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Top Product Yield Optimization of Depropanizer Column 1-2 in Alkylation Unit at PT. PI

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ABSTRACT - Alkylation Unit is a component of PT PI Unit, tasked with processing feedstocks similar to Spent Propane-Propylene from Polypropylene Unit and Residual Butane-Butylene from Polymerization Unit. The Alkylation Unit is used to produce products such as Light Alkilate, Refrigerant, LPG C-4, and by-products in the form of High Alkilate. Depropanizer Column 1-2 found in this component plays an important role in separating the propane-propylene mix from n-Butane and heavier components through pressurized distillation. Depropanizer Column feed comes from the overhead product of Desiobuthanizer Column 1-1, while 1-2 column is equipped with 40 valve trays. Therefore, this research aims to evaluate the performance and efficiency of Depropanizer Column 1-2. The evaluation process was carried out with feed flow rate, temperature, column pressure, and hydrocarbon composition of 40.152 tons/day, 55.48oC, 17.38 kg/cm2, and from the laboratory, respectively. The theoretical number of trays and reflux ratio were 28 pieces and 10 at 69% efficiency. Optimization experiments were conducted to determine the optimal operating conditions to obtain the highest revenue for the top product. Based on trial and error experiments with Aspen Hysys Study Case, the result showed that the optimal conditions are achieved when the column conditions operated at reboiler temperature of 95oC and reflux flow of 90 tons/day to obtain a top product yield of 5.4592 tons/day with purity of 99.5% w/w.

Keywords: depropanizer column 1-2, performance analysis, optimization, yield

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INTRODUCTION

PT PI, an oil refinery founded by two companies and purchased in 1965 and 1970, comprises five main units, including the Crude Distiller and Gas Plant. The process produced a refrigerant called Hydro Chloro Fluoro Carbons (HCFC) known as Freon. The substance was first identified by Charles Kettering and Thomas Migley, Jr. in 1928. Despite the effectiveness of Freon-based refrigeration systems, research from the 1970s stated that Freon, particularly the types containing Chlorine, contributed to the depletion of ozone layer. Ozone layer, consisting of O_3 molecules with three oxygen atoms, was naturally formed millions of years ago and accumulated in the stratosphere. The main function of this layer is to protect the earth from the ultraviolet radiations of the sun (Kilicarslan, et al., 2005). The leading cause of ozone layer depletion is the presence of chlorine (Cl), which acts as a catalyst in breaking down ozone molecules into oxygen. In addition, Freon poses a substantial risk due to the high global warming potential (GWP). For example, R12 has GWP index of 8500, and R22 has GWP index of 1900 (Kilicarslan et al., 2005).

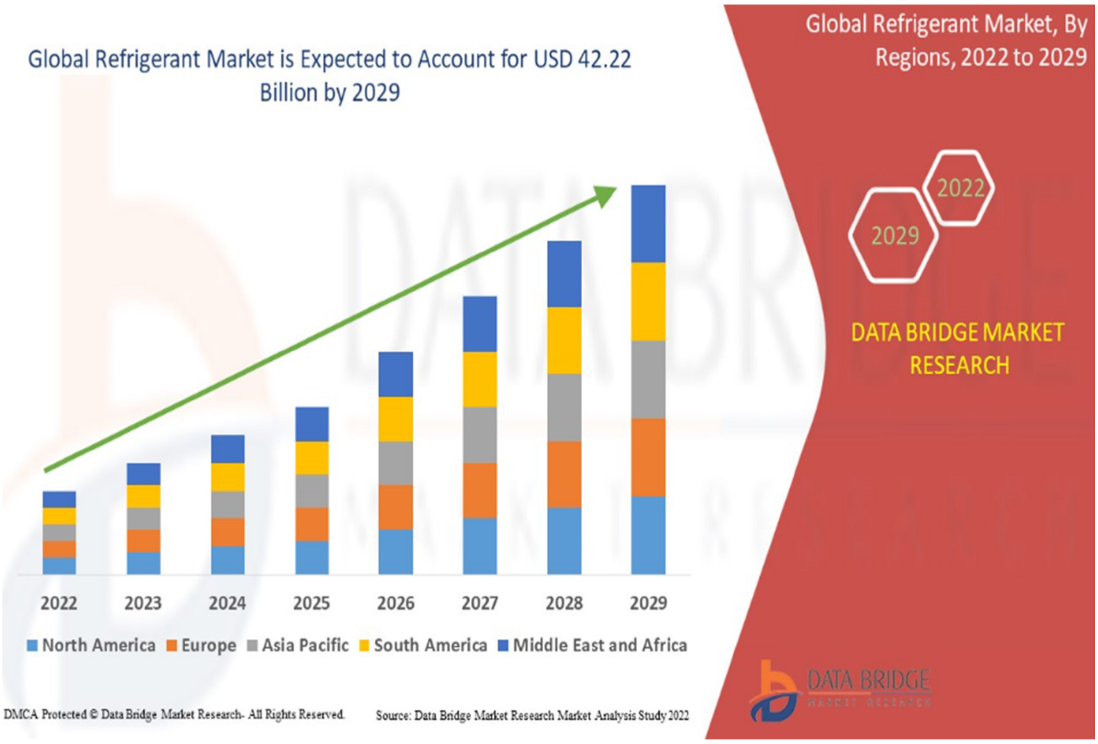

Figure 1
World refrigerant consumption trend 2022 - 2029 (data bridge market research market analyses study 2022)

