THE RENAISSANCE OF NRU TECHNOLOGY

Mathew Watt, Chart Industries, considers the basics of cryogenic NRU technology, as well as different process design aspects that should be considered for specific efforts. He also discusses the different equipment used in cryogenic NRU facilities, alongside different process technology options operators can utilise to produce valuable side products in NRU processes.

Historically, high nitrogen content in a natural gas field has created problems for natural gas producers when developing new projects. Nitrogen rejection units (NRUs) have the potential to break the economics of a project, since an NRU adds additional capital and operating costs to a gas processing facility.

Typically, nitrogen content in natural gas has to be reduced to <3 - 4% to meet pipeline quality specifications and calorific value. When natural gas is liquefied, the maximum allowable nitrogen content is further reduced to 1% due to process efficiency and to meet export specifications and safety for the LNG product.

With a number of key natural gas basins inside and outside the US featuring high nitrogen content, and the US emerging as the world's largest LNG exporter, NRU technology is experiencing a renaissance. This article will discuss the origins and basics of cryogenic nitrogen rejection alongside highlighting how design and construction can be optimised to reduce the financial and schedule impact of this 'necessary evil'.

The basics of cryogenic NRU technology will be explored, as well as different aspects that should be considered when deciding on the best option for a particular effort. The equipment used in NRUs will also be discussed, along with potential process options that can unlock additional revenue streams and methods to reduce operating costs to best suit the goals of the project. The article will end with discussion of current trends in NRU processing.

Process technology and options for nitrogen rejection

There are a number of potential technologies available to remove nitrogen, such as molecular sieve, membrane, lean oil adsorption, and cryogenic processing. The first two (molecular sieve and membrane) will generally not be applicable for gas streams over 20 million ft^3/d due to the limited economies of scale for these technologies and the high waste stream volumes. As the natural gas volumetric flow increases, the scale up options for membrane and molecular sieve is to duplicate the equipment instead of increasing the overall sizes, which reduces the cost advantages for scaling up. Additionally, waste streams for membrane and mole-sieve start to increase in volume as inlet streams rise, which can make the waste stream processing costs increase. Lean oil adsorption is discussed as an option for nitrogen rejection but there is little actual operating experience.

Therefore, cryogenic NRU technology is essentially the workhorse technology for capacities of 20 million ft^3/d and above, with recent developments to reduce overall capital costs and schedule driving the entry point for cryogenic technology significantly lower.

Chart's own experience spans more than 40 years, with plant capacities ranging from 15 to more than 900 million ft^3/d in a single train, and inlet nitrogen concentrations ranging from a few percent to >70%.

