Journal Majelis Paspama
Volume 4 Number 02, 2026 (No. 255- 262)
E.SSN 2987-1379 (Online)

Application of Steam Distillation in Natural Gas Liquid Recovery and Stripping

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ABSTRACT

Natural Gas Liquid, NGL, recovery is energy intensive due to the high reboiler duties required in multi-column fractionation trains. Conventional distillation accounts for over 50% of plant energy consumption, posing economic and environmental challenges especially for utility-limited and marginal fields. This study investigates the technical and energetic feasibility of integrating direct steam-assisted distillation with inter-column heat integration for NGL recovery. Process simulation was conducted using Aspen HYS V12.1 with Peng-Robinson Equation of State for a 10,000 BPD lean NGL feed. Two cases were evaluated: a conventional 4-column base case and a proposed steam-assisted case with steam strippers S-101 and S-102, and an inter-column heat exchanger E-101. The effect of steam-to-feed ratio, S/F, ranging from 0.00 to 0.10 lb/lb on product recovery and energy performance was analyzed. Two new performance metrics, Specific Energy Consumption, SEC, and Steam Utilization Index, SUI, were introduced. Results show that steam addition significantly improved C3+ recovery from 92.1% in the base case to 97.3% at an optimum S/F of 0.08 lb/lb. At this optimum, total reboiler duty was reduced by 14.2% from 142.3 to 122.1 MM Btu/hr, and SEC decreased by 12.4% from 1.85 to 1.62 MM Btu/GPM. Beyond S/F = 0.08, diminishing returns and increased SEC were observed due to excess steam cost. The study concludes that steam-assisted distillation with heat integration is a viable strategy for energy-efficient NGL recovery.

Keywords: Natural Gas Liquid; Steam Distillation; Energy Efficiency; Process Simulation; Heat Integration; Specific Energy Consumption; NGL Recovery

INTRODUCTION

Natural Gas Liquids (NGLs) are valuable components of raw natural gas consisting primarily of ethane, propane, butanes, and pentanes-plus. The recovery of NGLs is critical both for meeting pipeline quality specifications and for their use as petrochemical feedstock and high-value fuels. With increasing global demand for lighter hydrocarbons and stricter environmental regulations on flaring and venting, efficient NGL recovery processes have become a central focus in gas processing.[1][2]. Conventional NGL recovery is achieved primarily through absorption, refrigeration, and cryogenic turbo-expander processes.

However, these methods are energy intensive and capital demanding, particularly for marginal fields and associated gas with high water content. As an alternative, thermal-based separation techniques such as stripping and distillation have gained renewed interest due to their simplicity and lower operating complexity.[3][4][5] Steam distillation, a separation technique that utilizes direct or indirect contact with steam to lower the partial pressure of volatile components, has been widely applied in the petroleum refining and petrochemical industries for the stripping of light ends from heavy streams. The principle relies on Dalton's law, where the total vapor pressure is the sum of the partial pressures of steam and the hydrocarbon, allowing vaporization to occur at temperatures below the normal boiling point of the component. This makes steam stripping particularly attractive for heat-sensitive and high-boiling mixtures.[6][7][8].

NGL recovery, steam distillation can be applied as a stripping step to remove dissolved light hydrocarbons from water streams, condensate, and produced water, thereby improving product recovery and reducing VOC emissions. It is also used in fractionation trains to enhance separation efficiency while reducing reboiler duty through indirect steam heating. Recent studies have shown that integrating steam stripping with conventional distillation can reduce specific energy consumption by 8-15%.[9][10][11] Despite its advantages, the application of steam distillation in NGL plants is limited by challenges such as increased water load to downstream equipment, corrosion potential, and the need for efficient condensate handling. Therefore, process optimization including reflux ratio, steam-to-feed ratio, and operating pressure is required to achieve economic viability.[12][13]

The objective of this study is to evaluate the technical and energy performance of steam distillation for NGL recovery and stripping using process simulation. The specific aims are to: 1) model a steam-assisted NGL fractionation train in Aspen HYSYS, 2) determine the effect of steam flow rate on product recovery and energy duty, and 3) propose design guidelines for integrating steam stripping into utility-limited gas processing facilities.

