# RETROFIT FOR NGL RECOVERY PERFORMANCE USING A NOVEL STRIPPING GAS REFRIGERATION SCHEME

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## ABSTRACT

The NGL recovery business in North America is frequently referred to as a "Mature Business". While this seems to be an understatement when describing the prospects for new grass-roots cryogenic plants, there are opportunities for upgrading the performance of existing plants where the consolidation of old processing facilities and/or new gas production dictates. In cases where the feed gas capacity increases or the feed gas becomes richer over time, additional refrigeration is generally required to maintain $C_2$ or $C_3$ recovery levels.

This paper presents a novel design for the retrofit of such plants that's simple, inexpensive, and can be done using surplus equipment. This novel design could increase plant capacity up to 20 percent at original or higher recovery levels without adding additional recompression horsepower. It not only reduces or eliminates the need for inlet gas cooling via external refrigeration, but also eliminates the need for external reboiler heat.

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## INTRODUCTION

Recovery of natural gas liquids (NGL) components in gas not only may be required for hydrocarbon dew point control in a natural gas stream, but also yields a source of revenue, e.g., natural gas may include up to about fifty percent by volume of heavier hydrocarbons recovered as NGL. When market demand for ethane is high, high recovery of ethane needs to be achieved in the gas plants.

Most of the gas plants in operation today use conventional single-stage turboexpander technology for moderately high ethane recovery [1]. This process could utilize the particular advantages of an expander producing useable work normally used to recompress residue gas. Figure 1 illustrates the flow diagram for a 1970-vintage turbo expander process for ethane recovery [2]. After the inlet gas is treated to remove water and other contaminants, it's cooled by cold residue gas in gas/gas exchangers and cold column internal liquid in the reboilers. Propane refrigeration is often required to help in condensing the heavy components for a rich gas. Liquid condensed from the inlet gas is separated and fed to the tower for further fractionation after being flashed to the tower pressure. The remaining non-condensed vapor portion is subject to turbo-expansion to the top section of the de-methanizer, with the cold liquids acting as the top reflux to enhance recovery of heavier hydrocarbon components. In most cases, inlet gas is used to provide the reboiler duty due to the low temperature profile in the column.

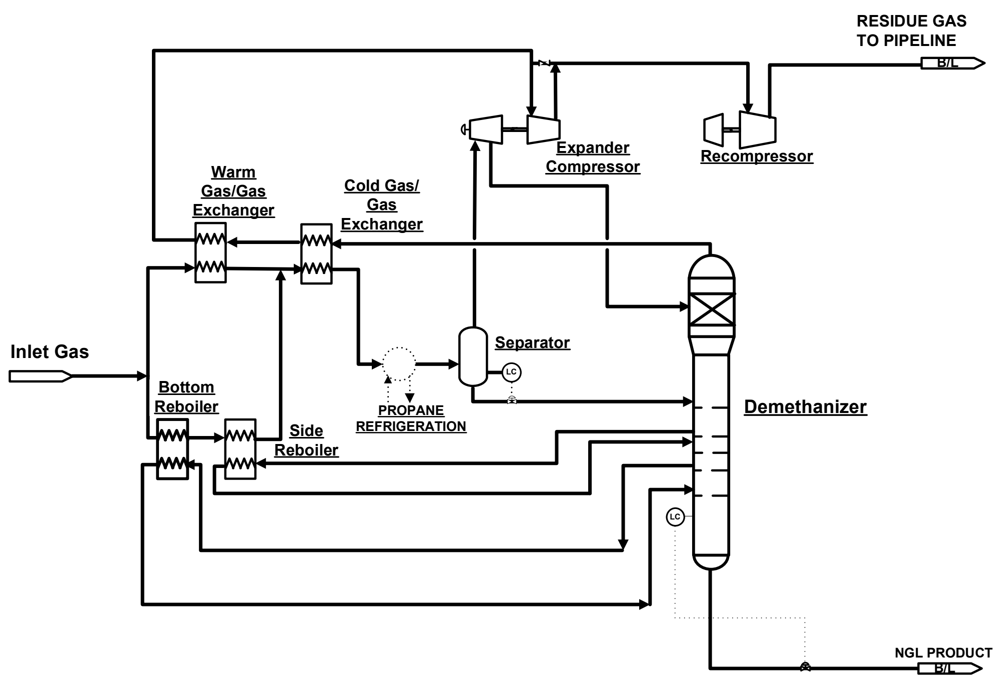


Figure 1- 1970's Vintage Expander Process

NGL recovery plant design is highly dependent on the operating pressure of de-methanizer. At medium to low pressure (i.e., 400 psia or lower), relative volatility of the key components is more favorable for the separation process, but the recompression horsepower, generally accounting for 25~50% of a gas plant's cost, would be so high that the process becomes less economical. While at high pressure (i.e., higher than 400 psia), the recompression horsepower could be reduced, but relative volatility decreases, making separation more difficult.

Technology developments for high NGL recovery plants have been directed to compensate the reduction in relative volatility with high column pressure in the past decades [2]. Since the recovery of hydrocarbon liquids is governed by the phase equilibrium at the top stage of de-methanizer, it can be enhanced by the combination of a higher, colder, or leaner top reflux. Many processes focus on improving the reflux stream by making it colder or leaner in ethane or propane (Figure 2). However, the temperature profile in the column rises with high column pressure, making the heat integration more difficult. Therefore, external heat resource is often required to provide additional reboiler duty. Besides, propane refrigeration is also required to achieve certain C2 recovery level.

