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Efficient Propane-Ethane Fractionation within Petrochemical Plant Operations

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ABSTRACT

Efficient propane-ethane fractionation is crucial in petrochemical complexes, enabling the production of high-purity products. This paper focuses on the treatment of ethane-propane mixtures recovered from natural gas, highlighting the interplay between key units: Gas Sweetening Unit (GSU), C2/C3 Recovery Unit, and Gas Cracker Unit (GCU). In the GSU, acid gases like CO2 are removed via chemical absorption using solvents like DEA, preventing freezing issues in downstream cryogenic processes. The 'sweetened' gas feeds into the C2/C3 Recovery Unit, where cryogenic conditions enable efficient ethane-propane separation. Optimizing fractionation in this unit enhances GCU performance, boosting ethylene and propylene yields. Process integration and energy efficiency are critical considerations. This study explores efficient propane-ethane fractionation strategies, aiming to improve overall petrochemical complex performance. Key aspects of this process include effective CO2 removal in the GSU, ensuring process reliability. Cryogenic separation in the C2/C3 Recovery Unit enables high-purity product recovery. The impact on GCU performance is significant, as efficient fractionation boosts downstream yields. Energy-efficient fractionation strategies are also crucial for reducing operating costs and environmental impact. By optimizing these aspects, petrochemical complexes can improve product yields, reduce energy consumption, and enhance overall efficiency. This research contributes to the development of efficient propane-ethane fractionation technologies, supporting the growth of the petrochemical industry.

Keywords:
C2/C3 ,Recovery, GCU,Units, Petrochemical,Gas.

INTRODUCTION

Propane-ethane fractionation is a crucial process in petrochemical plant operations, involving the separation of propane and ethane, key components of natural gas liquids (NGLs). This separation is essential for producing high-purity ethylene and propylene, vital feedstocks for various petrochemical products, such as plastics, chemicals, and fuels. The efficiency of this process significantly impacts the overall sustainability, safety, and profitability of petrochemical operations. This research focuses on efficient propane-ethane fractionation, exploring strategies to optimize separation processes, reduce energy consumption, and enhance product quality within petrochemical plant operations. Petrochemicals, derived from petroleum, are increasingly needed in daily life and industry, necessitating optimized production. Key petrochemicals include ethylene, propylene, butadiene, benzene, toluene, and xylenes. Benzene is used for dyes and detergents, while benzene and toluene are used for isocyanates. Synthesis gas produces ammonia and methanol, used for fertilizers and as solvents. Xylenes produce plastics and fibers. Petrochemical complexes recover ethane-propane (C2\C3) from natural gas, adding value by converting it into petrochemicals via Gas Processing Unit (GPU) and Gas Cracker Unit (GCU). Ethylene produces HDPE and LLDPE in polymer units. Propane-ethane fractionation is a critical process in petrochemical plants, producing high-purity products essential for various industrial applications. Researchers have explored various aspects of this process, including simulation and optimization (Abdulrahman & Zangana, 2021), which showed a 15% reduction in energy consumption. Process intensification (Al-Mutairi & El-Halwagi, 2010) achieved a 20% increase in separation efficiency. Integration with natural gas condensate recovery (Sun et al., 2023) improved overall process efficiency by 12%. Studies have also focused on multi-objective optimization (Salas et al., 2021), exergy analysis (Khajehpour et al., 2021), which identified a 10% potential energy savings, and the impact of natural gas composition on demethanizer design (Luyben, 2013). Industry guidelines and best practices for gas handling and processing have been documented by experts like Arnold & Stewart (1999) and Manning & Thompson (1991). This paper aims to contribute to the ongoing efforts to improve propane-ethane fractionation efficiency.

