Daniel J. Weidert and Richard B. Hopewell, Chart Energy and Chemicals, Inc., USA, explain why integrated nitrogen rejection units hold the key to unlocking gas processing.

HOLDING THE KEY

Historically, natural gas with high nitrogen content has hindered producers from monetising their reserves. In today's challenging market for natural gas producers, the following factors will play a main role in their investment decisions regarding bringing the gas to market:

- Demand for natural gas fuel.
- Separation of crude helium.
- Recovery of natural gas liquids (NGLs), in which the residue gas is also a product.
- Production of LNG.

Nitrogen has no calorific value. It dilutes the heating value of LNG or the natural gas fuel below the specified product value, and its removal is often necessary to meet product specifications. Although there are different nitrogen rejection technologies, a cryogenic nitrogen rejection unit (NRU), which this article will focus on, provides the highest methane recovery rate and is standard practice for plants with a capacity of greater than 15 million ft^3/d. Chart's experience ranges from 5 million ft^3/d to the world's largest single train NRU with integrated NGL extraction capability, which has a capacity of approximately 900 million ft^3/d.

Heat exchange: the key to auto-refrigeration

Cryogenic nitrogen rejection processes derive their cooling through auto-refrigeration. Designs are customised, as no application is identical in gas composition, or in the customer's processing objectives. The cornerstone of cryogenic NRU design is the brazed aluminum heat exchanger (BAHX). A limited supply of refrigeration is available within an auto-refrigerated process, creating an inherent requirement for highly efficient heat exchange. Process efficiency is gained by minimising the temperature approach between the hot and cold streams (Figure 1). As the temperature approach decreases, the required surface area increases. With that in mind, the heat exchanger of choice must offer a high surface area economically. A BAHX is the ideal choice for the auto-refrigerated NRU process.

The flexibility of BAHXs allow multiple heat exchange services to be combined into a single compact application. This feature significantly reduces installation and operation costs, engineering, insulation, interconnect piping, support systems, testing, documentation, transportation and site arrangements.

Compact and lightweight BAHXs provide a heat transfer area density of approximately 1000 - 1500 m^2/m^3, which is 6 - 10 times

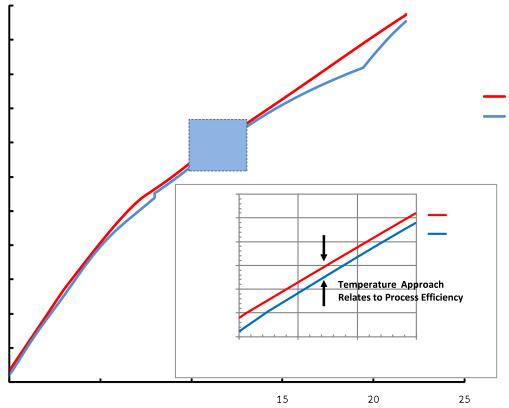

Figure 1. Example BAHX composite heating/cooling curves.

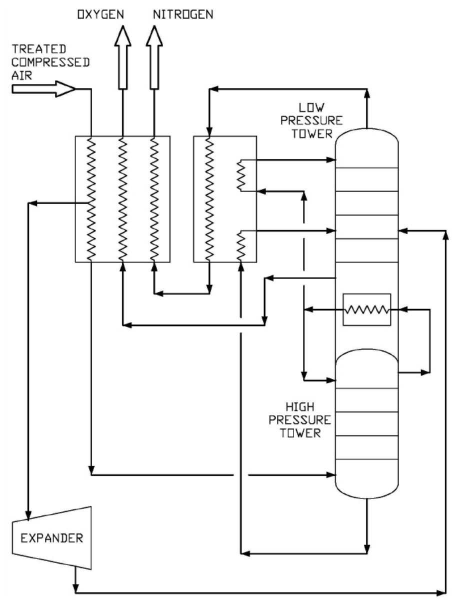

Figure 2. Two column air separation process.[1]

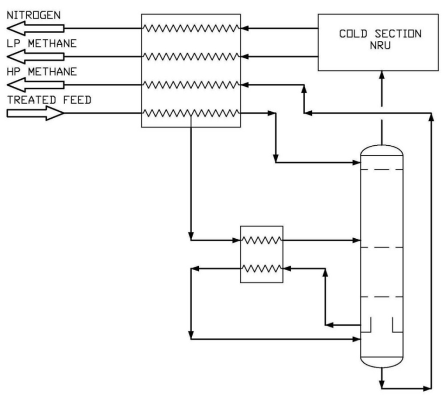

Figure 3. Prefractionator system.

greater than a spiral wound heat exchanger, and at least 20 times greater than conventional shell and tube technology. This characteristic advantage of a BAHX, coupled with the enhanced heat transfer performance of aluminum plate-fin construction, results in significantly lower cost (25 - 50% less) and substantially lower weight (95% less) than what is provided by a stainless steel shell and tube exchanger.

Background: nitrogen rejection units

The early NRUs were a derivation of the two column air separation process technology.[1] This process consisted of an integrated, high pressure rectifying column and low pressure stripping column, arranged where the low pressure column is reboiled by condensing the warmer overhead stream from the high pressure column (Figure 2). Since a higher relative volatility exists between nitrogen/methane compared to nitrogen/oxygen (~5 times) at low pressure, the separation of methane/nitrogen is easier.[1] However, the NRU high pressure column typically operates at a significantly higher pressure (2100 kPag), compared to 600 kPag for its air separation counterpart. At this higher operating pressure, the relative volatility advantage decreases substantially.