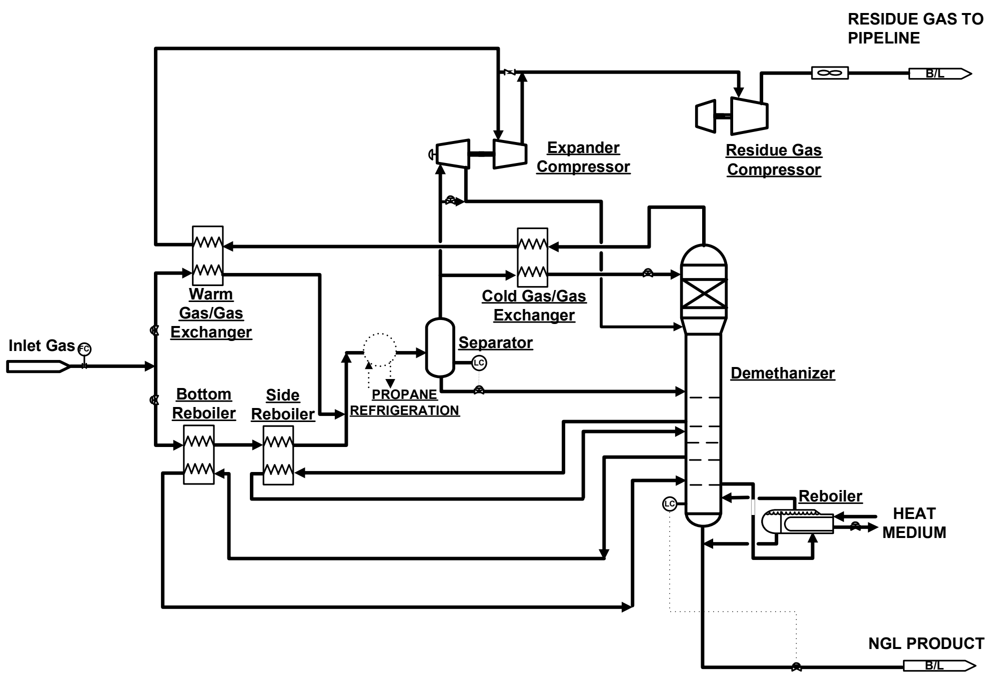


Figure 2 - Process Development with Reflux Scheme

While those processes focus on improving the reflux stream, IPSI LLC developed Stripping Gas Refrigeration Scheme (Enhanced NGL Recovery Process $^{SM}$) that focuses on the bottom of the de-methanizer [3]. This scheme can offer significant enhancements to the state-of–the-art NGL recovery process developed over the past two decades. Figure 3 is the flow diagram for this scheme (the box with dashed line at the bottom). It utilizes a slipstream from the de-methanizer bottom. This stream is totally or partially vaporized, providing additional refrigeration for inlet gas cooling. The flashed vapor generated from the self-refrigeration cycle is recycled back to the column, where it serves as stripping gas. Stripping gas increases the critical pressure thus enhancing the relative volatility. Alternatively, it maintains or increases NGL recovery levels at higher column pressure. Besides, it lowers the temperature profile in the column and makes the heat integration easier. This self-refrigeration design can augment to almost any leading NGL-recovery technology. It enhances the operational efficiency and reduces capital and operating costs of NGL recovery plants.