Table 1
Indonesia refrigerant import data sample, March 2020 (Harmita, 2004)

Date	HS Code	Product Description	Origin Country	Port of Loading	Port of Discharge	Qty	Unit	Value in USD
3/30/2020	84819010	Refrigerant Distributor M22-06-12	Hungary	Koper	Tanjung Perak	20.0	PCE	71.41
3/30/2020	84819010	Refrigerant Distributor M22-05-20	Hungary	Koper	Tanjung Perak	50.0	PCE	444.22
3/23/2020	84819010	Refrigerant Distributor M22-05-14	Hungary	Koper	Tanjung Perak	75.0	PCE	259.86
03/11/2020	84819010	Refrigerant Distributor M22-05-14	Hungary	Budapest	Cengkareng Soekarno Hatta U	5.0	PCE	18.07
03/02/2020	84819010	Refrigerant Distributor M22-05-10	Hungary	Koper	Tanjung Perak	100.0	PCE	170.44
3/31/2020	29037100	Refrigerant Gas R22	China	Shanghai	Tanjung Perak	39997.6	KGM	78818.8
3/30/2020	84185019	Refrigerant=r134a	China	Nansha New Pt	Tanjung Priok	25.0	PCE	14308.17
3/30/2020	84186950	Refrigerant: R410a	China	Ningbo Pt	Tanjung Priok	2.0	HIU	3445.19
3/27/2020	29037100	3420 Cylinders Of Refrigerant R22	China	Shanghai	Tanjung Priok	46512.0	KGM	89946.0
3/27/2020	29037100	Refrigerant Gas R22	China	Shanghai	Tanjung Priok	77520.0	KGM	152760.0

The data shows a growing demand for refrigerants globally, with an anticipated investment of $42.22 billion by 2029. Despite the increasing demand, Indonesia relies on imports from China and Hungary to meet domestic refrigerant needs. A detailed overview of refrigerant imports in the country is shown in the following table:

The refrigerant produced by PT. PI is environmentally friendly because it does not contain HCFC. This production ocThe The refrigerant produced by PT. PI is environmentally friendly because it does not contain HCFC. This production occurs at the Alkylation Unit, the top product of Depropanizer Column. Therefore, the refrigerant is designed to replace the synthetic refrigerant R-22. By using PT. PI Refrigerant, users can optimize the performance of refrigeration systems without compromising reliability and efficiency.

This research aims to identify the factors that impacts on the performance of Depropanizer Column 1-2, assess the actual performance of the column, and determine optimal operating conditions to maximize yield in accordance with product specifications. Furthermore, the research aims to evaluate the yield of upper and lower products post-optimization, analyze the increase in profit pre- and post-optimization, and understand the operating conditions post-optimization process. Based on these challenges, the title Optimization of Product Yield of Depropanizer Column 1-2 in the Alkylation Unit at PT. PI was obtained.

METHODOLOGY

Materials and equipment

This research was conducted at PT PI from December 1, 2022 to February 28, 2023.

Materials

Optimization of Depropanizer Column 1-2 in Alkylation Unit included the use of the following materials:

Design data for Depropanizer Column 1-2.

Log sheet for Depropanizer Column 1-2.

Laboratory analysis for both top and bottom products.

Equipment

The equipments used are:

Personal Protective Equipment such as Wear Pack, safety shoes, helmets, masks etc.

Stationery and laptop.

Microsoft Office software, namely Ms. Word, Excel, PowerPoint, and Aspen Hysys.

Research subject

This research focused on Depropanizer Column 1-2 Alkylation Unit, located at PT. PI.

Research variables

The independent variables used are reflux flow rate and reboiler temperature in Depropanizer Column 1-2. The dependent variables comprised overall efficiency, %recovery, %purity, yield product, %product yield, and Revenue.

Reflux flow is important in re-establishing contact between liquid and vapor, to increase product purity. This is in addition to the use of the reboiler temperature which impacts the vapor reaching the top of the column, leading to a change in the top yield. All changes in the independent variables require energy and affect the revenue value obtained.

Work method

Work methods are implemented to improve efficiency, productivity, and safety during the execution of tasks or projects. The working methods for this research are as follows:

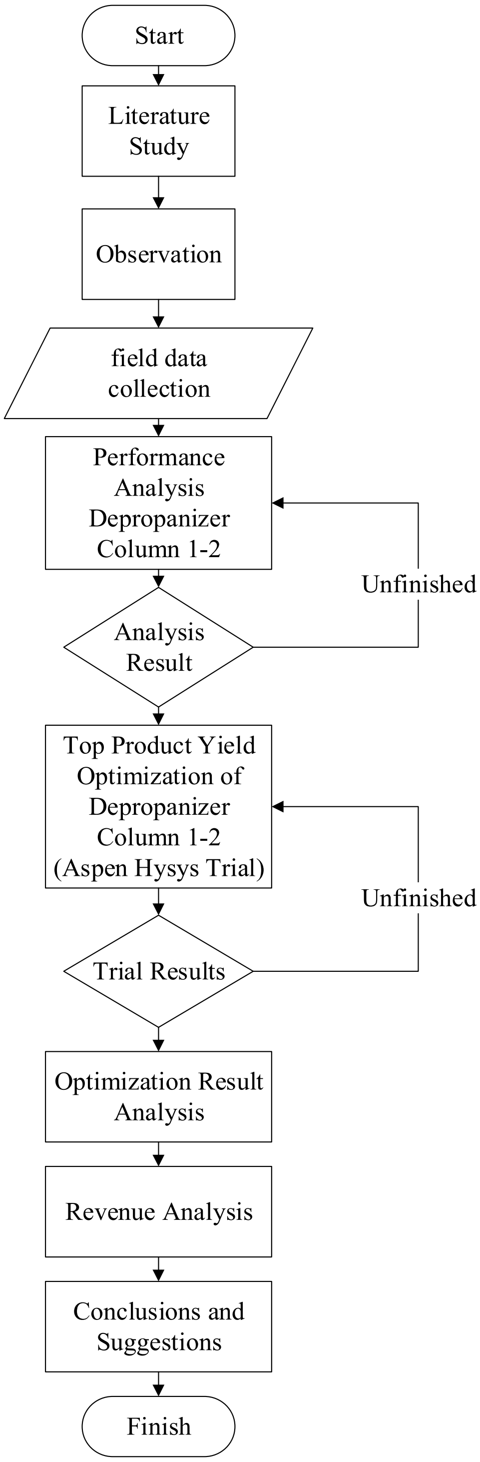

Figure 2
Research method

The work method starts with a literature research and observation, progressing to field data collection and subsequent performance analysis. Following this, optimization stage was conducted using the trial method in Aspen Hysys. The results of the trial tests are carefully analyzed, with a specific focus on revenue outcomes post-optimization, followed by comparisons. Through comprehensive analysis, conclusions and suggestions were derived, leading to the completion of the work method.

RESULT AND DISCUSSION

Performance analysis of depropanizer columns 1-2

Performance analysis aims to determine the efficiency of process equipment and determine the suitability for continued use or when maintenance is required. To calculate the performance analysis of Depropanizer Column 1-2, specific data should be collected, such as:

Table 2
Equipment specifications

Depropanizer Colomn		
Properties	**Value**	**Unit**
Column Shape	Silinder	
Column Position	Vertikal	
Column Diameter	36	ft
Column Height	80' 11 7/8"	
Number of Trays	60	piece
Plate Tray Type	Valve Tray	
Tray Spacing	18	in
Design Temp	400	°F
Design Pressure	275	psig

Table 3
Actual condition design data

Actual Condition Design Data		
Pressure	17,38	Kg/cm^2
Reflux rate	100	Tons/day
Temperature	93,38	ºC
Feed flow rate	40,152	Tons/day
Top product flow rate	4,6224	Tons/day
Bottom product flow rate	35,530	Tons/day

Table 4
Flow composition

Composition	Feed	Top Product	Bottom Product
	% Mol		
Propena	0,002733261	0	0
Propana	0,994832332	0,013211129	0,01326
i-Butana	0,002035563	0,84700804	0,84696
n-Butana	0	0,018642625	0,01864
1-Butena	0	0,00716118	0,00716
i-Butena	0	0,079421037	0,07942
Butene-Trans	0	0,028576807	0,02858
Butene-Cis	0	0,005386639	0,00539
1,3-Butadiena	0	0,000592544	0,00059
M-Acetylene	0,000398844	0	0,00000
Total	1	1	1

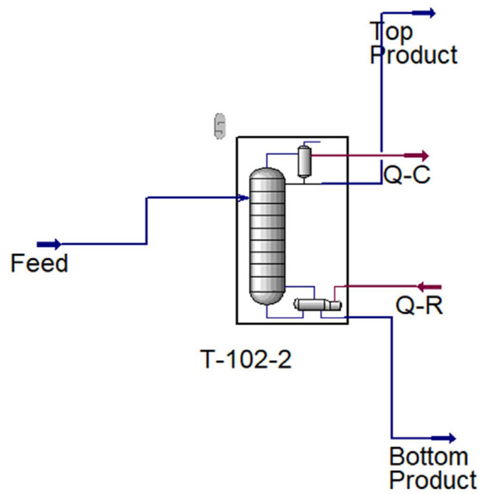

Figure 3
Column simulation

The simulation of Depropanizer Column 1-2, designed with Aspen Hysys is shown in Figure 3. The simulated data reflects the average values obtained during observation.

