# Guidelines offered for choosing cryogenics or absorption for gas processing

Yuv R. Mehra, Thomas K. Gaskin Advanced Extraction Technologies Inc. Houston

Worldwide, the gas-processing industry meets a variety of economic and recovery objectives. These range from simply meeting a gas-transportation specification to achieving extremely high ethane recovery for providing feed to an ethylene facility.

Choosing a cost-effective processing technology requires consideration of a broad range of factors. With the recent commercialization of the evolutionary, enhanced solvent absorption process, it is timely to question the notion that "the cryogenic processes have replaced the absorption processes."

*Poco Petroleums Ltd.'s O'Chiese gas plant in central Alberta added a 60-MMscfd enhanced absorption NGL-recovery unit.*

For propane-plus recovery applications, use of a cryogenic "two-tower" design has intrinsic advantages at inlet-gas pressure levels greater than 1,200 psig. For lower-pressure gases, the total energy requirement for heat and compression for enhanced absorption is now equal to that of a comparable cryogenic process. Moreover, the enhanced absorption requires substantially lower compression.

For ethane-plus recovery applications, cryogenic processes are more efficient in the range of 60-85% ethane recovery. Enhanced absorption offers distinct advantages in terms of $CO_2$ tolerance and flexibility in choosing which product streams carry the $CO_2$ present in the inlet natural gas.

Both cryogenic and enhanced absorption processes must be carefully considered for any other applications because relative value and importance of other variables may dictate which technology to use for the most cost-effective facility.

The objective of information provided here is to allow rapid evaluation of how well a potential project's design basis matches available technology options. This process helps identify which hurdles must be overcome and evaluations completed before building a cost-effective plant for specific project objectives.

## Propane plus recovery

Early plants either circulated a heavy lean oil for recovery at ambient conditions or refrigerated the gas for heavier liquids knock-out without lean oil.

The lean-oil concept was significantly expanded in the later 1950s and early 1960s by refrigerating the circulating lean oils and using lighter oils to improve absorption efficiency. However, sponge-oil systems were required to reduce losses of lighter lean oils and to help maintain the molecular weight of the lean oil (Fig. 1).

Cryogenic turboexpander processes entered the commercial market in the 1960s with the initial designs having minimal heat integration and little or no reflux. Introduction of the Gas Subcooled Process (GSP) in the 1970s (Fig. 2) by Ortloff Engineers Inc., Midland, Tex., and use of dephlegmators by ABB Randall Corp., Houston (Fig. 3), were significant efficiency improvements.

Even though the cryogenic turboexpander processes were introduced primarily for recovery of ethane, improvements and options for propane-plus recovery have continued through the introduction of residue-reflux systems, two-tower systems (Fig. 4), such enhancements to the original GSP process as Recycle Split-Vapor (RSV) process, and the Delpro process.

In 1997, Advanced Extraction Technologies Inc., Houston, re-introduced through commercial utilization in Canada enhanced solvent-based absorption, incorporating improvements in the presaturation and chilling locations.

This incorporation allowed the use of lighter $C_5$+ NGL components as the preferred solvent (Fig. 5).

In the past 20 years, advances in the mechanical equipment utilized by all processes have led to improved efficiencies, including the use of plate-fin exchangers, higher efficiency expander-compressors, improved tray and packing designs, and more-flexible and accurate process-simulation programs.

## Evaluation variables

Primary variables that affect the choice of the most cost-effective process for a given application include: inlet conditions (gas pressure, richness, and contaminants), downstream conditions (residue-gas pressure, liquid products desired, and liquid fractionation infrastructure), and overall conditions (utility costs and fuel value, location, existing location infrastructure, and market stability).

## Inlet pressure

Expander-based cryogenic processes require a high inlet pressure to produce a desired tower top temperature for achieving optimal propane recovery. As such, to preclude installation of a refrigeration system, the low-pressure gases must be compressed.