Table 1. Component concentration for inlet natural gas

Component	Carbon dioxide	Water	C4+	Mecury
	<100 ppm	<1 ppm	<2%	<0.01 µg/Nm^3

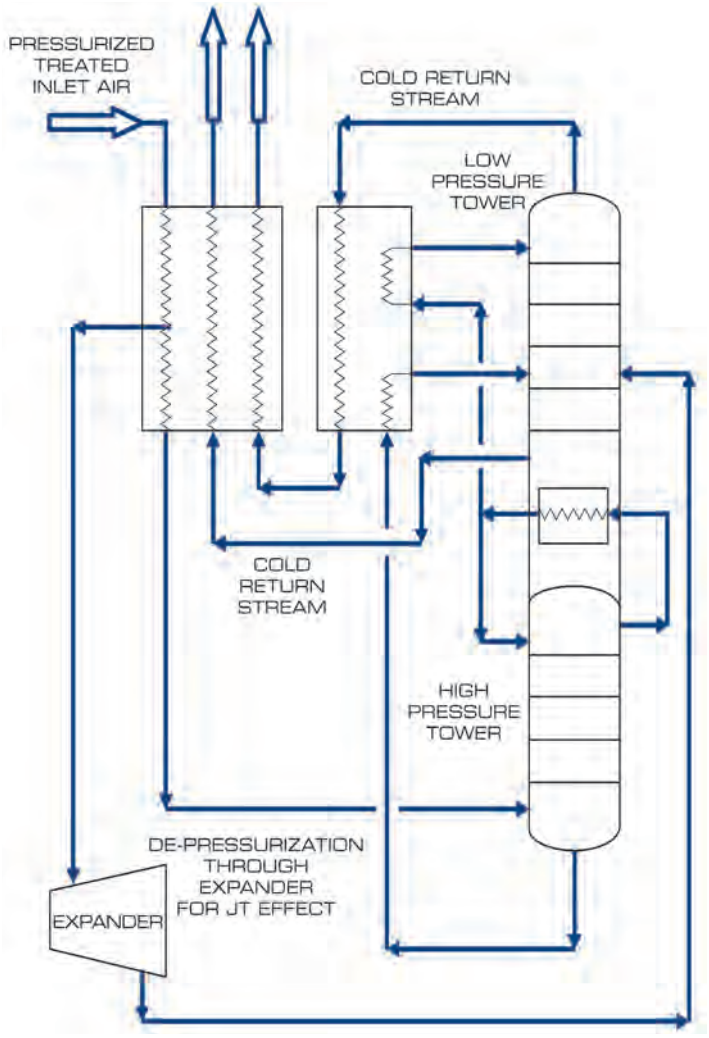


Figure 1. Example of an open-loop or self-refrigerated air separation process. Air is the fluid that creates the refrigeration and also becomes the product.

Basic cryogenic NRU process technology

In a natural gas processing plant, the NRU will be installed at the back end of the facility, post NGL recovery and de-methanation. This is the ideal location for the NRU installation as the NRU incoming gas will have been treated, with most freezing and fouling components removed from the NRU feed gas.

A cryogenic NRU technology requires the removal of all components that will cause freezing and fouling issues within the cryogenic process. The first step is usually the removal of water and, depending on the concentrations, carbon dioxide and heavier hydrocarbons. Table 1 provides the approximate level of water, carbon dioxide, heavier hydrocarbons, and mercury ranges that are needed to eliminate the risk of fouling and freezing in the NRU.

Since most natural gas streams going to an NRU will have already been through gas processing, carbon dioxide will generally have been removed to an acceptable level using an acid gas removal unit (AGRU), such as an amine unit, and water will have been removed using a glycol drying unit and/or mole-sieve dehydration. The heavier hydrocarbons in the natural gas streams (generally ethane+) have usually been removed by an NGL recovery unit and de-methanisation column.

As consideration is given to the addition of an NRU, a review of the gas plant operating conditions will indicate if a modification needs to be made to meet the NRU inlet gas requirements. If the gas plant operation or design cannot be economically modified to meet the NRU inlet gas requirements, then further treatment will need to be added upstream of the NRU. This could include an additional mole-sieve unit or other items.

When the feed stream enters the NRU, the first step is to cool the stream to an adequate temperature for cryogenic distillation. This means the incoming gas stream must be cooled close to or into the two-phase region before entering the cryogenic distillation column. The refrigeration is generally provided by the natural gas itself through what is called self-refrigeration or open-loop refrigeration, meaning the incoming feed stream pressure is used in concert with depressurisation steps to generate the required refrigeration. This is shown in the simplified diagram of Figure 1.

Figure 1 shows an air separation unit (ASU) process as an example of open-loop refrigeration. A high pressure inlet air stream enters the process where it is initially cooled through a multi-stream heat exchanger. At an appropriate temperature, the warmer entering air stream is depressurised through an expander, from the inlet pressure to the operating pressure creating the Joule-Thomson effect (J-T effect), and causing the warmer gas stream to decrease further in temperature and creating the required refrigeration needed to operate the entire process. Cooling comes from cold vapours returning from the cryogenic distillation process. After the separation process is completed in the distillation column, the separated streams are sent back through the multi-stream heat exchanger to recover the refrigeration by transferring heat duty between the incoming hot gas stream and the cold out-going product streams.