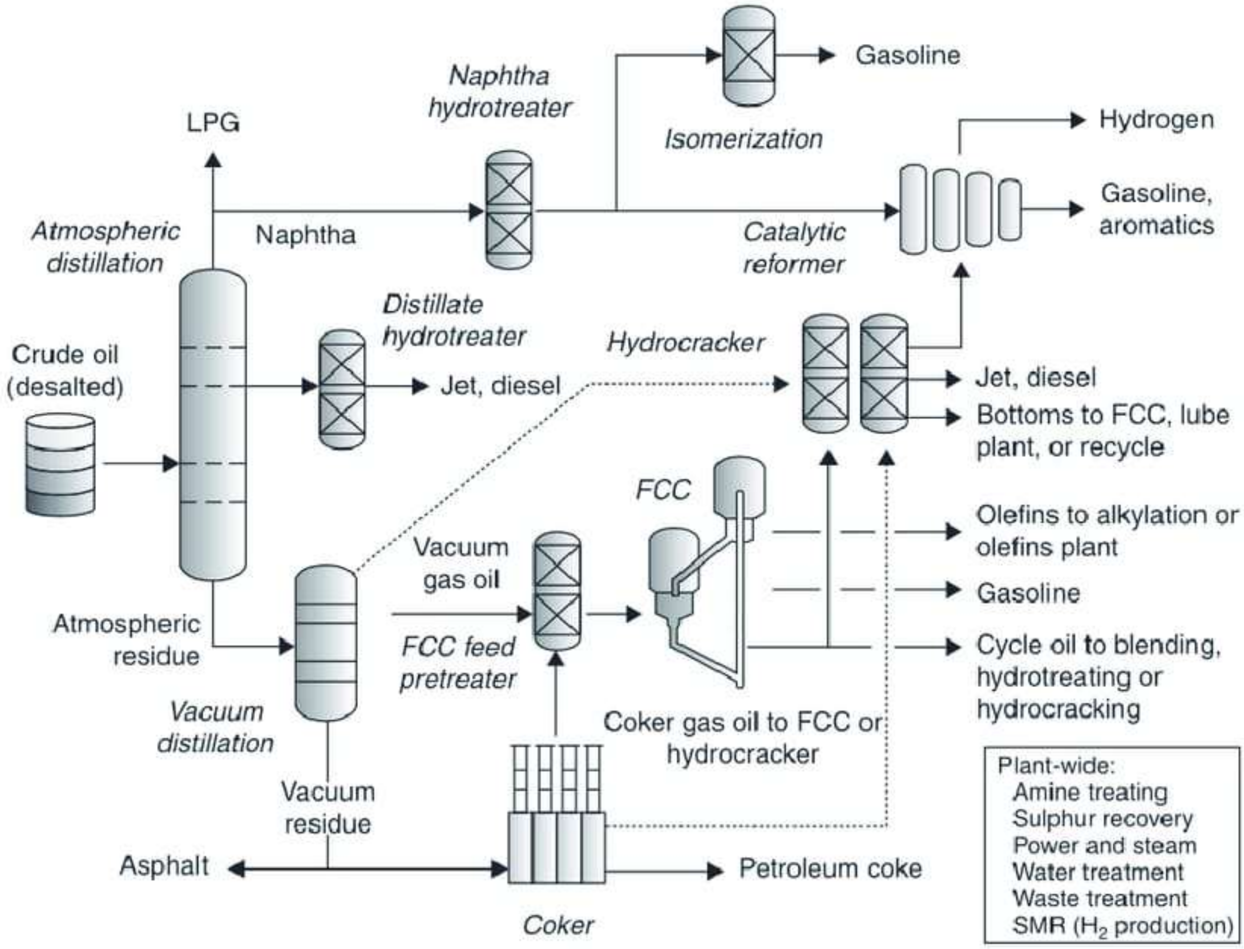

Figure 1: Petroleum Plant Layout

MAIN PRODUCTS
LLDPE\HDPE

Products	End Use
Propylene	Feedstock poly propylene
Spent alumina	Refractories
Furnace Oil	Fuels
C4 Mix	Lube oil antioxidant
Pyrolysis gasoline	Fuels,blended gasoline
Butene-1	Copolymer for LLDPE
C5 and gasoline mix	Fuels, SBP Solvent

