THINKING OUTSIDE THE BOX

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ABSTRACT

Nitrogen Rejection Units (NRUs) are becoming essential to the natural gas value chain as increased nitrogen levels, in associated gas produced from oil wells, jeopardize pipeline and liquefaction specifications. Creative solutions outside of the conventional approach provide capital efficiency and operating flexibility.

This paper provides insight into the development of nitrogen rejection projects from the perspectives of the operating company and the technology provider. Guidelines from the operator to determine the best infrastructure configuration, develop the design basis, and select the right technology based on product specifications provided. Additionally, the technology provider offers strategies for sound NRU design, fabrication and commissioning.

OPERATOR GUIDELINES

Introduction

A rapidly changing marketplace has presented many challenges for the midstream operating company. Over the course of the last twenty years, the development of various shale plays has contributed to a variety of creative solutions for processing gas and delivering the gas commodity to a point of sale. Moreover, as the trade deal with the European Union (EU) begins to take shape with the EU commitment to purchase $750 billion in US energy, a heavy exportation of US LNG is anticipated. As a result, compliance with inert gas specifications as mandated by LNG markets will be required by all operators. More specifically, this discussion will focus on the removal of nitrogen as an inert gas to meet conventional pipeline specifications.

As an operator with significant infrastructure and multiple processing facilities, the approach to enhance capital efficiency and operating flexibility was accomplished by analyzing the available Nitrogen Removal Unit (NRU) technology and strategically integrating the NRU into the overall system.

Project Outline

Various gas gathering areas within the Permian Basin have continued to produce elevated levels of nitrogen. When aggregated at the NGL Recovery plants (the Cryo Unit) this results in average values for nitrogen content in the residue sales gas exceeding various point of sale specifications for inert gases, which includes nitrogen. This trend has held steady throughout several years, and with the prospect of tighter downstream market sensitivity to nitrogen (i.e. LNG Exports), the need for nitrogen treatment to maintain sales has increased.

While the range of nitrogen in the sales gas streams varies, averages range from 4-5 mol%, for a specific market area, with target sales requirements at <3 mol%. When evaluating how to strategically utilize NRU technology to achieve these goals, various options were considered for size, placement, and interconnectivity with the Cryo Unit, which consists of multiple individual trains. Summarizing some of the options evaluated:

- Full treatment of the entire sales gas stream – considered cost prohibitive due to equipment size, with no benefit for "over-treating" beyond the target sales requirement of 3 mol% nitrogen.
- Treatment at each individual plant – considered cost prohibitive due to space and multiple non-standard design sizes.
- Slip, or bypass-and-blend, stream treatment – ultimately chosen for ability to provide consistent flow to a single design NRU.

An objective approach was taken to evaluate the NRU technology provider for engineering, design and fabrication of the NRU package. The midstream industry NRU technology providers offer several varying designs with both subtle and obvious differences. The general industry reputation from operators is that NRUs are difficult to run consistently and maintain product specifications while also minimizing methane losses. Add to this the complexity of potential looming environmental regulations and taxes on methane emissions and the importance of a reliable, easy to operate unit cannot be understated. With the advent of installing an NRU at the tail end of multiple Cryo Units, operator's best chance for success is to mimic standard cryogenic gas plant operations as much as possible.

- Multi-pass core heat exchangers can be difficult to operate and manage subtle process changes when compared to conventional heat exchangers. Many NRU packages are designed for a small footprint and contain stacked equipment modules and internal equipment that cannot be observed or traced out by operations. A Joule-Thomson self-refrigeration rather than external refrigeration systems, and managing a lean reflux, add to the complexity of operating these systems. When combined with the sensitive nature of the typical NRU design to small changes in inlet gas feed rate and composition, the lack of intuitiveness and transparency in the NRU operation makes it imperative to provide operations with as much information and resources as possible to effectively run the system in the context of a larger gas plant. The extent to which a technology provider can provide operators with the transparency, information, procedures, and training necessary to operate the NRU was considered the greatest determining factor in selection of the NRU technology provider. Emphasis was placed on providing adequate operational data and information to perform effective troubleshooting, diagnosis, and mitigation by operators familiar with typical cryo plant equipment.

- Compression was another key consideration in the evaluation. A Reliability, Availability, and Maintainability (RAM) study was conducted and found that nearly 40% of the issues associated with operation of the NRU revolved solely around compression. The available NRU designs offer several options for how compression is utilized, often requiring three separate “services”. Simplicity was prioritized to enhance operability. By eliminating interstage services utilized for process exchange, reducing this to only two services (a feed pressure boost service, a re-compression service), reliability of compression operations was enhanced.

SELECTION GUIDELINES

There are many ways to remove nitrogen from a gas stream. Generally, the technologies used to accomplish this are as follows:

- Membrane Separation
- Pressure Swing Absorption
- Cryogenic Distillation

Membrane Separation

For membrane separation, a semi-permeable membrane is used to separate gases based on molecule size or diffusivity. This is used for bulk removal for nitrogen content and works better for nitrogen content above 15%. The advantage of this system resides mainly in the fact that it does not involve intricate equipment components and is very simple in terms of operation and maintenance. However, it is not ideal for polishing nitrogen to low levels and often has high methane losses in the permeate stream contributing to emissions and loss of profits. It also requires large amounts of compression and recompression.