The keys to creating enough refrigeration to operate the process are the pressure and composition of the incoming gas to generate the J-T effect and the ability to recover the generated refrigeration through an efficient heat transfer mechanism.

Early NRU technology was derived from the classic two-column air separation technology. The NRU process initially followed the same principles as ASU technology, with a two column integrated design having a high pressure column and a low pressure column with the low pressure column being reboiled by the condensing duty of the warmer overhead stream from the high pressure column. In this two column integrated NRU design, the low pressure column will generally operate near 15 - 25 psig (100 - 175 kPag), which means that the high pressure column usually needs to operate around 400 psig (2750 kPag) to develop the temperature difference between the low-pressure high-methane reboiling fluid and the high-pressure high-nitrogen condensing fluid.

This integrated two column NRU design is still in operation for older NRU plants and it is still considered for some newer facility designs. This is generally due to its long history of operating success and well known physics. The two column integrated design comes at a higher capital cost due to the two columns, and the need to stack the high pressure and low pressure columns, or if the columns are not stacked to include pumps into the design.

NRU process designs have changed significantly since these first integrated two column NRUs were developed, and the technology continues to develop as customer requirements change. One important aspect of the methane-nitrogen separation is that the relative volatility of methane and nitrogen is quite high when compared to many other types of separations. This understanding quickly led to the de-integration of the two columns and instead allowed for the use of flash drums in place of the high pressure column or using a prefractionation column, where the prefractionation column concentrated a nitrogen stream to around 30 - 35% nitrogen from the top of the column with a high purity methane stream from the bottom of the prefractionation column. The high nitrogen concentrated stream would then be sent to the lower pressure NRU column, where final separation would take place.

The flash drum designs and prefractionation designs have lower capital costs when compared to the integrated two column designs. This is due to replacing the high pressure column with flash drums. When using a prefractionation column, the columns are not stacked, the column is shorter than the high pressure column, and reflux is usually not required in the prefractionation column.

The process performance with the flash drums or prefractionation column, in most cases, is equivalent, and the operating stability is often improved with changing inlet gas compositions. The flash drums and/or prefractionation columns create a fairly consistent high nitrogen content stream of around the 35% nitrogen content that can then be fed to the NRU column. The high nitrogen content stream is fairly stable, even with fluctuations in the content of the nitrogen in the incoming gas. This allows for the NRU column to operate with a much more stable feed, producing consistent results for both the nitrogen vent stream and the methane product stream.

Single column NRU designs have also been developed over the years. These have generally been considered to have lower efficiency than the two column designs, as they are limited in the ability to remove methane from the nitrogen vent stream and are not as stable when dealing with variations in feed gas compositions. The big advantage for the single column NRU design is in the capital cost, which can be significantly lower than that for other designs. The capital cost must be weighed against the efficiency, the stability of operation, and methane product losses in the nitrogen vent to reach an appropriate project decision.

Equipment considerations

The brazed aluminium heat exchanger (BAHX)

The key to making an NRU work efficiently is the heat exchanger technology. The BAHX is the cornerstone of the technology since it is the use of the BAHX that allows for the efficient transfer of duty between the cold outgoing streams and the incoming hot streams of the NRU process which recovers the generated refrigeration, allowing for the efficient cryogenic distillation of the nitrogen and methane.

A BAHX is a highly compact, very dense heat transfer device. The heat transfer area density is usually between 800 - 1500 m^2 of heat transfer surface area for every cubic metre of volume (800 m^2/m^3 - 1500 m^2/m^3). This is

6 - 10 times greater than for spiral wound heat exchangers and at least 20 times greater than conventional shell and tube heat exchangers. The high surface area density allows for very tight temperature pinches between the hot and cold heat transfer streams within the heat exchanger. As a result of the high surface area density, it is common to have temperature pinches less than 2°C (3.6°F). An example of a BAHX composite heating and cooling curve is shown in Figure 2.

The tighter that the temperature approach can effectively be designed, the more efficient the process. The gap between the heating and cooling curve is directly proportional to the overall process efficiency. It is the temperature gap between the hot and cold streams that represent the lost duty or entropy of the process, essentially the refrigeration that cannot be recovered and is lost.