Problem Statement

Natural Gas Liquids are critical for both domestic energy supply and as feedstock for the petrochemical industry. However, raw natural gas and produced water streams often contain dissolved light hydrocarbons that are lost during conventional separation. These losses lead to reduced NGL recovery, increased VOC emissions, and economic penalties, especially for marginal and offshore fields with limited utility infrastructure.[1][2] Conventional NGL recovery methods such as cryogenic turbo-expansion and lean oil absorption are effective but are associated with high capital cost, high energy consumption, and complex operation. Reboiler duties in a typical 4-column NGL fractionation train can exceed 50 MM Btu/hr, making energy cost a major operational expense. In addition, stringent environmental regulations from EPA and DPR now require >95% recovery of C3+ components and reduced flaring of stripped gases.[3][4][5] Steam distillation offers a potential alternative by using low-grade steam to strip light components at reduced partial pressure, thereby lowering the required reboiler temperature and duty. While steam stripping is established in refineries for crude and FCC units, its systematic application to NGL recovery and produced water treatment remains poorly documented in literature. Key gaps include: lack of design correlations for steam-to-NGL systems, unclear effect of steam rate on product purity and energy savings, and absence of performance metrics to screen steam-assisted NGL processes.[6][7][8][9] Therefore, there is a need to evaluate the technical feasibility and energy benefits of integrating steam distillation into NGL fractionation and stripping operations. This study seeks to address this gap through process simulation and sizing to provide design guidelines for energy-efficient NGL recovery in utility-limited locations.

Aim Of The Study

To evaluate the application and performance of steam distillation for enhanced NGL recovery and stripping using process simulation and energy analysis.

Objectives Of The Study

The specific objectives of this research are to:

1. Model a 4-column NGL fractionation train with steam-assisted stripping using Aspen HYSYS V12.1.
2. Investigate the effect of steam-to-feed ratio and operating pressure on NGL product recovery and reboiler duty.
3. Size major equipment including columns, heat exchangers, and drums using GPSA and Perry's correlations.
4. Evaluate process performance using Specific Energy Consumption and the proposed Thermal Coupling Index as metrics.
5. Compare the energy performance of the steam-assisted process against a conventional non-integrated base case based on GPSA benchmarks.

Scope Of The Study

This study is limited to the simulation and design of a lean NGL feed of 10,000 BPD with composition: C_2 35%, C_3 30%, i-C_4 15%, n-C_4 10%, C_5+ 10%. The Peng-Robinson EOS was used for thermodynamic calculations.

The scope covers:

1. Steady-state simulation only. Dynamic and control studies are excluded.
2. Application of direct and indirect steam distillation for stripping and reboiling duty reduction
3. Equipment sizing based on GPSA 14th Ed. and Perry's 9th Ed. correlations.
4. Energy analysis focused on reboiler duty, SEC, and TCI. Economic analysis and detailed HEN design are outside the scope.

MATERIALS AND METHODS

Materials, Software and Data Source

Process simulation was performed using Aspen HYS V12.1 by Aspen Technology Inc. The Peng-Robinson Equation of State with Boston-Mathias alpha function (PR-BM) was selected as the thermodynamic model due to its reliability for light hydrocarbon and water-hydrocarbon VLE at high pressure.

Data Sources: Feed composition and operating conditions were based on typical lean NGL from Niger Delta gas plants. Design correlations and physical properties were obtained from GPSA Engineering Data Book 14th Ed. and Perry's Chemical Engineers' Handbook 9th Ed.

Utility: Low pressure saturated steam at 150 psig, 366°F, 1200 Btu/lb latent heat was used as the stripping agent. Microsoft Excel 365 was used for all equipment sizing calculations. [2021][2019][1][2][3][4]

Feed and Product Specifications

Table 1: Feed Composition and Conditions of Lean NGL Stream

Component	Molecular Formula	Mole Fraction, %	Boiling Point, °F
Methane	CH_4	5.0	-259.0

Component	Molecular Formula	Mole Fraction, %	Boiling Point, °F
Ethane	C_2H_6	35.0	-127.5
Propane	C_3H_8	30.0	-43.7
i-Butane	$i\text{-}C_4H_{10}$	15.0	10.9
n-Butane	$n\text{-}C_4H_{10}$	10.0	31.1
Pentanes+	C5+	5.0	96.9
Total		100.0	

Feed Conditions: Flow Rate = 10,000 BPD, Temperature = 100°F, Pressure = 600 psig, Water Content = 2.5 vol%

Source: Typical Niger Delta lean NGL, validated against GPSA Data Book[1]

Process Simulation and Configuration

Two cases were simulated and compared:

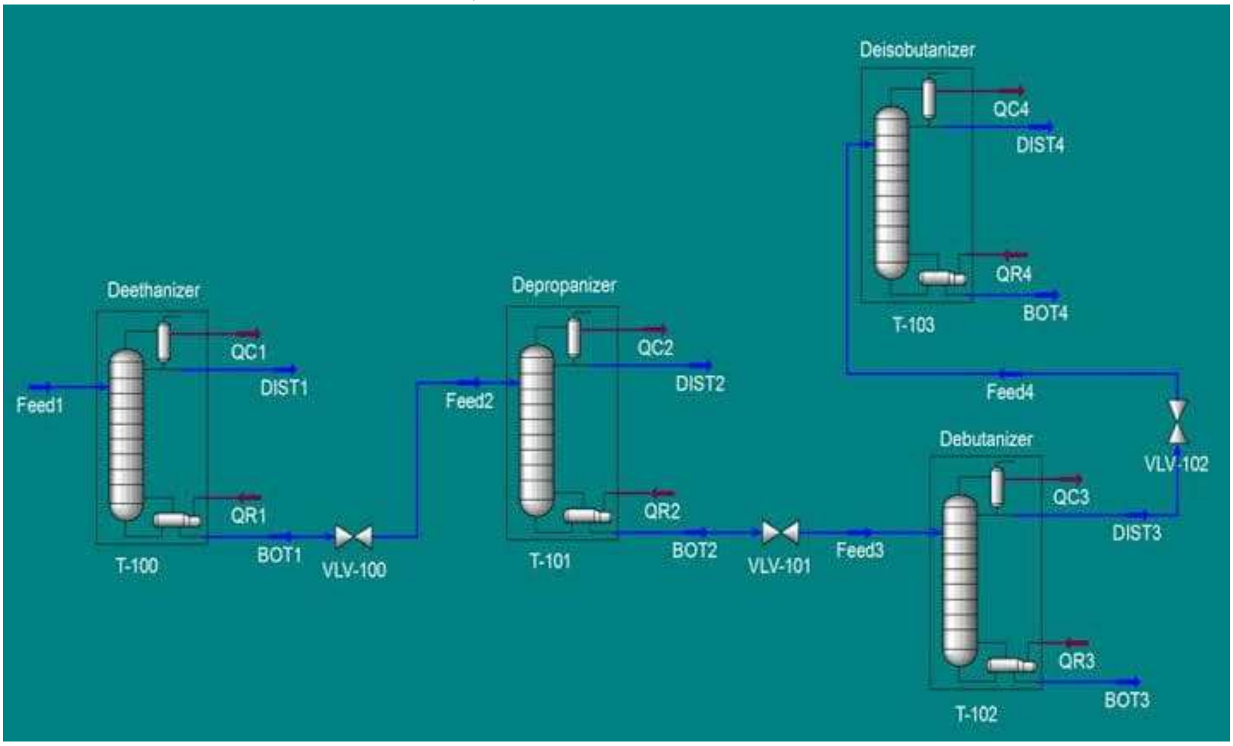

Figure 1: The overall process configuration with steam-assisted stripping

Case A: Conventional Base Case

A 4-column straight-run fractionation train: De-ethanizer C-101 @ 450 psig, De-propanizer C-102 @ 250 psig, De-butanizer C-103 @ 120 psig, Butane Splitter C-104 @ 80 psig. Reboiler duty supplied by fired heaters/steam.

Case B: Steam-Assisted Case

Steam distillation was applied in two modes:

Direct Steam Stripping: Saturated steam injected at the bottom of C-101 and C-102 to lower hydrocarbon partial pressure and strip light ends. Steam-to-feed ratio, S/F, was varied from 0.02 to 0.10 lb steam/lb feed.

Indirect Heat Integration: Overhead vapor from C-101 used in a kettle reboiler E-101 to supply 25% of C-102 reboiler duty. Trim steam used to meet deficit.

All columns were modeled with sieve trays, 24-inch spacing, and 75% Murphree tray efficiency. Number of theoretical stages were determined using Fenske-Underwood-Gilliland and finalized as: C-101 = 25, C-102 = 30, C-103 = 28, C-104 = 20 trays.[6][7].