Figure 1. Membrane Skid

Pressure Swing Adsorption

Pressure Swing Adsorption (PSA) is also used for separating nitrogen from natural gas. The PSA process relies on the principle of adsorption, where specific gas molecules adhere to a surface under controlled pressure and temperature. The process involves alternating high and low pressures to enable adsorption and desorption cycles. PSA systems typically include molecular sieves as the medium where gas molecules adhere and detach based on controlled pressure variations. This technology also suffers from a similar disadvantage in that methane losses tend to be higher than desired. It is also difficult to scale up the size of the equipment and requires much compression.

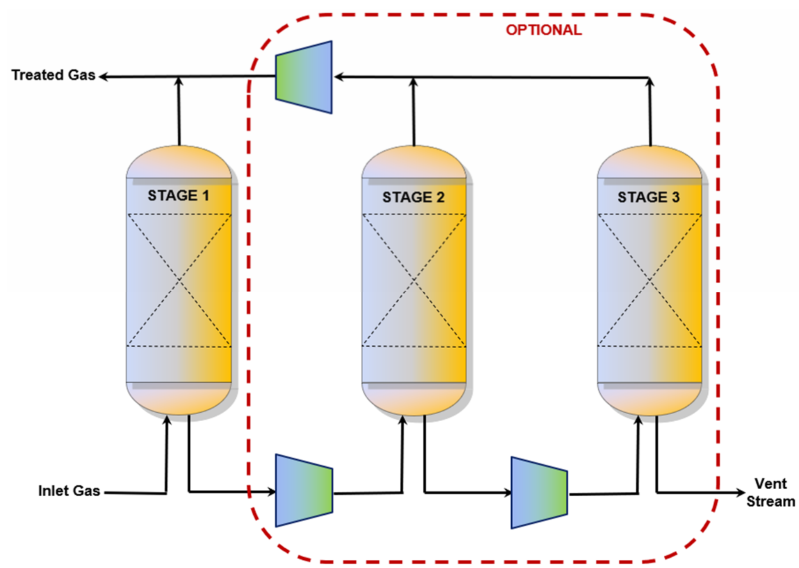

Figure 2. PSA Flow Schematic

Cryogenic Distillation

Cryogenic distillation more commonly referred to as Nitrogen Rejection Unit (NRU), is almost always the only technically and commercially feasible process solution for nitrogen removal from natural gas of moderate to high nitrogen content as it consumes far less power per unit of gas processed, to meet product and vent product specs. An NRU can use a relatively simple process when designed as a stand-alone unit configuration, is reliable, flexible in maintaining product specifications even with varying feed composition and, importantly, is environmentally the best approach for emissions control. This technology will be the focus of further discussion. Below is a rendering of a cryogenic distillation process for removal of nitrogen from a natural gas stream.

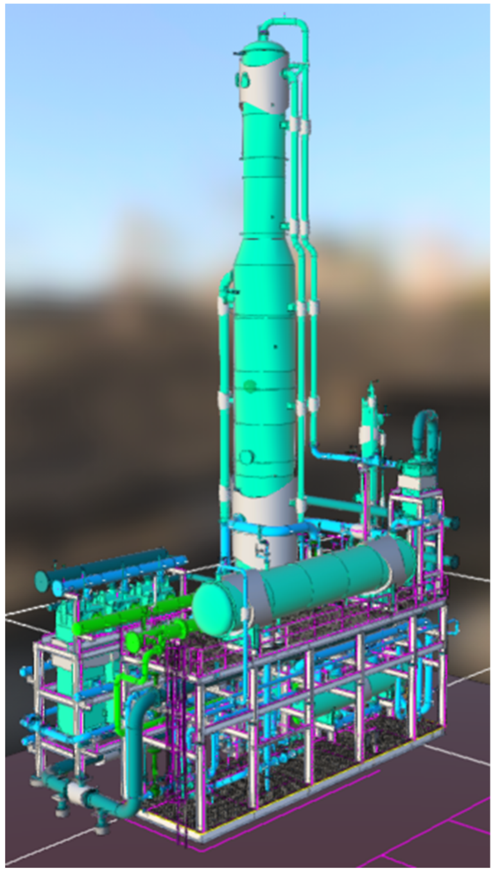

Figure 3. NRU Rendering

NRU GUIDELINES

<u>Design Concepts</u>

The NRU utilizes cryogenic temperatures to separate gases based on their boiling points. Depending on the inlet gas pressure, the nitrogen removal from natural gas is achieved via the refrigeration provided by the pressure expansion, via an expander or a JT valve, with efficient heat integration which produces the cryogenic temperatures that allow the liquification of feed gas stream. This liquified stream is then fed to the distillation column that is used to separate the lighter nitrogen component from the rest of the stream. The methane rich liquid product from the distillation column is utilized as a refrigerant for cooling inlet gas as well as providing the distillation condensing duty requirements. The reflux system is used to help maintain low methane content in the nitrogen vent stream. A typical design specification for methane content out of the vent is less than 1.0 mol%. A robust reflux system can easily manage the amount of methane in the vent stream.