BAHX can also accommodate multiple streams in a single unit with 6 to 10 being typical but BAHX have been produced with >20 process steams. This contrasts with other heat exchanger types where 2 and 3 streams are the norm.

Today's BAHX are much larger and more complex than what was previously available just 10 to 15 years previous. This capability has led to NRUs with reduced numbers of heat exchangers which simplifies plant layout and reduces overall equipment cost and schedule.

Cold boxes

Proper cold conservation or insulation of the cryogenic process is an important aspect of an NRU design. The coldest part of the plant will reach temperatures around -160°C (-260 °F). Limiting the ambient and solar radiant heat load to the NRU process is important for proper operation and good performance. Installing the NRU system into a cold box has generally been considered the standard in the industry.

A cold box is a box-like assembly built from structural steel and covered on all sides with thin plate sheet metal. The NRU equipment that needs to be protected from heat ingress is installed within the box and normally perlite insulation is filled into the box around the equipment. This provides for excellent cold conservation, long-term life of the insulation, and minimal maintenance. Cold boxes have been known to be in industrial service for decades with little to no maintenance activity. See Figure 3 for an example of an NRU design with a cold box. The sheet metal skin has been removed from the drawing to show the structure and internal details.

The secondary benefit of the cold box is that the NRU is completely shop built and shipped to site as a modularised unit, with significantly reduced on-site construction labour, cost, schedule, and risk.

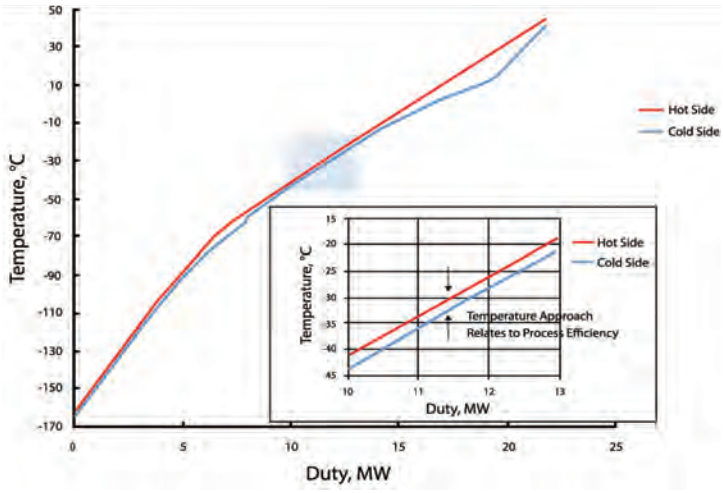


Figure 2. Example of a BAHX composite heating and cooling curves.

Cryogenic liquid pumps

The third major equipment items with most NRUs are the cryogenic liquid pumps. The pumps are used to increase the methane product pressure and send the liquid methane back through the NRU heat exchangers where it is vaporised and warmed before being sent out as product. Not all NRUs will have cryogenic liquid pumps. The design and specification requirements will determine if liquid pumps are necessary. If the design includes cryogenic liquid pumps, it is important to always have backup pumps ready. This means the design should include a fully installed spare pump that is kept cold and ready to start if the operating pump should fail. Some facilities use the philosophy of 2 x 100% pumps and others have used the 3 x 50% concept or some variation of the two. Having spare pumps ready to start on demand is critical to maintain high on-streams since a pump shutdown will trip the NRU.

NRU flexibility through process integration

This article has highlighted the fact that a cryogenic NRU is generally the optimal choice when nitrogen needs to be removed from a natural gas stream. A cryogenic NRU allows for process integration with other cryogenic processes that are often used within natural gas processing to extract and purify high value side products, including NGLs, helium, and liquid nitrogen. Because natural gas liquefaction is also a cryogenic process, the NRU can also be designed as part of an LNG facility.

A brief discussion of the production of LNG in concert with the NRU and helium recovery follows.

