{cal}/Rd_{allow}	1		Rd_{cal}/Rd_{allow}	1		Rd_{cal}/Rd_{allow}	1	

3.5 Mass Balance

3.5.1 Total Mass Balance

Table 3.2 Input mass balance

Component	Input (kg/h)		
	1	2	9
H ₂	316		265
CO	4,337		
C ₂ H ₄		4,127	
Total	4,653	4,127	265
Overall	9,045		

Table 3.3 Output mass balance

Component	Output (kg/h)			
	7	13	15	16
H ₂	26	2		
CO	355			
C ₂ H ₄	59	2	3	
C ₂ H ₆	48	8	25	
C ₃ H ₆ O	138	3	561	2
C ₆ H ₁₄ O			19	47
C ₃ H ₈ O		5	155	7,576
H ₂ O				11
Total	626	21	763	7,636
Overall	9,045			

3.5.2 Mass Balance for Each Equipment

a. Reactor 01 (R-101)

Table 3.4 Reactor 01 mass balance

Component	Input (kg/h)	Output (kg/h)
	3	4
H ₂	410	119
CO	5,638	1,656
C ₂ H ₄	4,343	291
C ₂ H ₆	179	249
C ₃ H ₆ O	506	8,762
Total	11,077	11,077
Overall	11,077	11,077

b. Separator 01 (V-101)

Table 3.5 Separator 01 mass balance

Component	Input (kg/h)	Output (kg/h)	
	4	5	8
H ₂	119	119	
CO	1,656	1,656	
C ₂ H ₄	291	276	15
C ₂ H ₆	249	227	21
C ₃ H ₆ O	8,762	644	8,118
Total	11,077	2,923	8,154
Overall	11,077	11,077	

c. Reactor 02 (R-102)

Table 3.6 Reactor 02 mass balance

Component	Input (kg/h)			Output (kg/h)
	8	9	12	10
H ₂		265	22	20
C ₂ H ₄	15		12	16
C ₂ H ₆	21		66	99
C ₃ H ₆ O	8,118		27	593
C ₆ H ₁₄ O			1	67
C ₃ H ₈ O			50	7,785
H ₂ O				12
Total	8,154	265	173	8,592
Overall	8,592			8,592

d. Separator 02 (V-102)

Table 3.7 Separator 2 mass balance

Component	Input (kg/h)	Output (kg/h)	
	10	11	14
H ₂	20	20	
C ₂ H ₄	16	13	3
C ₂ H ₆	99	74	25
C ₃ H ₆ O	593	30	562

Table 3.7 Separator 2 mass balance (continuation)

Component	Input (kg/h)	Output (kg/h)	
	10	11	14
C ₆ H ₁₄ O	67	1	66
C ₃ H ₈ O	7,785	55	7,730
H ₂ O	12		12
Total	8,592	194	8,399
Overall	8,592	8,592	

e. Distillation 01 (T-101)

Table 3.8 Distillation 01 mass balance

Component	Input (kg/h)	Output (kg/h)	
	14	15	16
C ₂ H ₄	3	3	
C ₂ H ₆	25	25	
C ₃ H ₆ O	562	561	2
C ₆ H ₁₄ O	66	19	47
C ₃ H ₈ O	7,730	155	7,576
H ₂ O	12		11
Total	8,399	763	7,636
Overall	8,399	8,399	

3.6 Heat Balance

3.6.1 Reactor 01 (R-101)

Table 3.9 Reactor 01 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	0.389	0.086
CO	0.499	0.185
C ₂ H ₄	0.418	0.034
C ₂ H ₆	0.027	0.044
C ₃ H ₆ O	0.189	1.155
Q _{reaction}		84.752
Q _{coolant}	84.837	
Total	86.170	86.170

3.6.2 Reactor 02 (R-102)

Table 3.10 Reactor 02 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	0.302	0.044
C ₂ H ₄	0.001	0.002
C ₂ H ₆	0.000	0.000
C ₃ H ₆ O	0.688	0.100
C ₃ H ₈ O	0.074	0.931
C ₆ H ₁₄ O	0.001	0.011
H ₂ O	0.000	0.003
Q _{reaction}		40.214
Q _{coolant}	40.239	
Total	41.306	41.306

3.6.3 Vaporizer 01 (E-101)

Table 3.11 Vaporizer 01 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₂ H ₄	0.291	0.282
Q _{vaporization}		2.820
Q _{steam}	2.811	
Total	3.102	3.102

3.6.4 Heat Exchanger 01 (E-102)

Table 3.12 Heat exchanger 01 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₂ H ₄	0.282	0.397
Q _{heating}		0.718
Q _{water}	0.834	
Total	1.116	1.116

3.6.5 Vaporizer 02 (E-103)

Table 3.13 Vaporizer 02 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	1.316	1.262
CO	1.344	1.297
Q _{vaporization}		2.268

Table 3.13 Vaporizer 02 heat balance (continuation)

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
Q _{steam}	2.167	
Total	4.828	4.828

3.6.6 Heat Exchanger 02 (E-104)

Table 3.14 Heat Exchanger 02 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	1.262	0.336
CO	1.297	0.384
Q _{heating}		3.787
Q _{water}	1.947	
Total	4.506	4.506

3.6.7 Heat Exchanger 03 (E-105)

Table 3.15 Heat Exchanger 03 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	0.090	0.053
CO	0.191	0.115
C ₂ H ₄	0.034	0.020
C ₂ H ₆	0.047	0.027
C ₃ H ₆ O	0.321	0.189
Q _{cooling}	0.269	
Q _{water}		0.548
Total	0.953	0.953

3.6.8 Vaporizer 03 (E-106)

Table 3.16 Vaporizer 03 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₂ H ₄	0.000	0.000
C ₃ H ₆ O	0.061	0.519
Q _{vaporization}		6.252
Q _{steam}	6.710	
Total	6.771	6.771

3.6.9 Vaporizer 04 (E-107)

Table 3.17 Vaporizer 04 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	1.164	1.156
Q _{vaporization}		0.170
Q _{steam}	0.162	
Total	1.326	1.326

3.6.10 Heat Exchanger 04 (E-108)

Table 3.18 Heat exchanger 04 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	1.156	0.245
Q _{heating}		1.846
Q _{water}	0.935	
Total	2.092	2.092

3.6.11 Heat Exchanger 05 (E-109)

Table 3.19 Heat exchanger 05 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	0.261	0.302
C ₂ H ₄	0.001	0.001
2H ₆	0.000	0.000
C ₃ H ₆ O	0.595	0.688
C ₃ H ₈ O	0.062	0.074
C ₆ H ₁₄ O	0.001	0.001
H ₂ O	0.000	0.000
Q _{heating}		0.139
Q _{water}	0.286	
Total	1.205	1.205

3.6.12 Condenser 01 (E-110)

Table 3.20 Condenser 01 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
H ₂	0.044	0.022
C ₂ H ₄	0.002	0.001
C ₂ H ₆	0.000	0.000

Table 3.20 Condenser 01 heat balance (continuation)

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₃ H ₆ O	0.100	0.051
C ₃ H ₈ O	0.931	0.414
C ₆ H ₁₄ O	0.011	0.005
H ₂ O	0.003	0.002
Q _{condensation}	0.649	
Q _{water}		1.246
Total	1.741	1.741

3.6.13 Vaporizer 05 (E-111)

Table 3.21 Vaporizer 05 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₃ H ₆ O	0.022	0.031
C ₃ H ₈ O	0.325	0.485
C ₆ H ₁₄ O	0.004	0.006
H ₂ O	0.001	0.002
Q _{vaporization}		0.165
Q _{water}	0.336	
Total	0.689	0.689

3.6.14 Condenser 02 (E-112)

Table 3.22 Condenser 02 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₃ H ₆ O	0.023	0.020
C ₃ H ₈ O	0.007	0.006
C ₆ H ₁₄ O	0.000	0.000
H ₂ O	0.000	0.000
Q _{condensation}	0.004	
Q _{water}		0.007
Total	0.034	0.034

3.6.15 Reboiler 01 (E-113)

Table 3.23 Reboiler 01 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₃ H ₆ O	0.039	0.067
C ₃ H ₈ O	0.326	0.618

Table 3.23 Reboiler 01 heat balance (continuation)

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₆ H ₁₄ O	0.004	0.007
H ₂ O	0.001	0.002
Q _{heating}		0.337
Q _{steam}	0.660	
Total	1.031	1.031

3.6.16 Heat Exchanger 06 (E-114)

Table 3.24 Heat Exchanger 06 heat balance

Component	Q _{in} (10 ⁶ kJ/h)	Q _{out} (10 ⁶ kJ/h)
C ₃ H ₆ O	0.000	0.000
C ₃ H ₈ O	0.596	0.020
C ₆ H ₁₄ O	0.007	0.000
H ₂ O	0.002	0.000
Q _{cooling}	0.719	
Q _{water}		1.304
Total	1.324	1.324

CHAPTER IV

PLANT DESIGN

4.1 Plant Location

One of the important things to consider is choosing a place to build a plant and determining its location. Starting from production to distribution and marketing, this is very important for the economic and operational sustainability of the plant. In choosing a location to build a plant, several factors are considered including the availability of raw materials, marketing, transportation, the surrounding environment, supporting facilities, and others.

The n-propanol plant with a capacity of 60,000 tons/year is planned to be established in Cijeruk District, Serang Regency, Banten. The selection of this location is based on several considerations as follows:

4.1.1. Primary Factor

a. Raw Materials Availability

This plant will be established in Serang Regency because its location is close to the raw material, ethylene and syngas, suppliers. Ethylene is obtained from PT. Chandra Asri Pacific Tbk and syngas from PT Krakatau Steel Tbk in Cilegon Regency, Banten, which means the location is still in one province. The distance between the n-propanol plant and the raw material location is about 40 km. Access to the raw material supply is also easy to access by land transportation

b. Product Marketing

It is expected that the location of the plant will be close to other sectors that require n-propanol as the main and/or supporting raw material. Banten is close to large industrial areas in Java such as Cilegon, Gresik, Cikarang, and Cikampek, which require a lot of n-propanol as a raw material. So, the n-propanol plant is established in a strategic location for marketing n-propanol products that can be used in various industries, such as cosmetics, perfume, dye solutions, antifreeze, soap, acetone, and other chemical products.

c. Utility

In the production process, supporting facilities for the process or what is called utilities is one of the important things. These utilities include water, electricity, fuel, and others. For that, the location of the plant that is close to the availability of good utility facilities is very beneficial. In this plant, water can be obtained from the Cikambuy River. Electricity needs are obtained from the State Electricity Company (PLN) which has a power plant with a capacity of $\pm 10,000$ MW, if there is a disruption, a backup generator can be used.

d. Transportation

Adequate transportation facilities are also an important factor in selecting a location for establishing a plant because they

are needed for the provision of raw materials, transportation, and marketing of products. In terms of transportation facilities, Banten Regency is relatively strategic because it is equipped with adequate land transportation facilities that connect various major cities in Java such as Surakarta, Semarang, and Surabaya. In addition, Banten is also close to Merak Port, making it easier to distribute raw materials and products.

e. Labor Force

A plant in an area will certainly provide many jobs for the people around it. It is hoped that the establishment of the n-propanol plant can provide jobs for the surrounding community. However, for the production process to run well, skilled and qualified workers are an important factor. So, this plant needs employees with vocational or secondary education as well as bachelor's or master's degrees according to needs.

4.1.2. Secondary Factor

a. Plant Expansion

The n-propanol plant that will be established must consider expanding its area in the next few years. This is done to anticipate the increasing demand for the goods produced. Therefore, the location chosen to establish the plant must be in an area that has sufficient land. In this case, Banten Regency meets these criteria because it has a large space in the

surrounding area which is a plantation, rice fields and is located on the outskirts of the city.

b. Government Policy

Banten Regency has been designated by the government as an industrial area that is open to investors. This meets the requirements of industrial development policies. The government has also assisted in industrial development by providing permits, taxes, and other development access.

c. Surrounding Environment

The people around Banten are open to the development of Banten Regency as an industrial city. This is because the establishment of an industry will open up wide employment opportunities for the community and improve the community's economy as a whole.

d. Climate and Soil Condition

Most of the area of Banten Regency is lowland with an altitude of 2-12 meters above sea level. Most of the land in Banten Regency consists of alluvial, grumosol, red Mediterranean, and litosol soil types. The climate of Banten Regency is classified as tropical. When compared to winter, summer has more rainfall. The average temperature in Banten Regency is 25-28 ° C with an average rainfall of 1,686 mm. (Meteorology, Climatology and Geophysics Agency (BMKG))

Banten). The climate conditions considered are air humidity, sunlight, wind, and others. By considering these climate conditions, the plant establishment area in Banten Regency has met these conditions.

e. Supporting Facilities

Banten Regency has very adequate public facilities and infrastructure. The facilities in question are such as health facilities, education, places of worship, banking, housing, and so on. The supporting facilities mentioned above have been facilitated in Banten Regency which is an industrial area.

4.2 Plant Layout

The plant layout includes office/administration areas, process equipment areas, raw material and product storage areas, process support unit areas, employee facilities and other areas that support the continuity of the plant production process. The plant layout must be designed in such a way that production operations can run economically efficiently and optimally, for example goods traffic and employee access. In addition, the security factor is also very important. The placement of production equipment must be arranged in such a way that employee safety and comfort while working can be guaranteed. In general, the plant layout is divided into several main parts as follows:

4.2.1. Office/Administration

Office administration is an activity that is directly related to the administration system within the scope of the office. The management system in an office scope is one part of management that provides information according to the administrative field needed to support the effective work of an activity. The office area is the center of the factory's administrative and financial activities, as well as matters with external parties and parties within the factory itself. This area is usually located at the front of the factory area.

4.2.2. Production

The production area is where production operations take place. This area includes storage of raw materials and products, placement of process equipment and control room. This area is in a separate place from other areas for security purposes.

4.2.3. Installation and Utility

The installation and utility area is a place that provides supporting process needs, such as water, heating steam, cooling water, electricity, and fuel.

4.2.4. Public Facilities

This area is a center for public facilities that can be used by employees, including housing/mess, polyclinics, places of worship, canteens, parks, and so on.

4.2.5. Security

The security area is a place to store security equipment to anticipate and minimize the impacts caused by explosions, smoke, fires, toxic gas leaks, and other things. Therefore, it is necessary to provide fire extinguishers at several dangerous points that can trigger fires.

4.2.6. Waste Management

The establishment of a factory must also consider the aspect of environmental sustainability. For this reason, a special area is needed that is used as a waste processing area so as not to damage the surrounding environment. Production waste will undergo further processing and testing to ensure the limits of hazardous components contained so that it is safe if disposed of into the environment.

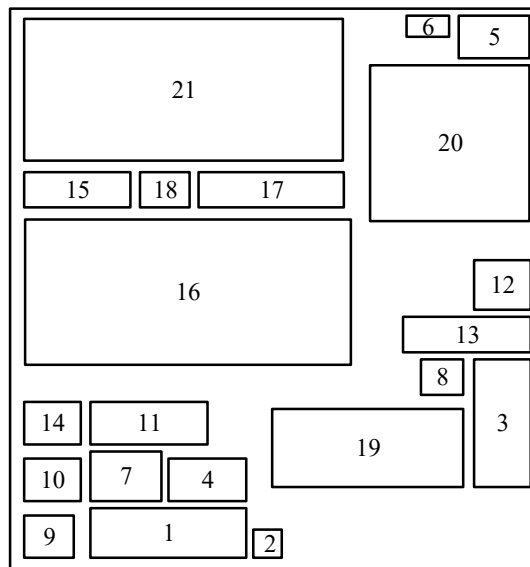
4.2.7. Expansion

In order to anticipate the possibility of an increase in production capacity due to increasing product demand, it needs to be considered. The construction of the n-propanol factory is planned to use a land area of 25,915 m² and a building area of 15,252 m².

The details of the plant layout for plant buildings can be seen in Table 4.1 and Figure 4.1.

Table 4.1 Details of land area and plant building

No.	Location	Width (m)	Length (m)	Area (m ²)
1	Main office	14	44	616
2	Security post	8	8	64
3	Mess	36	16	576
4	Visitor parking area	12	22	264
5	Truck parking area	12	20	240
6	Truck weighing area	6	12	72
7	Technical and production office	14	20	280
8	Clinic	10	12	120
9	Mosque	12	14	168
10	Canteen	12	16	192
11	Garage	12	33	396
12	Fire brigade unit	14	16	224
13	Equipment warehouse	10	36	360
14	Laboratory	12	16	192
15	Utility	10	30	300
16	Process area	41	92	3,772
17	Control Room	10	41	410
18	Utility control	10	14	140
19	Garden	54	22	1,188
20	Storage tank area	44	45	1,980
21	Plant expansion	40	90	3,600
Building Area				15,154
Land Area				23,700



Scale 1:2000

Figure 4.1 Details of plant layout

4.3 Machines Layout

The layout of the process equipment or machines layout is the optimum arrangement of the factory process equipment. The design of the optimum layout of the process equipment can be economically beneficial because it can minimize construction costs and production operations can run efficiently. In addition, this is important because it is related to the safety, security, and comfort of employees while working. Some things to consider in arranging the layout of the process equipment are as follows:

4.3.1. Raw Materials and Products Flow

The right flow of raw materials and products will provide great economic benefits, as well as support the smooth and safe production process.

4.3.2. Air Circulation

Air circulation in and around the process area must be ensured to be smooth. Smooth air circulation is needed to avoid air stagnation in a place in the form of accumulation of hazardous chemicals that can endanger worker safety. In addition, the direction of the wind also needs to be considered.

4.3.3. Lighting

Lighting throughout the factory area must be adequate, especially at night because the factory operates 24 hours a day. In addition, in certain places where there are process tools that have a high risk of danger, additional lighting needs to be provided.

4.3.4. Human and Vehicle Traffic

Human and vehicle traffic in the process area must be a concern including the distance between tools, the width of the road and ease of access for employees to reach the process tools. This is done so that if there is a problem with the tool, employees can quickly repair it to minimize the potential dangers that can be caused. In addition, if an explosion or fire occurs on the tool, vehicles and fire extinguishers can easily reach the tool.

4.3.5. Process Equipment Layout

In arranging the layout of process equipment, the distance between process equipment must be carefully calculated, especially for equipment that operates at high temperatures and pressures.

These equipment must be placed in a special location separate from other process equipment. This is intended so that if an explosion or fire occurs in the equipment, it does not immediately endanger other equipment.

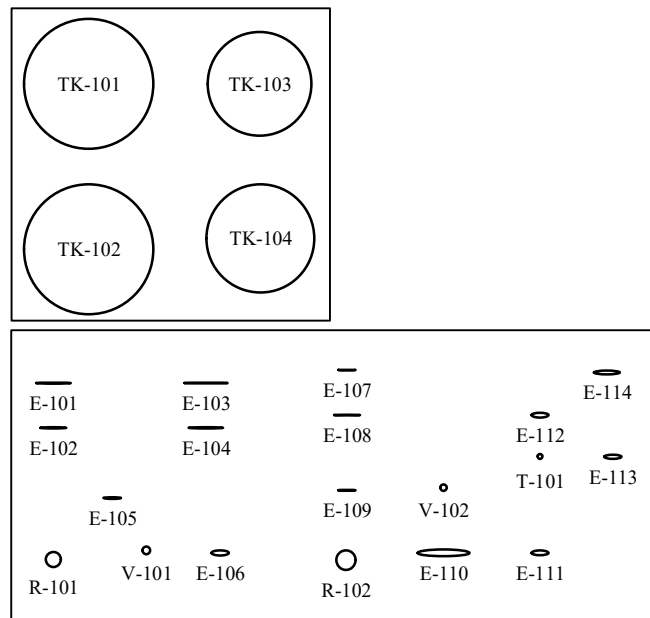
4.3.6. Economy Factor

Arranging the layout of the process equipment appropriately and optimally is expected to minimize operating costs so that it can be economically profitable, but must still prioritize safety and security aspects.

4.3.7. Equipment Maintenance

Ease of tool maintenance can also be considered in the placement of process tools. This is because tool maintenance is important to keep the tool operating properly and long-lasting. Good tool placement will provide enough space to repair or clean the equipment.

The machine layout can be seen in Figure 4.2.



Legend:

- | | | | |
|------|----------------------|-------|----------|
| 1. E | : Heat exchanger | 4. V | : Vessel |
| 2. R | : Reactor | 5. TK | : Tank |
| 3. T | : Distillation tower | | |

Scale 1:1000

Figure 4.2 Details of machine layout

4.4 Company Organization

4.4.1 Company Type

The planned form of company for this n-propanol factory is a Limited Liability Company. The form of a Limited Liability Company (LLC) company is a legal entity. This legal entity consists of shares and must be established using an authentic deed. Where this authentic deed contains information about the names of the company, the objectives of the company, the amount of capital and the location of the head office.

This company was established from an association of shareholders with a separate legal entity. The highest authority is the general meeting of shareholders which is usually held once a year. The directors and commissioners are elected by the general meeting of shareholders. The commissioners are tasked with conducting their own audits or assisted by the factory accountant if the company experiences some things that are not right. The company's capital obtained from the sale of shares if the company loses, the owner only loses his capital and does not touch on personal assets to pay off his debts. Some things to consider in choosing this form of company are as follows:

a. Capital Income

In LLC, capital is obtained through the sale of shares in the capital market. Capital is divided into shares, so that it is possible if someone wants to participate in investing a small amount of capital but does not prevent large capital input. So that it will facilitate movement in the capital market and capital collection by selling shares becomes effective.

b. Authority and Responsibility of Shareholders

The Authority and Responsibility of Shareholders is that shareholders are only responsible for depositing the full amount of capital stated in each share without participating in managing the company. This makes the smoothness of production

relatively more stable because the management of the company is only held by the company's leaders.

c. Company Owners and Managers

The company owners are the shareholders, while the company managers are the board of directors and their staff who are supervised by the Board of Commissioners.

d. Corporate Survival

If there is a change of shareholders from their positions, it will not affect the directors, staff, or employees who work in it. This is because the shareholders do not directly participate in managing the company.

4.4.2 Organization Structure

The company's organizational system chosen is the staff and line organization system. In this system, the line of power is simpler and more practical in the division of work tasks, where an employee is only responsible to one superior. Power flows directly from the board of directors and then to the head of the section, to the head of the section, and then to the employees. The employees below are equipped with expert staff who are tasked with providing advice to the director. The advantages of this organizational system are as follows:

- a. There is unity in the leadership of the command because there is a clear division of authority and power.

- b. Leaders can make decisions more quickly and give orders more quickly, because these orders can be given directly to the subordinates concerned.
- c. The leadership of various activities is held by only one person so the cost can be minimized.

Figure 4.3 shows the structure of the company.