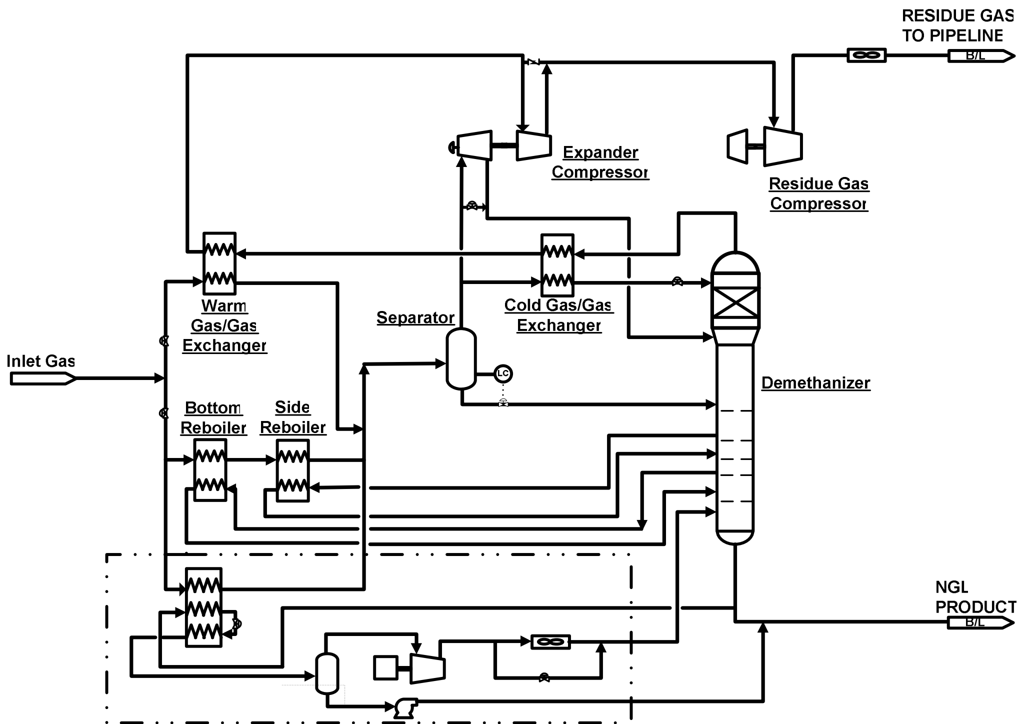


Figure 3 - Simplified Flow Diagram of Stripping Gas Refrigeration Scheme

The stripping gas refrigeration scheme is widely applicable not only for new, grass-root plants but for revamping old, existing plants. For new plant, stripping gas refrigeration scheme was selected by Enterprise for their second 300 MMcfd NGL recovery train at the Neptune plant in St. Mary Parish, LA [4].

This paper focuses on revamping existing plants using the stripping gas refrigeration scheme. In many cases, the economic return on retrofit investment is much more attractive as plant infrastructure and most of the existing equipments could be reused. There are opportunities for upgrading the performance of existing plants, e.g., plant capacity increases and/or the feed gas becomes richer over time. In these cases, additional refrigeration is generally required to maintain NGL recovery levels using conventional approach. Moreover, external heat resource is also required due to the high column pressure.

Retrofit design using the stripping gas refrigeration scheme could increase plant capacity up to 20 percent at original or higher recovery levels without adding additional recompression horsepower. It not only reduces or eliminates the need for inlet gas cooling via external refrigeration, but also reduces or eliminates the need for external reboiler heat. This design can upgrade the performance of the existing plant using surplus equipment, which is simple and inexpensive. This paper presents the retrofit design for an existing gas plant using stripping gas refrigeration scheme to show these benefits.

## FEATURES OF STRIPPING GAS REFRIGERATON SCHEME

When the plant capacity increases, generally it requires additional refrigeration to maintain NGL recovery levels. Besides, more recompression horsepower and additional reboiler duty are also required in the plant retrofit. Recompression horsepower can be reduced by increasing the column operating pressure. However, as the column operating pressure gets closer to the critical pressure, the separation is more difficult and NGL recovery levels have to be sacrificed. Moreover, higher column pressure reduces the expansion ratio across the expander and raises the temperature profile in the column, making the heat integration to the process more difficult. The plant has to use more external refrigeration and heat resource to meet the refrigeration and heat loads.

The stripping gas refrigeration scheme replaces conventional propane refrigeration with a self-refrigeration system that allows up to 20% more processing capacity at original or higher recovery levels without adding additional recompression horsepower. It generates internal refrigeration by expanding a liquid stream from the bottom of the de-methanizer. This stream is then heated by indirect heat exchange with inlet gas to generate a two-phase stream. The two-phase stream is flashed in a separator. The flashed vapor is compressed and recycled to the de-methanizer as a stripping gas, which increases the ethane and propane concentration in the column. The flashed liquid stream is pumped and mixed with other NGL product streams. The main features of this novel design are as follows:

- **Stripping gas increases relative volatility and allows higher column pressure at original or higher NGL recovery levels**

Figure 4 is the Methane/Ethane binary K chart. It shows that as the pressure is increased toward the critical pressure, the relative volatility (vertical dashed line) decreases, making fractionation more difficult. Figure 5 is the critical locus for Methane/Ethane/Propane system, which shows that critical pressure is highly dependent on C2 and/or C3 concentration. In result, the critical pressure of the system increases. Stripping gas mainly contains C2 and C3, which increase C2 and C3 concentration in the column. In result, the stripping gas increases the critical pressure of the system, thus increasing relative volatility and making the separation easier. Alternatively, the stripping gas refrigeration scheme allows higher column pressure with original or higher NGL recovery levels.

- **Stripping gas refrigeration scheme lowers column temperature profile and makes heat integration easier**

When column pressure is increased, generally the temperature profile in the column increases, making the heat integration difficult. However, stripping gas generated in the stripping gas refrigeration scheme recycles ethane and propane back to the de-methanizer. Therefore, it reduces the temperature profile within the column, especially for the trays in the middle of the column.

The significant temperature reduction makes the heat integration inside the reboiler much easier and maximizes the use of inlet gas for providing reboiler duty. On the other hand, the temperature reduction in the column also enhances the ability to cool the inlet gas via side reboiler, thus eliminating the need for inlet gas cooling via external refrigeration.

In summary, stripping gas refrigeration scheme generates refrigeration internally, providing additional refrigeration for inlet gas cooling due to plant capacity increase. Besides, the recycled stripping gas also reduces or eliminates the need for external reboiler heat. The warmer the stripping gas, the less demand is placed upon the bottom reboiler, thereby saving fuel and energy cost.