For marginal-pressure cases, inlet-

Fig. 1

## REFRIGERATED LEAN OIL WITH SPONGE-OIL SYSTEM

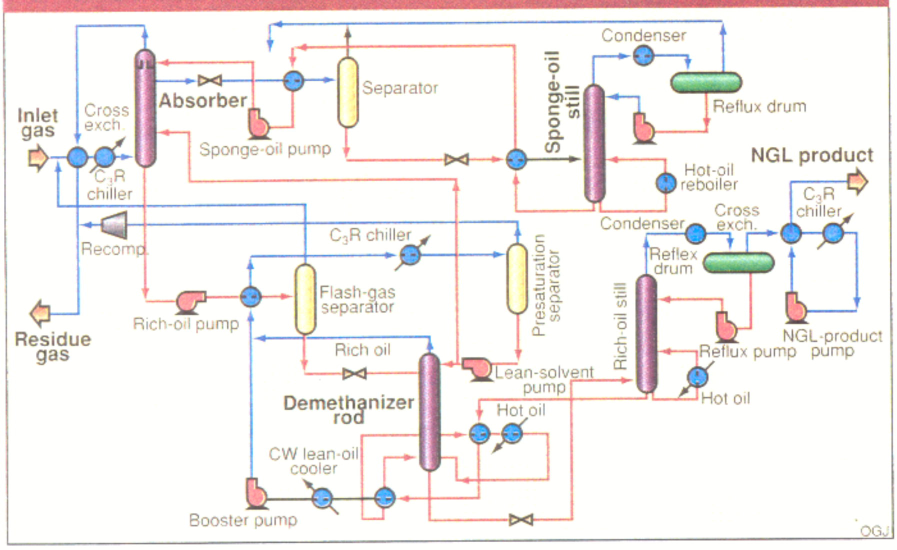
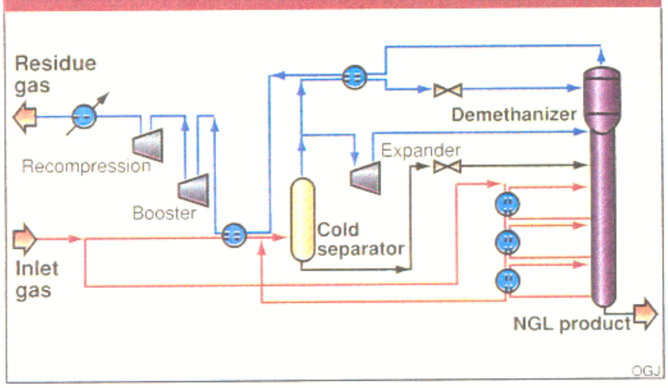



Fig. 2

## ORTLOFF GSP PROCESS




gas compression can be substituted via the use of pre-boost with expander energy, thereby eliminating a separate compressor service. Typically, an inlet pressure of greater than 750 psig is desired for most expander processes.

For inlet-gas pressures greater than 1,200 psig, the two-tower system has an intrinsic advantage of initial separation at higher pressures and subsequent de-ethanizing at lower pressure, thereby reducing the overall gas-recompression requirement.

Enhanced absorption performs well with a lower minimum inlet pressure (<450 psig) than cryogenics. In fact, operation at the lower end of its range improves performance by providing higher relative volatilities.

For inlet-gas pressures greater than 450-500 psig, enhanced absorption requires a dual-pressure absorber column consisting of high and low-pressure sections. The low-pressure section allows de-ethanization without exceeding critical conditions at the tower reboiler.

For inlet-gas pressures greater than 1,200 psig, enhanced absorption can still avoid critical conditions, but reduced relative volatility will reduce system efficiency.

### Propane recovery

Even with its low propane recoveries (typically 20-50%), a refrigerated low-temperature separator (LTS) system meets the minimum transportation needs of hydrocarbon dew point control for most gas pipelines. For higher propane recoveries, cryogenic temperatures or solvent-based absorption is required (Table 1).

More than 90% of propane is easily recovered from a typical gas stream. Propane recovery greater than 99% is possible with solvent systems or a two-tower cryogenic system.

Losses associated with use of inlet gas for reflux typically prevent a GSP plant from achieving 99% recovery. Recovery of butane-plus will be essentially 100%, however.

Enhanced absorption will achieve the 99%+ propane recovery, but with varying recoveries of heavier components depending upon the process configuration. Use of plate-fin exchangers and an inlet expander can allow an absorption plant to de-ethanize in a single absorber tower even with high-pressure inlet gas. Energy efficiency and solvent retention are improved by lower $C_5$+ k-values at the lower operating pressure.