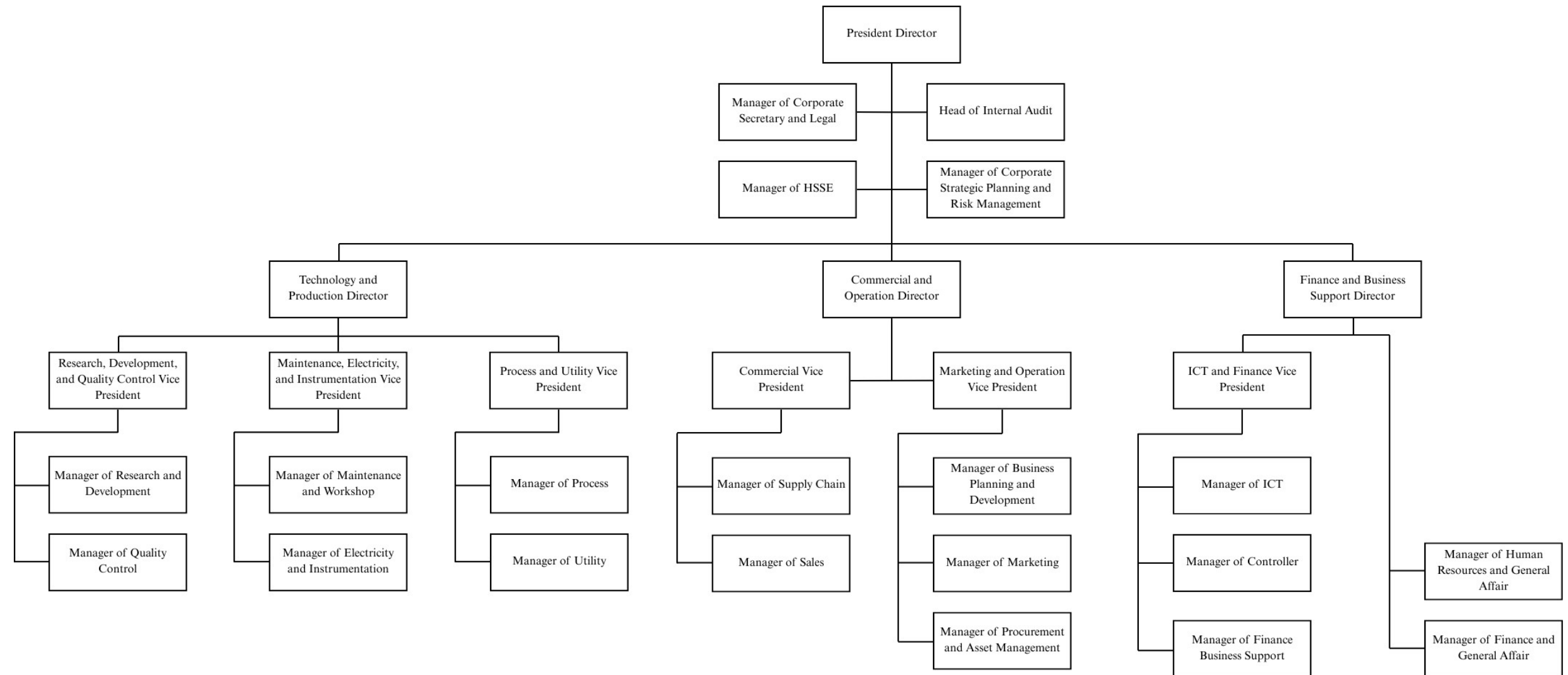


Figure 4.3 Organization structure

4.4.3 Duties and Authorities

a. Shareholder

The highest authority in an LLC is the shareholder. Shareholders are the people who raise capital to establish and run the company. The duties and authorities of shareholders are as follows:

- (1) Appoint and dismiss the board of commissioners and directors;
- (2) Approve the company's annual business results and profit and loss balance sheet;
- (3) Hold a general meeting of shareholders at least once a year.

b. Board of Commissioners

The Board of Commissioners is a board that is responsible to shareholders who have been appointed for shareholders. The Board of Commissioners is tasked with supervising the president director and assisting the president director in handling important matters. The Board of Commissioners is also tasked with assessing and approving the board of directors' plans regarding general policies, profit targets, allocation of funding sources, and marketing direction.

c. President Director

The President Director is the highest leader in the company and is fully responsible for the running of the company

to the Board of Commissioners. The duties and authorities of the president director are as follows:

- (1) Manage and implement company policies;
- (2) Responsible to the board of commissioners and shareholders for their work at the end of their term;
- (3) Maintain the stability of the company's organization and the continuity of good relations between shareholders, management, consumers and employees;
- (4) Appoint and dismiss department heads with the approval of shareholders;
- (5) Coordinate cooperation between directorates and departments under them.

d. Technology and Production Director

The Technology and Production Director oversees the operational activities of the divisions under his/her responsibility and assesses the work results of each unit to be followed up if there are problems in running it. The technology and production director is responsible for planning, formulating development, implementing technology, and controlling general policies in the preparation of production strategies.

e. Commercial and Operation Director

The Commercial and Operations Director plays a pivotal role in steering a company's commercial success and operational

efficiency. This senior leadership position demands a blend of strategic vision, market insight, operational expertise, and strong interpersonal skills to drive revenue growth, optimize processes, and lead diverse teams effectively. The role involves close collaboration with various departments, including marketing, sales, finance, IT, and manufacturing, to ensure cohesive execution of business objectives. This role is critical in maintaining competitive advantage, improving customer satisfaction, and delivering sustainable financial performance.

f. Finance and Business Support Director

The Finance and Business Support Director is a senior leadership role responsible for overseeing financial management and providing comprehensive business support to ensure effective operational and strategic performance. This role ensures robust financial planning, controls, and reporting while partnering with operational leaders to drive business performance. The position also emphasizes compliance, risk management, and governance to protect company assets and reputation. Strong leadership, analytical, communication, and systems skills are essential to succeed in this multifaceted role.

g. Vice President

(1) Research, Development, and Quality Control Vice President

The role of a Research, Development, and Quality Control Vice President is a senior executive position responsible for overseeing the company's research and development efforts, driving innovation, and ensuring the highest quality standards in product development and production processes. This role integrates strategic leadership in R&D with stringent quality control and regulatory compliance.

(2) Maintenance, Electricity, and Instrumentation Vice President

The Maintenance, Electricity, and Instrumentation Vice President is a critical leadership role responsible for the reliable operation and maintenance of electrical and instrumentation systems. This role combines technical expertise with strategic management to ensure operational continuity, safety, and regulatory compliance. The vice president oversees teams managing complex electrical infrastructure and instrumentation systems, driving continuous improvement through effective planning, budgeting, and staff development.

(3) Process and Utility Vice President

The Process and Utility Vice President plays a critical role in ensuring that utility services and process operations

run smoothly, safely, and efficiently. This executive is responsible for strategic oversight, operational excellence, regulatory compliance, and team leadership in managing essential utility infrastructure and process systems. The role is pivotal in supporting the organization's production capabilities and long-term growth objectives by optimizing resource use and maintaining high standards of safety and reliability.

(4) Commercial Vice President

The Commercial Vice President is a key driver of business performance, responsible for shaping and executing strategies that maximize revenue and profitability. This role requires a blend of strategic insight, operational expertise, and leadership to manage diverse teams and collaborate across departments. The vice president ensures the company remains competitive by responding to market dynamics, optimizing commercial operations, and fostering strong customer relationships.

(5) Marketing and Operation Vice President

The Marketing and Operation Vice President is a senior executive role responsible for overseeing both the strategic and operational aspects of the marketing function,

ensuring alignment with overall business goals and driving marketing efficiency and effectiveness.

(6) ICT and Finance Vice President

The ICT and Finance Vice President plays a pivotal role in bridging technology and finance functions to support organizational growth, risk management, and operational excellence. This role requires expertise in financial leadership, ICT governance, cyber risk management, and strategic planning. By integrating financial oversight with technology strategy, the vice president ensures that investments in digital infrastructure are financially sound and aligned with corporate objectives, while maintaining robust risk controls and compliance.

h. Manager

(1) Manager of Corporate Secretary and Legal

The Manager of Corporate Secretary and Legal is a senior strategic role that blends legal expertise with corporate governance and administrative management. This position ensures legal compliance, supports the board and management in governance, manages corporate documentation and meetings, and acts as a key liaison with stakeholders and regulators.

(2) Manager of HSSE

The Manager of HSSE ensures a safe, secure, and environmentally responsible workplace by developing robust policies, managing risks, conducting training, and ensuring compliance with regulatory requirements.

(3) Manager of Corporate Strategic Planning and Risk Management

The Manager of Corporate Strategic Planning and Risk Management plays a pivotal role in shaping the long-term direction of the organization by integrating strategic planning with risk management. This role ensures that corporate objectives are translated into actionable plans, risks are identified and mitigated, and resources are effectively allocated. The manager collaborates closely with senior leadership and cross-functional teams, facilitating alignment and communication to drive successful execution of the strategic agenda.

(4) Manager of Supply Chain

The Manager of Supply Chain is responsible for overseeing and managing the entire supply chain process to ensure efficient production flow, inventory management, and timely delivery of products to meet customer demand while optimizing costs and quality.

(5) Manager of Sales

The Manager of Sales plays a crucial role in driving business growth by leading the sales team, developing effective sales strategies, and maintaining strong client relationships. The Manager of acts as a bridge between the sales force and senior management, ensuring alignment and execution of sales objectives.

(6) Manager of Business Planning and Development

The Manager of Business Planning and Development plays a critical role in shaping the organization's strategic direction and driving growth initiatives. The manager collaborates with various stakeholders to ensure effective planning, resource allocation, and execution of business strategies that support sustainable success.

(7) Manager of Human Resources and General Affair

The Manager of Human Resources and General Affair is a multifunctional role combining strategic HR management with operational oversight of general affairs. This position ensures effective human capital management, compliance with labor regulations, and smooth office operations, contributing to a productive and compliant workplace environment. The manager plays a vital role in aligning HR and administrative functions with the

company's strategic objectives while supporting employee welfare and organizational efficiency.

(8) Manager of Finance and General Affair

The Manager of Finance and General Affair plays a critical role in ensuring the financial health and operational effectiveness of the organization. By combining financial oversight with general affair management, this position supports the company's strategic goals through sound financial practices and well-maintained operational infrastructure. The manager acts as a key liaison between finance and operational teams, driving efficiency, compliance, and service quality across both domains.

i. Head of Internal Audit

The Head of Internal Audit is responsible for ensuring the organization's internal control systems are robust, risks are effectively managed, and governance practices are followed. This role provides independent assurance to the Board and senior management, driving improvements in operational efficiency and compliance. This role is critical in safeguarding the company's assets and reputation while supporting strategic objectives through proactive risk assessment and control evaluation.

4.4.4 Employee System

The employee system in the n-propanol plant is divided into 3 groups, and employee salaries vary depending on employee status, position, responsibility, expertise, work experience, and so on.

a. Permanent Employees

Permanent employees are employees who are appointed and dismissed by a Director's Decree and receive a monthly salary.

b. Daily Employees

Daily employees are employees who are appointed and dismissed without a Director's Decree and receive wages at the end of each week.

c. Contract Employees

Contract workers are employees who are hired only when needed. These employees usually get a contract salary for a job.

Table 4.2 shows the details of the number of employees and employee salaries.

Table 4.2 Number of employees and employee salaries

Position	Person	Salary	Total
President Director	1	IDR 50,000,000	IDR 50,000,000
Technology and Production Director	1	IDR 30,000,000	IDR 30,000,000
Commercial and Operation Director	1	IDR 30,000,000	IDR 30,000,000
Finance and Business Support Director	1	IDR 30,000,000	IDR 30,000,000
Research, Development, and Quality Control Vice President	1	IDR 20,000,000	IDR 20,000,000
Maintenance, Electricity, and Instrumentation Vice President	1	IDR 20,000,000	IDR 20,000,000
Process and Utility Vice President	1	IDR 20,000,000	IDR 20,000,000
Commercial Vice President	1	IDR 20,000,000	IDR 20,000,000
Marketing and Operation Vice President	1	IDR 20,000,000	IDR 20,000,000
ICT and Finance Vice President	1	IDR 20,000,000	IDR 20,000,000
Head of Internal Audit	1	IDR 20,000,000	IDR 20,000,000
Manager Corporate Secretary and Legal	1	IDR 20,000,000	IDR 20,000,000
Manager of HSSE	1	IDR 20,000,000	IDR 20,000,000
Manager of Corporate Strategic Planning and Risk Management	1	IDR 20,000,000	IDR 20,000,000
Manager of Research and Development	1	IDR 20,000,000	IDR 20,000,000
Manager of Quality Control	1	IDR 20,000,000	IDR 20,000,000
Manager of Maintenance and Workshop	1	IDR 20,000,000	IDR 20,000,000
Manager of Electricity and Instrumentation	1	IDR 20,000,000	IDR 20,000,000
Manager of Process	1	IDR 20,000,000	IDR 20,000,000
Manager of Utility	1	IDR 20,000,000	IDR 20,000,000
Manager of Supply Chain	1	IDR 20,000,000	IDR 20,000,000
Manager of Sales	1	IDR 20,000,000	IDR 20,000,000
Manager of Business Planning and	1	IDR 20,000,000	IDR 20,000,000
Manager of Marketing	1	IDR 20,000,000	IDR 20,000,000
Manager of Procurement and Asset	1	IDR 20,000,000	IDR 20,000,000
Manager of ICT	1	IDR 20,000,000	IDR 20,000,000
Manager of Controller	1	IDR 20,000,000	IDR 20,000,000
Manager of Finance Business Support	1	IDR 20,000,000	IDR 20,000,000
Manager of Human Resources and General Affair	1	IDR 20,000,000	IDR 20,000,000
Manager of Finance and General Affair	1	IDR 20,000,000	IDR 20,000,000
Corporate Secretary and Legal Employee	3	IDR 8,000,000	IDR 24,000,000
HSSE Employee	5	IDR 10,000,000	IDR 50,000,000
Corporate Strategic Planning and Risk Management Employee	4	IDR 8,000,000	IDR 32,000,000
Research and Development Employee	4	IDR 8,000,000	IDR 32,000,000
Quality Control Employee	4	IDR 8,000,000	IDR 32,000,000
Maintenance and Workshop Employee	7	IDR 10,000,000	IDR 70,000,000
Electricity and Instrumentation Employee	4	IDR 10,000,000	IDR 40,000,000
Process Employee	30	IDR 10,000,000	IDR 300,000,000
Utility Employee	8	IDR 10,000,000	IDR 80,000,000
Supply Chain Employee	5	IDR 8,000,000	IDR 40,000,000
Sales Employee	4	IDR 8,000,000	IDR 32,000,000
Business Planning and Development	4	IDR 8,000,000	IDR 32,000,000
Marketing Employee	4	IDR 8,000,000	IDR 32,000,000
Procurement and Asset Management	4	IDR 8,000,000	IDR 32,000,000
ICT Employee	4	IDR 8,000,000	IDR 32,000,000
Controller Employee	4	IDR 10,000,000	IDR 40,000,000
Finance Business Support Employee	3	IDR 8,000,000	IDR 24,000,000
Human Resources and General Affair	3	IDR 8,000,000	IDR 24,000,000
Finance and General Affair Employee	3	IDR 8,000,000	IDR 24,000,000
Doctor	2	IDR 8,000,000	IDR 16,000,000
Nurse	3	IDR 6,000,000	IDR 18,000,000
Driver	6	IDR 5,000,000	IDR 30,000,000
Cleaning Service	5	IDR 5,000,000	IDR 25,000,000
Gardener	5	IDR 5,000,000	IDR 25,000,000
	158	IDR 853,000,000	IDR 1,746,000,000

Employee salaries are paid on the 1st of each month. If the date is a holiday, salary payments will be made the day before.

The arrangement of employee working hours at the n-propanol factory is divided into 2, namely shift and non-shift, with planned operations 24 hours for 330 days per year.

a. Non-Shift Employees

Non-shift employees are employees who are not directly involved in the production process or factory security. Employees who are classified as working non-shift are directors and their staff, vice presidents, managers, and employees who work in the office. Non-shift employees will work 5 days a week with the following division of work:

Days : Monday to Friday

Working hour : 08.00-17.00 (for Friday 07.30-17.00)

Rest hour : 12.00-13.00 (for Friday 11.30-13.00)

b. Shift Employees

Shift workers are workers who directly handle the production process or manage certain parts of the factory related to security and production activities. Some of the engineering, warehouse, and other parts must be on standby for the safety and security of the factory. Shift workers will work alternately in a day and night, with the following shift divisions:

Shift I : 08.00-16.00

Shift II : 16.00-00.00

Shift III : 00.00-08.00

The division of shift work hours lasts for 8 hours per shift with 3 shift groups in 1 day. The change of shift group work hours is carried out every 6 working days followed by 2 day off. The division of shifts is carried out in 4 teams, where 3 teams get shift turns and 1 team is on holiday. The employee shift division schedule (cycle) can be seen in Table 4.3.

Table 4.3 Shift division schedule

Groups	Days									
	1	2	3	4	5	6	7	8	9	10
A	I	I	II	II	III	III			I	I
B	II	II	III	III			I	I	II	II
C			I	I	II	II	III	III		
D	III	III			I	I	II	II	III	III
Groups	Days									
	11	12	13	14	15	16	17	18	19	20
A	II	II	III	III			I	I	II	II
B	III	III			I	I	II	II	III	III
C	I	I	II	II	III	III			I	I
D			I	I	II	II	III	III		
Groups	Days									
	21	22	23	24	25	26	27	28	29	30
A	III	III			I	I	II	II	III	III
B			I	I	II	II	III	III		
C	II	II	III	III			I	I	II	II
D	I	I	II	II	III	III			I	I

4.4.5 Employment

Every employee has rights in terms of employment as stated in the laws and regulations. These rights include:

a. Benefit

Employee benefits consist of:

- (1) Allowances in the form of basic salary are given based on the employee's position.
- (2) Position allowances are given based on the position held by the employee.
- (3) Overtime allowance is given to employees who work outside working hours based on the number of hours worked.
- (4) Eid allowance is given in the amount of one month's salary to employees every year when the Eid al-Fitr holiday approaches.

b. National Holiday

For non-shift employees, national holidays are counted as working holidays. While for shift employees, national holidays are counted as overtime.

c. Leave Rights

Employee leave rights consist of:

- (1) Annual leave is given to each employee for 12 working days in one year. If the leave right is not used, the right will be lost for that year.
- (2) Sick leave is given to every employee who is sick based on a doctor's statement, including female employees who have given birth.

d. Employee Facility

In order to increase employee productivity, the company provides various facilities that can be used by employees to maintain their physical and mental condition, so that they do not feel bored in carrying out their daily work and activities in the company can run smoothly. The facilities provided by the company include:

(1) Polyclinic

The polyclinic is provided to maintain employee health which is one of the things that influences the efficiency of factory production. The polyclinic provided is handled by doctors and nurses.

(2) Prayer Place

The prayer place provided by the company is a mosque, so that employees can continue to carry out spiritual obligations and other religious activities.

(3) Uniform

The company provides two sets of work clothes every year to all employees to avoid gaps between employees. In addition, the company provides masks and various other personal protective equipment (PPE) as work safety equipment.

(4) Food and Drink

Food and drinks are provided once a day by the company, namely at lunch time. Food and drinks are planned to be managed by a catering company appointed by the company.

(5) Transportation

To ease the burden of employee expenses, the company provides transportation for employees who do not use private transportation in the form of shuttle buses. The bus will operate at several points where employees live to drop off and pick up employees when they are going to and from work.

(6) Employment Guarantee

The company provides life insurance and work accident insurance for employees managed by the Social Security Administration for Workers (JAMSOSTEK).

CHAPTER V

UTILITY

In running the production process in a plant, supporting facilities are very necessary. Utilities are very important supporting facilities to ensure the smooth production process in the plant to run according to expectations. The utility unit in a plant consists of various components that support various operational needs. The utility unit consists of:

- (1) Water Supply and Treatment Unit
- (2) Steam Generation Unit
- (3) Electricity Generation Unit
- (4) Pressurized Air Supply Unit
- (5) Fuel Supply Unit
- (6) Waste Treatment Unit

5.1 Water Supply and Treatment Unit

5.1.1 Water Supply Unit

Water is one of the important components both as raw materials and supporting materials that are very essential in the production process. The water procurement and processing unit acts as a provider of water needs used for all activities in the plant. This unit not only acts as a water provider, but also processes water for various needs such as production processes, cooling, sanitation and fire fighting so that the water is ready for use. In the industry to meet

water needs generally use river water, well water, lake water to sea water. In the design of the n-propanol plant, the water source used is a water source from the Ciujung River. Considerations for using rivers as a source for obtaining water are:

- (1) Water from rivers has an easier and simpler processing process and the processing costs are more affordable.
- (2) River water is a water source with high continuity so that water supplies can be sufficient.
- (3) The location of the river is near the plant location.

The water produced by this utility unit is used for:

a. Boiler Feed Water

Steam in the plant is used as a heating medium. Boiler feed water is provided with an excess of 20%. Excess is a seam replacement lost due to 10% transmission leakage and a safety factor of 20%. The water used for the boiler must meet the requirements so that the water does not damage the boiler. Table 5.1 shows the requirements for boiler feed water.

Table 5.1 Requirements for boiler feed water (Perry, 2008)

Parameter	Total (ppm)
Total dissolved solid	3500
Alkalinity	700
Dissolved solid	300
Silica	60-100
Zinc	0.1
Lead	0.5
Oxygen	0.007
Hardness	0
Turbidity	175

Table 5.1 Requirements for boiler feed water (Perry, 2008) (continuation)

Parameter	Total (ppm)
Oil	7
Phosphate residue	140

Things that must be considered to prevent scaling, fouling and foaming include:

- (1) Corrosion that occurs in the boiler is caused by water containing acid solutions and dissolved gases such as O_2 , CO_2 , H_2S , and NH_3 . O_2 entering due to aeration or contact with outside air.
- (2) The formation of scale that occurs due to water hardness and high temperatures, generally in the form of carbonate and silica salt deposits.
- (3) Water taken back from the heating process can cause foaming in the boiler due to the presence of large amounts of insoluble organic matter. The foaming effect occurs mainly at high alkalinity.

b. Cooling Water

Cooling water is produced by a cooling tower. This cooling water unit processes water with a cooling process, to be used as water in the cooling process on the heat exchanger of a

device that requires cooling. The considerations for water to be used as cooling media are:

- (1) Water is a material that can be obtained in large quantities;
- (2) Easy to process and organize;
- (3) Can absorb a relatively high amount of heat per unit volume;
- (4) Does not shrink significantly within limits with changes in cooling temperature;
- (5) Does not decompose.

c. Sanitary Water

Sanitary water is water that will be used for sanitation purposes such as needs in housing, offices, laboratories, mosques, and others. The quality of sanitary water must follow physical standards, chemical standards, and bacteriological standards.

- (1) Physical standards:
 - a) Temperature below air temperature;
 - b) Clear in color;
 - c) Tasteless;
 - d) Odorless.
- (2) Chemical standards:
 - a) Neutral pH (6.5 – 7.5);
 - b) Does not contain organic and non-inorganic substances dissolved in water;

- c) Does not contain dangerous heavy metals such as mercury (Hg) and lead (Pb).

(3) Bacteriological standard

- a) Does not contain bacteria, especially pathogenic bacteria;
- b) Does not contain toxin-producing microbes.

5.1.2 Water Treatment Unit

In the design of the n-propanol plant, the water source used comes from river water located relatively close to the plant location. River water used in the plant environment must undergo a processing process first to meet the desired water quality standards. The stages in river water processing include:

a. Screening

Before the processing process, water from the river must go through initial filtration to separate water from large dirt such as garbage, twigs, leaves and other objects carried by the water. After the initial filtration process, the water is pumped to the sedimentation tank.

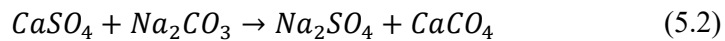
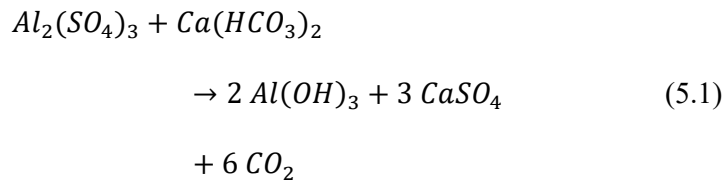
b. Sedimentation

After undergoing the initial filtration stage, the water will go through a sedimentation process. Sedimentation is the process of separating dirt particles using gravity. In this process, small particles that could not be successfully filtered in the previous

filtration stage, such as mud and sand, will settle at the bottom of the tank due to gravity.

c. Flocculation

Flocculation aims to form clumps of colloids that are still dispersed in solution and do not settle in the sedimentation tank, by adding chemical compounds. Generally, flocculants that are commonly used are alum ($Al_2(SO_4)_3$) and sodium carbonate (Na_2CO_3). The reactions that occur in flocculation are shown by eq. 5.1 and eq. 5.2.



d. Clarifier

The water resulting from the flocculation process will flow to the clarifier to separate the lumps by sedimentation. The water that has been flowed to the clarifier with a regulated flow will be stirred using a stirrer. The water that comes out of the clarifier will go through the overflow at the edge, while the sediment that forms will settle naturally due to the influence of gravity. This sediment will disappear periodically with a blowdown process according to the specified time.

e. Sand Filter

After going through the clarifier stage, the water produced will flow to the sand filter which aims to filter fine particles that are still left in the water and have not settled. Filtering is done using a sand filter made of anthracite, sand, and gravel as a filter medium.

f. Temporary Reservoir

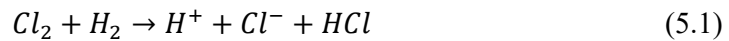
Water that has gone through the filtration stage can be called clean water and is collected in a temporary water tank.

The water is then distributed for the following purposes:

- (1) Domestic and service water;
- (2) Cooling water;
- (3) Steam water.

g. Chlorination

Water chlorination is the process of adding chlorine (Cl_2) or hypochlorite to water. The purpose of this chlorination process is to kill bacteria and microbes in water so that the water is safe for daily use. In this process, chlorine dissolved in water will produce hypochlorous acid shown with eq. 5.3 which then the hypochlorous acid will decompose as shown in eq. 5.4.