Process Stages

Gas Processing Unit (GPU) Operations

For Efficient Propane-Ethane Fractionation, a general model equation could involve optimizing the separation process using parameters like reflux ratio, feed composition, and column pressure. A simplified equation for propane-ethane separation efficiency (E) could be:

$$E = f(R, x\_F, P, T)$$

where:
E = separation efficiency
R = reflux ratio
x_F = feed composition (ethane/propane ratio)
P = column pressure
T = temperature

Within the Gas Processing Unit (GPU), two critical components support Efficient Propane-Ethane Fractionation:

1. Gas Sweetening Unit (GSU)
2. C2/C3 Recovery Unit

In the Gas Sweetening Unit (GSU), CO_2 is removed from the feed gas using Diethanolamine (DEA) as a solvent, preventing freezing in downstream cryogenic processes. This "sweetening" process removes acid gases (H_2S and CO_2), preparing the gas for the C2/C3 Recovery Unit, where efficient propane-ethane fractionation occurs under cryogenic conditions, optimizing ethane and propane recovery for further processing

PROCESS DESCRIPTION

Absorption Process:

In the Absorption Section, raw gas (52 kg/cm²a, 30°C) enters two parallel high-pressure Absorbers, where it's counter-currently contacted with 40 wt% DEA solvent on 30 Valve Trays, removing H_2S and CO_2, and enabling efficient propane-ethane fractionation in downstream C2/C3 Recovery Unit processes.

n the Gas Sweetening Unit, CO_2 in the feed gas reacts with DEA (R2NH) to form amine carbonate (R2NCOO- + R2NH2+), while a secondary reaction with water forms bicarbonate ions. Efficient removal of CO_2 via these reactions enables effective propane-ethane fractionation in the C2/C3 Recovery Unit, preventing CO_2 freezing issues in cryogenic processes.

$CO_2 + 2R_2NH \rightarrow R_2NCOO^- + R_2NH_2^+$

$CO_2 + H_2O \rightarrow HCO_3^- + H^+$

These acids (HCO_3^- and H^+) react with DEA (R_2NH) to form amine bicarbonate, further removing CO_2 and enabling efficient propane-ethane fractionation in the C2/C3 Recovery Unit.

$HCO_3^- + R_2NH \rightarrow R_2NH_2^+ + CO_3^{2-}$

$R_2NH + H^+ + HCO_3^- \rightarrow R_2NH_2^+ + HCO_3^-$

The treated gas exits the Absorber column top at 45°C, with CO_2 levels reduced to <50 ppmv, meeting specifications for the C2/C3 Recovery Unit, where efficient propane-ethane fractionation occurs under cryogenic conditions, optimizing ethane and propane recover

Treated Gas Scrubbing and Cooling

In the Water Wash Column, treated gas from the Absorber is scrubbed with water to remove entrained DEA, utilizing pall rings for efficient contact. The DEA-rich water is sent to the Rich Amine Flash Drum. The gas, now cooled to 40°C, exits the unit at 50 kg/cm²a, ready for C2/C3 Recovery Unit processing, supporting efficient propane-ethane fractionation

RICH AMINE CIRCUIT

In the Rich Amine Circuit, rich DEA solution from the Absorber and Water Wash Column is flashed in the Rich Amine Flash Drum (6.5 kg/cm²a, 70°C), desorbing co-absorbed hydrocarbons, which are routed to fuel gas, preparing the amine for regeneration and supporting efficient propane-ethane fractionation in the C2/C3 Recovery Unit

AMINE REGENERATION

The rich amine solution is heated, stripping acid gases (H_2S and CO_2) in the Regenerator, producing lean amine for reuse and an acid gas stream for further processing, supporting efficient propane-ethane fractionation, Lean amine (~126°C) is cooled to 45°C via Rich/Lean Amine Exchanger and cooling water, then sent to storage. Regenerator overhead vapors are condensed, with CO_2 (acid gas) vented safely and condensate refluxed back to the column, supporting efficient propane-ethane fractionation in the C2/C3 Recovery Unit by removing CO_2.

AMINE FILTRATION

Amine filtration removes impurities (hydrocarbons, corrosion products, degradation products) from stored DEA solution using:

- Activated Carbon Filter (corrosion products, hydrocarbons)
- Cartridge Filter (carbon particles)
- Pre-coat Filter (cellulose)

This maintains amine quality, preventing corrosion and foaming, supporting efficient propane-ethane fractionation in the C2/C3 Recovery Unit.

