

EFFICIENT, HIGH RECOVERY OF LIQUIDS FROM NATURAL GAS UTILIZING A HIGH PRESSURE ABSORBER

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ABSTRACT

The development of cryogenic turbo-expander plants for the recovery of liquids from natural gas has evolved significantly over the years. The primary focus of developers has been on the reduction of operating and capital costs while maintaining high recoveries through lowering the horsepower demand for recompression of the residue gas. Other major developments over the years include improved heat integration through the addition of multiple side reboilers and the implementation of reflux streams to improve recovery. We have seen other innovations developed to improve the processes tolerance to carbon dioxide.

One element common to most turbo-expander processes is that both the recovery of product and the stabilization of product are carried out at essentially the same pressure whether it is with a single tower scheme or with a dual tower scheme. Although this is suitable for many conditions of inlet pressure and composition, there are instances, when another approach is more efficient.

A process scheme for the recovery of liquids from natural gas has been developed which is in the patenting process that allows for the independent, optimum selection of the operating pressure for each the recovery process and stabilization process. This scheme is applicable to both ethane and propane recovery. This paper describes this process, embodiments of its use, and its benefits.

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INTRODUCTION

Inlet gas conditions, including composition, temperature, and pressure as well as recovery objectives dictate the selection of the optimum process technology. Inlet gas at elevated pressure (> 1000 psig), especially gas with high coincident carbon dioxide content can present special challenges to the process designer.

Several recent exposures to gas at these conditions have turned these challenges to opportunity. An opportunity for the development of an efficient cryogenic turbo-expander based hydrocarbon recovery scheme particularly suitable for natural gas at elevated pressure with or without high carbon dioxide content.

This paper discusses our *High Pressure Absorber (HPA) Process*, applicable to propane and ethane recovery. The fundamentals upon which it was developed, its benefits, applications, and finally conversion from propane to ethane recovery are discussed.

PROCESS FUNDAMENTALS

Propane Recovery

The traditional two-tower scheme for the recovery of propane and heavier components from natural gas has been used in the natural gas processing industry for nearly fifteen years. It is an energy efficient process capable of recovering essentially all of the contained propane. A typical configuration of this process is shown in Figure 1.