Typical specifications for inert components (i.e. carbon dioxide, nitrogen) in a gas pipeline is less than 3.0 mol%. The specification for LNG is more stringent at less than 1.0 mol%. This specification can be met with a single or dual column design, and the selection is typically governed by the nitrogen content in the feed gas stream.

If the process gas stream contains more than 25.0 mol% nitrogen, a single column is the best option for enhanced efficiency, simplicity, and cost effectiveness. It may also be the right solution for moderate nitrogen content with less than 25.0 mol% nitrogen if the capacity is low and the operation prioritizes simplicity and cost effectiveness over enhanced efficiency. Below is a typical process flow diagram (PFD) for a single column design.

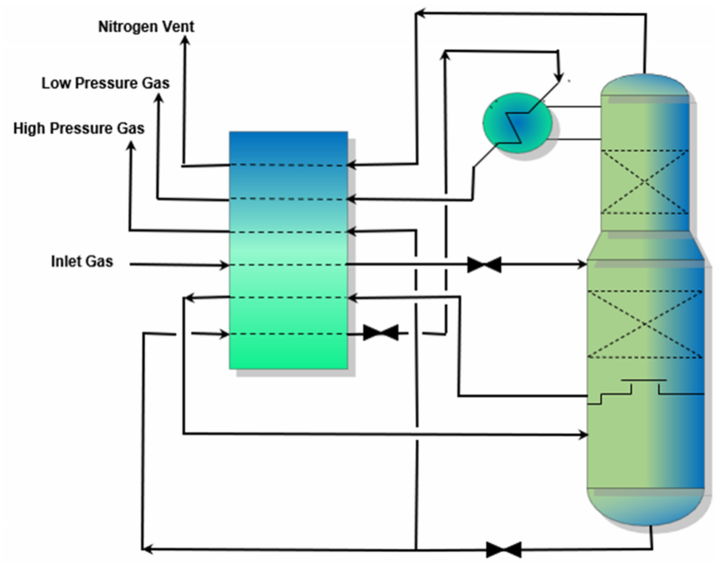

Figure 4. Single Column PFD

A dual column design should be considered if the process gas has nitrogen content levels lower than 25.0 mol%. If efficiency and power savings are critical to the operation, then this design should be implemented even though there are additional complexity and equipment resulting in higher front-end cost, enhanced performance promotes CAPEX savings overall due to lower compression power requirements. A simplified PFD of the dual column system is displayed as follows.

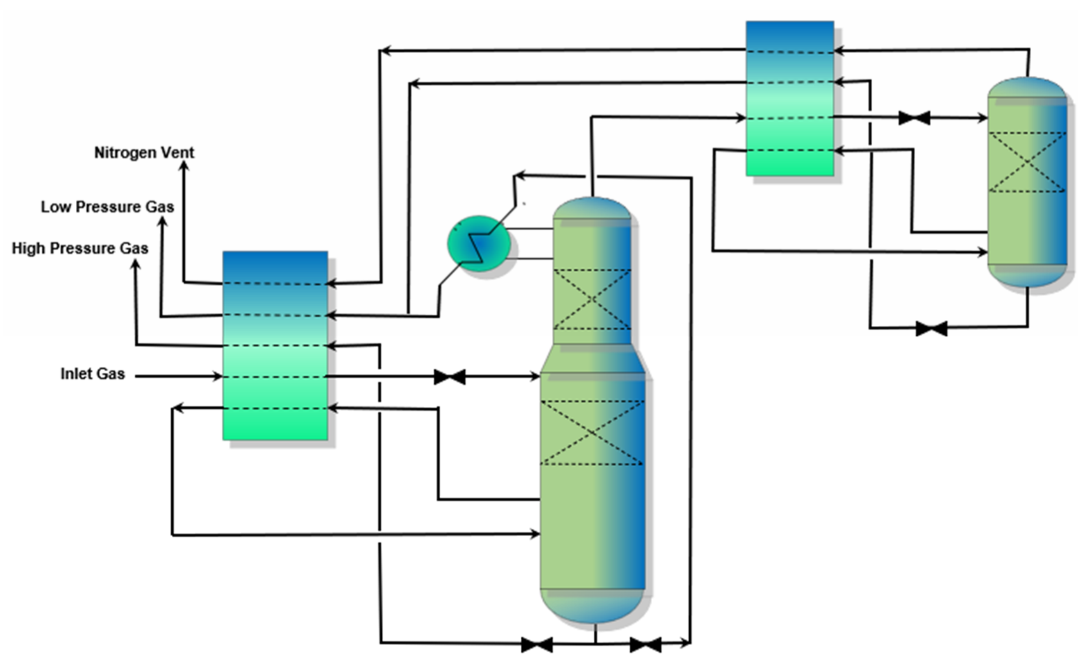

Figure 5. Dual Column PFD

Strategic Placement

The NRU can be strategically placed in a variety of different locations relative to the greater processing facility. It just depends on the existing infrastructure and the most efficient method for integrating the NRU system or if it is a greenfield installation.