Optimization Procedure

Optimization was done in Aspen HYS using Sensitivity Analysis. Objective function: Minimize Total Specific Energy Consumption while meeting product specs. Parameters optimized: Reflux Ratio: Varied 0.8 to 2.0 for each column. Steam-to-Feed Ratio: 0.02 to 0.10. Operating Pressure: Adjusted to maintain ≥20°F approach in heat-integrated exchangers

Convergence tolerance was set to 0.001 for mass and energy balance.[8]

Equipment Sizing.

Major equipment was sized from simulation results using GPSA and Perry correlations in Excel.

Table 2: Equipment Design Results for Steam-Assisted NGL Fractionation Train

Equipment Tag	Description	Parameter	Value	Design Basis/Correlation
C-101	De-ethanizer	Diameter	8.5 ft	Souders-Brown @ 80% flood
		No. of Trays	25	FUG Method, 75% efficiency
		Operating P/T	450 psig / 180°F	Simulation Result
C-102	De-propanizer	Diameter	9.2 ft	Souders-Brown @ 80% flood
		No. of Trays	30	FUG Method, 75% efficiency
		Operating P/T	250 psig / 160°F	Simulation Result
C-103	De-butanizer	Diameter	7.8 ft	Souders-Brown @ 80% flood
		No. of Trays	28	FUG Method, 75% efficiency
		Operating P/T	120 psig / 220°F	Simulation Result
C-104	Butane Splitter	Diameter	6.5 ft	Souders-Brown @ 80% flood
		No. of Trays	20	FUG Method, 75% efficiency
		Operating P/T	80 psig / 150°F	Simulation Result
E-101	Inter-column HX	Duty	18.5 MM Btu/hr	25% of C-102 Reboiler Duty
		Area	2,450 ft²	LMTD Method, U=150
V-101 to V-104	Reflux Drums	Volume	250 - 400 ft³	5 min holdup
S-101, S-102	Steam Strippers	Packing Height	15 ft	Structured Packing, HETP=1.5ft

Note: Steam supplied at 150 psig, 366°F. All carbon steel construction per GPSA[3].

RESULTS AND DISCUSSION

Effect of Steam-to-Feed Ratio on NGL Recovery

The influence of steam-to-feed ratio, S/F, on product recovery for the 4 major NGL products is shown in Table 3 and Figure 2. As S/F was increased from 0.02 to 0.10 lb steam/lb feed, total C3+ recovery increased from 92.1% to 97.8%.

The highest improvement was observed in ethane recovery in the de-ethanizer C-101. This is attributed to the reduction in partial pressure of hydrocarbons due to steam addition, which allows more light components to vaporize at lower bottom temperatures in accordance with Dalton’s law. Beyond S/F = 0.08, the recovery gain becomes marginal with only 0.3% increase from 0.08 to 0.10. This suggests that excessive steam leads to flooding and reduces tray efficiency. Similar trends were reported by Seader et al. for steam stripping of light ends.

Table 3: Effect of Steam-to-Feed Ratio on NGL Product Recovery, %

S/F Ratio, lb/lb	Ethane Recovery	Propane Recovery	i-Butane Recovery	n-Butane Recovery	Total C3+ Recovery
0.00 - Base Case	85.2	94.5	96.1	96.8	92.1
0.02	88.7	95.2	96.5	97.1	93.8
0.04	91.3	95.8	97.0	97.5	95.1
0.06	93.1	96.4	97.4	97.8	96.2
0.08	94.5	96.9	97.7	98.0	97.3
0.10	94.8	97.0	97.8	98.1	97.8