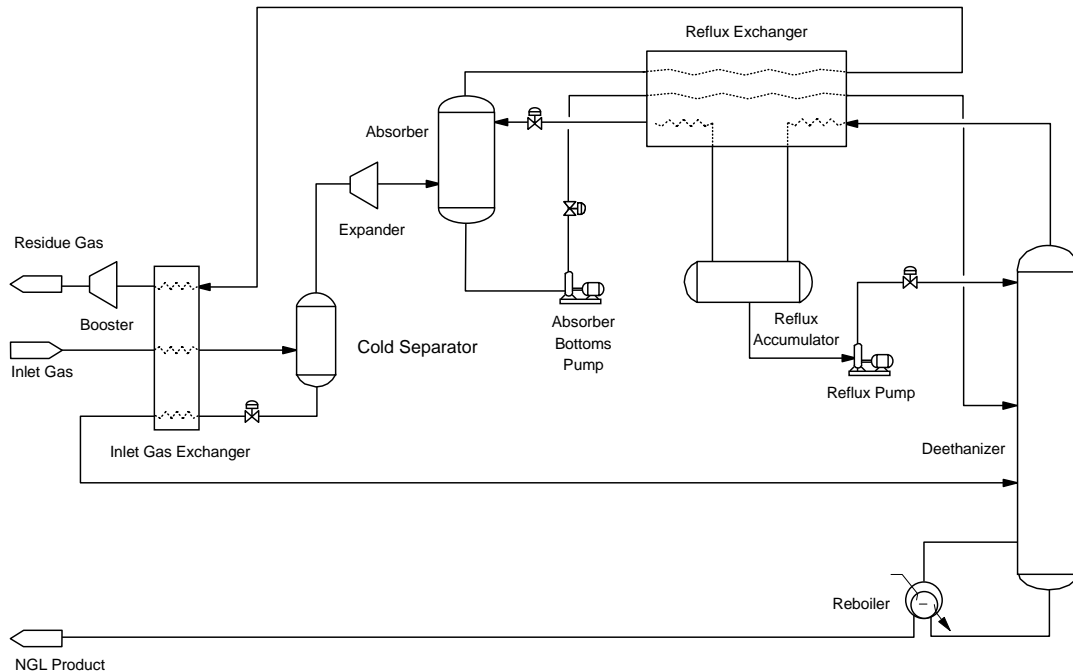


Figure 1 – Traditional Two Tower Scheme for the Recovery of Propane

The two-tower scheme has been applied with many variations, including arrangement of heat exchange, source of deethanizer reflux, and physical arrangement of the towers. The key fundamentals of the process however, are similar for all variations. The first and most fundamental aspect is that the absorber (recovery tower) operates at a pressure slightly (30–50 psi) below the pressure of the deethanizer tower (stabilizer). The second fundamental feature of the two-tower scheme is that the partially condensed net deethanizer overhead is used to reflux the absorber column to achieve high propane recovery. Finally, cryogenic pumps are required to deliver absorber bottoms liquid to the deethanizer.

The design objective of any propane recovery scheme is to achieve the required recoveries with minimal capital and operating expense. For a cryogenic turbo-expander based process this is achieved primarily by minimizing residue gas recompression. In pursuit of this goal, the absorber pressure is operated at as high a pressure as possible while still meeting recovery objectives. With the traditional process, there is however an upper limit to the absorber pressure. The upper limit is a constraint of the deethanizer, which must operate at pressures low enough to prevent the loss of separation efficiency and to maintain phase stability (i.e. avoid critical conditions). Figure 2 shows the pressure-enthalpy relationship for the liquid in the bottom of a typical deethanizer.

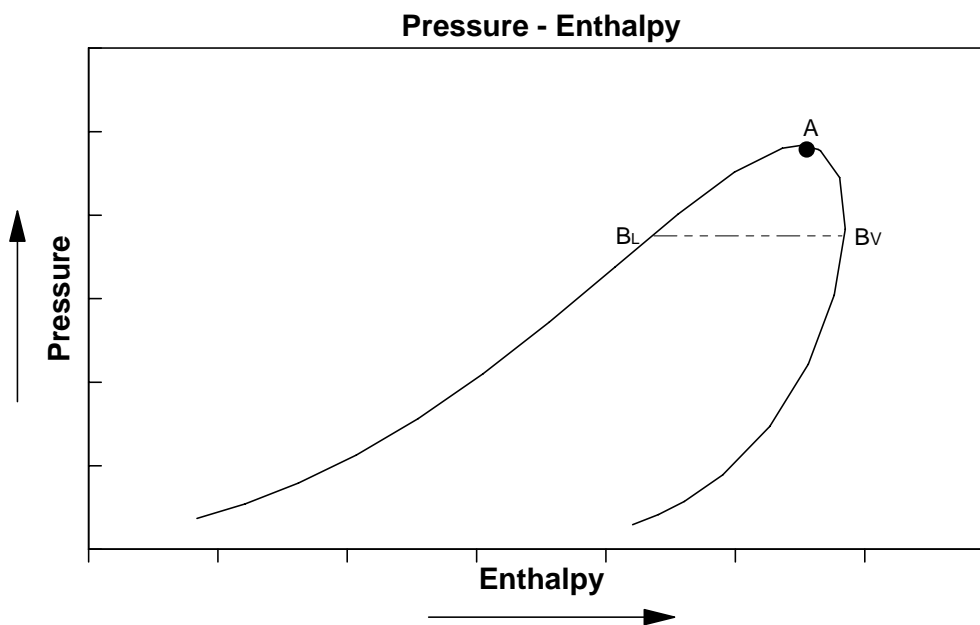


Figure 2 – Pressure/Enthalpy relationship for Deethanizer Bottoms Liquid

Typical maximum deethanizer pressures are 425 to 475 psig, represented by the B_L-B_V operating line. As the operating conditions in the deethanizer approaches point A, the critical point, the thermal and physical properties of vapor and liquid approach one another. It is crucial that the operating conditions in the column do not encroach too closely to critical conditions. Application of a set of thermal and physical properties criteria that reflect the stability and separation efficiency of the fractionator is essential.