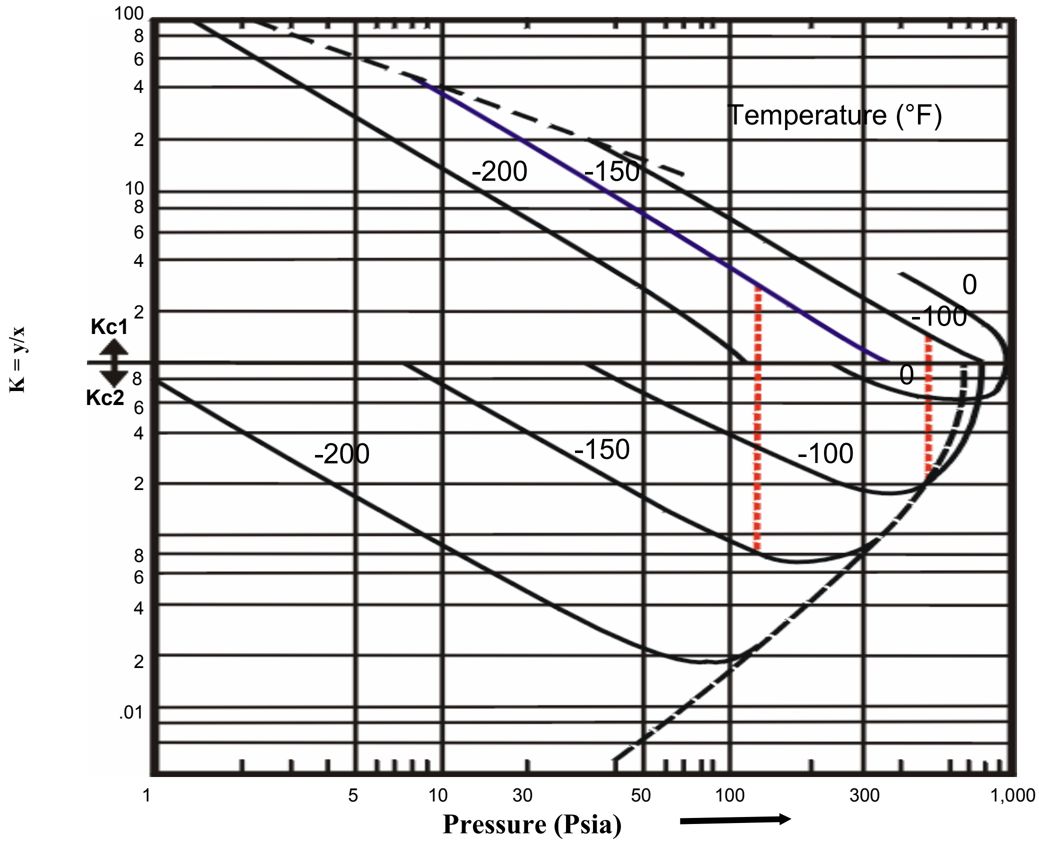


Figure 4 - Methane /Ethane Binary K Chart [5]

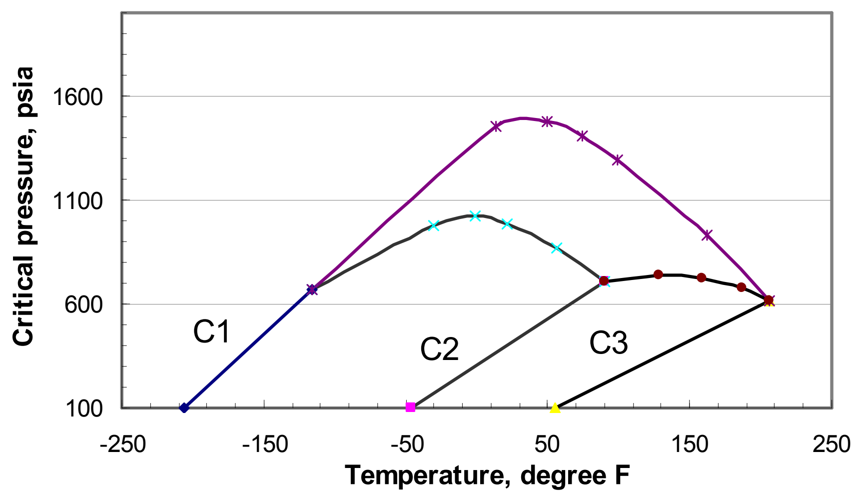


Figure 5- Critical Locus for Methane, Ethane and Propane System [5]

- **The stripping gas refrigeration scheme allows higher capacity without adding additional recompression horsepower**

Another significant advantage achieved by the stripping gas refrigeration scheme is reducing the horsepower. Reduction of recompression horsepower can be achieved by operating de-methanizer column at high operating pressure while maintaining the NGL recovery levels. As a result of its ability to maintain high NGL recovery levels at higher operating pressure, it's expected plant capacity can be increased as much as 20% without adding additional recompression horsepower, thus increasing product revenue by the same percentage.

- **The stripping gas refrigeration scheme provides same advantages to the existing plant in ethane rejection mode**

It's noteworthy that the stripping gas refrigeration scheme also provides same advantages to the plant in ethane rejection mode. Again, because the concentration of ethane and propane in de-ethanizer column is increased, the temperature profile of the trays is significantly reduced. It makes heat integration inside the reboiler much easier and maximizes the use of inlet gas for providing reboiler duty. Therefore, the refrigeration and heating loads could be reduced. Besides, the relative volatility of ethane/propane is also increased, thus the separation efficiency inside the tower is increased. The advantages that stripping gas refrigeration scheme provides to both ethane recovery and ethane rejection mode improve the plant operating flexibility and profitability.