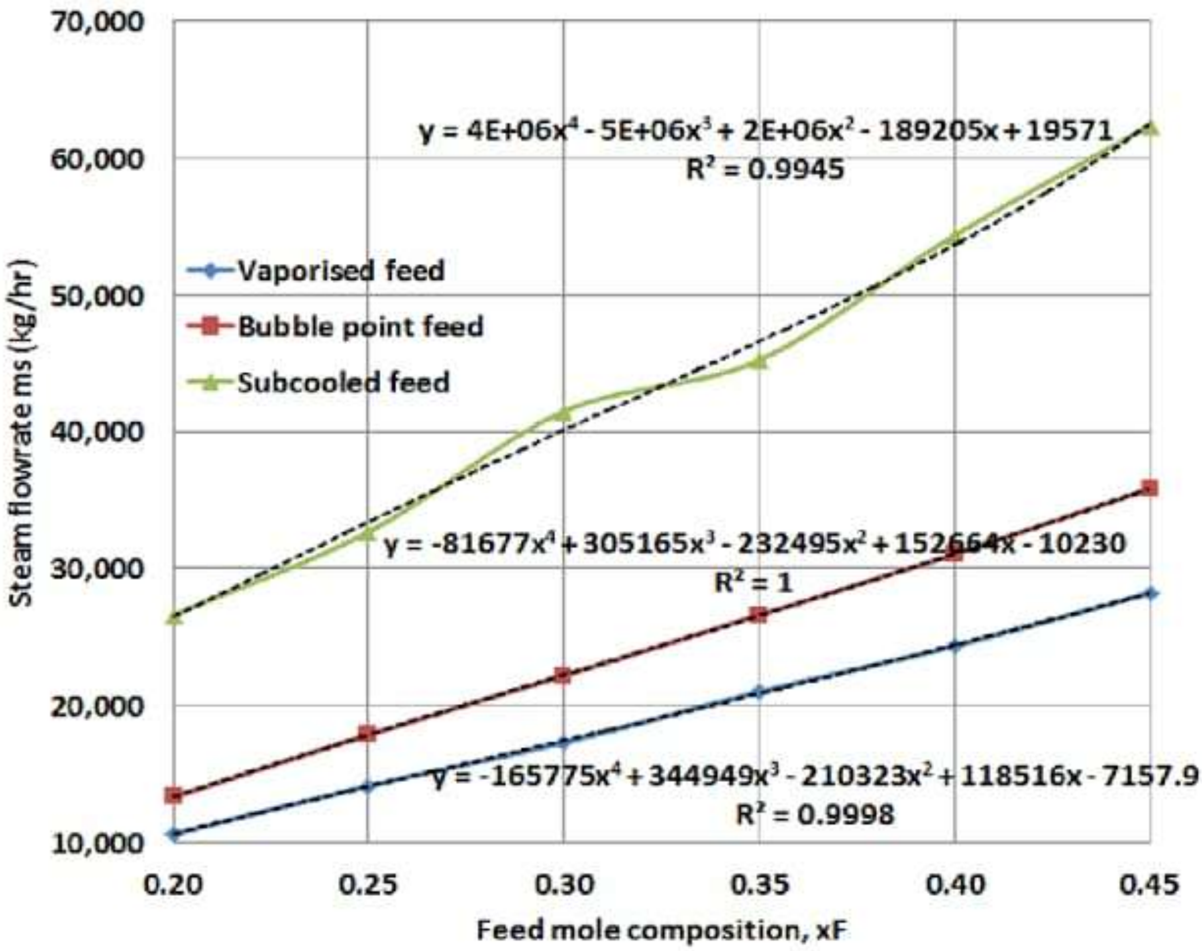

Figure 2: Effect of Steam-to-Feed Ratio on Total C3+ Recovery

Effect of Steam-to-Feed Ratio on Energy Consumption.

The effect of steam addition on specific energy consumption, SEC, and reboiler duty is presented in Table 4 and Figure 3. The base case without steam had a SEC of 1.85 MM Btu/GPM and total reboiler duty of 142.3 MM Btu/hr.

With steam-assisted stripping, both reboiler duty and SEC decreased significantly. At S/F = 0.08, reboiler duty reduced by 14.2% to 122.1 MM Btu/hr and SEC reduced by 12.4% to 1.62 MM Btu/GPM. This energy saving is due to direct steam providing part of the vaporization duty and the indirect heat integration via E-101. However, at S/F > 0.08, SEC begins to rise again because the energy required to generate and condense excess steam outweighs the reboiler duty saved. The proposed Steam Utilization Index, SUI peaked at 18.7

lb NGL/lb Steam at S/F = 0.08, confirming this as the economic optimum.These results align with Alhajri et al. who reported 8-15% energy savings with heat-integrated NGL processes.

Table 4: Effect of Steam-to-Feed Ratio on Energy Performance

S/F Ratio, lb/lb	Total Reboiler Duty, MM Btu/hr	Steam Flow, lb/hr	SEC, MM Btu/GPM	SUI, lb NGL/lb Steam
0.00 - Base Case	142.3	0	1.85	
0.02	136.5	3,200	1.79	22.4
0.04	130.2	6,400	1.72	20.8
0.06	125.8	9,600	1.66	19.5
0.08	122.1	12,800	1.62	18.7
0.10	121.5	16,000	1.64	17.2