Table 5
Depropanizer column 1-2 mass balance

Componen	Output		Input
	Top	Bottom	Feed
		kg/h	
Propena	0,443	0,000	0,443
Propana	191,78	25,575	217,359
i-Butana	0,469	1243,1	1243,57
n-Butana	0,000	27,357	27,357
1-Butena	0,000	10,786	10,786
i-Butena	0,000	120,86	120,864
Butene-Tr	0,000	43,444	43,444
Butene-Cis	0,000	8,185	8,185
1,3-Butadiena	0,000	0,937	0,937
M-Acetylene	0,047	0,000	0,047
Total	192,743	1480,25	1672,99

The calculation of Overall Tray performance follows the method outlined in Chemical Engineering Design Coulson & Richardson Vol. 6. The specific formula used for determining column performance based on Tray Overall is (S. R. K, 1989):

$$\%eff = \frac{Number\ of\ theoretical\ trays\ (N)}{Number\ of\ actual\ trays\ (Na)} 100\% \quad (1)$$

The results obtained from the calculation:

Number of Actual Tray (Na) :40 pieces
Number of Theoretical Tray (N) :28 pieces

$$\%eff = \frac{28}{40} \times 100\% = 69\ \% \quad (2)$$

Determining the recovery percentage. To assess the performance of the column, the recovery percentage need to be calculated. This metric indicates the percentage of expected components included in both the main and side products (Harmita, 2004). The higher the inclusion of anticipated components in the main product, the more accurate the results.

$$\% = \frac{\text{components in top } (C3{+}C3{=})}{\text{components in feed } (C3{+}C3{=})} \times 100\% \quad (3)$$

Table 6
C3 Mix composition

Tons/h	Feed	*Top Product*	*Bottom Product*
Propana	0,2360	0,2262	0,0098
Propena	0,0011	0,0011	0

In this case, the intended components at the top are a mixture of C3, specifically propane and propene. The percent recovery of these two components included in the top product is calculated as follows:

$$\% = \frac{(0{,}2262 + 0{,}0011)\frac{ton}{h}}{(0{,}2360 + 0{,}00195)\frac{ton}{h}} \times 100\% \quad (4)$$

$$\% = 95{,}5\ \%$$

The percent recovery calculation for C3 stated that 95.5% and the remaining 4.5% were included in the top and bottom products, respectively. This depicts a high level of efficiency in the recovery process in Depropanizer1-2 Column, with minimal impurities detected. Purity, characterized as the absence of contamination, holds significant importance (Rossen, 2017). The refrigerant product specifications require a minimum of 99.5% w/w C3, while purity in December 2022 was 99.7% w/w.

This implied that the product produced by Depropanizer column was of exceptional quality and met the minimum specifications. The level of purity is closely related to the operational efficiency of a device. Weeping or Dumping is a phenomenon that occurs when liquid drips from the tray due to low vapor pressure. Excessive weeping results in dumping, causing the liquid to drip to the bottom of the column, consequently reducing or stopping the top product flow. A significant pressure drop is a clear indicator of weeping in the column. Flooding is a phenomenon where liquid accumulates at the downcomer, impeding downward flow. This occurs due to excessive vapor pressure, causing the vapor to bypass the intended route through the tray. Consequently, the vapor causes a blockage, trapping the liquid and resulting in an extremely low or non-existent level at the bottom (Geankoplis, 1983). To sustain optimal column performance, it is important to prevent the outlined chaleenges during operation. However, any impediment to the efficiency of the column has significant repercussions on the overall economic viability of the unit.

The internal condition of the column can be evaluated through simulation using Hysys software. The results obtained from are shown in Figure 4.