All the above advantages could be further improved at higher operating pressure or with richer inlet gas. At higher column pressure which is closer to the critical pressure, the critical pressure increase by introducing stripping gas has more effect on the relative volatility. Generally the degree of enhancement increase is proportional to the operating pressure. Also the richer the inlet gas, the more improvement to the column performance as the stripping gas increases C2 and C3 concentration in the column more significantly.

## EXAMPLE OF USING STRIPPING GAS REFRIGERATION SCHEME

Next we will use an existing plant to demonstrate the benefits of applying stripping gas refrigeration scheme.

**Original Plant Design**

Figure 6 provides a schematic illustration of an existing gas plant, which is a single-stage expander plant. The inlet gas is cooled by indirect heat exchange with column overhead vapors and reboilers as explained below. The raw gas is produced at 823 psia and 85.0°F with a capacity of 125 MMSCFD (Dry basis). After the raw gas feed is filtered, cleaned and dehydrated, it is split into 2 parts: One part is directed to gas/gas heat exchanger where the temperature of the feed stream is reduced by indirect heat exchange with the overhead vapors from de-methanizer. The other part is directed to a series of reboilers where the temperature of the feed stream is reduced by indirect heat exchange with the drawoff liquids from de-methanizer. The combined stream flows to the expander feed separator where it is separated into vapor and liquid. The liquid flows to the de-methanizer, while the vapor produced is split to reflux exchanger, to J-T valve and to expander respectively. Gas passing through the reflux exchanger is cooled and totally condensed by indirect heat exchange with the overhead vapor phase from de-methanizer, and then directed to the top tray of the column. Gases passing through the J-T valve and the expander are directed to the tray next to the top one. Overhead vapors produced in de-methanizer flow to reflux exchanger and gas/gas heat exchanger where they provide indirect heat exchange to cool the inlet gas. The heated overhead vapors then flow to expander-compressor and residue gas recompressor where they are compressed to the desired pipeline pressure of 730 psia.

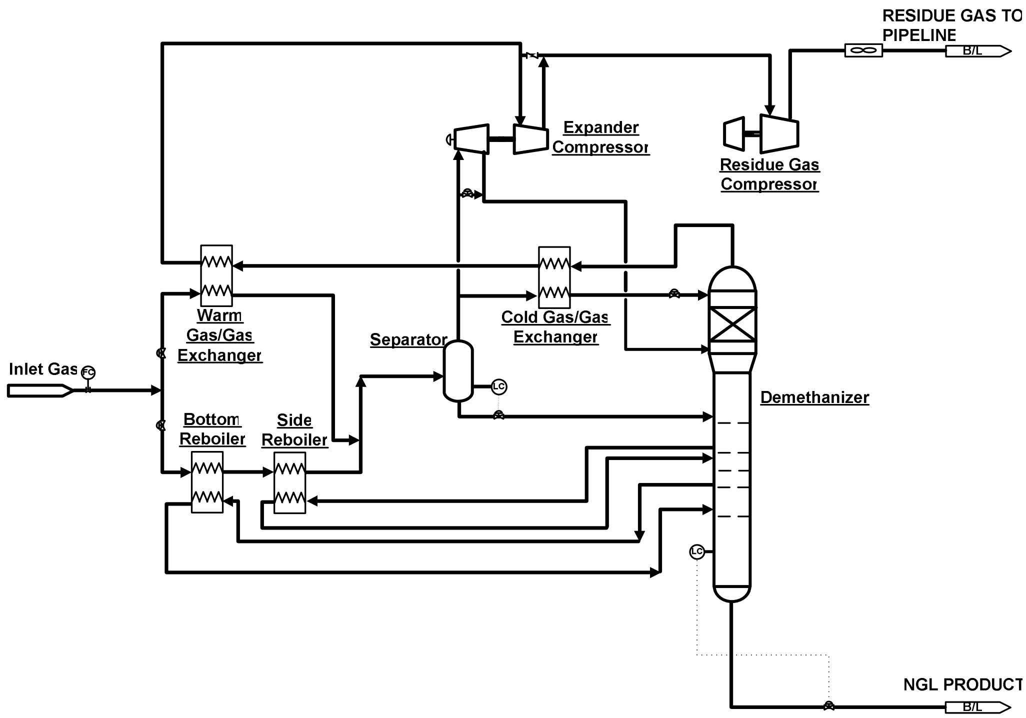


Figure 6 - Simplified Flow Diagram of the Existing Plant

There is no external refrigeration and external heat resource. The inlet gas provides the full reboiler heat. The existing plant provides C2 recovery at 65.1% and C3 recovery at 98.7% with column operating pressure at 250 psia. The column design pressure is 350 psia. The operating parameters for the existing plant are summarized in Table 1.

This plant has an incentive to process 20% more gas over the original design. It requires retrofit design shall be able to keep or increase the original C2 and C3 recovery levels without adding additional recompression power. Besides, the retrofit design shall reuse existing equipments to the maximum extent.