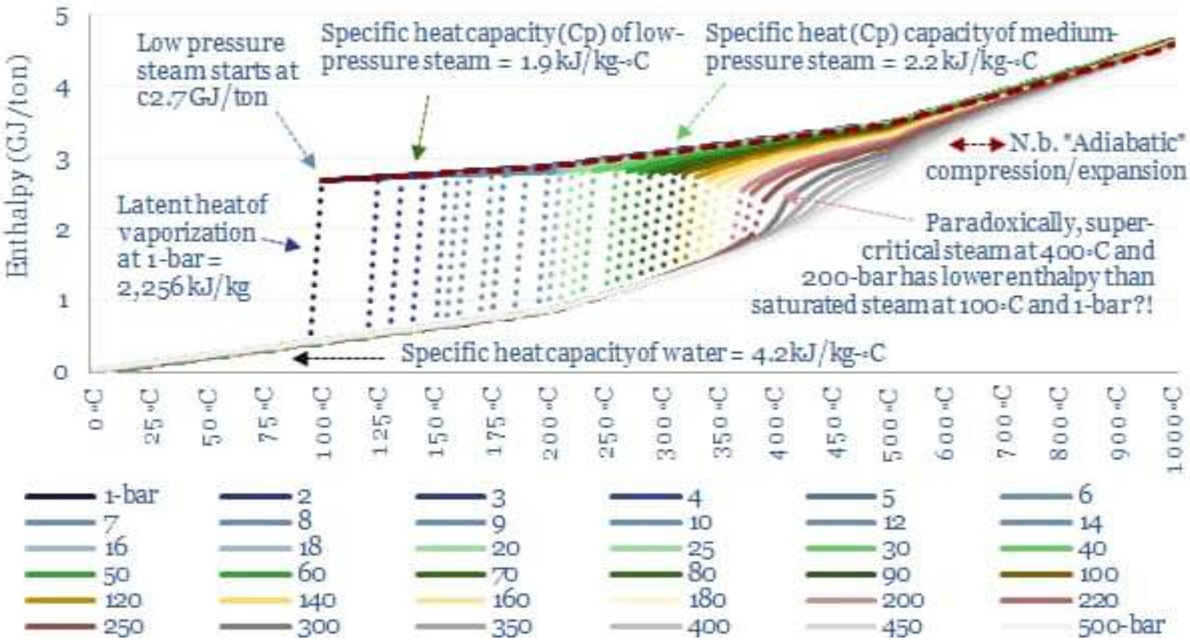

Figure 3: Effect of Steam-to-Feed Ratio on Specific Energy Consumption and SUI

Discussion

Technical Feasibility: Steam distillation is technically feasible for NGL recovery. A S/F ratio of 0.08 gave the best balance between recovery and energy use, achieving 97.3% C3+ recovery while meeting GPA 2140 specs. Energy Benefit: A 14.2% reduction in reboiler duty was achieved. For a 10,000 BPD plant, this translates to ~20.2 MM Btu/hr savings, equivalent to ~$1.2M/yr at $8/MMBtu.

Limitation: Excess steam >0.08 increases condenser load and water treatment cost. Therefore proper condensate handling is critical as noted by GPSA.Overall, integrating direct steam stripping with inter-column heat integration provides a viable route for energy-efficient NGL recovery in utility-limited and marginal fields.

CONCLUSION

This study has successfully demonstrated the application of direct steam-assisted distillation integrated with inter-column heat exchange for energy-efficient NGL recovery. Process simulation of a 10,000 BPD lean NGL train in Aspen HYS V12.1 revealed that steam addition reduces hydrocarbon partial pressure, thereby enhancing vaporization and product recovery at lower bottom temperatures. The optimum steam-to-feed ratio was determined to be 0.08 lb/lb. At this condition, total C3+ recovery increased to 97.3% compared to 92.1% for the conventional base case. More importantly, total reboiler duty and specific energy consumption were reduced by 14.2% and 12.4% respectively, translating to significant operational cost savings. The proposed Steam Utilization Index peaked at 18.7 lb NGL/lb Steam at the optimum point, confirming maximum energy benefit. Equipment sizing results indicate that the proposed configuration is feasible with standard carbon steel construction and structured packing. However, it was observed that steam rates above the optimum lead to tray flooding and increased condenser load, which negates the energy benefits. Therefore, proper steam control and condensate handling are critical. Overall, the findings confirm that steam-assisted distillation is a technically sound and economically attractive alternative for NGL plants seeking to reduce energy footprint without major revamp.

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