LEAN AMINE

Lean amine from the Regenerator is stored in the Amine Storage Tank, blanketed with N_2 to prevent oxidation and degradation. From here, it's pumped back to Absorbers, maintaining amine quality for efficient CO_2 removal and supporting propane-ethane fractionation in the C2/C3 Recovery Unit.

AMINE DRAINAGE COLLECTION

Amine drainage is collected in the underground Amine Sump Drum, where solvents are recovered and recycled to the Solvent Circuit via a submerged pump, minimizing losses and maintaining amine inventory for efficient CO_2 removal, supporting propane-ethane fractionation in the C2/C3 Recovery Unit.

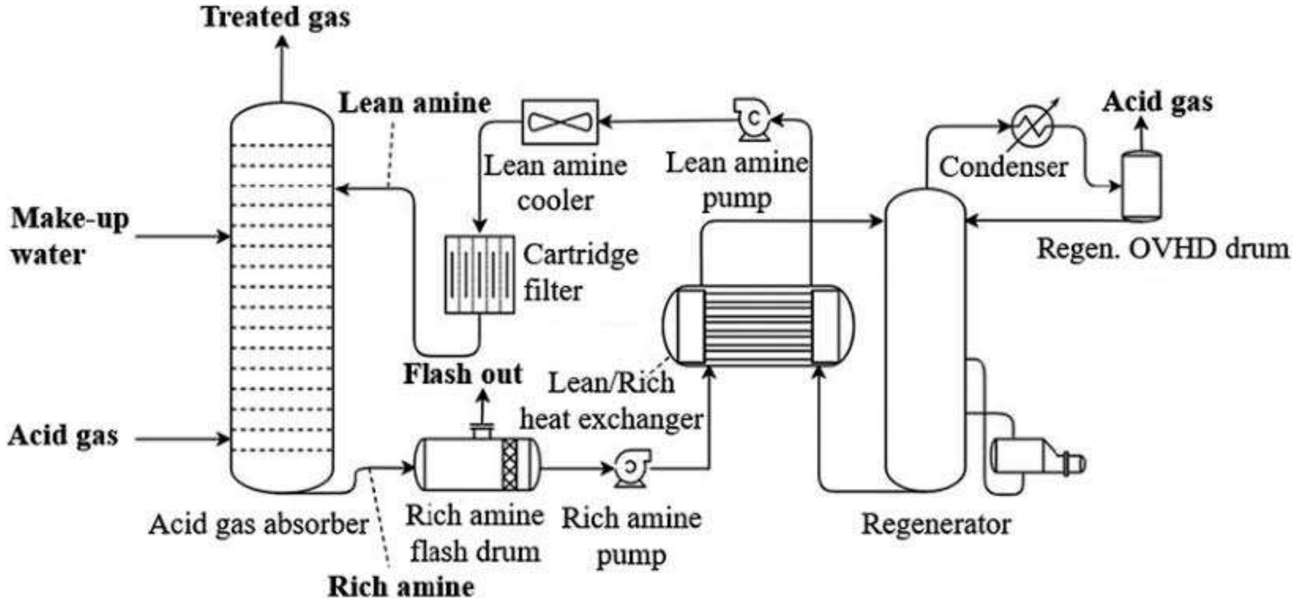

Figure 2: Process Flow Diagram of Amine Gas Sweetening Unit.

C2/C3 RECOVERY UNIT

The C2/C3 Recovery Unit uses Turbo-Expander cryogenic process to recover ethane and propane from feed gas, supplying feedstock to the Gas Cracker Unit for ethylene production, enabling efficient propane-ethane fractionation.

Feed Gas Compression Stage

Sweetened gas from Gas Sweetening Unit (50 kg/cm²a, 40°C) is scrubbed in the Feed Gas Knock Out Drum, then compressed to 55 kg/cm²a in the Feed Gas Expander Compressor, preparing it for cryogenic processing and efficient propane-ethane fractionation in the C2/C3 Recovery Unit.