**Plant Retrofit Options**

The column in the existing plant has design pressure of 350 psia and operating pressure of 250 psia, so it's feasible to increase column operating pressure to retain same recompression horsepower in the retrofit.

This work studied the process of plant retrofit using stripping gas refrigeration scheme and conventional method. Process comparison of these two methods from simulation is listed in Table 2. All simulations in this work are performed using HYSYS. The simulation procedure is summarized to the following:

I. Simulated the original plant design with current operating parameters shown in Table 1.
II. Simulated the retrofit plant with plant capacity increase using conventional method and stripping gas refrigeration scheme at the conditions listed below:
   - Plant capacity is increased to 150 MMSCFD (20% increase over the existing plant).
   - Column operating pressure is increased to 310 psia to retain roughly same recompression HP of 6265 HP as the existing plant

- C2 recovery of the plant can achieve 74.4% versus 65.1% of the existing plant. Recoveries of C3 and C4+ are roughly the same as the existing plant.
- Keep the same efficiency for expander, expander compressor and residue gas compressors.
- Keep the same UA for all existing heat exchangers
- Keep the same inlet gas condition and delivery pressure.

**A. Retrofit using Conventional Approach**

In the plant retrofit, the column pressure is increased to 310 psia to maintain same recompression horsepower. It requires external refrigeration to get C2 recovery of 74.4% in the conventional approach. As the temperature profile in the column is high due to the high column pressure, the reboiler duty provided by inlet gas is not enough any more. Therefore, external heat resource is required to provide additional reboiler duty.

Table 2 lists the external refrigeration gas power requirement. For a two stage propane compressor, the compressor horsepower is about 1208. External refrigeration package for the above retrofit includes two stage compressors, condensers, refrigerant accumulators, economizers and refrigerant storage, which is not cost effective. Besides, it also requires external heat resources to provide reboiler duty of 2.46 MM BTU/hr.

Table 1 - Operating Parameters of the Existing Plant

| **Existing Plant** | |
|---|---|
| Inlet gas temperature | 85.0°F |
| Inlet gas pressure | 823 psia |
| Plant capacity | 125 MMSCFD (dry) |
| De-methanizer design pressure | 350 psia |
| De-methanizer operating pressure | 250 psia |
| Send-out gas temperature | 120.0°F |
| Send-out gas pressure | 730 psia |
| Components | Mole Percent |
| Nitrogen | 0.2356 |
| CO2 | 0.0035 |
| Methane | 85.4774 |
| Ethane | 8.4127 |
| Propane | 3.6167 |
| i-Butane | 0.7069 |
| n-Butane | 0.8197 |
| i-Pentane | 0.2254 |
| n-Pentane | 0.2049 |
| n-Hexane | 0.1783 |
| n-Heptane | 0.0743 |
| n-Octane | 0.0297 |
| n-Nonane | 0.0149 |
| C2 + GPM | 3.9 |
| Ambient temperature | 85.0°F |
| C1/C2 mole ratio in NGL product | 0.02 |

**B. Retrofit using Stripping Gas Refrigeration Scheme**

Figure 3 in previous section shows the retrofit design for the above existing plant using stripping gas refrigeration scheme. This scheme generates refrigeration internally to provide additional refrigeration, which eliminates the external refrigeration required by conventional method. Warm stripping gas recycled to the column provides additional reboiler duty, which eliminates the external heat resource.

Compared to conventional method, the advantages of stripping gas retrofit design are:

- No propane refrigeration is required. Therefore, refrigeration supply and makeup is no longer a concern.
- No external heat resource is required, thus saving fuel and energy.
- Stripping gas compression HP is about 25% less than external refrigeration gas power.

Table 2 - Process Comparison: Conventional Method vs. Stripping Gas Refrigeration Scheme

| **Description** | Existing Plant | Retrofit using Conventional Method | Retrofit using Stripping Gas Refrigeration Scheme |
|---|---|---|---|
| **Dry Feed Gas, MMSCFD** | 125 | 150.0 | 150.0 |
| **DeC1 Pressure, psia** | 250 | 310 | 310 |
| **Liquid Recovery , %** | | | |
| Ethane | 65.1 | 74.4 | 74.4 |
| Propane | 98.7 | 98.8 | 98.8 |
| **Residue Gas, MMSCFD** | 110.7 | 131.7 | 131.7 |
| **Expander, MMSCFD** | 80.5 | 92.4 | 92.4 |
| **Compression HP** | | | |
| Recompression | 6,265 | 6,213 | 6,140 |
| External Refrigeration Gas Power | | 1,208 | |
| Stripping Gas Compression | | | 908 |
| **Total HP** | 6,265 | 7,421 | 7,048 |
| **External heat resource required** | | YES | NO |
| Duty, MM Btu/hr | | 2.46 | 0 |

Besides, stripping gas refrigeration scheme also has better column performance than conventional method. At column pressure of 310 psia, Figure 7 shows a tray-to-tray critical pressure increase by stripping gas refrigeration scheme compared to conventional method. Figure 8 shows a tray-to-tray relative volatility percentage increase by stripping gas refrigeration scheme compared to conventional method. Figure 9 shows a tray-to-tray temperature reduction profile by stripping gas refrigeration scheme compared to conventional method.