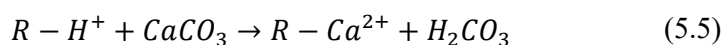


h. Demineralization

Demineralization is one method in water treatment that aims to remove minerals from water. The demineralization process is specifically used in the ion exchange process and the elimination of ion mineral contaminants to very low levels approaching zero. This process involves the use of resins in cation exchangers and anion exchangers.

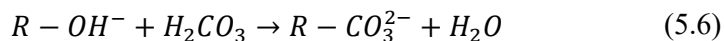
i. Cation Exchanger

Water from the clean water tank acts as boiler make up which is then flowed to the cation exchanger tank. The water flowed to the cation exchanger tank containing positively charged resin so that the positive ions in the water will exchange with the positive ions in the resin as shown in eq. 5.5.



j. Anion Exchanger

The water that has passed through the cation exchanger tank is then flowed to the anion exchanger tank. The anion exchanger tank serves to capture negative ions (anions) dissolved in water using a basic resin. The reactions that occur in this process are shown by eq. 5.6.



k. Deaeration

The output water from the demineralization process that will be used as boiler feed will be subjected to the deaeration process to

remove dissolved gases in the water, especially O_2 gas which has the potential to cause corrosion in the boiler. Corrosion in the boiler has very dangerous consequences, in addition to shortening the life of the boiler. Erosion in the boiler has the potential to cause an explosion due to pressure expansion that does not match the design pressure. To remove dissolved gases, the compound N_2H_4 (hydrazine) is added to bind O_2 and other dissolved gases.

5.1.3 Water Requirements

In plant design, water requirements are divided into several categories, such as water as a cooling medium, water as a steam medium, water for offices, and water for the environment. Table 5.2 shows the total water requirements for the n-propanol plant.

Table 5.2 Total water requirements

Type	Water Requirements (kg/h)
Cooling water	48,066
Steam water	9,466
Domestic water	1,325
Service water	450
Total	59,307

a. Cooling Water Requirements

Table 5.3 Cooling water requirements

Equipment	Water Requirements (kg/h)
R-101	11,180
R-102	9,764
E-105	2,211
E-110	4,936
E-114	10,019
Total	38,111

Table 5.3 shows the cooling water requirements for each equipment. The total cooling water requirement is 38,111 kg/h. The design was made with 20% overdesign and also some make-up water is needed, so the cooling water requirements will be 45,733kg/h.

b. Steam Water Requirements

Table 5.4 Steam water requirements

Equipment	Water Requirements (kg/h)
E-106	2,834
E-113	3,739
Total	6,574

Table 5.4 shows the cooling water requirements for each equipment. The total cooling water requirement is 6,574kg/h. The design was made with 20% overdesign and also some make-up water is needed, so the cooling water requirements will be 7,888 kg/h.

c. Domestic Water Requirements

According to World Health Organization (WHO) standards, each person's water requirement is 100 kg/day. The n-propanol plant has 158 employees and 4 messes that have 40 residents for each mess, the total domestic water requirement is 21,800 kg/day or 1,325 kg/h.

d. Service Water Requirements

Table 5.5 Service water requirements

Service	Water Requirements (kg/h)
Workshop	8
Polyclinic	13
Lab	13
Firefighter	167
Canteen, mushola, and garden	250
Total	450

Table 5.5 shows the service water requirements for each service. The total service water requirement is 450 kg/h.

5.2 Steam Generation Unit

Water from the boiler feed tank is fed to the boiler to generate steam. This unit aims to meet the steam needs in the production process, namely by providing the boiler with a steam requirement of 20,136 kg/hour. Steam from the boiler is used as a heating medium which results in steam and is fed into a heat exchanger as heating media, then the results in the form of dew are fed into the condensate tank and fed back to the boiler feed tank.

5.3 Electricity Generation Unit

The electricity needs of the n-propanol plant are met by PLN, in addition, electricity reserves are generated from the plant generator in case of power supply disruptions from the local PLN. This aims to ensure that the electricity supply can continue even though there are supply disruptions from PLN.

5.1 Process and Utility Electricity Requirements

Table 5.6 shows the electricity requirement for process unit and Table 5.7 shows the electricity requirements for utility unit.

Table 5.6 Electricity requirements for process unit

Equipment	Electricity Requirements (kW)
P-101 A/B	2
C-101	3
C-102	1
Total	6

Table 5.7 Utility unit electricity requirement

Equipment	Electricity Requirements (kW)
TU-203	0.1
CU-201	0.1
CT-201	18.6
BLU-201	3.7
BLU-202	3.7
PU-201 A/B	3.7
PU-202 A/B	3.7
PU-203 A/B	3.7
PU-204 A/B	3.7
PU-205 A/B	3.7
PU-206 A/B	3.7
PU-207 A/B	3.7
PU-208 A/B	3.7
PU-209 A/B	7.5
PU-210 A/B	55.9
PU-211 A/B	7.5
PU-212 A/B	55.9
PU-213 A/B	1.1
PU-214 A/B	2.2
PU-215 A/B	1.1
PU-216 A/B	1.1
PU-217 A/B	2.2
PU-218 A/B	1.1
PU-219 A/B	11.2
PU-220 A/B	1.1
PU-221 A/B	1.1
PU-222 A/B	11.2
CPU-201	1.4
Total	217.8

The total electricity requirements for both process and utility units are 224 kW. The design was made with 10% overdesign, so the electricity requirements will be 247 kW.

5.2 Instrumentation Electricity

The electricity requirements for instrumentation are estimated at 25% of the electricity requirements for both process and utility units with 10% overdesign, so the electricity requirements are 68 kW.

5.3 Lighting Electricity

The electricity requirements for instrumentation are estimated at 15% of the electricity requirements for both process and utility units with 10% overdesign, so the electricity requirements are 41 kW.

5.4 Air Conditioner Electricity

The electricity requirements for air conditioners are estimated at 15% of the electricity requirements for both process and utility units with 10% overdesign, so the electricity requirements are 41 kW.

5.5 Workshop and Laboratory Electricity

The electricity requirements for the workshop and laboratory are estimated at 15% of the electricity requirements for both process and utility units with 10% overdesign, so the electricity requirements are 41 kW.

Table 5.8 shows the total electricity requirements for the n-propanol plant.

Table 5.8 Total electricity requirements

Type	Electricity Requirements (kW)
Process and utility electricity	224
Instrumentation electricity	68
Lighting electricity	41
Air Conditioner electricity	41
Workshop and laboratory electricity	41
Total	414

5.4 Pressurized Air Unit

In this plant, compressed air is needed to drive control instruments as drivers of control devices in the plant that work pneumatically. The instrument air pressure used is 7.2 bar. In this n-propanol plant, 22 control devices require compressed air to drive them. The mechanism or process for making compressed air is that the ambient air is compressed using a compressor equipped with an air filter until it reaches a pressure of 7.2 bar, then the air flows to the control devices and process devices that need it. The total instrument air requirement is estimated at 41 m³/hour. The air used must be dry so that when it comes out of the blower, the air is passed through an air tank (drying vessel) containing silica gel.

5.5 Fuel Supply Unit

This unit aims to provide fuel used in the boiler. The fuel used is diesel at 2,250 L/hour.

5.6 Utility Process Flow Diagram

Figure 5.1 shows the utility process flow diagram.

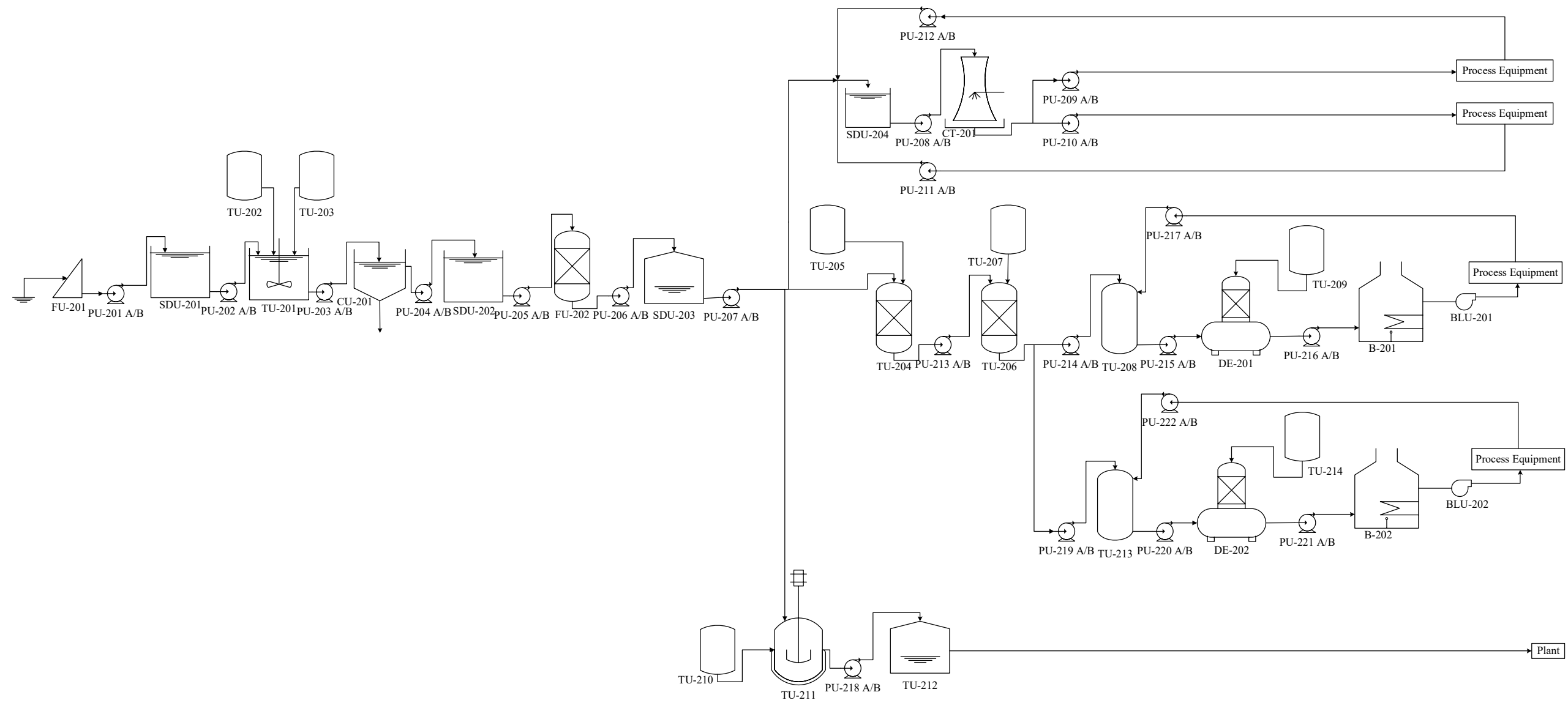


Figure 5.1 Utility process flow diagram

5.7 Utility Unit Specification

5.7.1. Screening

Code	: FU-201
Function	: To filter branches or leaves that enter the equipment
Material	: Carbon Steel SA-283 Grade A
Price, Rp	: Rp 360,762,659

Specification

Hole size, cm	: 1 cm
Width, m	: 2.438 m
Length, m	: 3.048 m

5.7.2. Sand Filter Tank

Code	: FU-202
Function	: To filter flocculant and sand
Material	: Reinforced concrete
Price, Rp	: Rp 74,839,062

Specification

Area, m ²	: 13.155 m ²
Width, m	: 3.223 m
Length, m	: 3.223 m
Stack height, m	: 1.612 m

5.7.3. Flocculation Tank

Code	: TU-201
Function	: Mixing coagulant and hardness reducing chemicals.
Type	: Vertical tank with mixer
Material	: Carbon Steel SA-283 Grade A
Price, Rp	: Rp 347,330,007

Specification

Diameter, m	: 5.822 m
Height, m	: 5.822 m
Liquid height, m	: 5.240 m

Mixer Specification

Mixer type	: Propeller
Blade amount	: 3 blades
Diameter	: 1.940 m
Rotation speed, rpm	: 34.851 rpm
Power, W	: 124.283 W

5.7.4. CaOH Storage Tank

Code	: TU-202
Function	: To store CaOH 5 %
Storage time	: 7 days
Phase	: Liquid
Type	: Cylindrical tank

Price, Rp : Rp 963,313,058

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 75.265 m³

Diameter, m : 3.632 m

5.7.5. Al₂(SO₄)₃ Storage Tank

Code : TU-203

Function : To store Al₂(SO₄)₃ 5 %

Storage time : 7 days

Phase : Liquid

Type : Cylindrical Tank

Price, Rp : Rp 1,416,185,332

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 219.343 m³

Diameter, m : 5.188 m

5.7.6. Cation Exchanger

Code : TU-204

Function : Removes minerals in water by
binding positive ions in water

Type : Cylindrical Tank

Price, Rp : Rp 305,113,100

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 5.256 m³

Diameter, m : 1.874 m

5.7.7. H₂SO₄ Storage Tank

Code : TU-205

Function : To store H₂SO₄ 2 %

Storage time : 7 days

Phase : Liquid

Type : Cylindrical Tank

Price, Rp : Rp 379,952,162

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 3571.167 m³

Diameter, m : 15.567 m

5.7.8. Anion Exchanger

Code : TU-206

Function : Removes minerals in water by
binding negative ions in water

Type : Cylindrical Tank

Price, Rp : Rp 305,113,100

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 5.256 m³

Diameter, m : 1.874 m

5.7.9. NaOH Storage Tank

Code : TU-208

Function : Mixing circulating condensate and
boiler feed make-up water at 3 atm

Type : Cylindrical Tank

Price, Rp : Rp 623,658,852

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 14.495 m³

Diameter, m : 2.809 m

5.7.10. Boiler Feed Tank

Code : TU-208

Function : Mixing circulating condensate and
boiler feed make-up water at 3 atm

Type : Cylindrical Tank

Price, Rp : Rp 623,658,852

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 14.495 m³

Diameter, m : 2.809 m

5.7.11. **N₂H₄ Storage Tank**

Code : TU-209

Function : To store N₂H₄ 5 % at 3 atm

Storage time : 30 days

Phase : Liquid

Type : Cylindrical Tank

Price, Rp : Rp 389,546,914

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 4.398 m³

Diameter, m : 1.776 m

5.7.12. **Cl₂ Storage Tank**

Code : TU-210

Function : To store Cl₂ 5 %

Storage time : 7 days

Phase : Liquid

Type : Cylindrical Tank

Price, Rp : Rp 105,542,267

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 0.001 m³

Diameter, m : 0.112 m

5.7.13. Chlorination Tank

Code : TU-211

Function : Mixing chlorine to water

Type : Cylindrical Tank

Price, Rp : Rp 189,976,081

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 2.140 m³

Diameter, m : 1.400 m

5.7.14. Water Storage Tank

Code : TU-212

Function : To store domestic and service water

Storage time : 1 day

Type : Cylindrical Tank

Price, Rp : Rp 951,799,356

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 42.814 m³

Diameter, m : 3.792 m

5.7.15. Boiler Feed Tank

Code : TU-213

Function : Mixing circulating condensate and
boiler feed make-up water at 20 atm

Type : Cylindrical Tank

Price, Rp : Rp 466,304,927

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 6.890 m³

Diameter, m : 2.063 m

5.7.16. N₂H₄ Storage Tank

Code : TU-209

Function : To store N₂H₄ 5 % at 20 atm

Storage time : 30 days

Phase : Liquid

Type : Cylindrical Tank

Price, Rp : Rp 285,923,597

Specification

Material : Carbon Steel SA-283 Grade A

Volume, m³ : 1.742 m³

Diameter, m : 1.304 m

5.7.17. Clarifier

Code : CU-201

Function	: Coagulates and precipitates colloidal
	dirt carried by water
Type	: Cylinder tank with mixer and cone bottom
Material	: Carbon Steel SA-283 Grade A
Price, Rp	: Rp 347,330,007

Specification

Diameter, m	: 7.902 m
Height, m	: 7.902 m
Cone height, m	: 0.988 m

Mixer Specification

Mixer type	: Propeller
Blade amount	: 3 blades
Diameter	: 2.634 m
Rotation speed, rpm	: 25.679 rpm
Power, W	: 93.213 W

5.7.18. Sedimentation Tank 01

Code	: SDU-201
Function	: Pecipitate coarse dirt carried by river water
Material	: Reinforced concrete
Price, Rp	: Rp 1,176,316,543

Specification

Width, m : 6.151 m

Length, m : 6.151 m

Height, m : 3.075 m

5.7.19. Sedimentation Tank 02

Code : SDU-202

Function : Precipitate flocculant from
flocculation

Material : Reinforced concrete

Price, Rp : Rp 1,176,316,543

Specification

Width, m : 4.594 m

Length, m : 4.594 m

Height, m : 2.297 m

5.7.20. Temporary Water Storage

Code : SDU-203

Function : Temporary storage for water before
divided for further process

Material : Reinforced concrete

Price, Rp : Rp 1,176,316,543

Specification

Width, m : 6.367 m

Length, m : 6.367 m

Height, m : 3.184 m

5.7.21. Water Tank

Code : SDU-204

Function : Mixing circulating cooling water
and make-up cooling water

Material : Reinforced concrete

Price, Rp : Rp 1,548,592,904

Specification

Width, m : 10.094 m

Specification

Length, m : 10.094 m

Height, m : 5.047 m

5.7.22. Cooling Tower 01

Code : CT-201

Function : Cool the water that will be used as a
coolant

Type : Counterflow induced draft

Material : Carbon Steel SA-283 Grade A

Price, Rp : Rp 11,444,619,679

Operation Condition

T in, °C : 65 °C

T out, °C : 20 °C

Specification

Area, m² : 3.318 m²

Width, m : 1.821 m

Length, m : 1.821 m

Height, m : 6.686 m

Power, W : 18,642.5 W

5.7.23. Deaeration 01

Code : DE-201

Function : Removes CO₂ and O₂ gas from
water at 3 atm

Type : Cylinder tank

Material : Carbon Steel SA-283 Grade A

Price, Rp : Rp 811,715,983

Specification

Volume, m³ : 17.394 m³

Diameter, m : 2.808 m

Height, m : 2.808 m

5.7.24. Deaeration 02

Code : DE-202

Function : Removes CO₂ and O₂ gas from
Water at 20 atm

Type	: Cylinder tank
Material	: Carbon Steel SA-283 Grade A
Price, Rp	: Rp 811,715,983

Specification

Volume, m ³	: 6.890 m ³
Diameter, m	: 2.062 m
Height, m	: 2.062 m

5.7.25. Boiler 01

Code	: B-201
Function	: To produce steam as heating media
Type	: Fire tunnel boiler
Material	: Carbon Steel SA-283 Grade A
Price, Rp	: Rp 4,970,081,316

Operation Condition

T in, °C	: 30 °C
T out, °C	: 134 °C
Pressure, atm	: 3 atm

Specification

Area, m ²	: 170.667 m ²
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Fuel Tank Specification

Storage time	: 3 days
Volume, m ³	: 129.623 m ³
Diameter, m	: 5.485 m

Height, m : 5.485 m

5.7.26. **Boiler 02**

Code : B-201

Function : To produce steam as heating media

Type : Fire tunnel boiler

Material : Carbon Steel SA-283 Grade A

Price, Rp : Rp 5,795,229,951

Operation Condition

T in, °C : 30 °C

T out, °C : 260 °C

Pressure, atm : 20 atm

Specification

Area, m² : 58.879 m²

Fuel Tank Specification

Storage time : 3 days

Volume, m³ : 64.929 m³

Diameter, m : 4.356 m

Height, m : 4.356 m

5.7.27. **Blower Utility 01**

Code : BLU-01

Function : Transport steam as heating media
to equipments

Site elevation, m : 0 m

Price, Rp : Rp 11,513,702

Operating Conditions

Temperature in, °C : 134 °C

Temperature out, °C : 134 °C

Pressure in, bar : 3.040 bar

Pressure out, bar : 3.040 bar

Specification

Stage : Single-stage (1 stage)

Type : Centrifugal

Motor power, W : 3728.5 W

Material : Carbon Steel SA-283 Grade A

5.7.28. Blower Utility 02

Code : BLU-01

Function : Transport steam as heating media
to equipments

Site elevation, m : 0 m

Price, Rp : Rp 1,918,950

Operating Conditions

Temperature in, °C : 260 °C

Temperature out, °C : 260 °C

Pressure in, bar : 20.265 bar

Pressure out, bar : 20.265 bar

Specification

Stage	: Single-stage (1 stage)
Type	: Centrifugal
Motor power, W	: 3728.5 W
Material	: Carbon Steel SA-283 Grade A

5.7.29. Compressor Utility 01

Code	: CPU-01
Function	: To supply pressurized air for instruments
Site elevation, m	: 0 m
Price, Rp	: Rp 1,038,152,120

Operating Conditions

Temperature in, °C	: 30 °C
Temperature out, °C	: 165 °C
Pressure in, bar	: 2.026 bar
Pressure out, bar	: 8.212 bar

Specification

Compression ratio	: 4.053
Stage	: Single-stage (1 stage)
Volumetric efficiency	: 74.5%
Type	: Positive displacement
Minimum RPM	: 630 RPM
Actual RPM	: 690 RPM

Motor power, W : 1378.4 W

Material : Carbon Steel SA-283 Grade A

Table 5.9 Specification of pump utility

Code	PU-201 A/B	PU-202 A/B	PU-203 A/B	PU-204 A/B
Function	Transport water from FU-201 to SDU-201	Transport water from SDU-201 to U-201	Transport water from TU-201 to CU-201	Transport water from CU-201 to SDU-202
Pump head, m	5 m	5 m	5 m	5 m
Motor power, W	3,728.5 W	3,728.5 W	3,728.5 W	3,728.5 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 95,947,516	Rp 95,947,516	Rp 95,947,516	Rp 95,947,516
Code	PU-205 A/B	PU-206 A/B	PU 207 A/B	PU-208 A/B
Function	Transport water from SDU-202 to FU-202	Transport water from FU-202 to SDU-203	Transport water from SDU-203 to 3 different water process areas	Transport water from SDU-204 to CT-201
Pump head, m	5 m	5 m	5 m	5 m
Motor power, W	3,728.5 W	3,728.5 W	3,728.5 W	3,728.5 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 95,947,516	Rp 95,947,516	Rp 95,947,516	Rp 95,947,516

Table 5.9 Specification of pump utility (continuation)

Code	PU-209 A/B	PU-210 A/B	PU-211 A/B
Function	Transport water from CT-201 to process area and increase the pressure to 3 atm	Transport water from CT-201 to process area and increase the pressure to 20 atm	Transport water from process area to SDU-204 and decrease the pressure to 1 atm
Pump head, m	25 m	195 m	25 m
Motor power, W	7,457 W	55,297.5 W	7,457 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 74,839,062	Rp 74,839,062	Rp 74,839,062
Code	PU-212 A/B	PU-213 A/B	PU-214 A/B
Function	Transport water from process area to SDU-204 and decrease the pressure to 1 atm	Transport water from TU-204 to TU-206	Transport water from TU-206 to TU-208 and increase the pressure to 3 atm
Pump head, m	195 m	5 m	25 m
Motor power, W	55,297.5 W	1,118.6 W	2,237 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 74,839,062	Rp 51,811,659	Rp 40,297,957

Table 5.9 Specification of pump utility (continuation)

Code	PU-215 A/B	PU-216 A/B	PU-217 A/B	PU-218 A/B
Function	Transport water from TU-208 to DE-201	Transport water from DE-201 to B-201	Transport water from process area to TU-208 and decrease the pressure to 1 atm	Transport water from TU-211 to TU-212
Pump head, m	5 m	5 m	25 m	5 m
Motor power, W	1,118.6 W	1,118.6 W	2,237 W	1,118.6 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 40,297,957	Rp 40,297,957	Rp 40,297,957	Rp 15,351,603
Code	PU-219 A/B	PU-220 A/B	PU 2021A/B	PU-222 A/B
Function	Transport water from TU-206 to TU-213 and increase the pressure to 20 atm	Transport water from TU-213 to DE-202	Transport water from DE-202 to B-202	Transport water from process area to TU-213 and decrease the pressure to 1 atm
Pump head, m	195 m	5 m	5 m	195 m
Motor power, W	11,185.5 W	1,118.6 W	1,118.6 W	11,185.5 W
Material	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A	Carbon steel SA-283 Grade A
Price, Rp	Rp 28,784,255	Rp 28,784,255	Rp 28,784,255	Rp 28,784,255

CHAPTER VI

ECONOMY ANALYSIS

To find out whether the factory that is established can be profitable and feasible or not to be established from an economic perspective, an economic evaluation is needed. One important part of this factory design is the price estimate of the tools that will be used in the factory's needs because the price is used as a basis for estimating the economic evaluation of the feasibility of capital investment in a factory's production activities by reviewing the need for investment capital that can be returned and the occurrence of a break-even point.