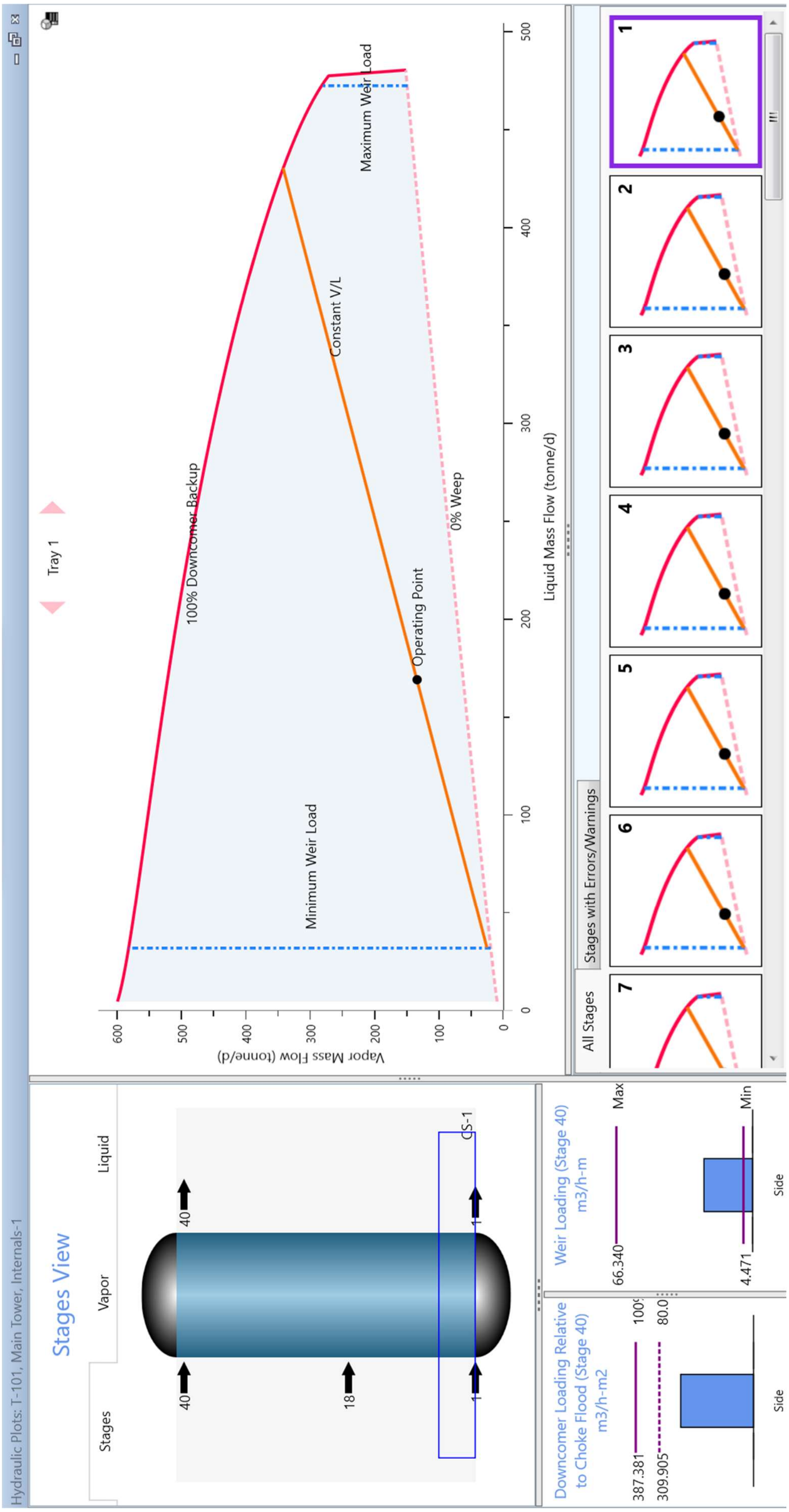

Figure 4
Actual operating conditions of depropanizer column 1-2

The simulation results shows the absence of weeping or flooding from each tray, across all operating points. This illustrated in the weeping and flooding boundaries denoted by pink and red dotted lines. The results illustrated that the column operated efficiently without encountering any obstacles.

Optimization of depropanizer column operating conditions

Optimization, a systematic process to achieve the best results, is synonymous with performing an optimal state. Therefore, this research applied optimization analysis to break down the initial data using specific methods. The main focus is to reduce the research duration, to achieve optimal acceleration, considering various cost alternatives (Weight, 2020).

The optimization process was carried out to increase the yield of the top product by raising reboiler temperature to meet the minimum specification target and the highest revenue value. To maintain the quality of minimum purity, it is necessary to adjust reflux flow. The increase in reflux leads to a rise in the L/V in the enriching section, thereby reducing the required equilibrium stage for the specified product quality. The same number of stages produces better quality by ensuring contact between liquid and vapor.

Refrigerant Product has purity of 99.7% w/w in actual operating conditions with reboiler temperature, reflux flow, and pressure of 93.37 C, 100 tons/day, and 17.38 kg/respectively.

The product need adhere to the reboiler operating conditions of 80 and 140^{o}C, reflux flow of 85 to 135 tons/day and pressure level of 15.5 to 17.5 kg/cm^2 to meet a minimum specification of 99.5% w/w. Reboiler temperature and reflux flow were the independent variables used to optimize product yield for maximum profit. Reboiler temperature functioned as a regulator, and influenced the amount of top product produced.

This is in accordance with the principle that higher temperatures result in increased vapor formation, producing more top products. Reflux flow functions as a corrector, enhancing purity of the stream. The working principle of reflux depends on the division of the flow into two, namely the product and return flow. The return flow facilitates optimal separation between the heavier and lighter fractions in the column.

Trial and Error Optimization

The trial and error method is widely applicable across various fields, including science, technology, mathematics, and problem-solving. In science, this method is often used in experiments to test hypotheses and observe the response of a system to various variables. Iterative testing and repetition provide deeper insights into the studied phenomena. In mathematics, trial and error is often used to find numerical solutions or solve problems lacking clear analytical solutions. By experimenting with different values or adopting iteration methods, problem-solving progresses gradually until an accurate solution is achieved (Elstein et al., 2002).

The control of the independent variable, particularly reboiler temperature, is achieved by adjusting the flow of heating oil. This heating oil serves as a supplier of heat to the columns in the alkylation unit. However, reflux flow is regulated by adjusting the valve opening, with the assistance of a pump, to facilitate fluid drainage into Depropanizer Column 1-2.

A trial and error method is applied to the reboiler temperature and reflux flow to optimize depolarizer. The process included maintaining purity at the minimum specification while experimenting with different dependent variables. The collected data was analyzed to identify the configuration that maximizes profit.

The trial was conducted by adjusting the independent variables, namely reboiler temperature and reflux flow in the range of 90 to 95^{o}C and 85 to 95 tons/day with intervals of 0.5^{o}C and 5 tons/day, respectively. The dependent variables considered were product purity, yield, reboiler and condenser loads. Furthermore, strict measures were adopted to ensure the top product purity was maintained at > 99.5% w/w, in accordance with the minimum specifications. The trial test was conducted using Aspen Hysys to generate 121 data, as shown in Figure 5.