Enhanced absorption will have higher $C_5$+ recovery and lower energy consumption than a conventional refrigerated lean-oil plant.

### Other factors

Richness of the inlet gas affects energy consumption of plants that employ refrigeration, typically the LTS and the absorption-based processes. Expander-based processes are adversely affected by rich gas when addition of an external refrigeration system is required because of large energy removal from the system in the liquid product and gas-cooling curves that deviate substantially from a straight line.

The need for fractionated liquid products can be important.

Without additional towers, the LTS and cryogenic plants will produce a single $C_3$+ product, while enhanced absorption will typically produce separate fractionated $C_3/C_4$ mixed and $C_5$+ products.

The enhanced absorption plant is additionally capable of producing an HD-5 propane stream at the top of the regenerator column. This can help unload a downstream fractionator and produce a fractionated propane product for local markets, thereby increasing netbacks.

Availability of existing facilities, such as slug-catchers, initial knock-out drums, and filters, reduce the cost of any new plant.

With the presence of an LTS, external refrigeration system is not required for a downstream cryogenic turboexpander plant.

An enhanced-absorption facility will benefit from an existing LTS by requiring no further dehydration or inlet-gas chilling, and operation of the existing de-ethanizer can be combined into the solvent system.

For propane-plus recovery, $CO_2$ freezing will not be a problem for any system. Removal of mercury, when present, will be required for systems that use aluminum plate-fin exchangers.

Remote locations often favor use of the simplest components and construction materials. As such, the requirement for stainless-steel metallurgy, high-speed expanders, and molecular sieves associated with cryogenic processes can be disadvantageous, especially with the use of stainless metallurgy in a saltwater environment.

Provisions for future ethane recovery are sometimes included in the design basis for a propane-plus recovery unit. Among deep propane-recovery designs,