For this reason, in designing this n-propanol factory, several factors are reviewed in calculating the economic evaluation, including:

- (1) Capital investment
 - a) Fixed capital investment
 - b) Working capital investment
- (2) Manufacturing cost
 - a) Direct manufacturing cost
 - b) Indirect manufacturing cost
 - c) Fixed manufacturing cost
- (3) General cost
- (4) Economic feasibility analysis
 - a) Percent Return on Investment (ROI)
 - b) Pay Out Time (POT)

- c) Break Even Point (BEP)
- d) Discounted Cash Flow Rate of Return (DCFRR)

6.1 Equipment Price Estimation

The price of process equipment on each tool is influenced by the current economic conditions. The price of equipment will be different every year, the price can increase or decrease depending on economic conditions, so it will be difficult to determine the exact price of equipment. To estimate the price of equipment can be done by knowing the price of the operating equipment index in that year.

The equipment price analysis was conducted in 2024 for the purchase of equipment in the construction year, namely 2028. In the economic analysis, the prices of equipment and other factory needs are calculated in the analysis year. The following is a price index which in chemical engineering is called the CEP index or Chemical Engineering Plant Cost Index (CEPCI) that can be obtained from Perry (2008).

To estimate the price of the equipment, an approximate equation 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 as written in eq. 6.1 (Perry, 2008).

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

Where:

E_x : Price in 2028

E_y Price according to reference in 2014

N_x : Index in 2028

N_y : Index reference year in 2014

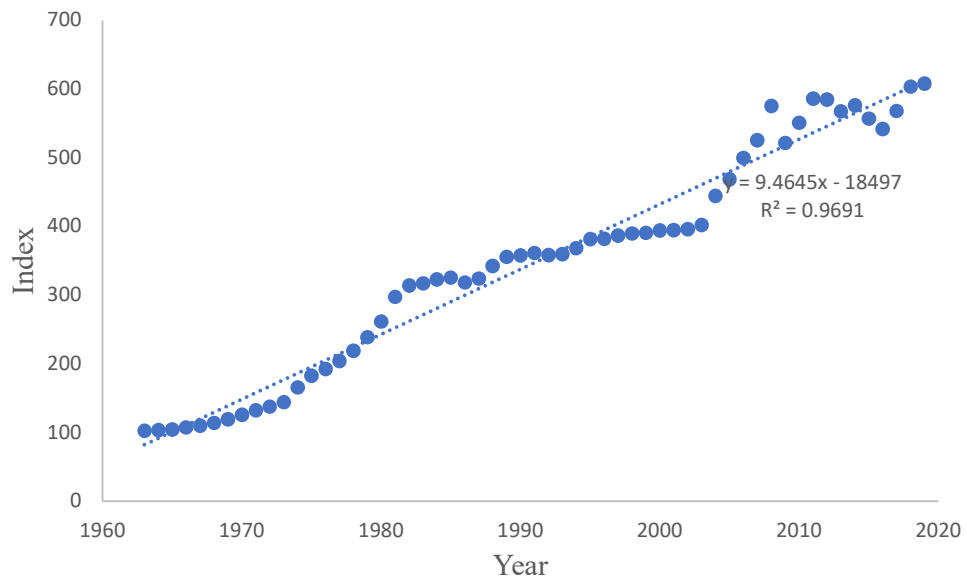


Figure 6.1 CEP index graph

The equation obtained from Figure 6.1 is $y = 9.4645x - 18497$. Using the equation, the CEP Index value in design years can be found, so the CEP Index value in design year 2028 is 697.006 and CEP Index value for year 2014 as reference year according to Perry (2008) is 576.1. Based on the CEP index value, the price of the process equipment and the utility equipment can be determined as shown in Table 6.2 and Table 6.3, respectively.

Table 6.1 Process unit price estimation

Code	Name	Quantity	Ey (2014)	Ex (2028)	Ex (2028)
R-01	Reactor 01	1	\$83,200	\$100,661	IDR 1,596,566,662
R-02	Reactor 02	1	\$67,200	\$81,303	IDR 1,289,534,612
TK-101	Storage Tank 01	1	\$200,000	\$241,974	IDR 3,837,900,630
TK-102	Storage Tank 02	1	\$200,000	\$241,974	IDR 3,837,900,630
TK-103	Storage Tank 03	1	\$425,500	\$514,800	IDR 8,165,133,590
TK-104	Storage Tank 04	1	\$174,800	\$211,485	IDR 3,354,325,151
T-101	Distillation Tower 01	1	\$1,357,300	\$1,642,156	IDR 26,045,912,626
V-101	Separator 01	1	\$12,600	\$15,244	IDR 241,787,740
V-102	Separator 02	1	\$11,300	\$13,672	IDR 216,841,386
P-101 A/B	Pump 01	2	\$7,600	\$9,195	IDR 291,680,448
CP-101	Compressor 01	1	\$2,500	\$3,025	IDR 47,973,758
CP-102	Compressor 02	1	\$2,500	\$3,025	IDR 47,973,758
E-101	Vaporizer 01	1	\$1,800	\$2,178	IDR 34,541,106
E-102	Heat Exchanger 01	1	\$1,500	\$1,815	IDR 28,784,255
E-103	Vaporizer 02	1	\$1,500	\$1,815	IDR 28,784,255
E-104	Heat Exchanger 02	1	\$1,800	\$2,178	IDR 34,541,106
E-105	Heat Exchanger 03	1	\$1,600	\$1,936	IDR 30,703,205
E-106	Vaporizer 02	1	\$26,400	\$31,941	IDR 506,602,883
E-107	Vaporizer 03	1	\$1,100	\$1,331	IDR 21,108,453
E-108	Heat Exchanger 04	1	\$1,500	\$1,815	IDR 28,784,255
E-109	Heat Exchanger 05	1	\$1,300	\$1,573	IDR 24,946,354
E-110	Condenser 01	1	\$78,700	\$95,217	IDR 1,510,213,898
E-111	Vaporizer 05	1	\$20,100	\$24,318	IDR 385,709,013
E-112	Condenser 02	1	\$25,200	\$30,489	IDR 483,575,479
E-113	Reboiler 02	1	\$24,500	\$29,642	IDR 470,142,827
E-114	Heat Exchanger 06	1	\$35,600	\$43,071	IDR 683,146,312
Total				\$3,347,831	IDR 53,245,114,391

Table 6.2 Utility unit price estimation

Code	Name	Quantity	Ey (2014)	Ex (2028)	Ex (2028)
FU-201	Screening	1	\$18,800	\$22,746	IDR 360,762,659
FU-202	Sand Filter Tank	1	\$3,900	\$4,718	IDR 74,839,062
TU-201	Flocculation Tank	1	\$18,100	\$21,899	IDR 347,330,007
TU-202	CaOH storage tank	1	\$50,200	\$60,735	IDR 963,313,058
TU-203	Alum Storage Tank	1	\$73,800	\$89,288	IDR 1,416,185,332
TU-204	Cation exchanger	1	\$15,900	\$19,237	IDR 305,113,100
TU-205	H2SO4 Storage Tank	1	\$19,800	\$23,955	IDR 379,952,162
TU-206	Anion exchanger	1	\$15,900	\$19,237	IDR 305,113,100
TU-207	NaOH Storage Tank	1	\$9,800	\$11,857	IDR 188,057,131
TU-208	Boiler Feed Tank	1	\$32,500	\$39,321	IDR 623,658,852
TU-209	N2H4 Storage Tank	1	\$20,300	\$24,560	IDR 389,546,914
TU-210	Chlorine Storage Tank	1	\$5,500	\$6,654	IDR 105,542,267
TU-211	Chlorination Tank	1	\$9,900	\$11,978	IDR 189,976,081
TU-212	Water Storage Tank	1	\$49,600	\$60,010	IDR 951,799,356
TU-213	Boiler Feed Tank	1	\$24,300	\$29,400	IDR 466,304,927
TU-214	N2H4 Storage Tank	1	\$14,900	\$18,027	IDR 285,923,597
CU-201	Clarifier	1	\$18,100	\$21,899	IDR 347,330,007
SDU-201	Sedimentation Tank	1	\$61,300	\$74,165	IDR 1,176,316,543
SDU-202	Sedimentation Tank	1	\$61,300	\$74,165	IDR 1,176,316,543
SDU-203	Temp Storage	1	\$61,300	\$74,165	IDR 1,176,316,543
SDU-204	Water Tank	1	\$80,700	\$97,636	IDR 1,548,592,904
CT-201	Cooling Tower	1	\$596,400	\$721,566	IDR 11,444,619,679
DE-201	Deaeration 01	1	\$42,300	\$51,177	IDR 811,715,983
DE-202	Deaeration 02	1	\$42,300	\$51,177	IDR 811,715,983
B-201	Boiler 01	1	\$259,000	\$313,356	IDR 4,970,081,316
B-202	Boiler 02	1	\$302,000	\$365,381	IDR 5,795,229,951
BLU-01	Blower Utility 01	1	\$600	\$726	IDR 11,513,702
BLU-02	Blower Utility 02	1	\$100	\$121	IDR 1,918,950
CPU-01	Compressor Utility 01	1	\$54,100	\$65,454	IDR 1,038,152,120
PU-201 A/B	Pump Utility 01	2	\$5,000	\$6,049	IDR 191,895,032
PU-202 A/B	Pump Utility 02	2	\$5,000	\$6,049	IDR 191,895,032
PU-203 A/B	Pump Utility 03	2	\$5,000	\$6,049	IDR 191,895,032
PU-204 A/B	Pump Utility 04	2	\$5,000	\$6,049	IDR 191,895,032
PU-205 A/B	Pump Utility 05	2	\$5,000	\$6,049	IDR 191,895,032
PU-206 A/B	Pump Utility 06	2	\$5,000	\$6,049	IDR 191,895,032
PU-207 A/B	Pump Utility 07	2	\$5,000	\$6,049	IDR 191,895,032
PU-208 A/B	Pump Utility 08	2	\$5,000	\$6,049	IDR 191,895,032
PU-209 A/B	Pump Utility 09	2	\$3,900	\$4,718	IDR 149,678,125
PU-210 A/B	Pump Utility 10	2	\$3,900	\$4,718	IDR 149,678,125
PU-211 A/B	Pump Utility 11	2	\$3,900	\$4,718	IDR 149,678,125
PU-212 A/B	Pump Utility 12	2	\$3,900	\$4,718	IDR 149,678,125
PU-213 A/B	Pump Utility 13	2	\$2,700	\$3,267	IDR 103,623,317
PU-214 A/B	Pump Utility 14	2	\$2,100	\$2,541	IDR 80,595,913
PU-215 A/B	Pump Utility 15	2	\$2,100	\$2,541	IDR 80,595,913
PU-216 A/B	Pump Utility 16	2	\$2,100	\$2,541	IDR 80,595,913
PU-217 A/B	Pump Utility 17	2	\$2,100	\$2,541	IDR 80,595,913
PU-218 A/B	Pump Utility 18	2	\$800	\$968	IDR 30,703,205
PU-219 A/B	Pump Utility 19	2	\$1,500	\$1,815	IDR 57,568,509
PU-220 A/B	Pump Utility 20	2	\$1,500	\$1,815	IDR 57,568,509
PU-221 A/B	Pump Utility 21	2	\$1,500	\$1,815	IDR 57,568,509
PU-222 A/B	Pump Utility 22	2	\$1,500	\$1,815	IDR 57,568,509
Total				\$2,463,537	IDR 40,484,094,796

6.2 Calculation Base

Capacity	: 60,000 ton/year
Operational Time	: 330 days
Equipment period	: 10 years
Currency conversion	: 1 \$ = 15,860.8 (November 19 th , 2024)
Construction year	: 2028
UMR Serang	: Rp 4,857,353.01

Table 6.3 Raw material price

No.	Component	Price (\$/kg)	Price (Rp/kg)
1.	Ethylene	0.114	1,814
2.	Syngas	0.686	10,883
3.	Hydrogen	1.715	27,207
4.	Rhodium-Silica	35.451	562,284
5.	Nickel-Kieselguhr	22.872	362,764

Table 6.4 Utility material price

No.	Component	Price (\$/kg)	Price (Rp/kg)
1.	Al ₂ (SO ₄) ₃	0.126	1,995
2.	Cl ₂	0.343	5,441
3.	H ₂ SO ₄	0.069	1,088
4.	NaOH	0.457	7,255
5.	N ₂ H ₄	0.686	10,883
6.	CaOH	0.229	3,628
7.	Solar (kWh)	0.114	1,814
8.	Cation resin	0.778	12,334
9.	Anion resin	0.789	12,515

Table 6.5 Product price

No.	Component	Price (\$/kg)	Price (Rp/kg)
1.	n-Propanol	2.287	36,276

6.3 Cost Components

6.3.1 Capital Investment

Capital investment is the total cost to establish factory facilities and equipment, and to operate the factory.

a. Fixed Capital Investment

Fixed Capital Investment is the cost required to establish factory facilities. Fixed capital investment includes Physical Plant Cost (PPC) as shown in Table 6.6 and Direct Plant Cost (DPC) as shown in Table 6.7. Table 6.8 shows the total of fixed capital investment for n-propanol plant.

Table 6.6 Physical Plant Cost (PPC) details

No.	Component	Price (\$)	Price (Rp)
1.	Purchased equipment cost	3,448,952	54,703,132,840
2.	Installation cost	1,483,049	23,522,347,121
3.	Instrumentation cost	517,343	8,205,469,926
4.	Piping cost	2,966,098	47,044,694,242
5.	Electrical cost	517,343	8,205,469,926
6.	Insulation cost	517,343	8,205,469,926
7.	Building cost	3,942,733	62,534,900,000
8.	Land & yard improvement	2,695,939	42,759,750,000
Total		17,583,212	278,883,810,742

Table 6.7 Direct Plant Cost (DPC) details

No.	Component	Price (\$)	Price (Rp)
1.	Engineering and construction	3,516,642	55,776,762,148
Total		3,516,642	55,776,762,148

Table 6.8 Fixed capital investment total

No.	Component	Price (\$)	Price (Rp)
1.	PPC	21,099,855	334,660,572,890
2.	DPC	21,099,855	334,660,572,890
3.	Contractor's fee	421,997	6,693,211,458
4.	Contingency	2,109,985	33,466,057,289
Total		44,731,692	709,480,414,527

b. Working Capital Investment

Working capital investment is the cost required to run a business or capital to run a factory operation for a certain period. Several sources of capital can be obtained in establishing a factory, namely from bank loans, personal money, or from investors. The ultimate goal of investment is to gain profit from the capital that has been invested, some characteristics of good investment are able to generate maximum profit, quick return on investment, adhere to good laws, adequate technology, safety, etc.

Table 6.9 shows the detail of working capital investment for n-propanol plant.

Table 6.9 Working capital investment details

No.	Component	Price (\$)	Price (Rp)
1.	Raw material inventory	2,568,805	40,743,294,604
2.	In-process inventory	777,506	12,331,873,628
3.	Product inventory	4,319,480	68,510,409,046
4.	Available cash	4,319,480	68,510,409,046
5.	Extended credit	103,667,521	1,644,249,817,102
Total		115,652,792	1,834,345,803,426

6.3.2 Manufacturing Cost

Manufacturing cost is the cost required to produce a product.

Manufacturing cost consists of direct manufacturing cost, indirect manufacturing cost, and fixed manufacturing cost which is always related to the manufacture of a product.

a. Direct Manufacturing Cost

Direct manufacturing costs or direct costs are expenses that are still directly related to the manufacture of products related to producing a product in a factory. Table 6.10 shows the direct manufacturing cost details.

Table 6.10 Direct manufacturing cost details

No.	Component	Price (\$)	Price (Rp)
1.	Raw material	30,907,008	490,209,876,925
2.	Utility material	81,354	1,290,341,676
3.	Employees salary	1,320,993	20,952,000,000
4.	Supervise	7,706,414	122,229,883,812
5.	Maintenance	1,789,268	28,379,216,581
6.	Plant Supplies	357,854	5,675,843,316
7.	Royalties	53,678	851,376,497
Total		42,216,568	669,588,538,808

b. Indirect Manufacturing Cost

Indirect Manufacturing Costs or indirect costs are costs that are not directly related to the production units in the factory.

Table 6.11 shows the direct manufacturing cost details.

Table 6.11 Indirect manufacturing cost details

No.	Component	Price (\$)	Price (Rp)
1.	Payroll overhead	264,199	4,190,400,000
2.	Laboratory	264,199	4,190,400,000
3.	Plant overhead	1,320,993	20,952,000,000
4.	Packaging and shipping	2,400,000	38,065,920,000
Total		4,249,390	67,398,720,000

c. Fixed Manufacturing Cost

Fixed manufacturing cost or fixed costs are costs incurred by the factory during operating conditions or not. Expenditures that are constant or fixed do not depend on time and production levels. Table 6.12 shows the fixed manufacturing cost details.

Table 6.12 Fixed manufacturing cost details

No.	Component	Price (\$)	Price (Rp)
1.	Depreciation	4,473,169	70,948,041,453
2.	Property tax	447,317	7,094,804,145
3.	Insurance	447,317	7,094,804,145
Total		5,367,803	85,137,649,743

Table 6.13 shows the total of manufacturing cost.

Table 6.13 Manufacturing cost total

No.	Component	Price (\$)	Price (Rp)
1.	Direct manufacturing cost	42,216,568	669,588,538,808
2.	Indirect manufacturing cost	4,249,390	67,398,720,000
3.	Fixed manufacturing cost	5,367,803	85,137,649,743
Total		51,745,022	822,124,908,551

6.3.3 General Expenses

General expenses consist of expenses related to the functions of the company that are not included in manufacturing costs. Costs must be incurred to ensure the smooth running of the company as a whole. Table 6.14 shows the details of general expenses.

Table 6.14 Total general expenses

No.	Component	Price (\$)	Price (Rp)
1.	Administration	4,811,535	76,314,786,539
2.	Sales	4,811,535	76,314,786,539
3.	Finance	12,830,759	203,506,097,436
4.	Research	12,830,759	203,506,097,436
Total		35,284,586	559,641,767,950

Production cost consists of manufacturing cost and general expenses.

Table 6.15 shows the total of production cost.

Table 6.15 Total production cost

No.	Component	Price (\$)	Price (Rp)
1.	Manufacturing cost	51,745,022	822,124,908,551
2.	General expenses	35,284,586	559,641,767,950
Total		87,118,347	1,381,766,676,501

6.4 Profit Analysis

6.4.1 Profit before taxes

Total sales : Rp 1,903,296,000,000

Total production cost : Rp 1,381,766,676,501

Profit before taxes : Total sales – total production cost

: Rp 521,529,323,499

6.4.2 Profit after taxes

Tax 25% from profit : Rp 130,382,330,875

Profit before taxes : Profit before taxes – tax
: Rp 391,146,992,624

6.5 Feasibility Analysis

Feasibility analysis is to determine the profit obtained to obtain maximum profit and to be able to see the results of small or large profits so that it can be categorized as a potential or non-potential factory from an economic perspective, there are several ways to see the feasibility of a factory:

6.5.1 Return on Investment (ROI)

Return On Investment (ROI) is the percentage of profit obtained each year from the level of investment issued. A low-risk factory has a minimum ROI before tax of 11 %, while a high-risk factory has a minimum ROI before tax of 44 %. The amount of money received or lost is called profit/loss or interest. Return on investment can be calculated with eq. 6.2.

$$\%ROI = \frac{Profit}{Fixed\ Capital\ Investment} \times 100\% \quad (6.2)$$

Before taxes, the amount of ROI calculated is 73.5 %, while after taxes the amount of ROI calculated is 55 %.

6.5.2 Pay Out Time (POT)

Pay Out Time is the length of time for the return of capital based on the profits obtained. This calculation is needed to find out in how many years the investment has been returned. The POT

requirement before tax for a high-risk chemical plant is a maximum of 2 years. Pay out time can be calculated with eq. 6.3.

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

Before taxes, the amount of POT (POTb) calculated is 1.2 years, while after taxes the amount of POT (POTa) calculated is 1.5 years.

6.5.3 Break-Even Point (BEP)

Break-even point is a point that indicates a level where costs and income are the same. With the break-even point we can determine the level of selling price and the number of units sold at a minimum and how much per unit is sold to make a profit. The BEP value of a chemical factory is generally in the range of 40-60%. Break-even point can be calculated with eq. 6.4.

$$BEP = \frac{Fa + 0.3Ra}{Sa - Va - 0.7Ra} \times 100\% \quad (6.4)$$

Where:

Fa : Annual fixed manufacturing cost at maximum production

Ra : Annual regulated expenses at maximum production

Va : Annual variable value at maximum production

Sa : Annual sales value at maximum production

Fa, Ra, and Va are shown in Table 6.16, Table 6.17, and Table 6.18, respectively.

Table 6.16 Annual fixed manufacturing cost at maximum production (Fa)

No.	Component	Price (\$)	Price (Rp)
1.	Depreciation	4,473,169	70,948,041,453
2.	Property Taxes	447,317	7,094,804,145
3.	Insurances	447,317	7,094,804,145
Total		5,367,803	85,137,649,743

Table 6.17 Annual regulated expenses at maximum production (Ra)

No.	Component	Price (\$)	Price (Rp)
1.	Employees salary	1,320,993	20,952,000,000
2.	Payroll overhead	264,199	4,190,400,000
3.	Plant overhead	1,320,993	20,952,000,000
4.	Supervise	7,706,414	122,229,883,812
5.	Laboratory	264,199	4,190,400,000
6.	General expenses	35,284,586	559,641,767,950
7.	Maintenance	1,789,268	28,379,216,581
8.	Plant supplies	357,854	5,675,843,316
Total		48,308,503	766,211,511,659

Table 6.18 Annual variable value at maximum production (Va)

No.	Component	Price (\$)	Price (Rp)
1.	Raw material	30,907,008	490,209,876,925
2.	Packaging and shipping	2,400,000	38,065,920,000
3.	Utility material	81,354	1,290,341,676
4.	Royalties and patents	53,678	851,376,497
Total		33,442,040	530,417,515,098

Annual sales value at maximum production is total sales which is Rp 1,903,296,000,000. From the calculation, the BEP for n-propanol plant is 38 %.

6.5.4 Shut Down Point (SDP)

Shut Down Point is a point or condition when determining a production activity must stop. The causes include variable costs that are too high, or it could also be due to management decisions due to

the uneconomical nature of a production activity (not generating profit). This is because the cost of continuing factory operations will be more expensive than the cost of closing the factory and paying fixed costs. Shut down point can be calculated using eq. 6.5.

$$SDP = \frac{0.3 Ra}{Sa - Va - 0.7Ra} \times 100\% \quad (6.5)$$

From the calculation, the SDP for n-propanol plant is 30 %.

6.5.5 Discounted Cash Flow Rate of Return (DCFRR)

Discounted cash flow rate of return is the estimated amount of profit earned each year. Based on investments that are not returned at the end of each year during the life of the plant. The DCFR limit itself is 1.5 times from bank interest. Discounted cash flow rate of return can be calculated with eq. 6.6.

$$\begin{aligned} \frac{(WC + FCI) \times (1 + i)^n}{CF} & \quad (6.6) \\ &= ((1 + i)^{n-1} + (1 + i)^{n-2} + \dots \\ &+ (1 + i)^{n-n}) \times \frac{WC + SV}{CV} \end{aligned}$$

Where:

FCI : Fixed capital investment

WCI : Working capital investment

CF : Cash flow

SV : Salvage value or depreciation

n : Plant period

i : DCFRR value

Table 6.19 shows the value of each variable for calculation.

Table 6.19 The value of each variable to calculate DCFRR

No.	Component	Value
1.	FCI	Rp 709,480,414,527
2.	WCI	Rp 1,834,345,803,426
3.	CF	Rp 665,601,131,513
4.	SV	Rp 70,948,041,453
5.	n	5 years

From the calculation, DCFRR value obtained is 14 %.