For inlet gas pressures in the range of 750 psig to 1,000 psig, the turbo-expander pressure drop required to meet recovery objectives results in a deethanizer operating pressure within the range of satisfactory operation. The result is an efficient, well-integrated process.

However, the same cannot be said when the inlet gas pressure is above this range. The required turbo-expander pressure drop is now dictated by the acceptable deethanizer operating pressure range. The required pressure drop across the expander becomes higher than that required to meet recovery objectives. The result is an inefficient process with excess refrigeration available and higher recompression demands. The opportunity exists for a propane recovery process, which efficiently handles inlet gas at pressures above 1,000 psig.

Ethane Recovery

State-of-the-art cryogenic ethane recovery processes typically utilize a single tower with one or more reflux streams. The differences from one scheme to the next include the source of the reflux stream(s) and slight differences in heat integration. Ethane recovery schemes are typically more highly heat integrated, utilizing inlet gas to provide the reboiling for the demethanizer with a bottom reboiler and one or more side reboilers. Figure 3 shows a typical ethane recovery process.

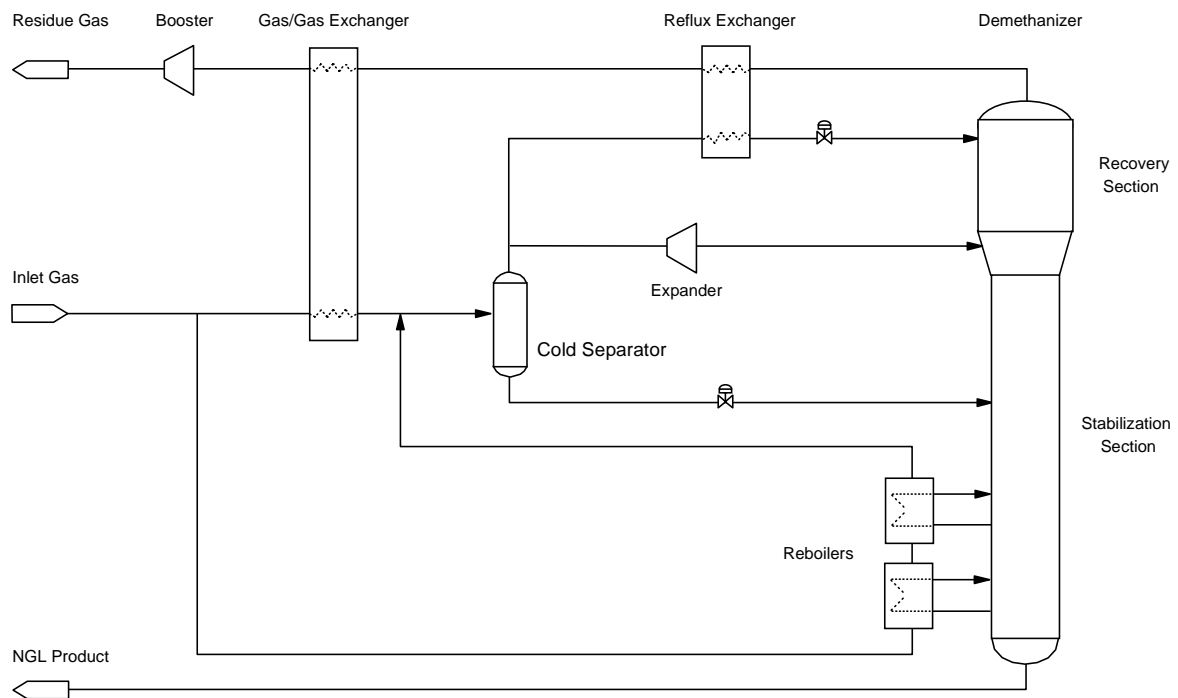


Figure 3 – Typical Ethane Recovery Process

Like propane recovery, the objective is to meet the required recovery demands with a minimum of capital and operating expense. And like propane recovery the key objective is to reduce recompression horsepower. This is achieved by operating the demethanizer at as high a pressure as practical. Usually, the tower's upper pressure limit for the demethanizer in ethane recovery is somewhat higher than for the deethanizer in propane recovery. Although the demethanizer can be operated at pressures in excess of 500 psig, efficient heat integration via reboilers, especially when processing cool inlet gas, and separation efficiency come into question. When operating a demethanizer at a normal pressure of 500 psig or greater, start-up and JT mode operation can prove to be difficult. Typically during these off-design modes, the demethanizer must operate at elevated pressures to counter the loss of expander boost. These pressures can be in excess of 600 psig if throughput is to be maintained, making operation very difficult.