Fig. 3

## ABB RANDALL DEPHLEGMATOR

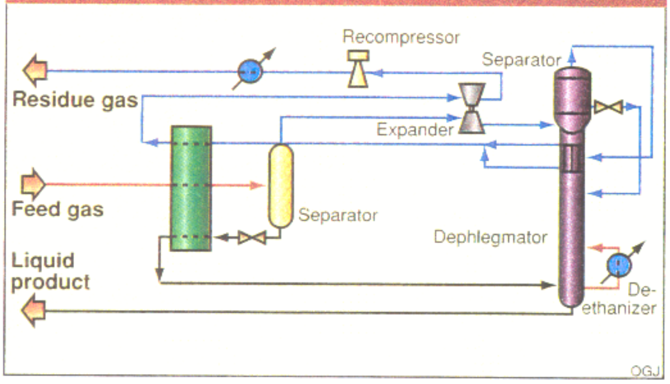



Fig. 4

## TWO-TOWER EXPANDER PLANT

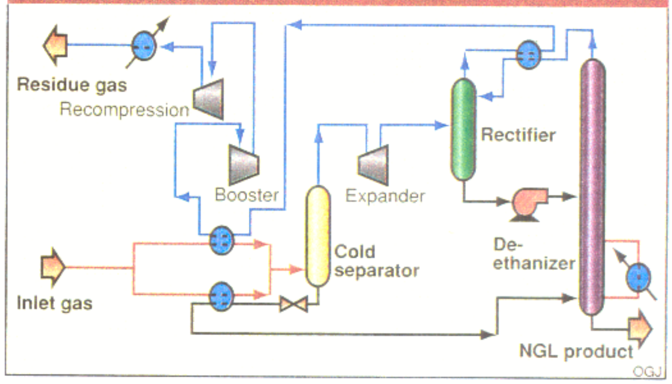



Fig. 5

## MEHRA PROCESS NGL TECHNOLOGY

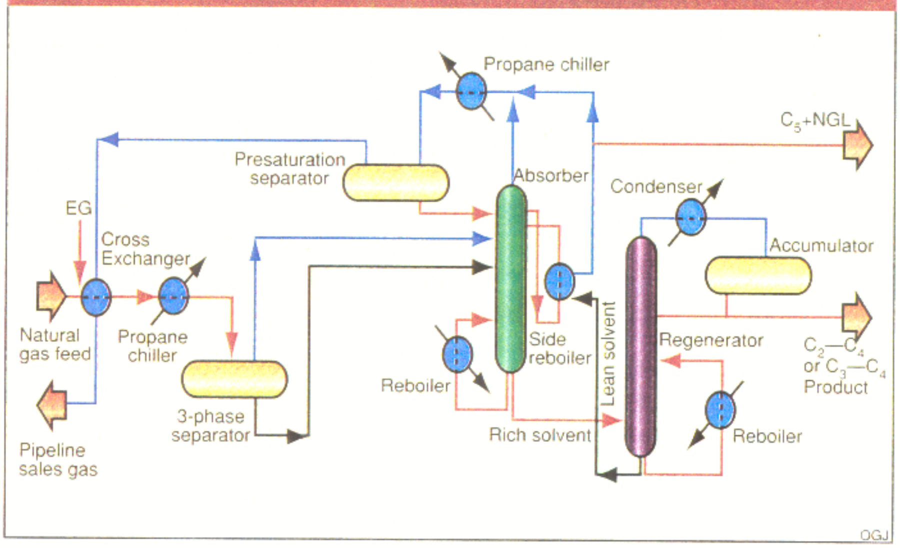



Table 1

## DESIRED PROPANE RECOVERY

| Propane recovery | LTS | Cryogenics | Enhanced absorption |
|---|---|---|---|
| 0-30% | Good | Inefficient | N/A |
| 30-80% | Cannot achieve | Inefficient | Efficient |
| 80-95% | Cannot achieve | Efficient | Efficient |
| 95%+ | Cannot achieve | Two-tower system | Efficient |

the two-tower system is the least suitable for incidental ethane recovery, with only 20-25% ethane recovery possible.

The GSP, residue reflux, and enhanced solvent-based designs are better suited for either intrinsic recovery capabilities or recovery through debottlenecking.

Utility and shrinkage cost bases are the same when gas-fired rotating equipment is used. When residue-gas value is high, process efficiency can be critical.

Since conventional refrigerated lean-oil plants are inefficient in comparison to cryogenic expander designs, absorption-based systems have been high fuel users. With improvements inherent in enhanced solvent absorption, total fuel consumption is essentially identical to that of a more-efficient, two-tower cryogenic system, whether on a fuel vs. percent-$C_3$ recovery or propane-plus product recovered (Fig. 6).

The total compression required for identical propane-plus recovered (Fig. 7) or percent-$C_3$ recovery (Fig. 8), however, is significantly lower for enhanced absorption when compared with the two-tower cryogenic system. Naturally, then, from initial capital and ongoing maintenance standpoints, a process requiring lower compression will generally be preferable.

In Figs. 6-8, comparison is based for an inlet and residue-gas pressure of 850 psig, with inlet gas containing 7.09 mole % (or 2.18 gal/Mcf) $C_3$-plus liquid content. The two curves for the enhanced-absorption process represent different molecular-weight solvent streams derived from the inlet gas.

## Application areas

Choosing the best process system for propane-plus recovery begins with obtaining a complete design basis with values for all streams and utility costs, along with the economic criteria to evaluate the options. Potential variations in the feed gas and pricing are equally important.

Table 2 summarizes ranges of variables discussed and identifies which process that range favors. This table can be used for initial screening and for learning what factors need further development before a process is selected.

Table 3 provides similar information but in the form of presenting an ideal case for installation of a plant of each design.

## Ethane-plus recovery

In contrast to the propane-plus recovery operations, ethane recovery is generally driven by product-over-fuel price differentials. Sometimes, there is a need either to purify methane as a chemical plant feedstock or to produce ethane as a dedicated feedstock for an ethylene plant.

These uses demand very different design considerations from those for recovering propane.