The figure shows that the optimum point for Refigerant product yield is situated on the 95^{o}C reboiler temperature graph. This optimal point is achieved at reflux of 90 tons/day, resulting in a specific yield of 5.4592 tons/day. After obtaining the trial data, the optimized revenue value was determined.

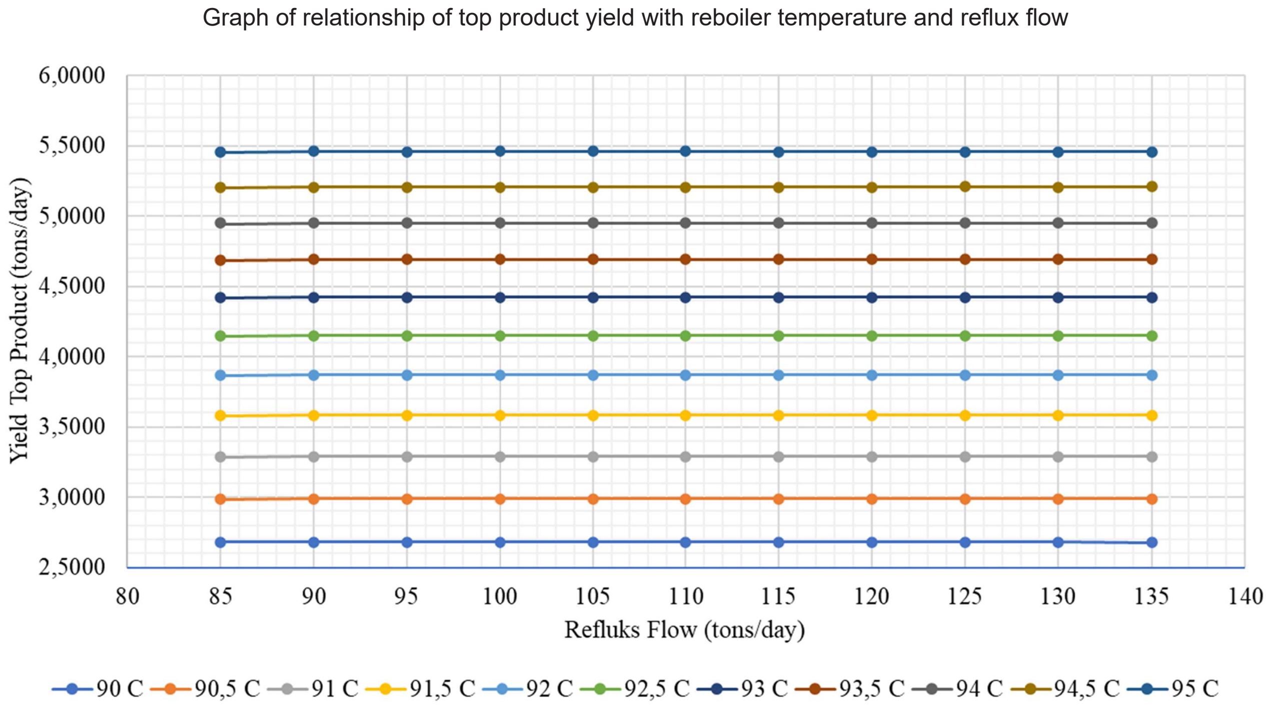

Figure 5
Graph of top yield relationship with reboiler temperature and reflux flow

Determination of optimum point

The process of determining the optimum operational point revolves around identifying the most economical conditions or where the highest revenue is generated. The total income earned by a company (Harnanto, 2019), is the selected metric. This choice was specifically made because Depropanizer Column 1-2, which functioned as an intermediate column, received feed from the preceding unit.

The revenue calculation was carried out using expenditures, feed prices, pump, reboiler, reflux, heating oil, and cooling water expenses. The analyzed loads was challenging due to the factors such as feeds from other units and unknown load prices. In the case of Depropanizer Column 1-2, revenue is mainly generated through the sale of Refrigerant and LPG, the major products manufactured. The purpose of calculating revenue is to support decision making by assessing the efficient use of limited resources and determining the selling value of the product:

Table 7
Product price of depropanizer column 1-2

	Price		
Refrigerat	Rp	160.000	Rp/kg
LPG	Rp	18.750	Rp/kg

From the data obtained, it was observed that the optimum point that produces the highest profit was identified at reboiler temperature and reflux of 95°C and 90 tons/day, respectively. The comparison between actual conditions and optimization results are as follows:

Table 8
Revenue of depropanizer column

Condition	Income		Revenue
	Refrigerant	LPG	Rp/Day
Actual	Rp740.134.656	Rp666.115.470	Rp1.406.250.126
Optimum	Rp873.465.505	Rp650.490.742	Rp1.523.956.247

Condition	Revenue Conversion	
	Rp/year	USD/year
Actual	Rp 513.281.295.990	$34.218.753,07
Optimum	Rp 556.244.030.146	$37.082.935,34

The calculations results, showed that revenue increased from $34,218,753/year to $37,082,935/year. This marked an 8.37% increase in profit compared to pre-optimization period.

Post-optimization operating conditions

The post-optimization operating conditions increased profit, and the smooth operation of the system without any obstacles. The comparison between actual and post-optimization operating conditions is shown in the following table.