Designing the demethanizer for these high off-design pressures is quite costly. Application of the *HPA Process* to ethane recovery can avoid many of the pitfalls associated with processing high-pressure inlet gas, especially with cool inlet gas.

HIGH PRESSURE ABSORBER PROCESS

Randall Gas Technologies has developed a process tailored for high inlet gas pressure. The *High Pressure Absorber (HPA) Process* results in the efficient recovery of hydrocarbon components from inlet gas at pressures in excess of 1,000 psig and up to 1500 psig. The HPA process is a dual tower scheme in both ethane and propane recovery options.

The key and unique process fundamental of the *HPA Process* is the independent operation of the absorber (recovery tower) and the deethanizer/demethanizer (stabilizer tower). The operating pressures of each of the towers are set independent of one another.

The absorber pressure is set to meet recovery objectives and provide the necessary process refrigeration. When set without regard to the deethanizer/demethanizer pressure, there is no upper limit to the absorber operating pressure.

The deethanizer operating pressure is set to obtain favorable separation efficiency. The deethanizer pressure is typically 50 to 250 psi *below* the absorber pressure.

A small compressor is used to deliver the net deethanizer overhead to the absorber as reflux via the absorber reflux condenser. This compressor is typically 5%-10% of the overall compression requirements and can be in tandem with the residue gas recompressor or can be a separate motor driven compressor. The discharge pressure of the compressor is at least as high as the absorber pressure but can be adjusted to a higher pressure to improve process heat integration and off-design operating conditions.

The absorber bottoms flows on pressure through the heat exchangers to the deethanizer or directly to the demethanizer in the case of ethane recovery without the need for a cryogenic bottoms pump. The benefits of the *HPA Process* include:

- Reduced overall HP requirements,
- Improved tolerance to carbon dioxide,
- Improved heat integration,
- Improved separation efficiencies and operating stability in the stripping column,
- Improved response/performance on loss of the turbo-expander or during start-up, and
- Readily converted from propane to ethane recovery operation.

Propane Recovery

Figure 4 is the *HPA Process* for propane recovery. Similar to the traditional two-tower scheme the only equipment difference is the substitution of the deethanizer overhead compressor for the absorber bottoms pump. Like the traditional two tower scheme, inlet gas at high pressure is cooled by exchange with residue gas and liquids from the cold separator. In the case where conditions in the cold separator are above the critical point, residue gas only is used. Alternately liquid from the absorber bottoms is used cool inlet gas after exiting the reflux exchanger.

The expander discharges to the absorber bottoms operating at a pressure from 550 psig to 650 psig. The leaner the inlet gas, the higher the pressure of the absorber can be set. The deethanizer operates at pressures ranging from 425 psig to 450 psig. The optimal pressure depends on the conditions in the bottom of the deethanizer.

The deethanizer overhead compressor discharge pressure is slightly above the operating pressure of the absorber. Increasing the discharge pressure above this point can eliminate pinch points in the reflux exchanger by raising the temperature at which the absorber reflux stream condenses. Since the load on the overhead compressor is relatively small, generally less than 5% of the total gas compression demand, the impact on overall compression is small.

When considering propane recovery, one is usually not concerned with the potential for carbon dioxide freezing. The reason is that the amount of carbon dioxide required in the feed (>6%-8%) to result in freezing in the absorber is far in excess of that typically allowed in residue gas and gas treating is required. However, in the case where the residue gas is reinjected or it is beneficial to treat residue gas, the HPA Process offers significant benefit. At the elevated pressure and correspondingly higher temperature the margin to the freezing point of carbon dioxide is increased by as much as 10°F or more.