A natural fit is just downstream of the multitude of Cryo Units based on the GSP and RSV standard cryogenic packages installed in the Permian Basin. This is what is defined as residue gas, essentially, the feedstock to the NRU package is rich methane residue gas. As there is most likely a two-stage residue compression package, the recommended split to feed the NRU is from the interstage compression to provide a high enough pressure and, ultimately, substantial expansion through the JT effect. It is unlikely that there would be enough cooling produced from pulling directly off the discharge of the expander-compressor. An example of this configuration is shown as follows.

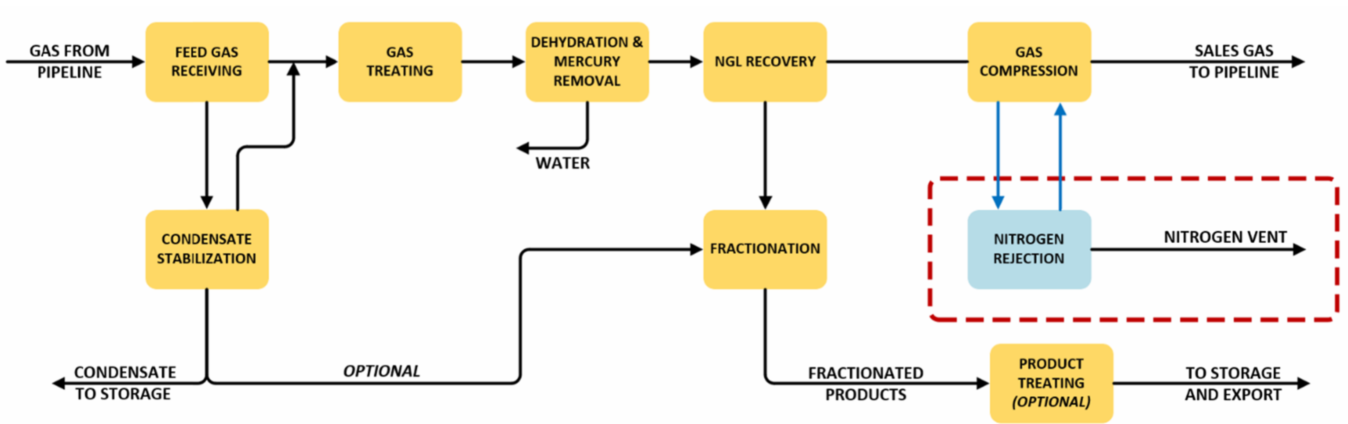

Figure 6. Existing NGL Plant Configuration

For greenfield opportunities, heat integration with the Cryo Unit can provide higher efficiency and optimize overall energy consumption. It is not often that this option is available given the maturity of the gas gathering and processing infrastructure in the US. However, in the international marketplace, this can be a more viable option. An example of this configuration is shown.