Table 9
Comparison of actual and post-optimization column conditions

Condition	Reboiler. Temp °C	Refluks Rate ton/day	Pressure kg/cm²g	Purity %massa
Actual	93,37	100	17,38	99,7
Optimum	95	90	17,38	99,5

Condition	Feed tons/day	Refrigerant Product tons/day	LPG Product tons/day
Actual	40,152	4,6258	35,5262
Optimum	40,152	5,4592	34,6928

Table 10
Operating condition design data

Operating Condition Design Data		
Pressure	15,5 – 19	Kg/cm^2
Reflux rate	85 – 135	Ton/d
Temperature	80 – 140	°C
Feed Flowrate	30 – 120	Ton/d
Top product Flowrate	Min. 2	Ton/d
Bottom product Flowrate	-	Ton/d

The results of actual conditions and optimization showed that reboiler temperature increased from 93.37 °C to 95°C. This signified a greater demand for energy and an increased feed flow evaporating into the top product. In terms of reflux flow, there was a decrease from 100 tons/day to 90 tons/day, depicting less contact between vapor and return flow. In addition, column pressure in actual conditions was maintained in the range of 17 to 17.8 kg/cm^2, ensuring that optimization was in accordance with these criteria. The natural decrease in purity of Refrigerant Product to 99.5% w/w was attributed to the increased bottom temperature of column. The top product yield also increased from 4.6258 tons/day to 5.4592 tons/day or by 18%. Meanwhile, the bottom product decreased from 35.5262 tons/day to 34.6928 tons/day or by 2.3%.

Optimization data was compared with the designed data in accordance with the design criteria. The operating conditions in the design data were smoothly conducted without presenting any obstacles that could endanger the equipment, operators, and the environment. Additionally, the manufactured products met the stipulated specifications. In the assessment of actual, design, and post-optimization conditions, the operating attributes were reviewed based on the following points:

Percent recovery of top product from depropanizer column

Table 11
C3 Mix post-optimization

Tons/h	Feed	*Top Product*	*Bottom Product*
Propana	0,2360	0,2354	0,0098
Propena	0,00195	0,0011	0

$$\% = \frac{(0{,}2354+0{,}0011)\frac{ton}{h}}{(0{,}2360+0{,}00195)\frac{ton}{h}} \times 100\% \quad (5)$$

$$\% = 99{,}39\ \%$$

The percent recovery before actual conditions was 95.5% and when compared to the post-optimization of 99.39%, the light component increased by 3.89%. This outcome showed a decrease in the presence of light components in the bottom product, which contributed to an increased yield of the top product.Figure 6 shows the two phenomena that occur in the column with the aid of Aspen Hysys. Firstly, weeping, an event where insufficient vapor pressure leads to liquid dripping from tray holes. Secondly, flooding, a condition resulting from over pressure that locks liquid, preventing the descent to the tray underneath. The results of the simulation confirm the absence of weeping or flooding on each tray, as all operating points fall in weeping and flooding boundaries. In addition, the comparison of operating points in pre- and post-optimization showed better results, with post-optimization points positioned farther away from flooding and weeping lines. The column operated optimally without operational issues in the post-optimization condition, which led to better satisfactory.