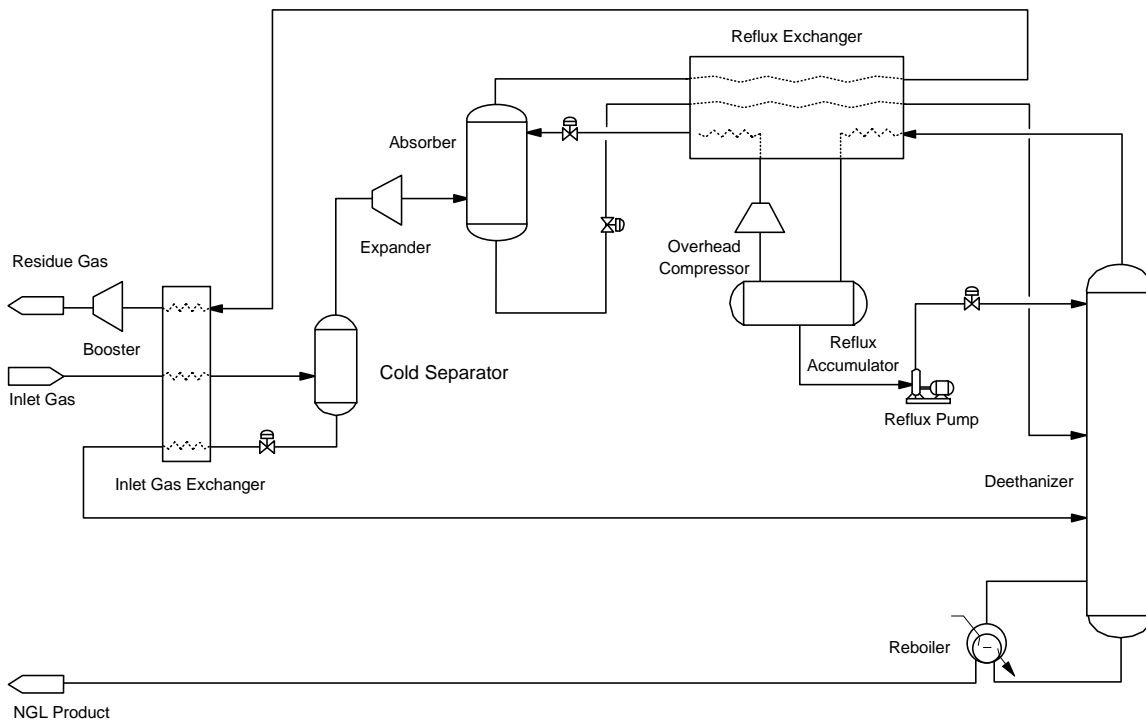


Figure 4 – HPA Process in Propane Recovery

HPA Process vs. Traditional Two-Tower Scheme – A Comparison

A comparison of the HPA Process to the traditional two-tower scheme (shown in Figure 1) was made for a mid-range liquids content natural gas stream of the following basis:

- Inlet gas flow of 400 mmscfd,
- 1250 psig inlet and residue pressure,
- CO₂ content of 7%,
- Propane recovery – 99%,
- Deethanizer pressure of 450 psig,
- Gas turbine driven recompression, and
- Fuel cost of \$3.00/mmbtu.

The results of this comparison are shown in Table I.

Table I – Two-Tower vs. HPA Process for Propane Recovery

Process Parameter	Traditional Two-Tower Scheme	HPA Process
Absorber Pressure, psig	420	545
Approach to CO ₂ Freezing, °F	-2	12.5
Residue Gas Compression, BHP	20,600	15,900
Overhead Compression, BHP	---	570
Utility Cooling, MMbtu/Hr	84.4	72.6
Reboiler Duty, MMbtu/Hr	28.2	27.1
Plate-Fin UA, BTU/°F-hr	3.2 X 10 ⁶	6.7 X 10 ⁶
Major Equipment Count	15	15
Fuel Cost, \$/mscf of inlet	\$0.039	\$0.032

As can be seen from the plate-fin requirements, a higher degree of heat integration is possible with the HPA Process when processing gas at elevated pressures. The two-tower scheme must make up for this loss in efficiency with added compression, approximately 25% more overall. In addition to the decreased cost for compression, an annual fuel savings of nearly \$1,000,000 is realized with the HPA Process. The HPA Process utility cooling for residue gas and LPG product is reduced by over 15% - a positive impact to both capital and operating expense.