Feed Gas Dehydration and Regeneration Process

Compressed gas is cooled (37°C → 18°C) and dried using molecular sieves to -100°C dew point in dual Dryers (12hr cycles), removing water to prevent cryogenic damage, enabling efficient propane-ethane fractionation in the C2/C3 Recovery Unit. Hot lean gas (320°C), generated by heating a slipstream in a Gas Fired Heater, regenerates the offline dryer, removing water and contaminants from molecular sieves, maintaining drying efficiency for propane-ethane fractionation.

Feed Gas Cooling and Separation Stage

Feed gas undergoes progressive cooling (-60°C) via heat exchange with lean gas and separator liquids, partially condensing it. The resulting vapor-liquid mix is separated in Separator 1, with liquids routed to Demathaniser for methane stripping, enabling efficient propane-ethane fractionation in the C2/C3 Recovery Unit. Uncondensed vapors from Separator 1 are cooled to -68°C in Feed Gas Chiller 2, then separated in Separator 2. The condensed liquid provides cold recovery in Feed Gas Chiller 1 before joining Separator 1 liquid, fed to Demathaniser Column (Tray 18) for methane removal. Separator 2 overhead gas expands isentropically in the Feed Gas Expander (22 kg/cm²a, -98°C), causing further condensation. The chilled mixture enters Demathaniser Column (Tray 8). Expansion work is recovered to compress feed gas, enhancing process efficiency.

FRACTIONATION

Demathaniser Column fractionates C2-C3 from Separator 1&2 liquids (-68°C) and Expander outlet (-98°C), removing methane to produce C2+ product, enabling efficient propane-ethane fractionation. Demathaniser Column (36 trays) strips methane from feed, producing C2+ product. Reboilers chill feed gas, recovering energy, and enabling efficient propane-ethane fractionation in the C2/C3 Recovery Unit. Overhead vapors (-98°C → -102°C) are condensed in Demathaniser Overhead Condenser using cold gas (-117°C) from Overhead Expander outlet, generating reflux for efficient methane stripping and C2/C3 recovery. Methane expansion (21.5 kg/cm²a → -117°C) in Overhead Expander generates cold gas, driving refrigeration and enabling efficient C2/C3 fractionation C2-C3 product from Demathaniser bottoms (90% C2 recovery) is sent to Cracker Unit or storage, completing efficient propane-ethane fractionation in the C2/C3 Recovery Unit.

Lean Gas Compression Stage

Lean gas compression boosts pressure (10 → 55 kg/cm²a), enabling efficient propane-ethane fractionation and pipeline transport. Key stages:

1. Demathaniser Overhead Expander Compressor (10 → 12 kg/cm²a)
2. 2-stage gas turbine-driven Lean Gas Compressors (12 → 55 kg/cm²a)
3. 36 T/hr Lean Gas diverted for Dryer Regeneration (compressed to 55 kg/cm²a)
4. Cooled lean gas (40°C) sent to pipeline, supporting C2/C3 Recovery Unit efficiency.

C2/C3 Storage Facilities

C2/C3 storage (8 spheres, 15m diameter, 1500m³ capacity) supports efficient propane-ethane fractionation by buffering 10% of production, enabling continuous GCU operation. Storage ensures supply flexibility:

1. 90% C2/C3 direct to GCU, 10% to storage
2. Storage supplies GCU during GPU shutdowns, maintaining C2/C3 Recovery Unit efficiency.