Figure 6.2 shows the graph for economy analysis of n-propanol plant.

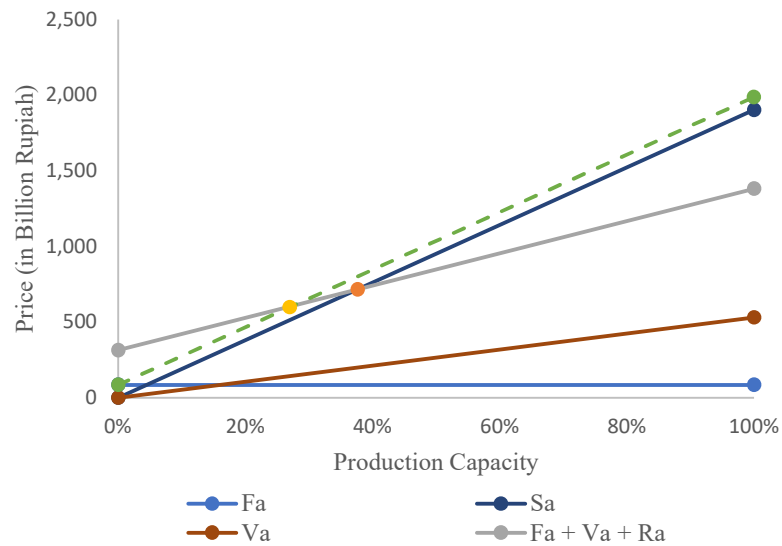


Figure 6.2 Economy analysis graph

CHAPTER VII

CONCLUSION

7.1 Conclusion

Based on the results of preliminary design calculations for an n-propanol plant from ethylene and syngas with a capacity of 60,000 tons/year, both technically and economically, the following conclusions can be drawn:

- (1) The establishment of the n-propanol factory with a capacity of 60,000 tons/year aims to meet domestic n-propanol needs and reduce dependence on imports. This factory also aims to open up employment opportunities and increase economic growth in Indonesia.
- (2) The n-propanol factory in the form of a Limited Liability Company (LLC) was established in Serang, Banten, Indonesia with a total land area of 25,915 m² and a total of 158 employees.
- (3) In terms of raw materials, marketing and environment, the location of the n-propanol factory in Serang, Banten is quite profitable because of the ease of obtaining raw materials, labor, and availability of water and electricity.
- (4) This factory is categorized as high risk based on the raw materials used, the processes involved, high temperatures and pressures, and the raw materials are flammable and explosive.
- (5) According to economy analysis shown in Table 7.1, the results of the feasibility test of the n-propanol factory are in accordance with the provisions of the chemical factory construction standards.

Table 7.1 Economy analysis conclusion

Component	Parameter	Evaluation Result	Note	Reference
ROI	ROI > 44 %	73.5 %	Feasible	Aries & Newton, 1955
POT	POT < 2 years	1.2 years	Feasible	Aries & Newton, 1955
BEP	40 % - 60 %	38 %	Feasible	Aries & Newton, 1955

- (6) Based on the results of the overall review conducted starting from the availability of raw materials, process operating conditions and economic evaluation results, it can be concluded that the n-propanol plant designed with a capacity of 60,000 tons/year is feasible to be established.

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ATTACHMENT

ATTACHMENT A
REACTOR I DESIGN

Function : To react 10706.043 kg/h ethylene with 14759.494 kg/h syngas to produce 13298.977 kg/h propanal.

Type : Fixed bed multitube

According to Kirk (1996), the operating conditions of the reaction for the production of propanal from ethylene and syngas are:

Temperature : 120 °C

Pressure : 20 atm

Phase : Gas

Catalyst : Rhodium-Silica

Shape : Sphere

Diameter : 6.35 mm

Bulk Density : 573.3 kg/m³

The reactants diffuse into the catalyst and the reaction occurs on the catalyst surface.

The reactor operates non-isothermal and non-adiabatically. The reaction is very exothermic so a cooling medium in the form of Dowtherm A is required. The reactants enter at a temperature of 100 °C and a pressure of 20 atm. Meanwhile, 3368.336 kg/h of coolant enters at a temperature of 30 °C with a co-current flow to the reactant flow. The conversion obtained was 60%, because there were still reactants that had not yet reacted, it was necessary to recycle the reactants from the top of Separator 01.

Design Objectives:

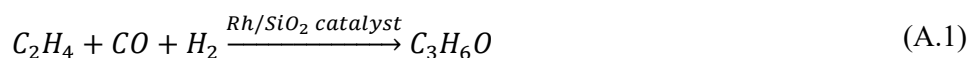
1. Determine the type of reactor;
2. Calculate the pressure drop;

3. Calculate the weight of the catalyst;

4. Determine the dimensions of the reactor.

The reaction mechanism of ethylene with syngas to become propanal is controlled by surface reactions. The reaction that occurs is:

Main reaction:



Side reaction:



1. Determination of Reactor Type

The multitube fixed bed reactor was chosen with the following considerations:

- 1) The reactant is in the form of a gas phase with a solid catalyst;
- 2) Long catalyst lifetime, about 12-15 months;
- 3) The reaction is exothermic so a large heat transfer area is needed so that contact with the coolant takes place optimally;
- 4) No separation of the catalyst from the reactor output gas is required;
- 5) Temperature control is relatively easy because it uses the shell and tube type.

2. Mathematical Modelling Formulation

- Assumption:
1. Steady-state conditions have been reached;
 2. Mass transfer due to diffusion is neglected;
 3. Gases are considered to obey the ideal gas law;
 4. Heat loss to the environment is negligible;

5. The temperature in the catalyst is the same.

2.1 Mass Balance

- Assumption:
1. Plug flow, there is no concentration gradient in the radial direction ($D/D_p = 8-50$) (Rase, 1977);
 2. Negligible axial dispersion ($L/D_p \geq 100$) (Rase, 1977);
 3. Intra-particle and interphase concentration gradients are ignored;
 4. Steady-state.

The formulation of the mass balance model was carried out in a pipe containing a catalyst as much as ΔV with X_A conversion.

$$Z = \frac{40D\Delta V}{ID^2} \quad (\text{A.3})$$

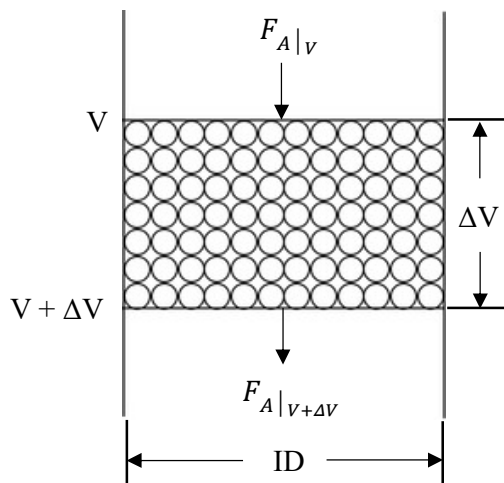


Figure A.1 Mass balance of component A through tube with catalyst

$$(\text{rate of input}) - (\text{rate of output}) = (\text{rate of acc.}) \quad (\text{A.4})$$

$$F_{A|V} - (F_{A|V+\Delta V} + (-r_A)\Delta V) = 0$$

$$F_{A|V} - F_{A|V+\Delta V} - (-r_A)\Delta V = 0$$

$$\frac{-F_{A|V+\Delta V} - F_{A|V}}{\Delta V} = (-r_A)$$

$$\text{If } \lim_{\Delta V \rightarrow 0} (\Delta V)$$

$$-\frac{dF_A}{dV} = (-r_A)$$

$$\text{If } F_A = F_{A0}(1 - X_A), \text{ so } dF_A = -F_{A0} dX_A$$

$$F_{A0} \frac{dX_A}{dV} = (-r_A)$$

$$\frac{dX_A}{dV} = \frac{(-r_A)}{F_{A0}}$$

$$\frac{dX_A}{dV} = \frac{kC_A^{0.98}C_B^{-0.75}C_C^{0.95}}{F_{A0}}$$

$$\frac{dX_A}{dV} = \frac{k(C_{A0}(1 - X_A))^{0.98}(C_{B0} - C_{A0}X_A)^{-0.75}(C_{C0} - C_{A0}X_A)^{0.95}}{F_{A0}} \quad (\text{A.5})$$

Where,

V : Reactor volume, m³

F_A : Feed of component A

X_A : Conversion of component A

$\frac{dX_A}{dV}$: Conversion change over unit volume

$-r_A$: Reaction rate, kmol/m³ h

C_A : Concentration of component A, kmol/m³

C_B : Concentration of component B, kmol/m³

C_C : Concentration of component C, kmol/m³

2.2 Energy Balance

2.2.1 Heat Balance on Volume

- Assumption:
1. Plug flow, no temperature gradient in the radial direction ($D/D_p = 8-50$) (Rase, 1977);
 2. Negligible axial dispersion ($L/D_p \geq 100$) (Rase, 1977);
 3. Intra-particle and interphase concentration gradients are ignored;
 4. Steady-state;
 5. Gas heat capacity (C_p) and gas viscosity (μ) are a function of temperature and not a function of distance.

The preparation of the heat balance model was carried out in a pipe containing a catalyst along ΔZ with conversion X_A , gas temperature T , and coolant temperature T_p .

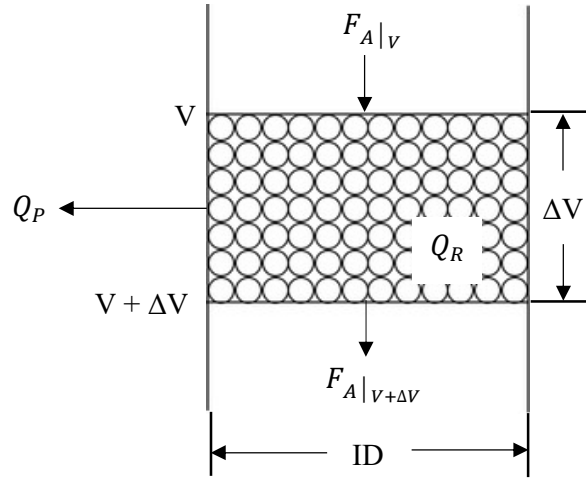


Figure A.2 Heat balance of component A through tube with catalyst

(rate of input) – (rate of output) = (rate of acc.)

$$\sum F_i C_{P_i} (T_{G|_V} - T_O) - \left[\sum F_i C_{P_i} (T_{G|_{V+\Delta V}} - T_O) + Q_R + Q_P \right] = 0$$

$$\sum F_i C_{P_i} (-\Delta T_G) = Q_R + Q_P$$

$$\text{If } T_G = \Delta H_R F_{AO} \Delta X_A$$

$$Q_P = UA(T_G - T_S)$$

$$A = \pi ODZ$$

$$\sum F_i C_{P_i} (-\Delta T_G) = \Delta H_R F_{AO} \Delta X_A + \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$\sum F_i C_{P_i} \left(\frac{-\Delta T_G}{\Delta V} \right) = \Delta H_R F_{AO} \frac{\Delta X_A}{\Delta V} + \frac{4UOD}{ID^2} (T_G - T_P)$$

$$\left(\frac{-\Delta T_G}{\Delta V} \right) = \frac{\Delta H_R F_{AO} \frac{\Delta X_A}{\Delta V} + \frac{4UOD}{ID^2} (T_G - T_P)}{\sum F_i C_{P_i}}$$

$$\text{If } \lim_{\Delta V \rightarrow 0} (\Delta V)$$

$$\frac{dT_G}{dV} = \frac{\Delta H_R F_{Ao} \frac{dX_A}{dV} + \frac{4UOD}{ID^2} (T_G - T_P)}{\sum F_i C_{P_i}} \quad (\text{A.6})$$

Where,

F_i : Feed for each component, kg/h

C_{P_i} : Gas heat capacity for each component, kJ/kmol K

T_G : Gas temperature, K

T_P : Coolant temperature, K

ΔH_R : Enthalpy of reaction, kJ/kmol

U : Overall heat transfer coefficient, kJ/h m² K

OD : Outside Diameter, m

$\frac{dT_G}{dV}$: Gas temperature change over unit volume

2.2.2 Heat Balance on Coolant

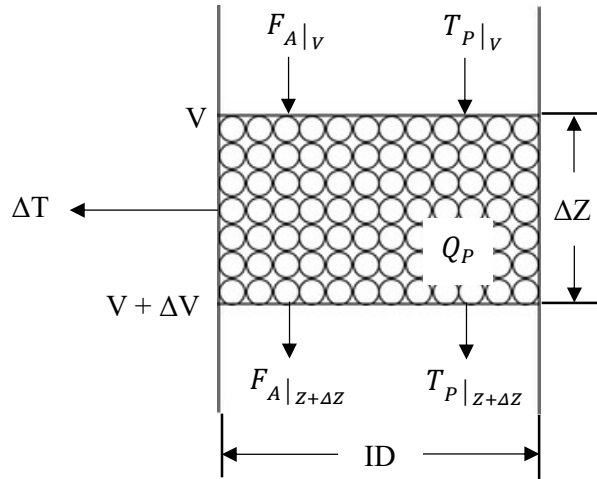


Figure A.3 Heat balance of coolant through tube with catalyst

(rate of input) – (rate of output) = (rate of acc.)

$$F_P C_{P_P} (T_{P|V} - T_{R|V}) - [F_P C_{P_P} (T_{P|V+\Delta V} - T_{R|V+\Delta V}) + Q_P] = 0$$

$$F_P C_{P_P} (-\Delta T_P) = \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$F_P C_{P_P} (-\Delta T_P) = \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$F_P C_{P_P} \left(\frac{-\Delta T_P}{\Delta V} \right) = \frac{4UOD}{ID^2} (T_G - T_P)$$

$$\left(\frac{-\Delta T_P}{\Delta V} \right) = \frac{4UOD(T_G - T_P)}{F_P C_{P_P} ID^2}$$

If $\lim_{\Delta V \rightarrow 0} (V)$

$$\frac{dT_P}{dV} = \frac{4UOD(T_G - T_P)}{F_P C_{P_P} ID^2} \quad (\text{A.7})$$

Where,

$\dot{m}_P$: Coolant mass over time, kg/h

C_{P_P} : Coolant heat capacity, kJ/kmol K

$\frac{dT_P}{dV}$: Coolant temperature change over unit volume

2.3 Pressure Drop

The pressure drop inside a pipe packed with catalysts can be calculated with:

$$\frac{dP}{dZ} = \frac{G}{\rho g D_e} \frac{1 - \varepsilon}{\varepsilon^3} \left[\frac{150(1 - \varepsilon)\mu}{D_p} + 1.75G \right] \quad (\text{A.8})$$

(Rase, 1977)

Where,

dP : Pressure drop, kg/m²

dZ : Catalyst height, m

G : Mass flow rate, kg/h m²

ρ : Gas density, kg/m³

D_e : Catalyst equivalent diameter, m

g : Gravity acceleration constant, m/h²

μ : Gas viscosity, kg/h m

3. Data and Estimation of Physical Properties

3.1 Gas Molecular Weight

$$M_{r_G} = \sum_{i=1}^N y_i M_{r_i} \quad (\text{A.9})$$

Where,

M_{r_G} : Gas mixture molar mass, kg/kmol

y_i : Gas fraction in mixture

M_{r_i} : Gas molar mas, kg/kmol

3.2 Gas Density

$$PV = nRT$$

$$\frac{n}{V} M_{r_G} = \frac{P}{RT} M_{r_G}$$

$$\rho_G = \frac{P}{RT} M_{r_G} \quad (\text{A.10})$$

Where,

ρ_G : Gas mixture density, kg/m³

P : Pressure, atm

R : Gas constant, m³/atm K kmol

T : Temperature, K

3.3 Gas Viscosity

$$\mu_i = A + BT + CT^2 \quad (\text{A.11})$$

(Yaws, 1999)

$$\mu_G = \frac{\sum y_i \mu_i M_{r_i}^{0.5}}{\sum y_i M_{r_i}^{0.5}} \quad (\text{A.12})$$

(Perry, 2008)

Where,

μ_i : Component i viscosity, kg/h m

μ_G : Gas mixture viscosity, kg/h m

A, B, C : Regression coefficients

M_{r_i} : Component i molar mass, kg/kmol

The values of A, B, and C to calculate viscosity for each component can be seen in Table A.1.

Table A.1 Regression coefficient for each component to calculate viscosity (Yaws, 1999)

Component	A	B	C
H2	27.758	0.212	-0.0000328
CO	23.811	0.53944	-0.00015411
N2	42.606	0.475	-0.0000988
CH4	3.844	0.40112	-0.00014303
C2H4	-3.985	0.38726	-0.0001127
C2H6	0.514	0.33449	-7.1071E-05
C3H6O	-14.885	0.32999	-0.00005949

3.4 Gas Heat Capacity

$$C_p = A + BT + CT^2 + DT^3 + ET^4 \quad (\text{A.13})$$

(Yaws, 1999)

$$C_{P_G} = \sum_{i=1}^N y_i C_{P_i} \quad (\text{A.14})$$

Where,

C_{P_i} : Component i heat capacity, kJ/kmol K

C_{P_G} : Gas mixture heat capacity, kJ/kmol K

$A, B, C, \text{ and } D$: Regression coefficients

The values of A, B, C, and D to calculate heat capacity for each component can be seen in Table A.2.

Table A.2 Regression coefficient for each component to calculate heat capacity (Yaws, 1999)

Component	A	B	C	D	E
H2	25.399	0.020178	3.8549E-05	3.188E-08	-8.759E-12
CO	29.556	-0.006587	0.00002013	-1.223E-08	2.262E-12
N2	29.342	-0.0035397	1.0076E-05	-4.312E-08	2.594E-13
CH4	34.942	-0.039957	0.00019184	-1.53E-07	3.93E-11
C2H4	32.083	-0.014831	0.00024774	-2.377E-07	6.827E-11
C2H6	28.146	0.043447	0.00018946	-1.908E-07	5.335E-11
C3H6O	58.911	0.0048385	0.00033514	-3.051E-07	-3.051E-11

3.5 Gas Thermal Conductivity

$$k = A + BT + CT^2 \quad (\text{A.15})$$

(Yaws, 1999)

$$k_G = \frac{\sum y_i k_{G_i} M_{r_i}^{1/3}}{\sum y_i M_{r_i}^{1/3}} \quad (\text{A.16})$$

(Perry, 2008)

Where,

k_G : Gas mixture thermal conductivity, kJ/m K

k_{G_i} : Component i thermal conductivity, kJ/m K

The values of A, B, and C to calculate conductivity for each component can be seen in Table A.3.

Table A.3 Regression coefficient for each component to calculate conductivity (Yaws, 1999)

Component	A	B	C
H2	0.03951	4.5918	-6.4933E-08
CO	0.00158	8.2511E-05	-1.9081E-08
N2	0.00309	0.00007593	-1.1014E-08
CH4	-0.0095	0.00014028	3.318E-08
C2H4	-0.0012	3.6219E-05	1.2459E-07
C2H6	-0.0194	0.0001547	3.8798E-08

3.6 Enthalpy of Reaction

$$\Delta H_R = \Delta H_R^\circ + \int_{298}^T \Delta C_{P_G} dT \quad (\text{A.17})$$

Where,

ΔH_R° : Enthalpy of reaction at standard temperature, kJ/kmol

dT : Temperature difference, K

4. Shell and Tube Specification

4.1 Tube Specification

The effect of the ratio D_p/D_t on the heat transfer coefficient in a tube containing catalyst granules compared to an empty pipe or h_w/h can be seen in Table A.4.

Table A.4 The effect of the ratio D_p/D_t on h_w/h (Smith, 1981)

D_p/D_t	0.05	0.1	0.15	0.2	0.25	0.3
h_w/h	5.5	7	7.8	7.5	7	6.6

4.2 Number of Tube Determination

4.2.1 Maximal Number of Tubes

$$G_t = \frac{\mu_G R_e}{D_P} \quad (\text{A.18})$$

Where,

G_t : Mass flow rate over unit area, kg/m² hr

R_e : Reynold Number

The value of Re was obtained from trial. The value Re should be turbulent or more than 100.

$$A_t = \frac{G}{G_t} \quad (\text{A.19})$$

$$A_o = \frac{\pi}{4} ID^2 \quad (\text{A.20})$$

$$N_{t_{max}} = \frac{A_t}{A_o} \quad (\text{A.21})$$

Where,

A_t : Tube area, m²

A_o : Pipe area, m²

G : Mass flow rate, kg/hr

$N_{t_{max}}$: Maximal number of tubes

4.2.2 Minimal Number of Tubes

$$V_{max} = \sqrt{\frac{4(\rho_B - \rho_G)gD_P}{3\rho_G f_D}} \quad (\text{A.22})$$

$$Q = \frac{G}{\rho_G} \quad (\text{A.23})$$

$$A_t = \frac{Q}{V_{max}} \quad (\text{A.24})$$

$$N_{t_{min}} = \frac{A_t}{A_o} \quad (\text{A.25})$$

Where,

V_{max} : Maximum velocity, m/h

f_D : Friction factor

Q : Volumetric flow, m³/hr

$N_{t_{min}}$: Minimum number of tubes

4.3 Shell Specification

The pipes are arranged in a triangular pitch, so that the turbulence that occurs in the fluid flow in the shell becomes large, thereby increasing the convection heat transfer coefficient.

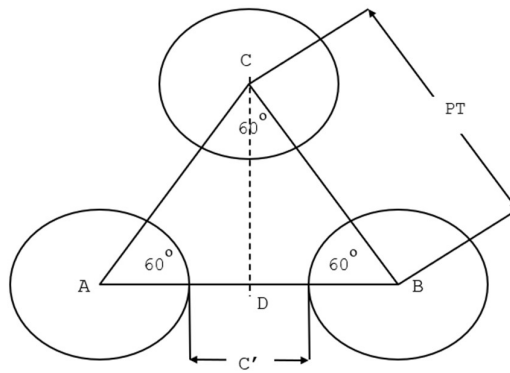


Figure A.4 Tube in triangular pitch arrangement

$$P_T = 1.25OD \quad (\text{A.26})$$

$$C' = P_T - OD \quad (\text{A.27})$$

$$CD = P_T \sin 60^\circ \quad (\text{A.28})$$

Where,

P_T : Pitch, in.

C' : Clearance, in.

CD : Triangle height, in.

To calculate the shell diameter, the total shell cross-sectional area is needed.

$$A_{Total} = 2NA_{ABC}$$

$$\frac{\pi}{4}ID_s^2 = 2N \left(\frac{1}{2} P_T^2 \sin 60^\circ \right)$$

$$ID_s = \sqrt{\frac{4N_t P_T^2 0.866}{\pi}} \quad (A.29)$$

Where,

A_{Total} : Total shell cross-sectional area, m²

A_{ABC} : ABC triangle cross-sectional area, m²

ID_s : Shell inside diameter, m

5. Mechanical Design

5.1 Tube

From Table A.3, the diameter of the pipe can be calculated.

$$\frac{D_p}{D_t} = 0.15$$

$$D_t = \frac{0.635 \text{ cm}}{0.15}$$

$$D_t = 4.233 \text{ cm} = 1.667 \text{ in.}$$

The pipe size can be seen in Table 11 from Kern (1950):

IPS : $1\frac{1}{2}$ in.

Sch no. : 40

OD : 1.90 in.

ID : 1.610 in.