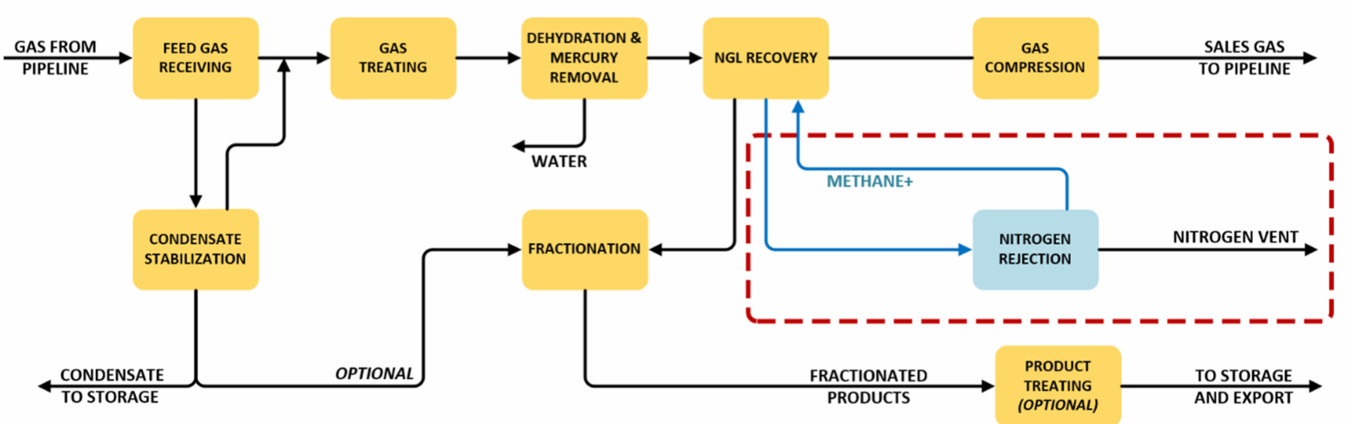

Figure 7. Greenfield NGL Extraction Configuration

Fabrication and Assembly Concepts

Historically, the equipment for many of the NRU’s installed has been enclosed in a metal structure or “Cold Box” with perlite insulation surrounding the equipment and piping. The idea is to minimize heat losses given the ultra-cold temperatures, and a plug-and-play installation at the construction site. For low-capacity installations, this is the recommended approach. The disadvantage of this method is evident as the operation logs run time. There is less ability to troubleshoot control variables such as levels. Since there is no visual on a level gauge, 100% trust is placed on instrumentation. Additionally, the purge system on the box is monitored continuously. However, if hydrocarbons are present in the purge stream, and a leak is detected, there is no easy way to determine the source of the leak because of restricted access. Even if the leak is found, and perhaps the culprit is the BAHE, it is very difficult to blank out the pass responsible for the leak. It is a confined space, and difficult to move around inside of the box. Sometimes the best solution is to cut the BAHE piping and pull it out of the box for repair. Though, this procedure contributes to an extended shutdown and loss of revenue.

As the applications become larger for NRU’s, a more conventional method has been adopted to limit the problems existing with the original Cold Box fabrication concept. In this case, the equipment, piping and instrumentation are assembled on modular skids without any enclosure. The distillation columns and piping are insulated with thick, cold pipe insulation, replacing perlite. The distillation columns are block mounted, or skid mounted depending on the size. The instruments are terminated into a junction box, and the instrument tubing is also run for on skid components. The reflux accumulator is pulled from the integral position within the distillation column and placed on skid which allows for visibility in reflux flow measurements resulting in better control of the methane emissions. Cold reflux pumps are necessary in this configuration, however cold service pumps are a proven technology being heavily used in the LNG market. Another major change is the installation of the BAHE on a stand-alone structure. The BAHE including the reflux condenser is insulated and set on micarta and beam with guides for thermal expansion. With this fabrication concept, trouble-shooting the operation is much more efficient given the ability to visually observe instruments and determine the source of leaks and, as mentioned previously, it gives the operations team a design that essentially the same setup as a typical standard Cryo Unit. Here are a few pitfalls to avoid when considering this method.

- The insulation must be designed to accommodate the ultra-cold temperatures. Much care must also be given to sealing the insulation. If an anomaly exists in the seal, an ice ball is likely to form.
- The piping design should be rigorous and include thermal expansion which may create a more elaborate pipe run with structures and guides beyond what an experienced pipe designer may allow for.
- Delivery of the BAHE and cold reflux pumps will likely set the overall timing for execution of the project. It is important to develop detailed design for these two components as soon as possible for the sake of providing the vendor with the necessary information for review and ultimately issuance of a purchase order.

Equipment Design Considerations

Robust equipment design is contingent on a well-developed design basis. For optimal flexibility in operation, it is important to gather the right team including commercial, technical, and operations personnel. The commercial aspects should be well outlined, because without a commercially sound contract, there is no project. The technical subject matter expert will be able to discern from a theoretical perspective if the commercial idea is feasible. Finally, the operations expert will be able to place a commonsense factor for the overall functionality of the project. By and large, operations must run the facility day to day. They must buy into the idea and apply hands on experience for executing a project. This collaboration will make for the most thoughtful and flexible design.

Distillation Column

A robust distillation column design is crucial to the operation of the NRU. Distillation design begins with generating vapor/liquid rates and ensuring the CO_2 content in the feed is at 50 ppm or less to eliminate the potential ice formation. CO_2 freeze can lead to operational difficulties including high differential pressure in the distillation column and heat exchangers. This is due to ice formation upon tower internals or in the passes internal to the BAHE.

Once the design case vapor/liquid rates have been established, the rates and phase properties can be input into a rigorous simulator to determine column design. Various process simulators have an internals' rating function embedded within the simulator which can be helpful but should always be verified with an alternate rating program measured against practical experience. Column diameter is dependent on the type of internals selected for the application and the respective hydraulics produced from this selection.

Random Packing is often used in NRU column design. It provides a column size and functionality that is acceptable in operation. The smaller diameter helps manage total CAPEX for the project so the decision to go with random packing is a more economic approach. Typical turndown for random packing is in the region of about 3:1. When designing a packed tower, a packing flood of 80% with a conservative system factor of 0.9 should be targeted. It is also important to design the distributors properly. A well-designed column distribution assembly ensures efficient operation, minimizes pressure drop while enhancing the overall performance of the separation process. The packing material is typically aluminum, and the distributors are made of stainless steel. These internals should be designed in tandem with a trusted internals supplier.