## Processes; variables

The slate of processes changes for ethane-plus recovery. The two-tower

Fig. 6

**TOTAL ENERGY FOR $C_3$+ RECOVERY**

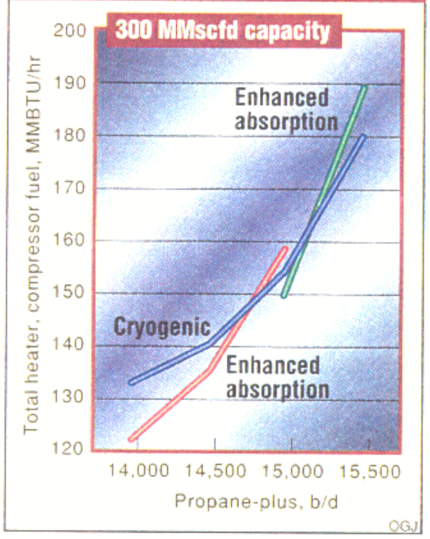
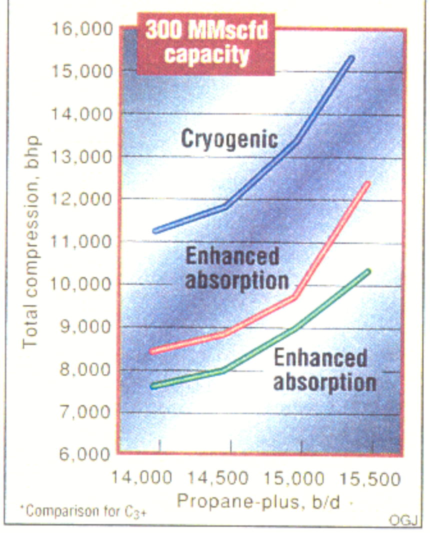



Fig. 7

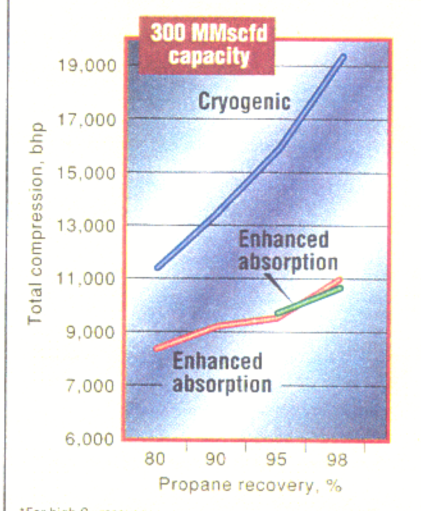
**TOTAL COMPRESSION***




*Comparison for $C_3$+

Fig. 8

**COMPRESSION REQUIRED***




*For high $C_3$ recovery

Table 2

**VARIABLE ADVANTAGE RANGE—PROPANE RECOVERY**

| Variable | Cryogenics | No clear advantage | Enhanced absorption |
|---|---|---|---|
| Existing facilities | — | No existing facilities | LTS |
| Pressure, psig | 1,200+ | 0-250, 450-1,200 | 250-450 |
| Propane recovery, % | — | 80-95 | 0-80, 95+ |
| Products required | — | $C_3$+ | Separate liquids |
| Water content | — | Medium/low | High |
| Gas richness | Low | Medium | High |
| Feed variability | Low | Medium | High |
| % $C_5$+ recovery | >85% | <80% | — |

system and the propane-refrigerated LTS are unsuitable for ethane recovery. The residue-reflux system is much better suited for the ethane-plus application than for the propane-plus recovery.

Both the GSP and the enhanced solvent systems are suitable for ethane-plus recovery. Although a conventional lean-oil plant can also accomplish high ethane recovery, it is too inefficient to consider.

All variables previously presented for propane-plus recovery equally apply for ethane-plus recovery. Specific to ethane-plus recovery designs, the impact of carbon dioxide in the feed gas, in the residue gas, and in the recovered ethane can be very significant.

In relatively few cases, the presence of nitrogen and/or helium can significantly affect the ability to recover ethane cost-effectively.

## Inlet pressure

The significance of inlet pressure for ethane-plus recovery is very similar to that for propane recovery. For inlet-gas pressures greater than 550 psig, a lower-pressure stripping section is required to complement the absorber in enhanced absorption and avoid operating at critical conditions within the bottom reboiler.

The two-tower cryogenic system holds an advantage at pressures greater than 1,200 psig for propane-plus recovery because propane can be substantially removed from natural gas in low-temperature, high-pressure separators operating in the range of 800 psig after initial expansion.