Weeping and Flooding

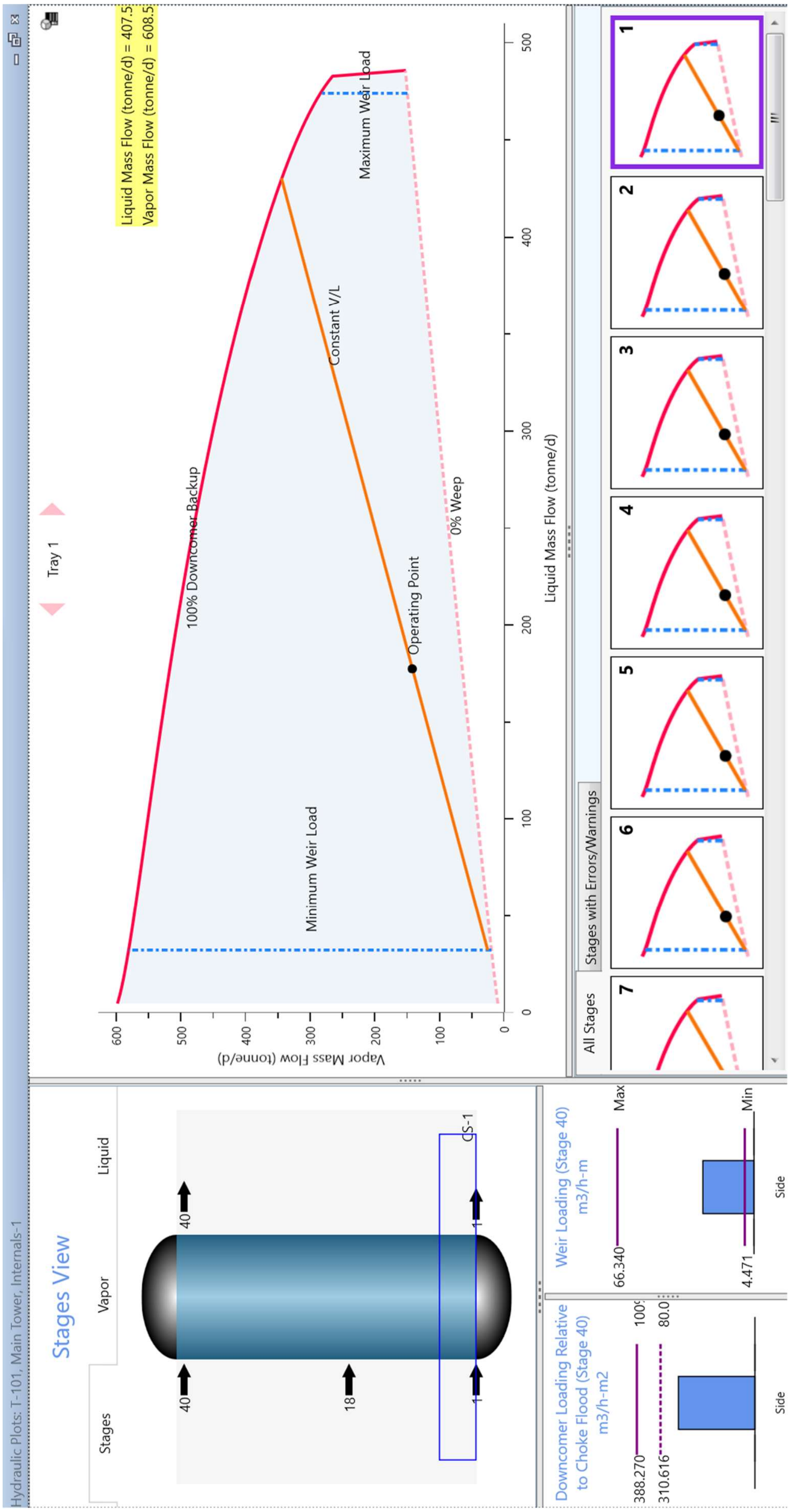

Figure 6
Operating conditions post optimization of depropanizer column 1-2

CONCLUSION

The following conclusions were obtained from the research.

The quality and quantity of the top product yield was influenced by factors such as reflux flow and reboiler temperature, respectively.

The overall tray efficiency performance analysis was 69%, classifying the column as being in good condition. The column successfully recovered 95.5% of the light component. The top product namely Refrigerant had purity of 99.7% w/w, which met the stipulated specifications. Through Aspen Hysys simulation, it was observed that under actual conditions, there was no flooding and weeping, ensuring the proper operation of the column.

Based on trial and error, 121 data were obtained. In optimization calculation conducted, it was found that the most optimal point was achieved at reboiler temperature and reflux flow of 95^{o}C, and 90 tons/day, respectively.

Post-optimization process, the top product yield rose from 4.6258 tons/day to 5.4592 tons/day, equivalent to 18% increase. The bottom product decreased from 35.5262 tons/day to 34.6928 tons/day, which is a 2.3% reduction.

Following revenue optimization calculations, the profit increased from $34,218,753/year to $37,082,935/year, reflecting an 8.37% increment compared to pre-optimization period.

After Aspen Hysys simulation optimization, the operating conditions ran smoothly without issues of weeping and flooding. The recovery of lightweight components improved significantly to 99.39%, compared to the initial 95.5%.

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GLOSSARY OF TERMS

Symbol	Definition
Weeping	The formation of small droplets of liquid on the walls of the column or condenser during the distillation process.
Flooding	When the relative flow rates of the vapor and liquid are such that the drag force is greater than or equal to the gravity force; then, the liquid stops flowing down the column.

REFERENCES

Christie, J. Geankoplis, (1983). "Transport Process and Unit Operation", PTR Prentice- Hall Inc, Englewood Cliffs, New Jersey.

Data Bridge. (2022). World Refrigerant Consumption Trend 2022 - 2029 (Data Bridge Market Research Market Analyses Study 2022). Online at https://www.databridgemarketresearch.com/reports/global-refrigerant-market.

Elstein, A. S., & Schwarz, A. (2002). Trial and Error in Diagnostic Reasoning", Academic Medicine.

Export Genius. (2022). Refrigerant Import Data of Indonesia | Refrigerant Importers. Online at https://www.indonesianimporter.com/indonesia-import-data/refrigerant.html.

Harmita, (2004). Petunjuk Pelaksanaan Validasi Metode dan Cara Perhitungannya, didalam: Majalah Ilmu Kefarmasian, Desember. Vol. 1, No.3, pp. 117 – 135. Jakarta: Departemen Farmasi FMIPA-UI.

Harnanto. (2019). Dasar-Dasar Akuntansi. Yogyakarta: ANDI.

Kilicarslan, Ali & Norbert Muller. (2005). A Comparative Study of Water as a Refrigerant with Some Current Refrigerants, INTERNATIONAL JOURNAL OF ENERGY RESEARCH, Int. J. Energy Res. 2005; 29:947– 959, Published online 18 July 2005 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/er.1084.

Rossen Donev. (2017). "Purity and Impurity in Proteins" Weansea Univerity

S. R.K., Chemical Engineering Volume. 6 Unit Operations, London: Pergamon Press, (1989).

Weight, Stephen J. (2020). Optimization | Definition, Techniques, & Facts | Britannica. University of Wisconsin.