As shown in the figures, the stripping gas refrigeration scheme offers better improvement to bottom column performance. e.g., the critical pressure in the middle of column (tray 11-13), where the side reboiler is located, is up to 21 psi higher than that in conventional method. In result, these trays have higher relative volatilities in the stripping gas refrigeration scheme (up to 7% compared to external refrigeration). Better relative volatility means an easier C1-C2 separation. The stripping gas refrigeration scheme also has a lower temperature profile in the middle of column (up to 10°F). A lower column temperature means better heat integration. Because the C2 recoveries are the same, the top and bottom temperatures or relative volatilities are also almost identical in both designs.

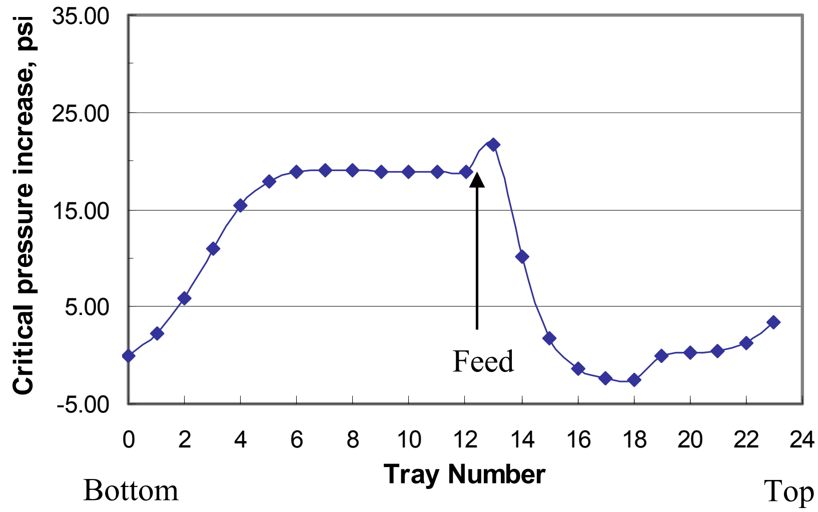


Figure 7 - The Increased Tray Critical Pressure at Column Pressure of 310 psia
(Stripping Gas Refrigeration Scheme vs. Conventional Method)

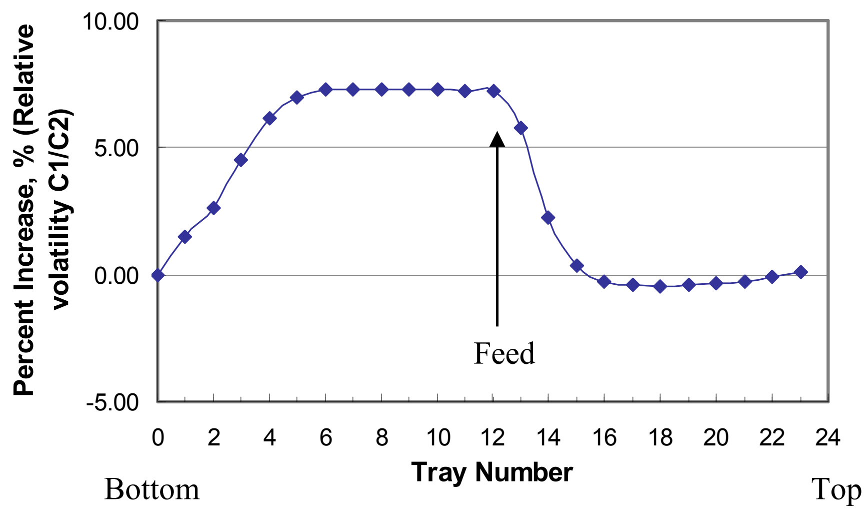


Figure 8 - The Increased Tray Relative Volatility at Column Pressure of 310 psia
(Stripping Gas Refrigeration Scheme vs. Conventional Method)

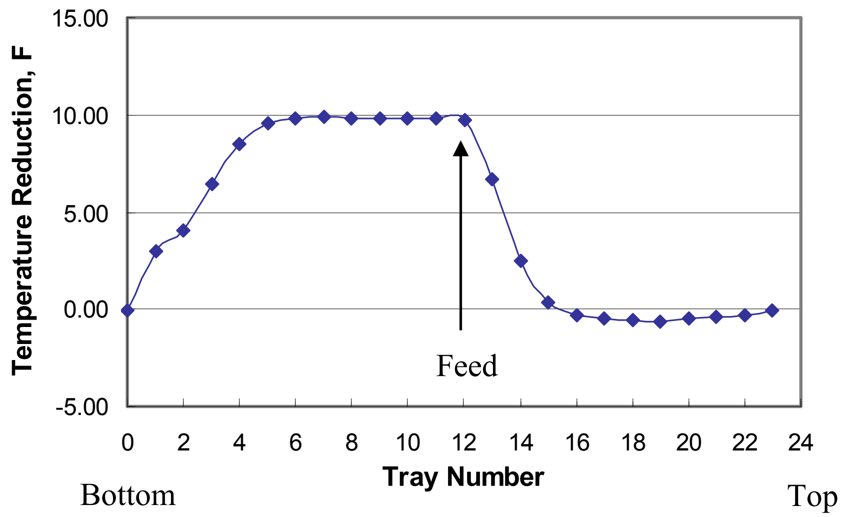


Figure 9 - Reduction of Tray Temperature at Column Pressure of 310 psia
(Stripping Gas Refrigeration Scheme vs. Conventional Method)