This is not possible for ethane recovery because a lower temperature is required, and the remaining gas (primarily methane) would become supercritical before substantial liquefaction of ethane. Therefore, any perceived advantage from high-pressure inlet gases held by cryogenics over enhanced solvent absorption no longer holds.

## Carbon dioxide

Carbon dioxide in the feed gas will normally split between the recovered ethane and the residue gas, potentially affecting specifications for both products. It can also freeze in the ethane-recovery process (Table 4).

Any process for recovery of ethane when carbon dioxide is present in the inlet-gas must either operate in a region that will avoid freezing and/or off-spec products or provide for carbon-dioxide removal from one or more streams.

Freezing within the recovery process can be reasonably predicted with a combination of data from the Gas Processors Suppliers Association (GPSA), process simulators, and related experience.

For high ethane recovery (> 85%), freezing in cryogenic processes can typically be avoided with inlet compositions of up to 1.0-1.25 mole % $CO_2$ by recovering the $CO_2$ in the liquid product. This approach avoids high concentrations at the top of the demethanizer, the coldest temperature point.

Additional reflux, either with higher residue-gas flow rates for the residue reflux designs or additional cold-separator vapor and some cold-separator liquid in the case of a GSP-type configuration, helps to avoid $CO_2$ freezing with only minor efficiency loss.

Potential freezing at the upper side reboiler should also be checked. For absorption processes, such as enhanced absorption, $CO_2$ freezing is not an issue because the minimum temperature in the process is greater than the freeze point of even pure carbon dioxide.

Processes recovering ethane will typically recover more than half of the inlet carbon dioxide in the recovered liquid when designed to minimize capital investment and operating costs for ethane recovery. As such, even minimal inlet $CO_2$ can lead to the need for liquid-product treating.

In a cryogenic expander plant, the demethanizer can be designed to reject

Table 3

## MOST, LEAST FAVORABLE CONDITIONS FOR PROPANE RECOVERY

| | | Pressure, psig | Gas richness | $C_3$ recovery | Existing facilities | Products desired |
|---|---|---|---|---|---|---|
| Cryogenics | Most | 850 | Low/med | 95-97 | None | $C_3$+ |
| | Least | 400 | High | <80% | LTS | Several |
| Enhanced absorption | Most | 400 | High | <80%, or 98% | LTS | Several |
| | Least | 1,400 | Low | 85% | None | $C_3$+ |

Table 4

## IMPACT OF $CO_2$ ON ETHANE RECOVERY

| Inlet $CO_2$ concentration, mole % | Cryogenic Problem | Cryogenic Solution | Enhanced absorption Problem | Enhanced absorption Solution |
|---|---|---|---|---|
| <0.2 | None | — | None | — |
| 0.2-1.2 | Liquid off-spec | Liquid treater | Liquid off-spec | Reject $CO_2$ into sales gas |
| 1.2-2.0 | Freezing | Inlet gas treater | Liquid off-spec | Reject $CO_2$ into sales gas |
| | Liquid off-spec | Product treater | | |
| 2.0+ | Freezing | Inlet gas treater | Sales gas off-spec | Choose treater location; gas or liquid product |
| | Liquid off-spec | Product treater | | |

Table 5

## VARIABLE ADVANTAGE RANGE—ETHANE RECOVERY

| Variable | Cryogenics | No clear advantage | Enhanced absorption |
|---|---|---|---|
| Inlet $CO_2$, mole % | — | 0-0.2 | >0.2 |
| Pressure, psig | 1,200+ | 550-1,200 | 250-550 |
| $C_2$ recovery, % | 60-85 | 45-60, 85-92 | 0-45, 92+ |
| Gas richness | Low | Medium | High |
| $N_2$, mole % | — | <2 | >2 |
| Water content | — | Medium/low | High |
| Feed stability | High | — | Low/medium |

Table 6

## MOST, LEAST FAVORABLE CONDITIONS FOR ETHANE RECOVERY

| | | Pressure, psig | $CO_2$, mole % | $N_2$, mole % | Gas richness | $C_2$ recovery | $H_2O$ |
|---|---|---|---|---|---|---|---|
| Cryogenics | Most | 850 | <0.2 | <0.2 | Low | 80% | Low |
| | Least | 500 | >3 | >2 | High | 95% | High |
| Enhanced absorption | Most | 500 | <1 | N/A | High | <45%, 90% | N/A |
| | Least | 1,200 | >2 | N/A | Low | 80% | N/A |

$CO_2$ overhead by using a warmer-than-optimal bottoms temperature provided that:

• $CO_2$ does not freeze in the tower.