Obviously, a designer would not design a process with a negative approach to freezing. Some additional requirements are necessary if the traditional two-tower scheme is to be used. Inlet gas treating or a reduction in product recovery is necessary to avoid freezing in the absorber.

Ethane Recovery

The *HPA Process* for ethane recovery, like the propane recovery option, includes two towers, a high-pressure absorber and a lower pressure fractionator. Setting of the pressures is independent and set for optimal recovery, heat integration and operating stability. The optimal recovery level for ethane when using this scheme is 85% - 90%. Figure 5 shows the HPA Process for ethane recovery.

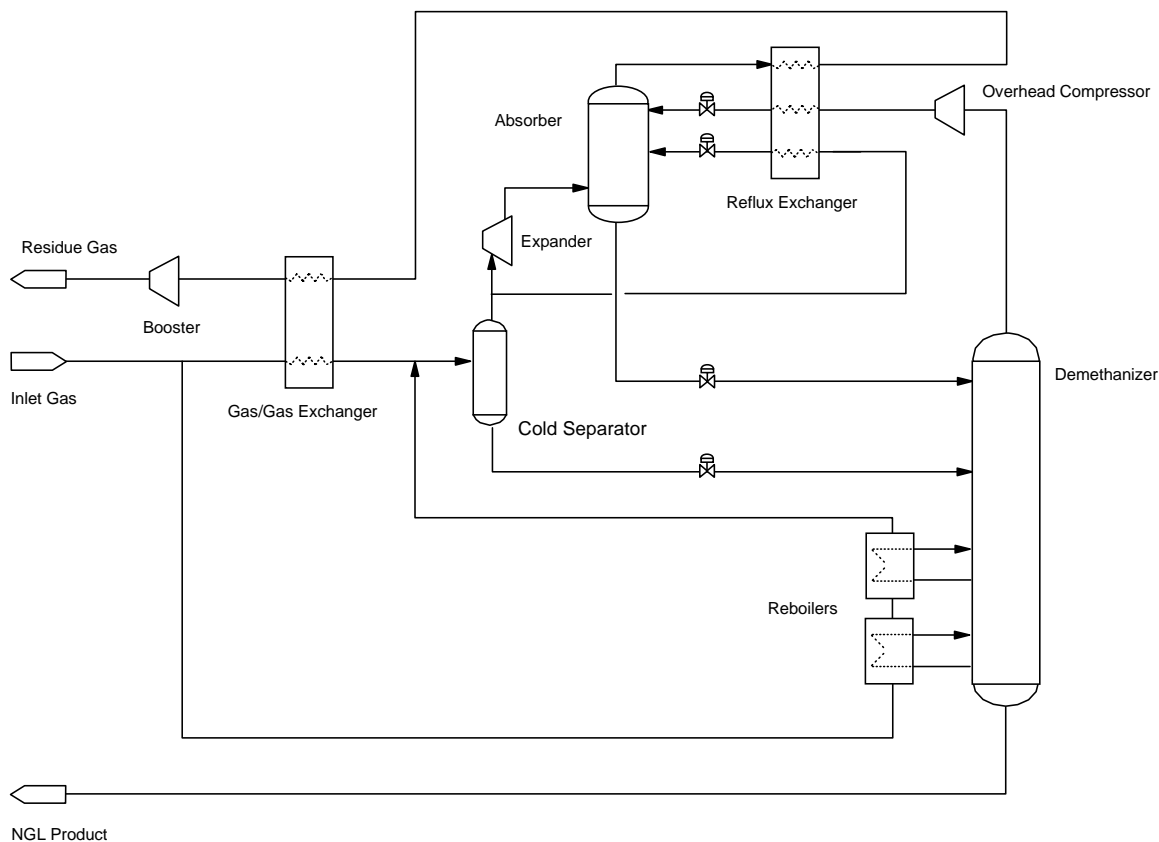


Figure 5 – HPA Process for Ethane Recovery

Like traditional ethane recovery schemes, the HPA Process has one or more reflux streams, in most instances two. In figure 5 below an intermediate reflux from the cold separator is used to improve recovery. The lean demethanizer overhead refluxed to the top of the absorber ensures essentially complete propane recovery even at modest ethane recoveries, below 80%.