Valve trays are selected when performance across a broad range of operating conditions is desired. Valve trays can be designed with weighted valves which can adjust to vapor and liquid flow rates as conditions change. This makes them flexible for fluctuating loads. The weighted valve also helps prevent weeping at lower flow rates which contributes to better turndown ability. Typical turndown for valve trays is 5:1. Additionally, the valve tray design tends to be more resilient to fouling which reduces the potential for maintenance. The major downside of valve trays is manufacturing and maintenance costs. The valve tray design generally yields larger diameter to accommodate vapor and liquid traffic, so this adds to overall CAPEX. Over time, the valve movement can cause wear the tray deck requiring inspection and potential replacement.

Below is a rendering of the distillation columns for an NRU.

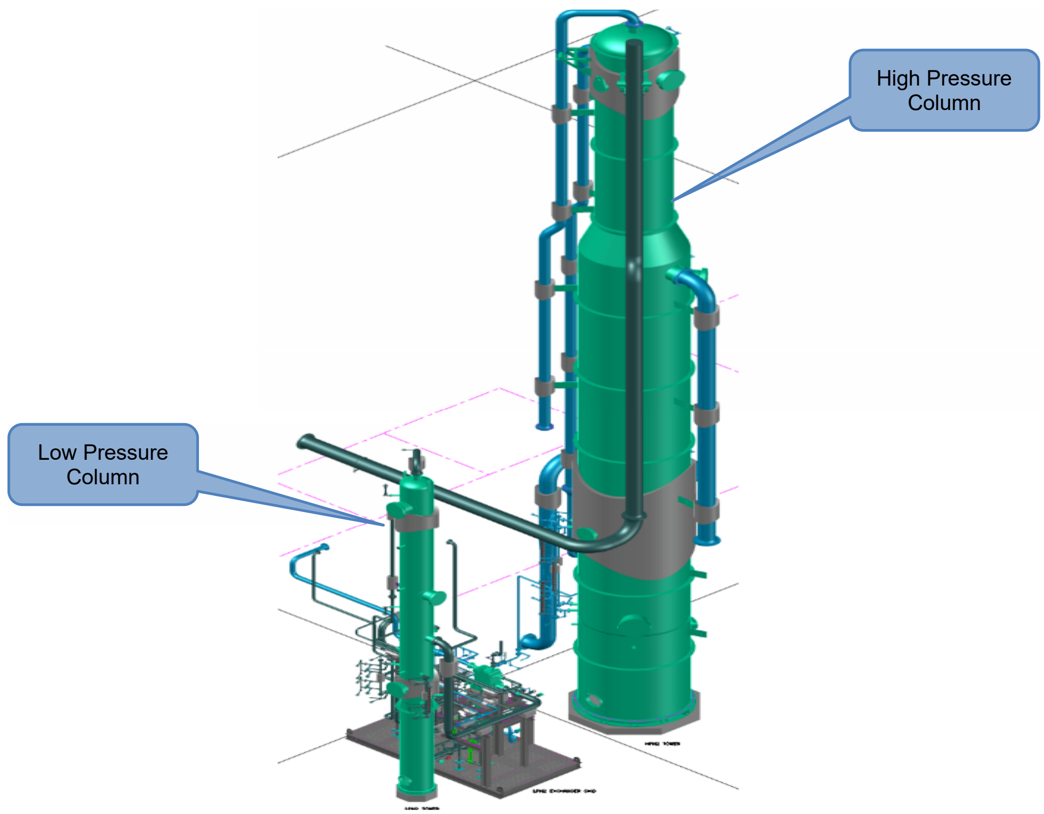

Figure 8. Distillation Columns

<u>Brazed Aluminum Heat Exchanger</u>

Brazed Aluminum Heat Exchangers (BAHE) are the standard for heat transfer in NRU applications. They are highly efficient and compact which allows them to be installed in limited spacing. They have higher overall heat transfer coefficients compared to shell-and-tube exchanger designs. This facilitates tight approach temperatures while maintaining a compact and economical design. Due to reduced pressure drop through exchanger passes, lower overall energy consumption is achieved by optimizing compression horsepower requirements. It also directly affects operating costs by reducing connected horsepower. They are engineered for temperatures as low as –320 °F and pressures as high as 2000 psig which makes them ideal for cryogenic service.

Fouling can occur when particulates build up on the heat transfer surfaces, impeding flow and reducing thermal performance. Due to the very small, closely spaced channels that are inherent with the exchanger design, even a small number of particulates can cause a significant rise in pressure drop and reduce heat transfer efficiency. It is, therefore, critical to have good upstream filtration to prevent fouling long term.

BAHE design begins with a robust design basis simulation. Once the temperature profiles have been established, it is important to work with an exchanger supplier to develop the best exchanger design possible. The exchanger is susceptible to thermal shock, so it is important to limit the temperature difference from pass to pass. It is normally limited to about 50-70 °F temperature difference with adjacent passes, depending on the stream phase. It typically takes a few iterations with the supplier to perfect the temperature profile in the simulation. Here is an example of what a BAHE with a multi-core configuration.