NRU with LNG

An analysis of an NRU heat balance will often reveal that not all the liquid methane produced at the bottom of the NRU column is needed to provide refrigeration back to the colder zones of the NRU. An NRU is often limited in refrigeration in the warmer zones of the NRU. This means that by adding refrigeration into the NRU at the warmer zones, a percentage of LNG can be extracted directly from the NRU as a liquid methane stream.

This can be accomplished with the use of a typical mechanical propane chiller and will often generate 5 - 10% of the methane as LNG for the cost of the mechanical chiller and additional BAHX surface.

NRU with helium recovery

With nitrogen in a natural gas stream, helium will generally also be present. The helium can be extracted within the NRU to provide not just the natural gas product but also a crude vapour helium stream. The crude helium stream will generally be extracted from the NRU at a concentration of 40 - 65% helium with the residual being nitrogen.

When considering extraction of helium with an NRU, the following factors should be reviewed:

- Helium concentration in the incoming gas and total available helium.
- Location of plant site in relation to a helium purification and liquefaction unit.

The helium extraction will add additional separation vessels, heat exchangers, and potentially a small helium upgrade column. The total amount of additional equipment depends on the concentration of helium in the feed gas, the required concentration of helium in the crude helium stream, and the desired recovery. Recovery levels for helium can range from 75% to easily over 95% depending on incoming feed and conditions.

Having a plant site strategically located to a helium purification and liquefaction unit is often not possible and has been a limiting factor in helium recovery from an NRU. A helium purification and liquefaction unit is a specialised process unit and it has been found that a production rate smaller than 700 l/hr (1250 kgmol/hr) will likely not be viable, except in very particular circumstances.

Current trends in NRU technology

Distillation column designs

There have been many updates to NRU column designs. The most obvious is a switch out from trayed designs to structured and even random packing. The decrease in pressure drop through the column has improved the efficiency for NRUs with packed columns while maintaining performance. Two aspects that need considering when dealing with packed columns is the ability of the process to maintain consistent pressure on the column and the potential of contaminating the columns with oils and heavy hydrocarbons, which can more easily foul the packed columns and reduce performance more than trayed columns.

Reduction in methane losses

The most impactful trend in NRU technology is the reduction of methane that is allowed to vent to the atmosphere with the nitrogen. This has been an ongoing trend for many years, but is recently becoming even stricter. Just 10 years ago it was often acceptable to vent 2% methane concentration in the nitrogen vent stream. This may seem significant but for a processing gas stream that has 6% nitrogen in the incoming gas it would mean a methane product loss of less than 0.1%. This methane loss was often included as a reporting requirement for environmental permits.