• Residue-gas specification is still met.

• The added inefficiency within the system can be tolerated while maintaining ethane recovery and preferably avoiding the need for adding a refrigeration system.

Within enhanced absorption, the $CO_2$ can be rejected overhead without the concern of tower freezing. The additional heat will be an inefficiency to the absorption system; however, additional new equipment is not required, and the desired ethane recovery can be maintained.

Mild $CO_2$ removal from natural gas to meet a residue-gas specification can also be accomplished with enhanced absorption in conjunction with ethane recovery. This approach purposefully drives $CO_2$ into the ethane product, thereby allowing liquid rather than gas treatment.

This purification with greater than 2 mole % $CO_2$ in the inlet gas is not possible within a cryogenic plant because freezing will result at either the top of the demethanizer tower or at the side reboiler.

As indicated in Table 4, enhanced absorption offers the highest flexibility in the presence of $CO_2$ by making its freezing a non-issue and by allowing the choice either to recover or reject any amount of $CO_2$.

Conversely, a cryogenic ethane-recovery facility may require treating at more than one location.

### Ethane recovery

An enhanced absorption plant designed for high propane recovery can also recover incidentally about 45% of the contained ethane. In other words, the ethane will be co-absorbed without an increase in solvent circulation.

A cryogenic plant can also recover this low percentage, but doing so will be inefficient because the same low pressure required for high ethane recovery must be used to allow the demethanization of the recovered liquid while using inlet-gas heat for tower reboiling.

Ethane recovery in an intermediate range (60-85%) is the normal range for a cryogenic expander plant, and the process is at its best efficiency. While enhanced absorption can also recover in this range, such an operation is not optimal.

Somewhat higher ethane recovery (85-93%) is also possible with both processes. At these recovery levels, however, the cryogenic processes are approaching a more asymptotic energy region, and the residue reflux approach in most cases becomes more efficient than a standard GSP.

At greater than 93% ethane recovery, cryogenic processing becomes much more difficult because of the $CO_2$ content, the gas recompression horsepower increases significantly, and addition of a refrigeration loop often becoming preferable to the asymptotic increase in recompressor horsepower.

At these high ethane-recovery levels, enhanced absorption also has increased power requirements. But with enhanced absorption, it can be done without the addition of new equipment services. And, of course, there are no $CO_2$ freezing concerns.

### Inlet-gas richness

Lean gas is ideal for cryogenic turboexpander processes, and rich gas is ideal for the absorption process. With lean gas, the cryogenic processes see almost straight-line cooling curves, enabling efficient heat exchange and no potential need for external refrigeration.

As the richness of inlet gas increases, exchanger pinch-points appear, initially requiring only additional recompressor horsepower. With rich gas, an external refrigeration system will be required to complement cryogenic processing to avoid the exchanger pinch-points and to provide the energy to compensate for the relatively large amount of energy leaving the system as liquid product.

The efficiency of enhanced absorption is quite the inverse: rich gas simply makes the recovery easier, and the required refrigeration system is part of the infrastructure.

With exceptionally lean gas (such as gas exiting from a propane-recovery plant and with the need for ethane recovery desired to feed an ethylene facility), solvent make-up would be required, a debit for enhanced absorption.

## Other factors; application

The slate of desired liquid products, water content, and compositional variability of inlet gas, plant location, and feed-contaminants' impact is quite similar for ethane recovery as for propane recovery.

The presence of large amounts of light inerts, however, will affect ethane recovery more strongly in a cryogenic plant than in an absorption plant.

The light components interfere with the efficiency and the ability to condense the reflux stream within the cryogenic process. For the absorption process, the lighter components are no different than absorption of ethane away from methane.