The mass flow velocity over unit area can be calculated with eq. A.18 with Re is 3100.

$$G_t = \frac{3100 \times 0.058}{0.0423} = 4295.112 \text{ kg/m}^2 \text{ h}$$

The tube area and the pipe area can be calculated with eq. 19 and eq. 20, respectively.

$$A_t = \frac{11076.745}{4295.112} = 2.548 \text{ m}^2$$

$$A_o = \frac{\pi}{4} (0.0409)^2 = 0.0013 \text{ m}^2$$

The maximum number of tubes can be calculated with eq. 21.

$$N_{t_{max}} = \frac{2.548}{0.0013} = 1940$$

To calculate the minimum number of tubes, the maximum velocity, volumetric flow, and tube area can be calculated with eq. 22, eq. 23, and eq. 24, respectively. The minimum number of tubes can be calculated with eq. 25 with the friction number that was obtained from fig. 70 from Brown (2005).

$$V_{max} = \sqrt{\frac{4 \times (553.393 - 13.028) \times 9.806 \times 0.00635}{3 \times 13.028 \times 1.8}} = 1.383 \text{ m/s}$$

$$= 4979.47 \text{ m/h}$$

$$Q = \frac{29380.216}{13.028} = 2255.114 \text{ m}^3/h$$

$$A_t = \frac{2255.114}{4979.47} = 0.453 \text{ m}^2$$

$$N_{t_{min}} = \frac{0.453}{0.0013} = 345$$

The number of tubes should be in between the maximum and the minimum number of tubes. So, for this reactor, 1900 tubes will be used. The pitch and clearance between tubes can be calculated with eq. A.26 and eq. A.27, respectively.

$$P_T = 1.25(1.9) = 2.375 \text{ in.} = 0.0603 \text{ m}$$

$$C' = 2.375 - 1.9 = 0.475 \text{ in.} = 0.012 \text{ m}$$

5.2 Shell

5.2.1 Body

The inner diameter of the shell can be calculated with eq. 29.

$$ID_s = \sqrt{\frac{4 \times 1900 \times (2.375)^2 \times 0.866}{\pi}} = 109.852 \text{ in.} = 2.790 \text{ m}$$

The thickness of the shell body can be calculated with:

$$t_s = \frac{Pr}{fE - 0.6P} + C \quad (\text{A.30})$$

(Rase and Barrow, 1957)

Where:

r : Radius, m

f : Maximum allowable stress, psi

E : Welding efficiency

C : Allowable corrosion, in.

Carbon Steel SA-212 Grade B will be used as the material. The properties can be found in Brownell (1959):

f : 17500 psi

E : 0.85

C : 0.125 in.

The pressure that will be used is the design pressure with 20% overdiseign in psi. So, the thickness of the shell body is:

$$t_s = \frac{352.704 \times \frac{109.852}{2}}{17500 \times 0.85 - 0.6 \times 352.704} + 0.125 = 1.446 \text{ in.}$$

The outer diameter of the shell can be calculated by:

$$OD_s = ID_s + 2t_s \quad (\text{A.31})$$

$$OD_s = 109.852 + 2 \times 1.446 = 112.745 \text{ in.} = 2.864 \text{ m}$$

A standard outer diameter of 114 in. and a standard thickness of 1.5 in was chosen (Brownell, 1959). So, the inner diameter of the shell will become:

$$ID_s = OD_s - 2t_s$$

$$ID_s = 114 - 2 \times (1.5) = 111 \text{ in.}$$

The height of the shell can be calculated using eq. A.3 with simulation using Runge Kutta 2nd order Heun's method in table A.5 and calculated with 10% overdiseign.

$$H_s = \frac{4 \times 40.8 \times 39.37^3}{111^2} \times 1.1 = 7.189 \text{ m} \quad (\text{A.32})$$

5.2.2 Head

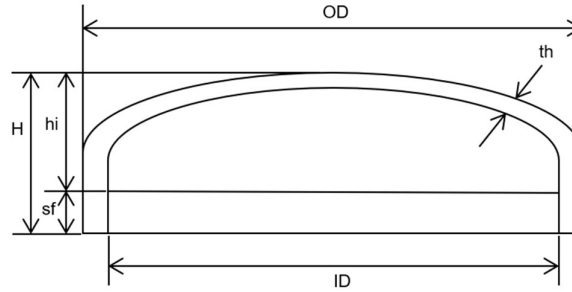


Figure A.5 Elliptical dished head

The head will use the same material as the body. The thickness of the head can be calculated with:

$$t_h = \frac{PID_s}{2fE - 0.2P} + C \quad (\text{A.33})$$

(Rase and Barrow, 1957)

$$t_h = \frac{352.704 \times 111}{2 \times 17500 \times 0.85 - 0.2 \times 352.704} + 0.125 = 1.444 \text{ in.}$$

A standard thickness of 1.5 in was chosen (Brownell, 1959). The outer diameter of the head can be calculated with:

$$OD_h = ID_s + 2t_h \quad (\text{A.34})$$

$$OD_h = 111 + 2 \times 1.5 = 114 \text{ in.}$$

The height inside of the head can be calculated with:

$$h_i = \frac{ID_s}{4} \quad (\text{A.35})$$

(Brownell, 1959)

$$h_i = \frac{111}{4} = 27.75 \text{ in.}$$

Straight flange (sf) that's chosen is 4.5 in (Brownell, 1959). The total height of the head is:

$$H_h = t_h + h_i + sf \quad (\text{A.36})$$

$$H_h = 1.5 + 27.75 + 3 = 32.25 \text{ in.}$$

5.3 Reactor Height

The total height of the reactor can be calculated with:

$$H_r = H_s + 2H_h \quad (\text{A.37})$$

$$H_r = 283.019 + 2 \times (32.25) = 347.519 \text{ in.}$$

5.4 Isolator

Assumptions:

1. Steady-state condition
2. Isolator outer wall temperature = $T_3 = 50^\circ\text{C}$
3. Outside air temperature = $T_4 = 30^\circ\text{C}$

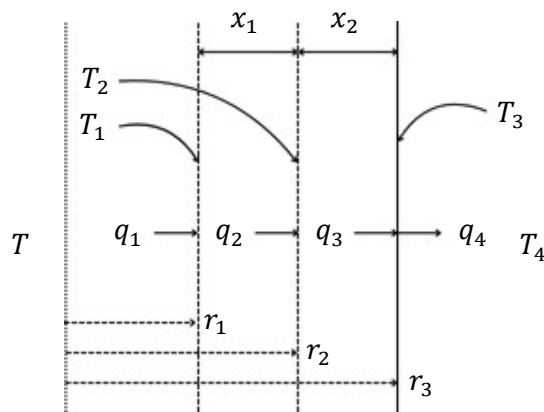


Figure A.6 Shell and isolator thickness and temperature

Description:

r_1 : Shell inner radius

r_2 : Shell outer radius

r_3	: Isolator outer radius
x_1	: Shell thickness
x_2	: Isolator thickness
T	: Coolant temperature
T_1	: Inner shell temperature
T_2	: Outer shell temperature
T_3	: Outer isolator temperature
T_4	: Outside air temperature

The material that was chosen for the isolator is Asbestos. The important properties of asbestos are:

k_A	: 0.111 BTU/h ft ² (°F/ft)
ε	: 0.96
ρ	: 36 lb/ft ³
C_p	: 0.25 BTU/lb °F

(Perry, 2008)

For carbon alloy, as the material for the shell, some important properties are:

k_c	: 26.463 BTU/h ft ² (°F/ft)
ID_s	: 9.25 ft
t_s	: 0.125 ft
H_s	: 23.585 ft

Heat transfer from the reactor to the surroundings through the reactor walls and isolator occurs through several steps:

1. Convection transfer of coolant in the shell to inner shell wall (q_1);

2. Conduction transfer from inner shell wall to wall outer shell (q_2);
3. Conduction transfer from the outer shell wall to the surface outer isolator (q_3);
4. Convection and radiation transfer from the outer surface isolator to the outside air (q_4).

To obtain the convection coefficient between asbestos and air, the average temperature between them needs to be calculated.

$$T_f = \frac{T_3 + T_4}{2} \quad (\text{A.38})$$

$$T_f = \frac{50 + 30}{2} = 40 \text{ } ^\circ\text{C} = 313.15 \text{ } K$$

The properties of air can be obtained from Holman (2002) by doing interpolation. The properties that are obtained are:

$$\begin{aligned} \rho & : 1.130 \text{ kg/m}^3 \\ C_p & : 1.006 \text{ kJ/kg } ^\circ\text{C} \\ \mu & : 1.906 \times 10^{-5} \text{ kg/m} \\ \nu & : 1.502 \times 10^{-5} \text{ m}^2/\text{s} \\ k_a & : 0.0272 \text{ W/m } ^\circ\text{C} \\ \alpha & : 0.2417 \text{ m}^2/\text{s} \\ Pr & : 0.705 \end{aligned}$$

For the thermal expansion coefficient, it can be calculated with:

$$\beta = \frac{1}{T_f} \quad (\text{A.39})$$

(Holman, 2002)

$$\beta = \frac{1}{313.15} = 0.0032 \text{ K}^{-1}$$

To determine the formula to calculate the convection coefficient between asbestos and air, the value of the Grashof number times the Prandtl number needs to be known.

$$G_{r_L} P_r = \frac{g\beta(T_3 - T_4)L^3}{\nu^2} P_r \quad (\text{A.40})$$

(Holman, 2002)

Where L is the height of the shell (H_s).

$$G_{r_L} P_r = \frac{9.806 \times 0.0032(50 - 30)9.967^3}{(1.502 \times 10^{-5})^2} \times 0.705 = 1.5088 \times 10^{12}$$

Because the value of $G_{r_L} P_r > 10^9$, the convention coefficient can be calculated with:

$$h_c = 1.31(\Delta T)^{1/3} \quad (\text{A.41})$$

(Holman, 2002)

$$h_c = 1.31(50 - 30)^{1/3} = 3.5558 \text{ W/m}^2 \text{ } ^\circ\text{C} = 0.626 \text{ BTU/h ft}^2\text{R}$$

The radiation coefficient can be calculated with:

$$h_r = \frac{\varepsilon\sigma(T_3^4 - T_4^4)}{(T_3 - T_4)} \quad (\text{A.42})$$

(Kern, 1950)

Where σ is Stefan-Boltzmann constant and T is in Rankine.

$$h_r = \frac{0.96 \times 1.73 \times 10^{-9}(581.67^4 - 545.67^4)}{(581.67 - 545.67)} = 1.191 \text{ BTU/h ft}^2\text{R}$$

The heat transfer can be calculated with:

$$dQ = kA \frac{dT}{dx} \quad (\text{A.43})$$

(Kern, 1950)

$$q = kA \frac{\Delta T}{x}$$

In steady state, $q_1 = q_2 = q_3 = q_4$.

$$q_2 = k_c A_1 \frac{(T_1 - T_2)}{x_1} = k_c \pi L (ID_s + 2x_1) \frac{(T_1 - T_2)}{x_1} \quad (\text{A.44})$$

If the temperature of the inner shell is the same as the reaction condition,

so:

$$q_2 = 26.463 \times \pi \times L (6.8125 + 2 \times 0.09375) \frac{(248 - T_2)}{0.09375}$$

$$q_2 = 1975.904 \times \pi \times L (248 - T_2)$$

$$q_3 = k_A A_2 \frac{(T_3 - T_2)}{x_2} = k_A \pi L (ID_s + 2x_1 + 2x_2) \frac{(T_2 - T_3)}{x_2} \quad (\text{A.45})$$

$$q_3 = 0.111 \times \pi \times L (6.8125 + 2 \times 0.09375 + 2x_2) \frac{(T_2 - 122)}{x_2}$$

$$\begin{aligned} q_4 &= (h_r + h_c) A_3 (T_3 - T_4) \\ &= (h_r + h_c) \pi L (ID_s + 2x_1 + 2x_2) (T_3 - T_4) \end{aligned} \quad (\text{A.46})$$

$$q_4 = (1.191 + 0.626) \pi L (6.8125 + 2 \times 0.09375 + 2x_2) (122 - 86)$$

$$q_4 = 64.9224 \times \pi \times L \times (6.8125 + 2 \times 0.09375 + 2x_2)$$

Where T is in Fahrenheit and x_1 and ID_s are in feet.

If $q_2 = q_4$, the equation of correlation between T_2 and x_2 are:

$$T_2 = 247.768 - 0.0662x_2 \dots \dots \dots (1)$$

If $q_3 = q_4$, the equation of correlation between T_2 and x_2 are:

$$T_2 = 122 + 589.3561x_2 \dots \dots \dots (2)$$

From equation (1) and (2), the value of T_2 and x_2 can be obtained, where T_2 is 247.643 °F and x_2 is 0.213 ft or 0.065 m.

5.5 Weight Hour Space Velocity

$$W_c = \frac{\pi}{4} D_t^2 H_s N_t \rho_B \quad (A.47)$$

$$WHSV = \frac{F_v}{W_c} \quad (A.48)$$

Where,

W_c : Catalyst weight, kg

$WHSV$: Weight hour space velocity, /h

F_v : Material flow rate, kg/h

The bulk density of Rhodium-Silica is 573.3 kg/m³ and the material flow rate is 29380.2163 kg/h. The tube diameter and the shell height are in meter.

$$W_c = \frac{\pi}{4} (1.61 \times 0.0254)^2 \times 7.189 \times 1900 \times 573.3 = 10502.783 \text{ kg}$$

$$WHSV = \frac{11706.745}{10502.783} = 1.055/h$$

5.6 Pressure Drop

Pressure drop along the catalyst inside the pipe can be calculated by doing integral to eq. A.8

$$P = \frac{G}{\rho g D_e} \frac{1 - \varepsilon}{\varepsilon^3} \left[\frac{150(1 - \varepsilon)\mu}{D_p} + 1.75G \right] Z$$

Where the porosity of the pile can be calculated with:

$$\varepsilon = 1 - \frac{\rho_B}{\rho_P} \quad (A.49)$$

where ρ_p is particle density. The particle density of Rhodium-Silica is 12410 kg/m³.

$$\varepsilon = 1 - \frac{12410}{573.3} = 0.954$$

So, the pressure drop is

$$\begin{aligned} P &= \frac{4295.112}{13.028 \times 9.806 \times 3600^2} \times \frac{1 - 0.954}{0.954^3} \\ &\quad \times \left[\frac{150(1 - 0.954) \times 0.0587}{0.00635} + 1.75 \times 4295.112 \right] \\ &\quad \times 7.188 = 0.015 \text{ atm} \end{aligned}$$

Table A.5 Simulation of reactor volume with Runge-Kutta 2nd order Heun's method

V (m ₃)	x	T _G (K)	T _P (K)
0.0000	0.0000	373.1500	303.1500
0.4000	0.0002	373.2532	303.3119
0.8000	0.0004	373.3563	303.4736
1.2000	0.0006	373.4593	303.6351
1.6000	0.0008	373.5622	303.7966
2.0000	0.0011	373.6650	303.9579
2.4000	0.0014	373.7677	304.1191
2.8000	0.0016	373.8703	304.2801
3.2000	0.0020	373.9729	304.4410
3.6000	0.0023	374.0753	304.6018
4.0000	0.0026	374.1777	304.7624
4.4000	0.0030	374.2799	304.9229
4.8000	0.0034	374.3821	305.0833
5.2000	0.0039	374.4842	305.2435
5.6000	0.0043	374.5862	305.4036
6.0000	0.0048	374.6881	305.5636
6.4000	0.0054	374.7899	305.7234
6.8000	0.0060	374.8917	305.8831
7.2000	0.0066	374.9933	306.0427
7.6000	0.0073	375.0949	306.2021
8.0000	0.0080	375.1964	306.3614
8.4000	0.0087	375.2978	306.5205
8.8000	0.0096	375.3991	306.6796
9.2000	0.0104	375.5003	306.8384
9.6000	0.0114	375.6015	306.9972
10.0000	0.0124	375.7026	307.1558
10.4000	0.0135	375.8036	307.3143
10.8000	0.0146	375.9045	307.4727
11.2000	0.0159	376.0054	307.6309
11.6000	0.0172	376.1062	307.7890
12.0000	0.0186	376.2069	307.9470
12.4000	0.0201	376.3076	308.1048
12.8000	0.0217	376.4082	308.2625
13.2000	0.0235	376.5088	308.4200
13.6000	0.0253	376.6092	308.5775
14.0000	0.0273	376.7097	308.7348
14.4000	0.0294	376.8100	308.8920
14.8000	0.0317	376.9104	309.0490
15.2000	0.0341	377.0106	309.2059
15.6000	0.0367	377.1109	309.3627
16.0000	0.0394	377.2111	309.5193
16.4000	0.0424	377.3112	309.6758
16.8000	0.0455	377.4114	309.8322
17.2000	0.0488	377.5114	309.9885
17.6000	0.0524	377.6115	310.1446
18.0000	0.0562	377.7116	310.3006
18.4000	0.0603	377.8116	310.4565
18.8000	0.0646	377.9116	310.6122
19.2000	0.0692	378.0116	310.7678
19.6000	0.0740	378.1117	310.9233
20.0000	0.0792	378.2117	311.0786
20.4000	0.0847	378.3117	311.2339

Table A.5 Simulation of reactor volume with Runge-Kutta 2nd order Heun's method (continuation)

V (m ₃)	x	T _G (K)	T _P (K)
20.8000	0.0906	378.4118	311.3890
21.2000	0.0968	378.5118	311.5439
21.6000	0.1035	378.6119	311.6988
22.0000	0.1105	378.7121	311.8535
22.4000	0.1179	378.8123	312.0081
22.8000	0.1258	378.9125	312.1625
23.2000	0.1342	379.0128	312.3169
23.6000	0.1430	379.1132	312.4711
24.0000	0.1524	379.2136	312.6252
24.4000	0.1623	379.3141	312.7791
24.8000	0.1727	379.4147	312.9330
25.2000	0.1837	379.5154	313.0867
25.6000	0.1953	379.6162	313.2403
26.0000	0.2075	379.7171	313.3938
26.4000	0.2203	379.8182	313.5471
26.8000	0.2338	379.9193	313.7004
27.2000	0.2479	380.0206	313.8535
27.6000	0.2628	380.1221	314.0065
28.0000	0.2783	380.2236	314.1594
28.4000	0.2945	380.3253	314.3121
28.8000	0.3113	380.4272	314.4648
29.2000	0.3289	380.5292	314.6173
29.6000	0.3472	380.6314	314.7697
30.0000	0.3662	380.7337	314.9220
30.4000	0.3858	380.8362	315.0741
30.8000	0.4061	380.9388	315.2262
31.2000	0.4270	381.0416	315.3781
31.6000	0.4485	381.1444	315.5300
32.0000	0.4706	381.2474	315.6817
32.4000	0.4932	381.3505	315.8333
32.8000	0.5162	381.4537	315.9848
33.2000	0.5395	381.5570	316.1362
33.6000	0.5632	381.6603	316.2875
34.0000	0.5871	381.7636	316.4386
34.4000	0.6112	381.8669	316.5897
34.8000	0.6353	381.9702	316.7406
35.2000	0.6593	382.0734	316.8914
35.6000	0.6832	382.1765	317.0422
36.0000	0.7067	382.2795	317.1928
36.4000	0.7299	382.3823	317.3433
36.8000	0.7526	382.4849	317.4937
37.2000	0.7746	382.5872	317.6439
37.6000	0.7959	382.6892	317.7941
38.0000	0.8164	382.7909	317.9442
38.4000	0.8359	382.8923	318.0941
38.8000	0.8544	382.9932	318.2439
39.2000	0.8718	383.0937	318.3936
39.6000	0.8881	383.1938	318.5432
40.0000	0.9031	383.2933	318.6927
40.4000	0.9169	383.3924	318.8421
40.8000	0.9294	383.4910	318.9914

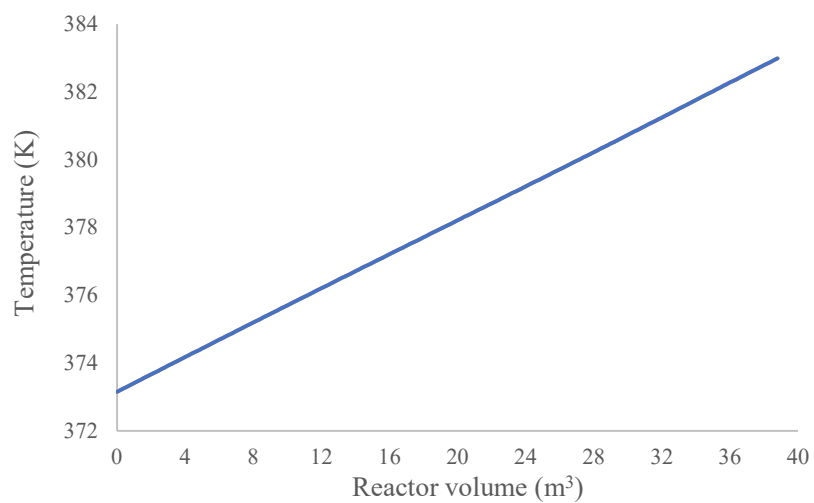


Figure A.7 Temperature vs reactor volume

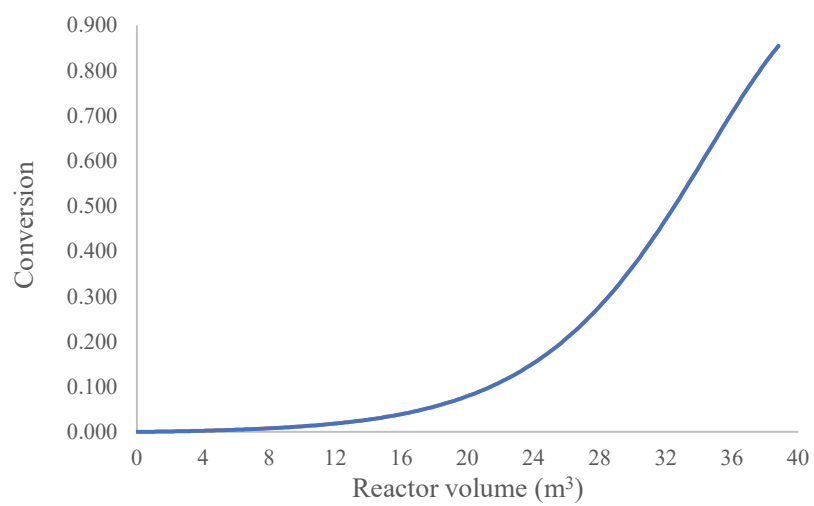


Figure A.8 Conversion vs reactor volume

ATTACHMENT B
REACTOR II DESIGN

Function : To react 14170.253 kg/h propanal with 491.396 kg/h hydrogen to produce 7575.7576 kg/h n-propanol.

Type : Fixed bed multitube

According to Unruh (1997), the operating conditions of the reaction for the production of n-propanol from the hydrogenation of propanal are:

Temperature : 150 °C

Pressure : 3 atm

Phase : Gas

Catalyst : Nickel-Kieselguhr

Shape : Sphere

Diameter : 4.55 mm

Bulk Density : 500 kg/m³

The reactants diffuse into the catalyst and the reaction occurs on the catalyst surface.

The reactor operates non-isothermal and non-adiabatically. The reaction is very exothermic so a cooling medium in the form of Dowtherm A is required. The reactants enter at a temperature of 100 °C and a pressure of 3 atm. Meanwhile, 3499.737 kg/h of coolant enters at a temperature of 105 °C with a co-current flow to the reactant flow. The conversion obtained was 60%, because there were still reactants that had not yet reacted, it was necessary to recycle the reactants from the top of Condenser 02.

Design Objectives: 1. Determine the type of reactor;
2. Calculate the pressure drop;

3. Calculate the weight of the catalyst;

4. Determine the dimensions of the reactor.

The reaction mechanism of propanal with hydrogen to become n-propanol is controlled by surface reactions. The reaction that occurs is:

Main reaction:



Side reaction:



1. Determination of Reactor Type

The multitube fixed bed reactor was chosen with the following considerations:

- 1) The reactant is in the form of a gas phase with a solid catalyst;
- 2) Long catalyst lifetime, about 12-15 months;
- 3) The reaction is exothermic so a large heat transfer area is needed so that contact with the coolant takes place optimally;
- 4) No separation of the catalyst from the reactor output gas is required;
- 5) Temperature control is relatively easy because it uses the shell and tube type.

2. Mathematical Modelling Formulation

- Assumption:
1. Steady-state conditions have been reached;
 2. Mass transfer due to diffusion is neglected;
 3. Gases are considered to obey the ideal gas law;
 4. Heat loss to the environment is negligible;

5. The temperature in the catalyst is the same.

2.1 Mass Balance

- Assumption:
1. Plug flow, there is no concentration gradient in the radial direction ($D/D_p = 8-50$) (Rase, 1977);
 2. Negligible axial dispersion ($L/D_p \geq 100$) (Rase, 1977);
 3. Intra-particle and interphase concentration gradients are ignored;
 4. Steady-state.