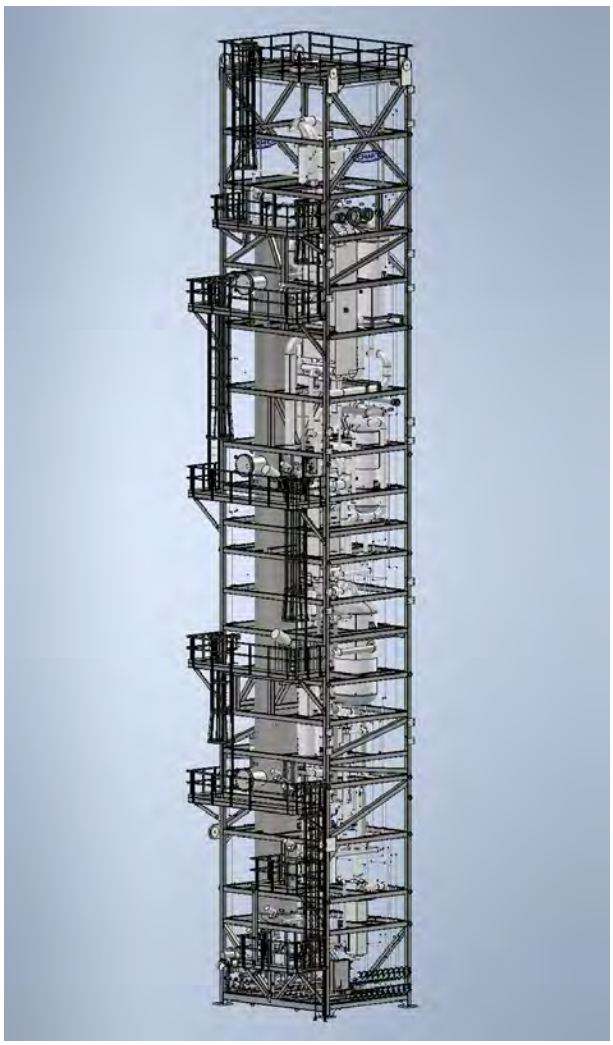


Figure 3. NRU cold box designs.

In recent years, requirements for methane content in the nitrogen vent have reduced to levels that are often in the hundreds of ppm range. To reach levels in this range, columns have had to include additional stages and reflux levels have needed to increase to improve the washing of the methane down the column. This generally requires more refrigeration to provide for the condensing needs for the added reflux.

Most NRUs, as noted previously, have open or self-refrigerated systems. To have enough refrigeration to provide the needed reflux load, NRU technology is shifting to add a heat pump refrigeration. This takes the form of a refrigeration compressor that uses a small amount of low pressure vapour from the NRU, compresses it, and then sends it back to the NRU where it is cooled then depressurised either through a depressurisation valve or potentially a small expander. This additional refrigeration provides for the condenser load of the column to reach the high vent purities being required by current environmental standards.

The refrigeration compressor has an added benefit. The most important of which is that it provides for

flexibility in operation. With a fully self-refrigerated process, the refrigeration is dependent on the incoming gas pressure and composition. If the incoming gas pressure drops, the available NRU refrigeration would decrease accordingly and the NRU would be forced to turn down. With a refrigeration compressor as part of the NRU, the loss of refrigeration due to a drop in pressure can be compensated for by increasing the flow and discharge pressure of the compressor, thereby compensating for the loss of incoming gas pressure.

High nitrogen in LNG plant

Along the US Gulf Coast many LNG plants are starting to see pipeline natural gas increase in nitrogen content. LNG export plants are often required by LNG specification to deliver product with a nitrogen content of less than 1%. With high nitrogen content in the natural gas, facilities are looking at ways to remove the nitrogen either before or after liquefaction. When removing nitrogen from the natural gas upstream of the LNG plant, there is no change in the overall NRU design concepts from what has been discussed earlier. Removing nitrogen from an already liquefied natural gas creates a different set of requirements that modifies the standard design concepts.

There are numerous ways to manage high nitrogen in an LNG product stream which would require a separate article to cover the many different possible solutions. Using NRU technology with an LNG feed stream is a viable option being considered by LNG producers. When feeding LNG directly to an NRU, the LNG product can provide the refrigeration requirements but it comes at a cost of some lost LNG to vapour which will need to be recycled for re-liquefaction, burned for power, or handled in other ways. Another generally accepted option is to flash the LNG into a tank or flash column. This creates a flash vapour with a high nitrogen concentration (usually around 20%). The vapour is sent to fuel gas or the NRU while the liquid is sent to product. The high nitrogen flash gas sent to an NRU will have the nitrogen removed and vented, and the methane product will be returned to the LNG plant for liquefaction.

Conclusion

Cryogenic NRU technology is the prime process technology that is used to remove nitrogen from natural gas. Numerous options need to be properly evaluated to develop the most cost effective and operationally viable solution. A critical area to consider is the composition of nitrogen over the life of the project, including efficiency, operability, and of course total installed cost. Helium can be used as an additional value stream where applicable. To reduce capital, maintenance, and power costs, the modularisation of an NRU with the use of a cold box can be advantageous. Trade-offs between what is generally a higher efficiency multi-column option vs a lower cost single column design should be a part of the evaluation. There are many options with NRUs and it is not always a straightforward decision.