Heat integration is improved with this design. The demethanizer pressure, being independent of the absorber pressure is set to achieve optimal heat integration. Specifically the tower pressure is established to result in a bottoms temperature, which can be reboiled using inlet gas. At demethanizer pressures above 400 psig – 450psig, the bottoms temperature can easily exceed the inlet gas temperature requiring an external source of heat input. In addition to this added source of heat input, a decline in overall process efficiency results due to the absence of heat removal via the reboiler.

The deethanizer overhead is compressed to a pressure, which insures sufficient condensing. A benefit of this design is that on loss of expander boost, the demethanizer is capable of operating at its normal design, ensuring separation efficiency and production of on-specification product. Figure 6 shows the absorber/demethanizer area of the HPA Process with typical conditions indicated. On loss of the boost generated by the expander due to a trip, the absorber pressure rises by typically 100 – 150 psig if flow is to be maintained. For the HPA Process this means the absorber pressure would need to

rise to 650 – 700 psig. Since the normal discharge pressure of the overhead compressor is above this point, no pressure increase for the demethanizer is required; process stability and constant throughput is achieved.

For a conventional ethane recovery scheme with the demethanizer operating at 400 psig, an increase to 500 – 550 psig would be necessary to maintain flow. Adequate heat input and separation efficiency are questionable at these conditions.

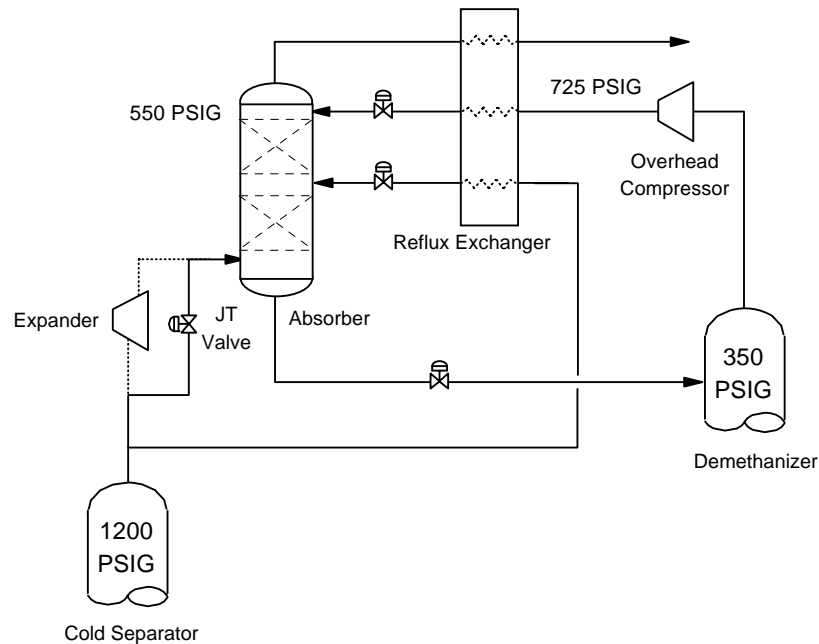


Figure 6 – Absorber-Demethanizer Area – HPA Process Ethane Recovery

Operating at an elevated pressure, the tolerance for carbon dioxide in the feed is improved in the HPA Process when compared to traditional ethane recovery schemes. Although the added margin to the freeze point is less than in the case of propane recovery, the HPA process can offer higher recoveries for the same CO₂ content when compared to traditional ethane recovery schemes.

CONVERSION FROM PROPANE TO ETHANE RECOVERY

Conversion from a propane recovery option to an ethane recovery option is readily achievable with the HPA Process. The primary reasons for this is that both schemes utilize a dual tower arrangement and an overhead compressor. The general process scheme, that is a dual tower process with high pressure absorber, is used. Changes to flow routing and some equipment additions are required to maximize heat integration and achieve the desired ethane recovery. Figure 7 shows the requirements for conversion to ethane recovery mode.

Ease of conversion from propane to ethane recovery is certainly enhanced if the prospect of this future conversion is known initially. With minimal pre-investment in the materials of construction, tower internals and valving future conversion is low cost and can be done with minimum schedule. The items listed below are required at the time of conversion:

- Supplemental residue gas recompression and cooling,
- New brazed aluminum exchanger for the demethanizer bottoms

- New brazed aluminum exchanger for the absorber intermediate reflux.
- Re-wheeling of the deethanizer overhead compressor.
- Piping required for additional equipment and flow re-routing.