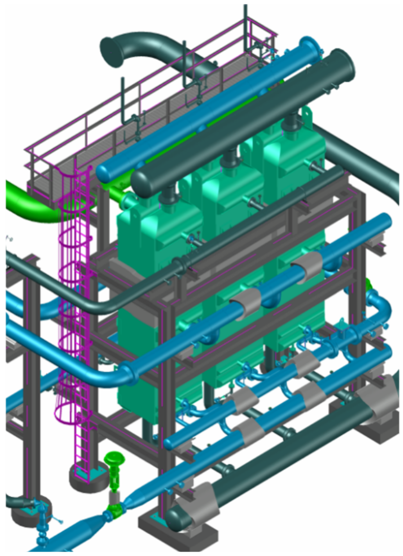

Figure 9. Brazed Aluminum Heat Exchanger

Reflux System

Reflux is used in a distillation column to enhance separation efficiency. The vapor – liquid contact allows a wash of key components to refine the exiting vent stream, limiting undesired content and control column temperature profiles. For the NRU, controlling methane in the nitrogen vent gas is crucial. Since the nitrogen vent stream exits to atmosphere in most cases, it is important to limit the methane gas to reduce methane emissions. A common specification of methane in the vent gas is less than 1% methane. This specification can be met if reflux is available.

The major equipment components of a reflux system include centrifugal reflux pumps, condenser, and reflux accumulator. The condenser cools and partially condenses the tower overhead vapor stream to create a stream mixture composition capable of washing the methane. The accumulator collects this two-phase mixture and directs the liquid to the top of the column via reflux pumps.

The reflux pumps are used to overcome pressure drop and elevation changes. Pumps maintain a stable and adjustable reflux flow to help achieve a desired reflux ratio under various conditions.

There are several cryogenic reflux pumps available on the market. It takes time to work through the proper pump design to make sure the best technology is utilized for the desired application. For example, sealless pumps are available for cryogenic service and effectively reduce maintenance issues. Using the sealless pumps simplifies the maintenance and eliminates other utilities required to maintain the seal. It is also important to note that the pump could require a heating fluid as part of the design. This should be taken into consideration and applied during the front-end engineering design (FEED). The following is an example of a reflux pump and skid.

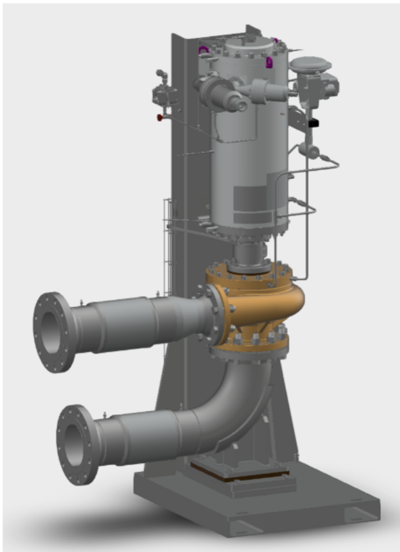

Figure 10a. Reflux Pump

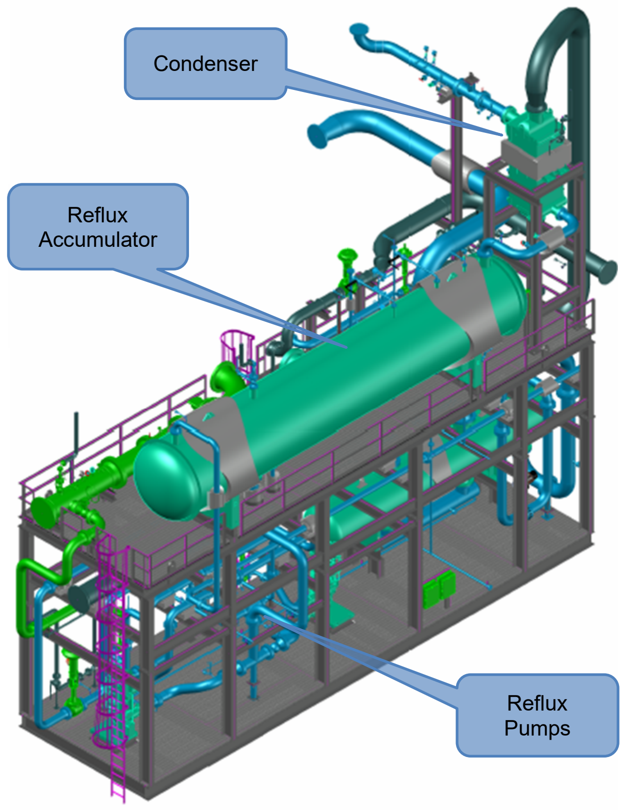

Figure 10b. Reflux Skid

Compression

Compression is integral and a key factor to the NRU operation and design. Compression allows for the proper pressure differential through the process to create the desired expansion, for low inlet pressure scenarios, producing the necessary cooling for nitrogen separation. It also boosts the pressure of the portion of the rich liquid methane stream after it has been letdown and used to provide the distillation condensing duty. This compression step allows the low-pressure methane stream to comingle with the remainder of the rich methane stream and directed back into additional compression stages or the residue sales market.