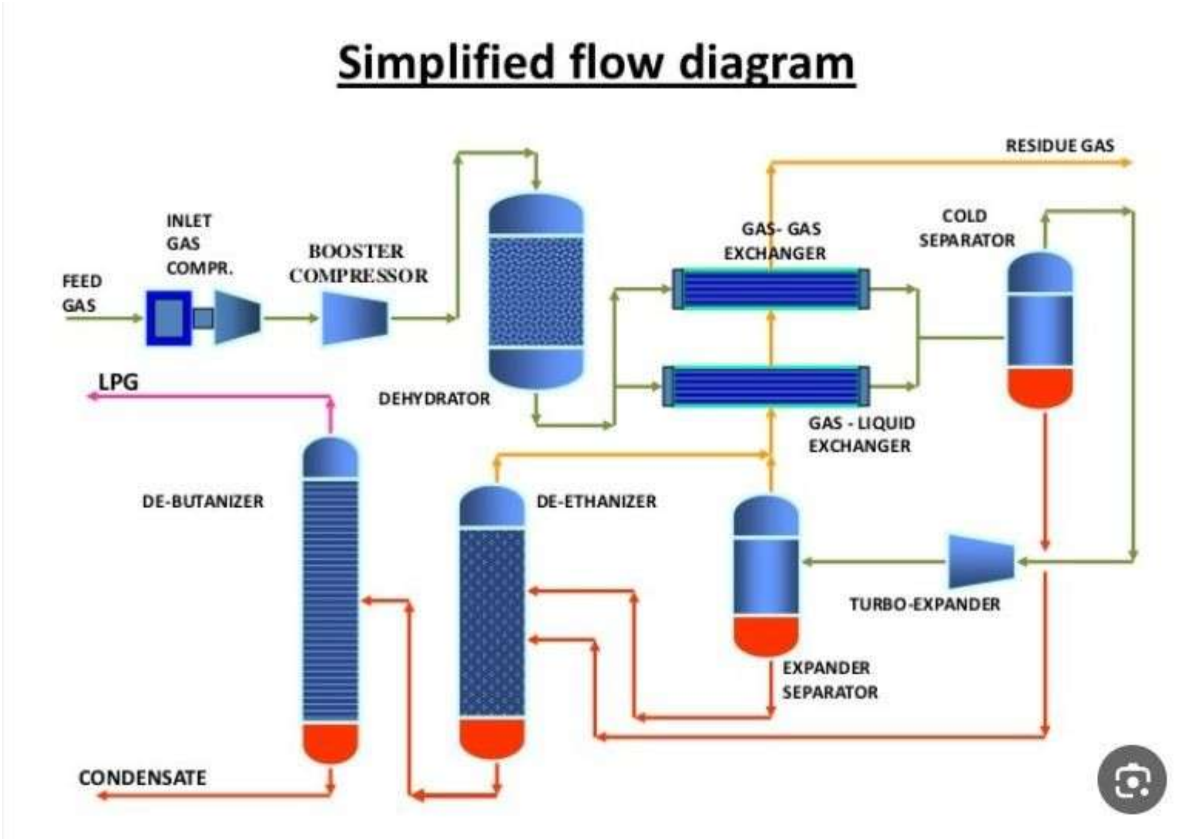

Figure 3: C2/C3 Process Flow Diagram

Core Function of Gas Cracking Unit

Gas Cracking Unit breaks down molecules into valuable products like ethylene and propylene via high-temperature endothermic cracking. The unit has two sections:

1. Hot section: vaporization, cracking, quenching, compression, caustic wash
2. Cold section: Demathaniser, product separation

Products are recovered for further processing.

CONCLUSION

This study presents an efficient method for recovering valuable petrochemicals from ethane-propane mixtures, crucial for both industrial applications and daily life. By optimizing recovery and processing techniques, this work enhances resource utilization and boosts overall benefits, contributing to a more sustainable and efficient petrochemical industry. The proposed approach integrates Gas Sweetening Unit (GSU), C2/C3 Recovery Unit, and Gas Cracker Unit (GCU) operations, ensuring effective CO_2 removal, high-purity product recovery, and improved GCU performance. Energy-efficient fractionation strategies and optimized operating conditions, including reflux ratio, column pressure, solvent circulation rate, and regenerator temperature, are key to achieving these outcomes. The results demonstrate improved product yields, reduced energy consumption, and enhanced process reliability. This research contributes to the development of efficient propane-ethane fractionation technologies, supporting the growth of the petrochemical industry while minimizing environmental impact. By adopting this approach, petrochemical complexes can optimize operations, reduce costs, and improve competitiveness in an increasingly demanding market. The findings of this study have significant implications for the future of petrochemical processing and energy efficiency.

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