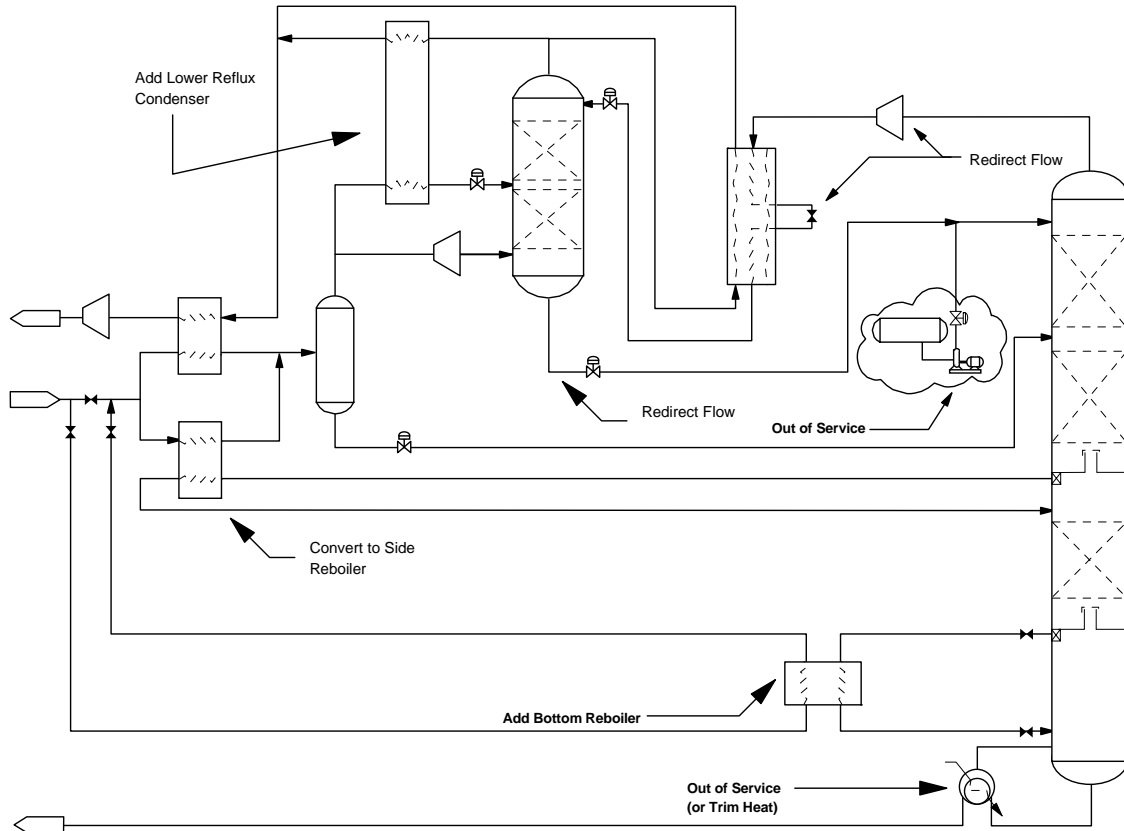


Figure 7 – Propane to Ethane Conversion

With the addition of more valving and piping the HPA process can be designed for dual mode operation, that is switching from ethane to propane recovery as market conditions dictate.

CONCLUSIONS

We have introduced a scheme suitable for the recovery of hydrocarbon liquids from natural gas at elevated inlet pressures (>1000 psig) and with or without high carbon dioxide content. The unique feature of this process lies in the pressure independence of the recovery tower (absorber) and the stabilizing tower (deethanizer/demethanizer). Each towers operating conditions are optimally selected to maximize the overall efficiency of the process. Benefits demonstrated include:

- Reduced overall HP requirements,
- Improved tolerance to carbon dioxide,
- Improved heat integration,
- Improved separation efficiencies and operating stability in the stripping column,
- Improved response/performance on loss of the turbo-expander and,
- Readily converted from propane to ethane recovery operation.