It is a balance to determine the right pressure profile across the processing unit. The compression requirements can be optimized through process simulators to help identify the right combination of inlet compression versus low pressure take away compression. The compression is defined based on the project requirements, feed conditions and capacity together with the product specifications. The NRU technology needs to be flexible in process variable changes to ensure the compressor system is designed effectively and to mimic the operation as much as possible as that of a typical residue compression package.

Multi-stage reciprocating compressors are suitable for high compressor ratios and small to medium flow rates. Centrifugal compressors are ideal for large throughputs in NRU applications but require surge control.

Construction and Startup Considerations

Careful installation and commissioning of the NRU can eliminate problems in operation as the unit is placed online and is expected to run without interruption. Cleanliness is likely the most critical factor when considering what must be done to prevent future issues. Best practices include blowing and scrubbing all piping to be installed particularly in and around BAHE service. An air compressor can be used to blow out large debris from piping as the fit up is ongoing. Additionally, and in conjunction, a pillow and rope can be used to scrub piping as it is flanged up. Startup screens for each BAHE pass are highly recommended to capture any particulates that may have slipped in without notice.

After startup occurs, the differential pressure on BAHE passes should stay within limits of the design basis. Typical pressure drop for these passes usually ranges between 3 and 5 psi, with some liquid services to have 1 to 2 psi. It is important to have instrumentation that gives accurate data for troubleshooting purposes. For example, if the differential pressure transmitter indicates a high differential pressure, >5 psi, for any given pass, there could be particulates that slipped into the BAHE. It is not uncommon to shut down after startup to back blow the exchanger passes to remove any debris present. Therefore, it is important to have a selection of burst plates available for back puffing should this activity be required. Burst plates at 25 psi, 50 psi, and 75 psi are usually sufficient for the procedure. Connections should be installed on the BAHE lines that allow reverse flow for back puffing. A jumper from fuel gas or the residue gas line can be used as the source. A substantial flow rate is not required.

It is also recommended to have spare screens just in case they are damaged during startup. In many cases, startup screens are left in as a permanent fixture and this is fine because it is good insurance for potential future plant upsets.

Another culprit contributing to potential problems is piping hydrotest water. It is difficult to completely remove hydrotest water once the piping has been installed and the process is pushing gas through the individual equipment components. It can add much time to the purging process because the dewpoint of the outlet purge gas will have to meet a bone-dry specification before the NRU can be placed online or risk water freezing in the various system circuits. It is recommended to pneumatically test the piping and components as much as possible to limit the entry of water. In addition, a proper dry-out procedure needs to be implemented to ensure that moisture is removed from the unit.

Lube oil can also create operational issues. Lube oil may enter the NRU as a result of entrainment from the lube oil system associated with inlet compression. It is necessary to have an efficient filter coalescer upstream of the NRU to reduce the chances of lube oil entry. A backup filter coalescer is recommended to run in parallel so there is a coalescer in service even when the filters are changed out. Bypassing the coalescer is never advised unless there is a sufficient backup.

One of the final steps done as part of the installation is inspection of the tower internals. The tower will require a good air purge for the work to be done inside the column, so the necessary equipment will need to be on hand to perform the inspections. A crane with a man basket and utility trough are suggested to move people and materials in and out of the towers with ease. An air compressor will also be needed in tandem with an air mover so that air can circulate. The air mover is placed on the bottom manway with entry into the column through the top manway. Be sure to have extra manway gaskets on hand to prevent any delays from flanging up. The inspector will confirm hardware related hold downs are in place, distributors are intact, and no damage to support rings or weld ins is visible. The inspection should yield pictures of the internals with a formal report indicating readiness to startup.

Finally, after the column inspection and control loop checks are completed, the purge and leak test process can be initiated. The purge procedure usually involves a three-step process. The first step is to pressure up to about 25% of the operating pressure, hold pressure for about 1 hour to check for leaks then blow down to low pressure (10 psig). For the next step, the system is pressured up to about 50% of the operating pressure, held for about 1 hour, again to check for leaks, and then blown down to 10 psig.

The final step is similar, with the adjustment of pressuring up to 100% of the operating pressure. The nitrogen vent is used for blowing down the system in each iteration.

Once the purge and leak test process is complete, first gas can be fed slowly to the NRU, confirming that water dew point is monitored all the while. It may take several days of sweeping gas through the system to meet the water dew point specification. After meeting water due point, the NRU is ready to cool down.

In conclusion, the integration of Nitrogen Rejection Units (NRUs) into the natural gas value chain is crucial for meeting pipeline and liquefaction specifications, especially with the increasing nitrogen levels in associated gas from oil wells. This paper has highlighted the importance of creative solutions that enhance capital efficiency and operational flexibility. By examining the perspectives of both the operating company and the technology provider, we have outlined key guidelines for determining the best infrastructure configuration, developing the design basis, and selecting the appropriate technology. As the global energy market evolves, particularly with the anticipated heavy exportation of US LNG to the European Union, compliance with inert gas specifications will become even more critical due to the potential demand. The insights provided here aim to guide operators in effectively integrating NRUs into their systems to ensure compliance and optimized performance.