The formulation of the mass balance model was carried out in a pipe containing a catalyst as much as ΔV with X_A conversion.

$$Z = \frac{40D\Delta V}{ID^2} \quad (\text{B.4})$$

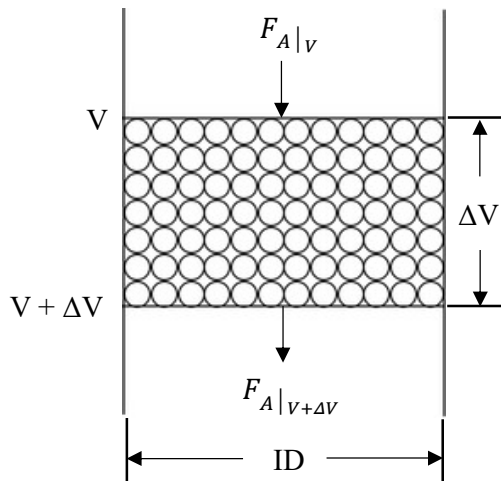


Figure B.1 Mass balance of component B through tube with catalyst

$$(\text{rate of input}) - (\text{rate of output}) = (\text{rate of acc.}) \quad (\text{B.5})$$

$$F_{A|V} - (F_{A|V+\Delta V} + (-r_A)\Delta V) = 0$$

$$F_{A|V} - F_{A|V+\Delta V} - (-r_A)\Delta V = 0$$

$$\frac{-F_{A|V+\Delta V} - F_{A|V}}{\Delta V} = (-r_A)$$

$$\text{If } \lim_{\Delta V \rightarrow 0} (\Delta V)$$

$$-\frac{dF_A}{dV} = (-r_A)$$

$$\text{If } F_A = F_{A0}(1 - X_A), \text{ so } dF_A = -F_{A0} dX_A$$

$$F_{A0} \frac{dX_A}{dV} = (-r_A)$$

$$\frac{dX_A}{dV} = \frac{(-r_A)}{F_{A0}}$$

$$\frac{dX_A}{dV} = \frac{k \frac{C_A}{C_B^{0.5}}}{F_{A0}}$$

$$\frac{dX_A}{dV} = \frac{k \frac{(C_{A0}(1 - X_A))}{(C_{B0} - C_{A0}X_A)^{0.5}}}{4F_{A0}} \quad (\text{B.6})$$

Where,

Where,

V : Reactor volume, m^3

F_A : Feed of component A

X_A : Conversion of component A

$\frac{dX_A}{dV}$: Conversion change over unit volume

$-r_A$: Reaction rate, $\text{kmol}/\text{m}^3 \text{ h}$

C_A : Concentration of component A, kmol/m³

C_B : Concentration of component B, kmol/m³

2.2 Energy Balance

2.2.1 Heat Balance on Volume

- Assumption:
1. Plug flow, no temperature gradient in the radial direction ($D/D_p = 8-50$) (Rase, 1977);
 2. Negligible axial dispersion ($L/D_p \geq 100$) (Rase, 1977);
 3. Intra-particle and interphase concentration gradients are ignored;
 4. Steady-state;
 5. Gas heat capacity (C_p) and gas viscosity (μ) are a function of temperature and not a function of distance.

The preparation of the heat balance model was carried out in a pipe containing a catalyst along ΔZ with conversion X_B , gas temperature T , and coolant temperature T_p .

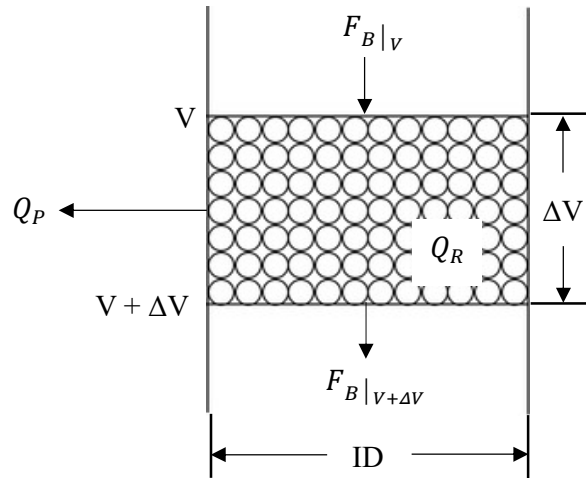


Figure B.2 Heat balance of component B through tube with catalyst

(rate of input) – (rate of output) = (rate of acc.)

$$\sum F_i C_{P_i} (T_{G|_V} - T_o) - \left[\sum F_i C_{P_i} (T_{G|_{V+\Delta V}} - T_o) + Q_R + Q_P \right] = 0$$

$$\sum F_i C_{P_i} (-\Delta T_G) = Q_R + Q_P$$

$$\text{If } T_G = \Delta H_R F_{Ao} \Delta X_A$$

$$Q_P = UA(T_G - T_S)$$

$$A = \pi ODZ$$

$$\sum F_i C_{P_i} (-\Delta T_G) = \Delta H_R F_{Ao} \Delta X_A + \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$\sum F_i C_{P_i} \left(\frac{-\Delta T_G}{\Delta V} \right) = \Delta H_R F_{Ao} \frac{\Delta X_A}{\Delta V} + \frac{4UOD}{ID^2} (T_G - T_P)$$

$$\left(\frac{-\Delta T_G}{\Delta V} \right) = \frac{\Delta H_R F_{Ao} \frac{\Delta X_A}{\Delta V} + \frac{4UOD}{ID^2} (T_G - T_P)}{\sum F_i C_{P_i}}$$

$$\text{If } \lim_{\Delta V \rightarrow 0} (\Delta V)$$

$$\frac{dT_G}{dV} = \frac{\Delta H_R F_{Ao} \frac{dX_A}{dV} + \frac{4UOD}{ID^2} (T_G - T_P)}{\sum F_i C_{P_i}} \quad (\text{B.7})$$

Where,

F_i : Feed for each component, kg/h

C_{P_i} : Gas heat capacity for each component, kJ/kmol K

T_G : Gas temperature, K

T_P : Coolant temperature, K

ΔH_R : Enthalpy of reaction, kJ/kmol

U : Overall heat transfer coefficient, kJ/h m² K

OD : Outside Diameter, m

$\frac{dT_G}{dV}$: Gas temperature change over unit volume

2.2.2 Heat Balance on Coolant

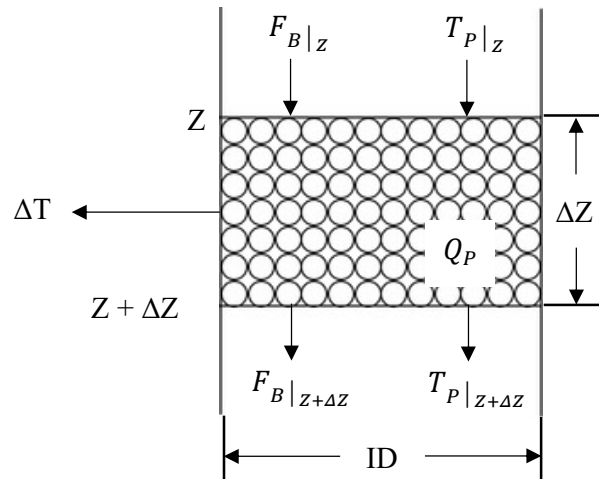


Figure B.3 Heat balance of coolant through tube with catalyst

(rate of input) – (rate of output) = (rate of acc.)

$$F_P C_{P_P} (T_{P|V} - T_{R|V}) - [F_P C_{P_P} (T_{P|V+\Delta V} - T_{R|V+\Delta V}) + Q_P] = 0$$

$$F_P C_{P_P} (-\Delta T_P) = \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$F_P C_{P_P} (-\Delta T_P) = \frac{4UOD\Delta V}{ID^2} (T_G - T_P)$$

$$F_P C_{P_P} \left(\frac{-\Delta T_P}{\Delta V} \right) = \frac{4UOD}{ID^2} (T_G - T_P)$$

$$\left(\frac{-\Delta T_P}{\Delta V} \right) = \frac{4UOD(T_G - T_P)}{F_P C_{P_P} ID^2}$$

If $\lim_{\Delta V \rightarrow 0} (V)$

$$\frac{dT_P}{dV} = \frac{4UOD(T_G - T_P)}{F_P C_{P_P} ID^2} \quad (\text{B.8})$$

Where,

$\dot{m}_P$: Coolant mass over time, kg/h

C_{P_P} : Coolant heat capacity, kJ/kmol K

$\frac{dT_P}{dV}$: Coolant temperature change over unit volume

2.3 Pressure Drop

The pressure drop inside a pipe packed with catalysts can be calculated with:

$$\frac{dP}{dZ} = \frac{G}{\rho g D_e} \frac{1 - \varepsilon}{\varepsilon^3} \left[\frac{150(1 - \varepsilon)\mu}{D_p} + 1.75G \right] \quad (\text{B.9})$$

(Rase, 1977)

Where,

dP : Pressure drop, kg/m²

dZ : Catalyst height, m

G : Mass flow rate, kg/h m²

ρ : Gas density, kg/m³

D_e : Catalyst equivalent diameter, m

g : Gravity acceleration constant, m/h²

μ : Gas viscosity, kg/h m

3. Data and Estimation of Physical Properties

3.1 Gas Molecular Weight

$$M_{r_G} = \sum_{i=1}^N y_i M_{r_i} \quad (\text{B.10})$$

Where,

M_{r_G} : Gas mixture molar mass, kg/kmol

y_i : Gas fraction in mixture

M_{r_i} : Gas molar mas, kg/kmol

3.2 Gas Density

$$PV = nRT$$

$$\frac{n}{V} M_{r_G} = \frac{P}{RT} M_{r_G}$$

$$\rho_G = \frac{P}{RT} M_{r_G} \quad (\text{B.11})$$

Where,

ρ_G : Gas mixture density, kg/m³

P : Pressure, atm

R : Gas constant, m³/atm K kmol

T : Temperature, K

3.3 Gas Viscosity

$$\mu_i = A + BT + CT^2 \quad (\text{B.12})$$

(Yaws, 1999)

$$\mu_G = \frac{\sum y_i \mu_i M_{r_i}^{0.5}}{\sum y_i M_{r_i}^{0.5}} \quad (\text{B.13})$$

(Perry, 2008)

Where,

μ_i : Component i viscosity, kg/h m

μ_G : Gas mixture viscosity, kg/h m

A, B, C : Regression coefficients

M_{r_i} : Component i molar mass, kg/kmol

The values of A, B, and C to calculate viscosity for each component can be seen in Table B.1.

Table B.1 Regression coefficient of each component to calculate viscosity (Yaws, 1999)

Component	A	B	C
H2	2.7758E+01	2.1200E-01	-3.2800E-05
C2H4	-3.9850E+00	3.8726E-01	-1.1270E-04
C2H6	5.1400E-01	3.3449E-01	-7.1071E-05
C3H6O	-1.4885E+01	3.2999E-01	-5.9490E-05
C3H8O	-1.4894E+01	3.2171E-01	-5.8021E-05
C6H14O	-1.4251E+01	2.9988E-01	-5.4923E-05
H2O	-3.6826E+01	4.2900E-01	-1.6200E-05

3.4 Gas Heat Capacity

$$C_p = A + BT + CT^2 + DT^3 + ET^4 \quad (\text{B.14})$$

(Yaws, 1999)

$$C_{P_G} = \sum_{i=1}^N y_i C_{P_i} \quad (B.15)$$

Where,

C_{P_i} : Component i heat capacity, kJ/kmol K

C_{P_G} : Gas mixture heat capacity, kJ/kmol K

$A, B, C, D, \text{ and } E$: Regression coefficients

The values of A, B, C, D, and E to calculate heat capacity for each component can be seen in Table B.2.

Table B.2 Regression coefficient of each component to calculate heat capacity (Yaws, 1999)

Component	A	B	C	D	E
H2	2.5399E+01	2.0178E-02	3.8549E-05	3.1880E-08	-8.7585E-12
C2H4	3.2083E+01	-1.4831E-02	2.4774E-04	-2.3766E-07	6.8274E-11
C2H6	2.8146E+01	4.3447E-02	1.8946E-04	-1.9082E-07	5.3349E-11
C3H6O	5.8911E+01	4.8385E-03	3.3514E-04	-3.0509E-07	-3.0509E-11
C3H8O	3.1507E+01	2.3082E-01	-7.8983E-05	6.3696E-09	8.6908E-13
C6H14O	9.2068E+01	1.1054E-01	5.8784E-04	-6.1854E-07	-1.7855E-10
H2O	3.3933E+01	-8.4186E-03	2.9906E-05	-1.7825E-08	3.6934E-12

3.5 Gas Thermal Conductivity

$$k = A + BT + CT^2 \quad (B.16)$$

(Yaws, 1999)

$$k_G = \frac{\sum y_i k_{G_i} M_{r_i}^{1/3}}{\sum y_i M_{r_i}^{1/3}} \quad (B.17)$$

(Perry, 2008)

Where,

k_G : Gas mixture thermal conductivity, kJ/m K

k_{G_i} : Component i thermal conductivity, kJ/m K

The values of A, B, and C to calculate conductivity for each component can be seen in Table B.3.

Table B.3 Regression coefficient of each component to calculate conductivity (Yaws, 1999)

Component	A	B	C
H2	3.9510E-02	4.5918E-04	-6.4933E-08
C2H4	-1.2300E-03	3.6219E-05	1.2459E-07
C2H6	-1.9360E-02	1.5470E-04	3.8798E-08
C3H6O	1.5500E-03	2.5422E-06	1.0588E-07
C3H8O	-3.3300E-03	2.8691E-05	1.0222E-07
C6H14O	-4.6600E-03	5.0338E-05	3.6643E-08
H2O	5.3000E-04	4.7093E-05	4.9551E-08

3.6 Enthalpy of Reaction

$$\Delta H_R = \Delta H_R^\circ + \int_{298}^T \Delta C_{p_G} dT \quad (\text{B.18})$$

Where,

ΔH_R° : Enthalpy of reaction at standard temperature, kJ/kmol

dT : Temperature difference, K

4. Shell and Tube Specification

4.1 Tube Specification

The effect of the ratio D_p/D_t on the heat transfer coefficient in a tube containing catalyst granules compared to an empty pipe or h_w/h can be seen in Table B.4.

Table B.4 The effect of D_p/D_t on h_w/h (Smith, 1981)

D_p/D_t	0.05	0.1	0.15	0.2	0.25	0.3
h_w/h	5.5	7	7.8	7.5	7	6.6

4.2 Number of Tube Determination

4.2.1 Maximal Number of Tubes

$$G_t = \frac{\mu_G R_e}{D_P} \quad (\text{B.19})$$

Where,

G_t : Mass flow rate over unit area, kg/m² hr

R_e : Reynold Number

The value of Re was obtained from trial. The value Re should be turbulent or more than 100.

$$A_t = \frac{G}{G_t} \quad (\text{B.20})$$

$$A_o = \frac{\pi}{4} ID^2 \quad (\text{B.21})$$

$$N_{t_{max}} = \frac{A_t}{A_o} \quad (\text{B.22})$$

Where,

A_t : Tube area, m²

A_o : Pipe area, m²

G : Mass flow rate, kg/hr

$N_{t_{max}}$: Maximal number of tubes

4.2.2 Minimal Number of Tubes

$$V_{max} = \sqrt{\frac{4(\rho_B - \rho_G)gD_P}{3\rho_G f_D}} \quad (\text{B.23})$$

$$Q = \frac{G}{\rho_G} \quad (\text{B.24})$$

$$A_t = \frac{Q}{V_{max}} \quad (\text{B.25})$$

$$N_{t_{min}} = \frac{A_t}{A_o} \quad (\text{B.26})$$

Where,

V_{max} : Maximum velocity, m/h

f_D : Friction factor

Q : Volumetric flow, m³/hr

$N_{t_{min}}$: Minimum number of tubes

4.3 Shell Specification

The pipes are arranged in a triangular pitch, so that the turbulence that occurs in the fluid flow in the shell becomes large, thereby increasing the convection heat transfer coefficient.

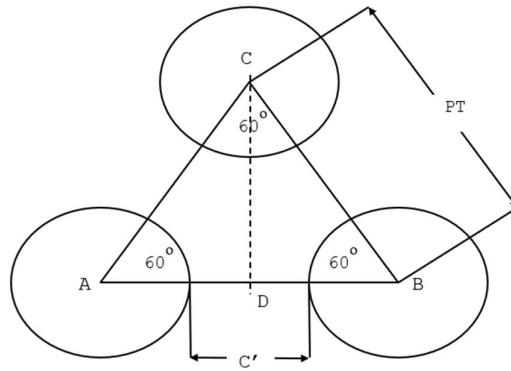


Figure B.4 Tube in triangular pitch arrangement

$$P_T = 1.25OD \quad (\text{B.27})$$

$$C' = P_T - OD \quad (\text{B.28})$$

$$CD = P_T \sin 60^\circ \quad (\text{B.29})$$

Where,

P_T : Pitch, in.

C' : Clearance, in.

CD : Triangle height, in.

To calculate the shell diameter, the total shell cross-sectional area is needed.

$$A_{Total} = 2NA_{ABC}$$

$$\frac{\pi}{4} ID_s^2 = 2N \left(\frac{1}{2} P_T^2 \sin 60^\circ \right)$$

$$ID_s = \sqrt{\frac{4N_t P_T^2 0.866}{\pi}} \quad (B.30)$$

Where,

A_{Total} : Total shell cross-sectional area, m²

A_{ABC} : ABC triangle cross-sectional area, m²

ID_s : Shell inside diameter, m

5. Mechanical Design

5.1 Tube

From Table B.4, the diameter of the pipe can be calculated.

$$\frac{D_P}{D_t} = 0.15$$

$$D_t = \frac{0.45 \text{ cm}}{0.15}$$

$$D_t = 3 \text{ cm} = 1.181 \text{ in.}$$

The pipe size can be seen in Table 11 from Kern (1950):

IPS : $1 \frac{1}{4}$ in.

Sch no. : 40

OD : 1.66 in.

ID : 1.38 in.

The mass flow velocity over unit area can be calculated with eq. B.19 with Re is 3100.

$$G_t = \frac{3100 \times 0.0410}{0.030} = 4189.331 \text{ kg/m}^2 \text{ h}$$

The tube area and the pipe area can be calculated with eq. B.20 and eq. B.21, respectively.

$$A_t = \frac{16817.042}{4189.331} = 4.014 \text{ m}^2$$

$$A_o = \frac{\pi}{4} (0.035)^2 = 0.0009 \text{ m}^2$$

The maximum number of tubes can be calculated with eq. B.22.

$$N_{t_{max}} = \frac{4.014}{0.0009} = 4160$$

To calculate the minimum number of tubes, the maximum velocity, volumetric flow, and tube area can be calculated with eq. B.23, eq. B.24, and eq. B.25, respectively. The minimum number of tubes can be calculated with eq. B.26 with the friction number that was obtained from Fig. 70 from Brown (2005).

$$V_{max} = \sqrt{\frac{4 \times (117 - 2.749) \times 9.806 \times 0.0045}{3 \times 2.749 \times 1.8}} = 1.172 \text{ m/s}$$

$$= 4219.318 \text{ m/h}$$

$$Q = \frac{16817.042}{2.749} = 6117.456 \text{ m}^3/\text{h}$$

$$A_t = \frac{6117.456}{4219.318} = 1.449 \text{ m}^2$$

$$N_{t_{min}} = \frac{01.449}{0.0009} = 1503$$

The number of tubes should be in between the maximum and the minimum number of tubes. So, for this reactor, 1600 tubes will be used. The pitch and clearance between tubes can be calculated with eq. B.27 and eq. B.28, respectively.

$$P_T = 1.25(1.66) = 2.075 \text{ in.} = 0.0527 \text{ m}$$

$$C' = 2.075 - 1.66 = 0.415 \text{ in.} = 0.010 \text{ m}$$

5.2 Shell

5.2.1 Body

The inner diameter of the shell can be calculated with eq. B.30 and the height is 4 times the inner diameter with an additional 20% overdesign.

$$ID_s = \sqrt{\frac{4 \times 2400 \times (2.075)^2 \times 0.866}{\pi}} = 106.742 \text{ in.} = 2.711 \text{ m}$$

The thickness of the shell body can be calculated with:

$$t_s = \frac{Pr}{fE - 0.6P} + C \quad (\text{B.31})$$

(Rase and Barrow, 1957)

Where:

r : Radius, m

f : Maximum allowable stress, psi

E : Welding efficiency

C : Allowable corrosion, in.

Carbon Steel SA-283 Grade A will be used as the material. The properties can be found in Brownell (1959):

f : 10350 psi

E : 0.85

C : 0.125 in.

The pressure that will be used is the design pressure with 20% overdesign in psi. So, the thickness of the shell body is:

$$t_s = \frac{52.9056 \times \frac{106.742}{2}}{10350 \times 0.85 - 0.6 \times 52.9056} + 0.125 = 0.447 \text{ in.}$$

The outer diameter of the shell can be calculated by:

$$OD_s = ID_s + 2t_s \quad (\text{B.32})$$

$$OD_s = 106.742 + 2 \times 0.447 = 107.637 \text{ in.} = 2.743 \text{ m}$$

A standard outer diameter of 108 in. and a standard thickness of 0.5 in was chosen (Brownell, 1959). So, the inner diameter of the shell will become:

$$ID_s = OD_s - 2t_s$$

$$ID_s = 108 - 2 \times (0.5) = 107 \text{ in.}$$

The height of the shell can be calculated using eq. B.4 with simulation using Runge Kutta 2nd order Heun's method in table B.5 and calculated with 10% overdesign.

$$H_s = \frac{4 \times 169.4 \times 39.37}{107^2} \times 1.1 = 32.120 \text{ m} \quad (\text{B.33})$$

5.2.2 Head

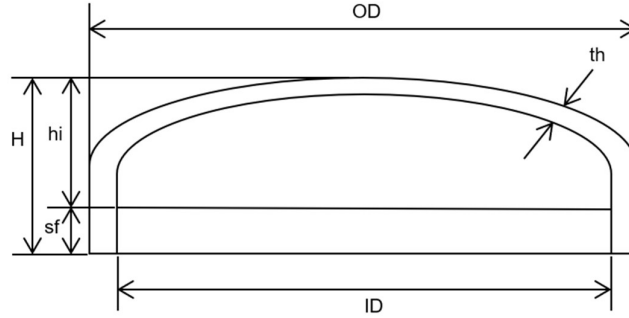


Figure B.5 Elliptical dished head

The head will use the same material as the body. The thickness of the head can be calculated with:

$$t_h = \frac{PID_s}{2fE - 0.2P} + C \quad (\text{B.34})$$

(Rase and Barrow, 1957)

$$t_h = \frac{52.9056 \times 107}{2 \times 10350 \times 0.85 - 0.2 \times 52.9056} + 0.125 = 0.447 \text{ in.}$$

A standard thickness of 0.5 in was chosen (Brownell, 1959). The outer diameter of the head can be calculated with:

$$OD_h = ID_s + 2t_h \quad (\text{B.35})$$

$$OD_h = 107 + 2 \times 0.5 = 108 \text{ in.}$$

The height inside of the head can be calculated with:

$$h_i = \frac{ID_s}{4} \quad (\text{B.36})$$

(Brownell, 1959)

$$h_i = \frac{107}{4} = 26.75 \text{ in.}$$

Straight flange (sf) that's chosen is 3 in (Brownell, 1959). The total height of the head is:

$$H_h = t_h + h_i + sf \quad (\text{B.37})$$

$$H_h = 0.5 + 26.75 + 3 = 30.25 \text{ in.}$$

5.3 Reactor Height

The total height of the reactor can be calculated with:

$$H_r = H_s + 2H_h \quad (\text{B.38})$$

$$H_r = 411.417 + 2 \times (30.25) = 471.917 \text{ in.}$$

5.4 Isolator

Assumptions:

1. Steady-state condition
2. Isolator outer wall temperature = $T_3 = 50^\circ\text{C}$
3. Outside air temperature = $T_4 = 30^\circ\text{C}$

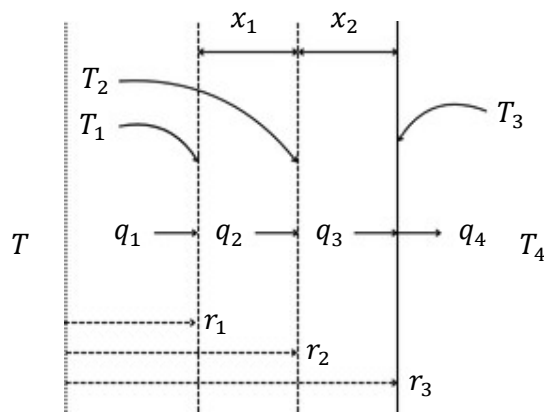


Figure B.6 Shell and isolator temperature and thickness

Description:

r_1 : Shell inner radius

r_2 : Shell outer radius

r_3	: Isolator outer radius
x_1	: Shell thickness
x_2	: Isolator thickness
T	: Coolant temperature
T_1	: Inner shell temperature
T_2	: Outer shell temperature
T_3	: Outer isolator temperature
T_4	: Outside air temperature

The material that was chosen for the isolator is Asbestos. The important properties of asbestos are:

k_A	: 0.111 BTU/h ft ² (°F/ft)
ε	: 0.96
ρ	: 36 lb/ft ³
C_p	: 0.25 BTU/lb °F

(Perry, 2008)

For carbon alloy, as the material for the shell, some important properties are:

k_c	: 26.463 BTU/h ft ² (°F/ft)
ID_s	: 7.427 ft
t_s	: 0.0364 ft
H_s	: 105.382 ft

Heat transfer from the reactor to the surroundings through the reactor walls and isolator occurs through several steps:

1. Convection transfer of coolant in the shell to inner shell wall (q_1);

2. Conduction transfer from inner shell wall to wall outer shell (q_2);
3. Conduction transfer from the outer shell wall to the surface outer isolator (q_3);
4. Convection and radiation transfer from the outer surface isolator to the outside air (q_4).