**Retrofit Design Considerations:**

Since the retrofit design specifies same UA for the exchangers and same recompression horsepower, all the existing exchangers and recompressor can be reused without modification. However, like other retrofit designs, the following critical equipments need to be checked in the retrofit design:

1. De-methanizer sizing margin needs to be checked. The retrofit design will operate the column at higher pressure. Although higher pressure could reduce the vapor volume flow caused by throughput increase, the existing plant usually has a sizing margin for the column.
2. Expander feed separator separation capacity and liquid surge time needs to be checked. With stripping gas refrigeration scheme, the temperature in the expander feed separator is lower than that in the original design, which makes the vapor density increased. It has the effect to reduce the vapor volume rate.
3. Expander frame size needs to be checked.

Preliminary calculation shows that the above critical items in the existing plant are appropriate for the retrofit design.

**Equipment Used in Stripping Gas Refrigeration Scheme:**

Table 3 summarizes the equipments used in stripping gas refrigeration scheme for the above retrofit design, which include one enhancement vapor compressor, one brazed aluminum exchanger, one suction K.O. drum, one air cooler and one pump. The novel design package could be done using the surplus equipment, which is simple and inexpensive. It can be configured into a simple add-on skid particularly suitable for retrofitting some existing gas plants, regardless of the original licensor. The installation of the retrofit package is simple and interruption of plant production is minimal.

Table 3 - Equipment Used in Stripping Gas Refrigeration Scheme

| Stripping Gas Refrigeration Scheme Package | |
|---|---|
| 1. Stripping gas compressor , HP | 908 |
| 2. BA Exchanger UA,MMBtu/Hr-°F | 0.53 |
| 3. Suction K.O. Drum | 5'-0"x10'-0", CS, 200 psig |
| 4. Stripping gas air cooler, MMBtu/hr | 5.6 |
| 5. HC Liquid Pump | 15 GPM, 5 HP |

Since the modification to the existing plant is not significant, operators only need to learn several pieces of equipment in the enhancement package and would require minimum training to become familiar with new plant's start-up and operation.

**Cost Comparison**

The study compared the relative cost using the two methods for upgrading the above existing plant (Table 4). Total Installation Costs (TIC) for small changes in feed rate are estimated using six-tenths rule.

Table 4 - Economic Comparison for the Retrofit Design

| Description | Existing Plant | Retrofit using conventional approach | Retrofit using stripping gas refrigeration scheme |
|---|---|---|---|
| Dry Feed Gas, MMSCFD | 125 | 150 | 150 |
| Add'l Compression | | 1208 HP | 908 HP |
| External Reboiler Duty, MMBtu/hr | | 2.46 | 0 |
| Estimated TIC, $MM | | 3.1 | 1.9 |
| Operating cost saving using stripping gas refrigeration scheme, $MM/year | | | 0.32 |

Note: Fuel gas price $7.2 /MM Btu is based on Henry Hub Spot price, July 2005
Operating cost is based on 350 days/year.

Tables 4 shows that stripping gas refrigeration scheme has lower installation cost. Besides, since it has less horsepower requirement and eliminates the external heat resource for the retrofit, it saves operating cost of 0.32 MM $/year compared to conventional approach.

**Cases with Richer Gas and Higher Column Pressure**

It's noteworthy that the stripping gas refrigeration scheme has even more advantages with richer gas or with higher column pressure. This work studied a richer case (4.7gpm) and a case with 350 psia column operating pressure. With 150 MMSCFD inlet gas capacity, process comparison of stripping gas refrigeration scheme and conventional method is listed in Table 5. Base case is the case discussed in the previous section. It shows that stripping gas refrigeration scheme offers more significant improvement to the process with richer gas or higher column pressure.

Table 5 - Process Comparison with Richer Gas and Higher Column Pressure (150 MMSCFD)

| **Stripping Gas Refrigeration Scheme** | Base case | High column pressure case | Rich case |
|---|---|---|---|
| Column pressure, psia | 310 | 350 | 310 |
| C2 + gpm | 3.9 | 3.9 | 4.7 |
| HP saving vs. conventional method | 25% | 29% | 30% |
| Relative volatility increase in the middle trays vs. the conventional method | 7.0% | 9.5% | 9.6% |

## CONCLUSIONS

Stripping gas refrigeration scheme provides overall energy integration and completely replaces propane refrigeration system. It can be configured into a simple add-on skid particularly suitable for retrofitting some gas plants, regardless of the original licensor. For the plant retrofit with (a) additional capacity, (b) same or higher NGL recovery levels, (c) same recompression HP, it provides more advantages than the conventional approach such as:

- No propane refrigeration is required
- No external heat resource is required
- Stripping gas compression horsepower is less than external refrigeration gas power.
- Lower operating cost
- Lower installation cost and less impact to the existing equipment.

Stripping gas refrigeration scheme provides even better improvement to the process with richer gas or higher column operating pressure.

## ACKNOWLEDGMENT

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