For ethane-plus recovery, enhanced absorption offers the best flexibility for feed gases containing $CO_2$ and has no potential for $CO_2$ freezing. Cryogenic processes have a "sweet spot" design range in the ethane-recovery range of 60-85% at which they are at their best efficiency.

Higher ethane recovery is possible with both processes, but cryogenics meet their limits first, especially in the presence of $CO_2$. Rich gas favors absorption, while lean gas is preferred by cryogenics.

Tables 5 and 6 present summary information for the range of variables discussed that favor one process or the other and the preferred or best advantage range for each process, respectively.

## Ethane recovery, rejection

When ethane-recovery economics are based solely on a varying value margin between ethane's fuel value and its value as chemical feedstock, the ability to reject or recover ethane can become very important to annual profitability of a gas-processing plant.

The U.S. Gulf Coast is the primary world market that fosters the demand for ethane flexibility because of the extensive infrastructure that allows ethylene producers to switch away from ethane feedstock to a variety of readily available feedstocks.

## Processes

The processes for ethane recovery are all suitable for recovering less ethane when required. The degree of rejection available depends on the flexibility incorporated into the original design.

For cryogenic facilities, the ability to realign side reboilers is typically required; this allows reheat of cold-separator liquids before their entry into the demethanizer tower while still providing some tower reboiling from the inlet gas.

This alignment capability can be added to an existing facility with appropriate care given to line expansion and access in the tight quarters around reboilers.

Addition of external heat is often required, as the tower pressure would need to be lowered to aid in ethane rejection while still reboiling solely with inlet gas. Lower pressure is typically not possible due to recompressor capacity.

An under-loaded plant can have more recompression available, just as compression can be added after initial start-up of a facility; either situation will enhance ethane-rejection capability. Waste heat from recompressor turbines is the most common source of heat for cryogenic processes.

Often, demethanizer-tower bottom diameter limits the ability to reject ethane. This is the most difficult bottleneck around which to retrofit.

For cryogenic processes, ethane recovery-rejection can often swing from the design high-recovery levels to about 10% of the inlet ethane with some loss of propane recovery. Typically, the rejection possible is insufficient to allow the NGL product to meet ethane content of propane specification without downstream de-ethanizing.

Recently, additional modifications to Ortloff's processes were proposed by adding residue reflux on top of use of inlet gas as reflux to improve propane-plus recoveries while rejecting ethane.[1]

With enhanced absorption, propane-plus recovery can be maintained without recovering ethane. Total energy consumption is reduced when ethane is not recovered from a properly designed enhanced absorption plant, as compared to an increase in energy use when ethane is rejected from a cryogenic plant.

To reduce or essentially eliminate ethane recovery, the solvent circulation rate is reduced and absorber stripping section's heat input is controlled to meet the desired ethane content in propane specification.

Condensation of the debutanizer overhead becomes easier and required utilities are reduced when ethane is not recovered in an absorption plant.

## Application areas

The ability to design for flexible ethane recovery can be integrated into cryogenics or absorption. Both types of processes will require additional capital investment to allow for this flexibility.

Absorption will have a lower utility requirement when operated in ethane-rejection, making the operations decision to reject ethane easy when ethane value is low.

Selection of cryogenics must consider an increase in utility consumption, a realignment of exchangers, and a start-up of external heat before a decision is reached to reject ethane.

## Reference


1. Pittman, R.N., Hudson, H.M., Wilkinson, J.D., and Cuellar, K.T., "Next Generation Processes for NGL/LPG Recovery," 77th Annual Convention of the Gas Processors Association, Dallas, Mar. 16-18, 1998.


## THE AUTHORS

*Mehra*

*Gaskin*


*Yuv R. Mehra is president and chief operating officer of Advanced Extraction Technologies Inc., Houston, and was previously with the El Paso companies (1978-86) and Fluor Daniel (1975-78). He holds 27 U.S. patents and an MS (1973) in chemical engineering from UCLA. He is a registered professional engineer in Texas and California.*

*Thomas K. Gaskin is a principal process engineer with Advanced Extraction Technologies Inc. and previously was lead process engineer for ABB Randall (1992-98) and senior process engineer for Shell Oil Co. (1977-92). He holds a BS (1977) in chemical engineering from Clarkson University, Potsdam, N.Y., and is a registered professional engineer in Texas.*