To obtain the convection coefficient between asbestos and air, the average temperature between them needs to be calculated.

$$T_f = \frac{T_3 + T_4}{2} \quad (\text{B.39})$$

$$T_f = \frac{50 + 30}{2} = 40 \text{ } ^\circ\text{C} = 313.15 \text{ } K$$

The properties of air can be obtained from Holman (2002) by doing interpolation. The properties that are obtained are:

$$\begin{aligned} \rho & : 1.130 \text{ kg/m}^3 \\ C_p & : 1.006 \text{ kJ/kg } ^\circ\text{C} \\ \mu & : 1.906 \times 10^{-5} \text{ kg/m} \\ \nu & : 1.502 \times 10^{-5} \text{ m}^2/\text{s} \\ k_a & : 0.0272 \text{ W/m } ^\circ\text{C} \\ \alpha & : 0.2417 \text{ m}^2/\text{s} \\ Pr & : 0.705 \end{aligned}$$

For the thermal expansion coefficient, it can be calculated with:

$$\beta = \frac{1}{T_f} \quad (\text{B.40})$$

(Holman, 2002)

$$\beta = \frac{1}{313.15} = 0.0032 \text{ K}^{-1}$$

To determine the formula to calculate the convection coefficient between asbestos and air, the value of the Grashof number times the Prandtl number needs to be known.

$$G_{rL}P_r = \frac{g\beta(T_3 - T_4)L^3}{\nu^2} P_r \quad (\text{B.41})$$

(Holman, 2002)

Where L is the height of the shell (H_s).

$$G_{rL}P_r = \frac{32.120 \times 0.0032(50 - 30)10.866^3}{(1.502 \times 10^{-5})^2} \times 0.705 = 1.955 \times 10^{12}$$

Because the value of $G_{rL}P_r > 10^9$, the convention coefficient can be calculated with:

$$h_c = 1.31(\Delta T)^{1/3} \quad (\text{B.42})$$

(Holman, 2002)

$$h_c = 1.31(50 - 30)^{1/3} = 3.5558 \text{ W/m}^2 \text{ } ^\circ\text{C} = 0.626 \text{ BTU/h ft}^2\text{R}$$

The radiation coefficient can be calculated with:

$$h_r = \frac{\varepsilon\sigma(T_3^4 - T_4^4)}{(T_3 - T_4)} \quad (\text{B.43})$$

(Kern, 1950)

Where σ is Stefan-Boltzmann constant and T is in Rankine.

$$h_r = \frac{0.96 \times 1.73 \times 10^{-9}(581.67^4 - 545.67^4)}{(581.67 - 545.67)} = 1.191 \text{ BTU/h ft}^2\text{R}$$

The heat transfer can be calculated with:

$$dQ = kA \frac{dT}{dx} \quad (\text{B.44})$$

(Kern, 1950)

$$q = kA \frac{\Delta T}{x}$$

In steady state, $q_1 = q_2 = q_3 = q_4$.

$$q_2 = k_c A_1 \frac{(T_1 - T_2)}{x_1} = k_c \pi L (ID_s + 2x_1) \frac{(T_1 - T_2)}{x_1} \quad (\text{B.45})$$

If the temperature of the inner shell is the same as the reaction condition,

so:

$$q_2 = 26.463 \times \pi \times L(7.427 + 2 \times 0.0364) \frac{(302 - T_2)}{0.0364}$$

$$q_2 = 5452.541 \times \pi \times L(302 - T_2)$$

$$q_3 = k_A A_2 \frac{(T_3 - T_2)}{x_2} = k_A \pi L (ID_s + 2x_1 + 2x_2) \frac{(T_2 - T_3)}{x_2} \quad (\text{B.46})$$

$$q_3 = 0.111 \times \pi \times L(7.427 + 2 \times 0.0364 + 2x_2) \frac{(T_2 - 122)}{x_2}$$

$$\begin{aligned} q_4 &= (h_r + h_c) A_3 (T_3 - T_4) \\ &= (h_r + h_c) \pi L (ID_s + 2x_1 + 2x_2) (T_3 - T_4) \end{aligned} \quad (\text{B.47})$$

$$q_4 = (1.191 + 0.626) \pi L (7.427 + 2 \times 0.0364 + 2x_2) (122 - 86)$$

$$q_4 = 64.9224 \times \pi \times L \times (7.427 + 2 \times 0.0364 + 2x_2)$$

Where T is in Fahrenheit and x_1 and ID_s are in feet.

If $q_2 = q_4$, the equation of correlation between T_2 and x_2 are:

$$T_2 = 301.909 - 0.0240x_2 \dots \dots \dots (1)$$

If $q_3 = q_4$, the equation of correlation between T_2 and x_2 are:

$$T_2 = 122 + 589.3561x_2 \dots \dots \dots (2)$$

From equation (1) and (2), the value of T_2 and x_2 can be obtained, where T_2 is 301.821 °F and x_2 is 0.305 ft or 0.0929 m.

5.6 Weight Hour Space Velocity

$$W_c = \frac{\pi}{4} D_t^2 H_s N_t \rho_B \quad (B.48)$$

$$WHSV = \frac{F_v}{W_c} \quad (B.49)$$

Where,

W_c : Catalyst weight, kg

$WHSV$: Weight hour space velocity, /h

F_v : Material flow rate, kg/h

The bulk density of Rhodium-Silica is 500 kg/m³ and the material flow rate is 16817.042 kg/h. The tube diameter and the shell height are in meter.

$$W_c = \frac{\pi}{4} (1.38 \times 0.0254)^2 \times 32.120 \times 2400 \times 500 = 12100.770 \text{ kg}$$

$$WHSV = \frac{16817.042}{12100.770} = 1.389/h$$

5.7 Pressure Drop

Pressure drop along the catalyst inside the pipe can be calculated by doing integral to eq. B.9.

$$P = \frac{G}{\rho g D_e} \frac{1 - \varepsilon}{\varepsilon^3} \left[\frac{150(1 - \varepsilon)\mu}{D_p} + 1.75G \right] Z$$

Where the porosity of the pile can be calculated with:

$$\varepsilon = 1 - \frac{\rho_B}{\rho_P} \quad (B.50)$$

where ρ_p is particle density. The particle density of Nickel-Kieselguhr is 6500 kg/m^3 .

$$\varepsilon = 1 - \frac{500}{6500} = 0.923$$

So, the pressure drop is

$$\begin{aligned} P &= \frac{4189.330}{2.749 \times 9.806 \times 3600^2} \times \frac{1 - 0.923}{0.923^3} \\ &\quad \times \left[\frac{150(1 - 0.923) \times 0.0410}{0.00455} + 1.75 \times 4189.330 \right] \\ &\quad \times 32.120 = 0.200 \text{ atm} \end{aligned}$$

Table B.5 Simulation of reactor volume with Runge-Kutta 2nd order Heun's method

V (m ₃)	x	T _G (K)	T _P (K)
0.0000	0.0000	373.1500	303.1500
1.1000	0.0353	373.4449	304.5611
2.2000	0.0688	373.7181	305.9494
3.3000	0.1006	373.9728	307.3152
4.4000	0.1307	374.2113	308.6584
5.5000	0.1594	374.4356	309.9793
6.6000	0.1867	374.6474	311.2780
7.7000	0.2127	374.8481	312.5547
8.8000	0.2374	375.0386	313.8097
9.9000	0.2610	375.2201	315.0432
11.0000	0.2835	375.3932	316.2554
12.1000	0.3050	375.5588	317.4466
13.2000	0.3256	375.7174	318.6172
14.3000	0.3452	375.8696	319.7673
15.4000	0.3641	376.0158	320.8973
16.5000	0.3821	376.1565	322.0074
17.6000	0.3993	376.2920	323.0980
18.7000	0.4159	376.4227	324.1693
19.8000	0.4317	376.5489	325.2217
20.9000	0.4470	376.6708	326.2554
22.0000	0.4616	376.7887	327.2707
23.1000	0.4756	376.9028	328.2679
24.2000	0.4892	377.0133	329.2473
25.3000	0.5021	377.1203	330.2092
26.4000	0.5147	377.2242	331.1539
27.5000	0.5267	377.3250	332.0816
28.6000	0.5383	377.4228	332.9927
29.7000	0.5495	377.5178	333.8873
30.8000	0.5602	377.6102	334.7659
31.9000	0.5706	377.7000	335.6286
33.0000	0.5807	377.7873	336.4758
34.1000	0.5904	377.8723	337.3076
35.2000	0.5997	377.9550	338.1244
36.3000	0.6087	378.0355	338.9264
37.4000	0.6175	378.1140	339.7139
38.5000	0.6259	378.1904	340.4871
39.6000	0.6341	378.2649	341.2463
40.7000	0.6420	378.3375	341.9916
41.8000	0.6496	378.4084	342.7234
42.9000	0.6570	378.4774	343.4419
44.0000	0.6642	378.5448	344.1474
45.1000	0.6712	378.6106	344.8399
46.2000	0.6779	378.6748	345.5199
47.3000	0.6844	378.7375	346.1874
48.4000	0.6908	378.7987	346.8428
49.5000	0.6969	378.8584	347.4862
50.6000	0.7029	378.9168	348.1178
51.7000	0.7087	378.9738	348.7379
52.8000	0.7143	379.0295	349.3467
53.9000	0.7198	379.0839	349.9443
55.0000	0.7251	379.1372	350.5310
56.1000	0.7302	379.1892	351.1069

Table B.5 Simulation of reactor volume with Runge-Kutta 2nd order Heun's method (continuation)

V (m ₃)	x	T _G (K)	T _P (K)
57.2000	0.7352	379.2400	351.6723
58.3000	0.7401	379.2897	352.2274
59.4000	0.7449	379.3383	352.7722
60.5000	0.7495	379.3859	353.3071
61.6000	0.7540	379.4324	353.8321
62.7000	0.7583	379.4779	354.3475
63.8000	0.7626	379.5223	354.8535
64.9000	0.7667	379.5659	355.3501
66.0000	0.7708	379.6085	355.8377
67.1000	0.7747	379.6502	356.3162
68.2000	0.7785	379.6909	356.7860
69.3000	0.7823	379.7309	357.2471
70.4000	0.7859	379.7699	357.6998
71.5000	0.7895	379.8082	358.1441
72.6000	0.7929	379.8456	358.5803
73.7000	0.7963	379.8823	359.0084
74.8000	0.7996	379.9182	359.4286
75.9000	0.8028	379.9533	359.8411
77.0000	0.8059	379.9877	360.2461
78.1000	0.8090	380.0214	360.6435
79.2000	0.8120	380.0544	361.0336
80.3000	0.8149	380.0867	361.4165
81.4000	0.8178	380.1183	361.7924
82.5000	0.8206	380.1493	362.1614
83.6000	0.8233	380.1797	362.5235
84.7000	0.8260	380.2094	362.8790
85.8000	0.8286	380.2386	363.2278
86.9000	0.8311	380.2671	363.5703
88.0000	0.8336	380.2951	363.9064
89.1000	0.8360	380.3225	364.2364
90.2000	0.8384	380.3493	364.5602
91.3000	0.8408	380.3756	364.8781
92.4000	0.8430	380.4014	365.1901
93.5000	0.8453	380.4266	365.4963
94.6000	0.8475	380.4514	365.7969
95.7000	0.8496	380.4756	366.0919
96.8000	0.8517	380.4994	366.3815
97.9000	0.8537	380.5227	366.6657
99.0000	0.8558	380.5455	366.9447
100.1000	0.8577	380.5679	367.2185
101.2000	0.8597	380.5898	367.4872
102.3000	0.8615	380.6113	367.7510
103.4000	0.8634	380.6324	368.0099
104.5000	0.8652	380.6530	368.2640
105.6000	0.8670	380.6733	368.5134
106.7000	0.8687	380.6931	368.7582
107.8000	0.8704	380.7125	368.9985
108.9000	0.8721	380.7316	369.2343
110.0000	0.8738	380.7503	369.4658
111.1000	0.8754	380.7686	369.6929
112.2000	0.8770	380.7866	369.9159
113.3000	0.8785	380.8042	370.1347

Table B.5 Simulation of reactor volume with Runge-Kutta 2nd order Heun's method (continuation)

V (m ₃)	x	T _G (K)	T _P (K)
114.4000	0.8800	380.8215	370.3495
115.5000	0.8815	380.8384	370.5603
116.6000	0.8830	380.8550	370.7673
117.7000	0.8844	380.8713	370.9703
118.8000	0.8858	380.8872	371.1697
119.9000	0.8872	380.9029	371.3653
121.0000	0.8886	380.9182	371.5573
122.1000	0.8899	380.9333	371.7457
123.2000	0.8912	380.9480	371.9307
124.3000	0.8925	380.9625	372.1122
125.4000	0.8938	380.9767	372.2904
126.5000	0.8950	380.9906	372.4653
127.6000	0.8963	381.0042	372.6369
128.7000	0.8975	381.0176	372.8053
129.8000	0.8986	381.0307	372.9706
130.9000	0.8998	381.0436	373.1329
132.0000	0.9009	381.0562	373.2922
133.1000	0.9021	381.0686	373.4485
134.2000	0.9032	381.0807	373.6019
135.3000	0.9043	381.0926	373.7524
136.4000	0.9053	381.1043	373.9002
137.5000	0.9064	381.1157	374.0452
138.6000	0.9074	381.1270	374.1875
139.7000	0.9084	381.1380	374.3272
140.8000	0.9094	381.1488	374.4643
141.9000	0.9104	381.1594	374.5989
143.0000	0.9114	381.1698	374.7310
144.1000	0.9123	381.1800	374.8606
145.2000	0.9132	381.1900	374.9878
146.3000	0.9142	381.1998	375.1127
147.4000	0.9151	381.2094	375.2352
148.5000	0.9160	381.2188	375.3555
149.6000	0.9168	381.2281	375.4735
150.7000	0.9177	381.2372	375.5894
151.8000	0.9186	381.2461	375.7031
152.9000	0.9194	381.2548	375.8146
154.0000	0.9202	381.2634	375.9242
155.1000	0.9210	381.2718	376.0316
156.2000	0.9218	381.2800	376.1371
157.3000	0.9226	381.2881	376.2407
158.4000	0.9234	381.2960	376.3423
159.5000	0.9242	381.3038	376.4420
160.6000	0.9249	381.3115	376.5399
161.7000	0.9256	381.3189	376.6359
162.8000	0.9264	381.3263	376.7302
163.9000	0.9271	381.3335	376.8227
165.0000	0.9278	381.3406	376.9135
166.1000	0.9285	381.3475	377.0026
167.2000	0.9292	381.3543	377.0901
168.3000	0.9299	381.3610	377.1759
169.4000	0.9305	381.3675	377.2602

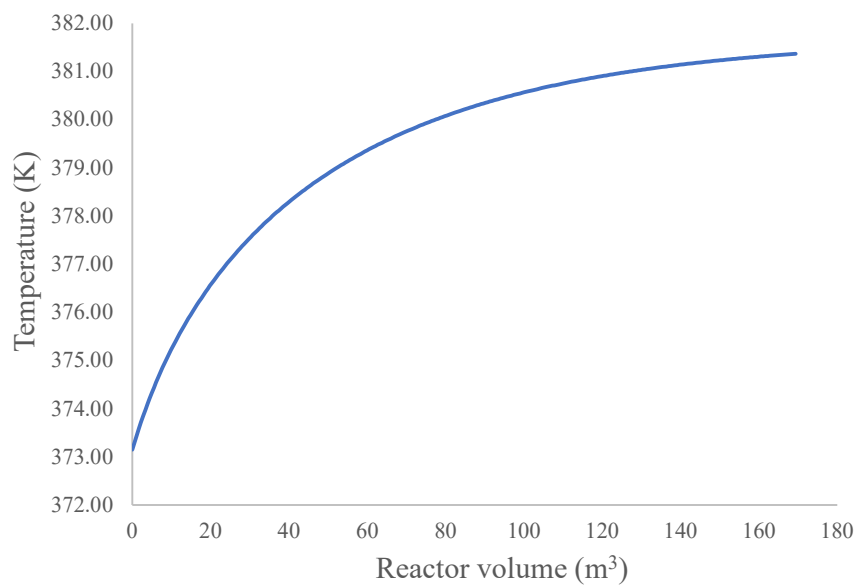


Figure B.7 Temperature vs reactor volume

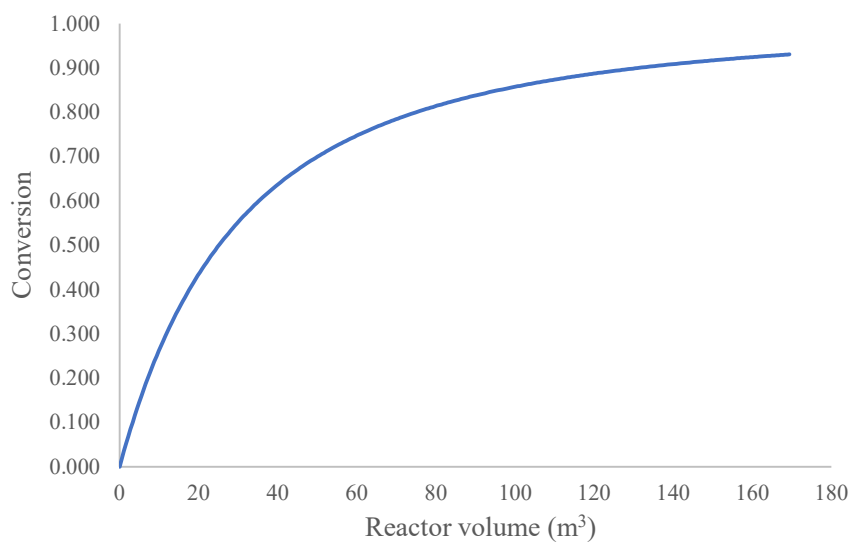


Figure B.8 Conversion vs reactor volume

ATTACHMENT C

PROCESS ENGINEERING FLOW DIAGRAM

(PEFD)

PROCESS FLOW DIAGRAM
PRELIMINARY DESIGN OF CHEMICAL PLANT OF N-PROPANOL
FROM ETHYLENE AND SYNGAS WITH CAPACITY OF 60,000
TONS/ YEAR

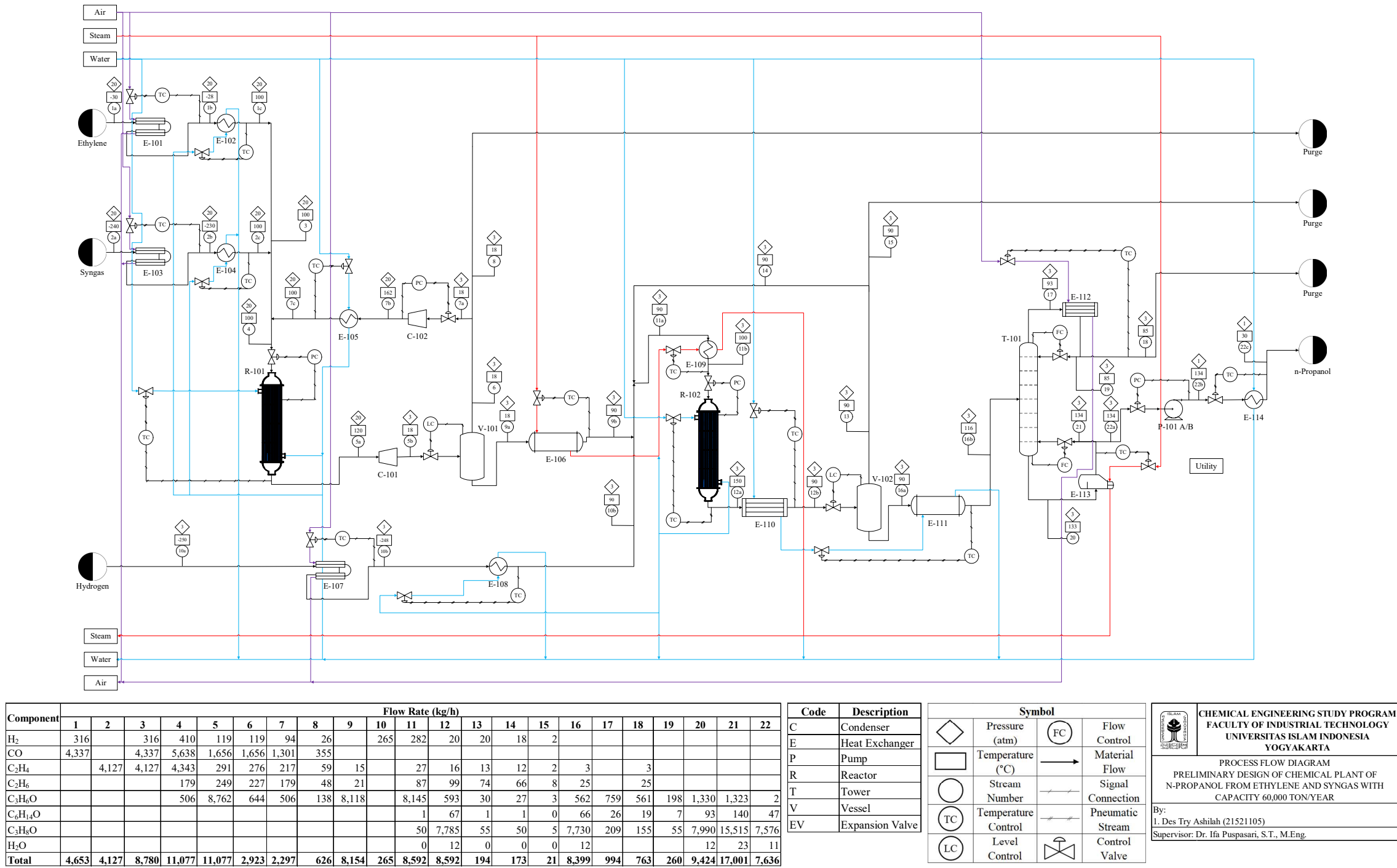


Figure C.1 Process engineering flow diagram

ATTACHMENT D
CONSULTATION CARD

CONSULTATION ADVISORY FORM

Name of Student : Des Try Ashilah
Student ID : 21521105
Semester/Academic Year : 8/2025
Supervisor : Dr. Ifa Puspasari, S.T., M.Eng.

Title of Project : Preliminary Design of n-Propanol from Ethylene and Syngas with Capacity of 60,000 Tons/Year

Starting Advisory Date : 8 October 2024
Last Advisory date : 3 June 2025

No	Date	Topic	Signature
1.	8 October 2024	Selecting the title	
2.	23 October 2024	Output 1 plant capacity Output 2 literature review Output 3 product specification	
3.	23 October 2024	Output 2 literature review	
4.	29 October 2024	Output 4 qualitative flow diagram	
5.	13 December 2024	Output 4 qualitative flow diagram Output 5 mass balance	
6.	16 January 2025	Output 5 mass balance	
7.	27 February 2025	Output 6 reactor	
8.	6 March 2025	Output 7 separation equipment	
9.	23 April 2025	Output 8 PFD Output 9 storage tank Output 10 transportation of material	

10.	16 May 2025	Output 11 heat exchanger	Ifa
11.	3 June 2025	Output 12 energy balance Output 13 plant design Output 14 utility Output 15 economy analysis Output 16 final draft	Ifa

Yogyakarta, 3 June 2025



Dr. Ifa Puspasari, S.T., M.Eng.