In addition, given the higher relative volatility, flash drums are often used in lieu of the high pressure column.[1] The number of drums incorporated is a function of the product purity and the need for helium recovery.

With the two column design, or with the substitution of flash drum(s) for the high pressure column, a nitrogen feed concentration of approximately 30 - 35% is required to achieve the necessary high purity separations. Below this nitrogen feed concentration, the quality of the nitrogen vent rapidly decreases. Lower nitrogen vent quality results in reduced recovery of the valuable methane product and increased methane emissions to the atmosphere.

Many natural gas streams have nitrogen concentrations below 30%. For these feeds, a prefractionator column and its associated equipment (Figure 3) were developed to process feed streams having concentrations as low as 4% nitrogen. Feed streams containing less than 6% nitrogen are augmented with additional recycled nitrogen.

In the prefractionator, an overhead intermediate product stream is produced, which contains greater than 35% nitrogen and is suitable for the final nitrogen-methane separation. The prefractionator system operates by condensing a portion of the incoming methane, thereby enriching the net vapour in its nitrogen content. Other advantages of the prefractionator are:

- A significant portion of the total methane residue product is produced at higher pressure, which results in lower methane recompression energy.
- Increased levels of carbon dioxide may be tolerated in the feed. At the prefractionator operating conditions, carbon dioxide in the range of 300 to 500 ppm will not freeze, and essentially all the carbon dioxide is removed in the bottom methane product.[1]
- The maximum capacity of a single train increases. Typically, greater than 50% of the total methane is recovered as its bottom product.[1]
- For large capacity systems, the prefractionator does not need to be included in a cold box. This allows additional space for a larger diameter low pressure NRU column.

NRU flexibility and integration

Within the framework of the NRU, the following will be discussed:

- Basic nitrogen rejection.
- NRU with helium recovery.
- NRU with liquid nitrogen production.
- NRU with partial LNG production.
- NRU with NGL recovery.
- NRU integration with LNG units.

Basic nitrogen rejection

Depending on the feed impurities, feed pretreatment typically consists of acid gas removal, dehydration and mercury removal. Carbon dioxide is removed to a defined parts per million (ppm) level to prevent freezing in the colder portions of the unit. Hydrogen sulfide is also typically removed to meet a pipeline specification of less than 4 ppm in the final methane residue. Amine treating is used to remove these acid gases. Molecular sieve dehydration is used to reduce the water content to less than 1 ppm. The water is removed to prevent freezing and hydrate formation. A downstream guard bed, containing sulfur impregnated activated carbon, is typically used to remove mercury to below detectable limits (0.01 µg/Nm^3). If not removed, mercury may condense and accumulate within the cold sections of the plant. A phenomenon known as liquid metal embrittlement can occur, and has the potential to cause failure of the BAHX.

After pretreatment, the feed gas flows through the prefractionator section to upgrade its nitrogen concentration to greater than 35%, prior to feeding the cold end section of the NRU. The prefractionator operates around 2500 kPag. As mentioned previously, a high pressure methane residue is removed as a bottom product. This liquid stream is revapourised and typically sent to the interstage suction of the methane residue compressor. A typical feed pressure to the prefractionator section is approximately 3800 kPag; however, feed pressure may vary over a wide range and is highly dependent on the desired methane residue stream pressure.

The overhead from the prefractionator feeds the cold end section of the NRU (Figure 4). Within this section, the nitrogen-enriched feed is heat exchanged, flashed and separated into multiple feeds for the low pressure NRU fractionator column. This column operates within a pressure range of approximately 100 - 500 kPag. The selected operating pressure depends on whether the nitrogen product will be vented or used for re-injection.

A high purity nitrogen distillate stream is produced with a residual methane content ranging from 1 - 3%. It is possible to produce a distillate having less than 1% methane, but achieving lower methane content requires added capital expenditure for equipment to produce a high purity reflux stream. The nitrogen product is heated against warmer process streams before exiting the NRU.

The methane bottoms product typically contains between 2 - 5% nitrogen; however, a purity as low as 0.5% nitrogen is possible. This liquid product serves as the major source of refrigeration for the NRU. The bottoms product is usually pumped and then re-vapourised by cross exchange against the incoming feed stream. Return pressure for cold recovery is controlled to ensure the appropriate vapourisation temperature for the process conditions. The vapourised methane flows to the low pressure suction of the methane residue compressor.

NRU with helium recovery

Helium is scarce, making it a valuable commodity. Under certain circumstances, it is economically advantageous to recover a crude helium product. These circumstances include:

- A gas stream with sufficient helium content.
- A plant site located within reasonable distance of a helium purification and liquefaction unit.

Integration of helium recovery within the NRU results in a far more complex system when compared to a basic NRU design. The design for helium recovery varies and is a function of the three constraints:

- The quantity of helium present in the feed.
- The helium purity required.
- The customer's requirements for helium recovery.

The processing scheme can be as simple as heat exchange and separation drums, or may include an additional helium upgrading column. Given the low quantity of helium, compared to the nitrogen and methane in the feed, these equipment items are much smaller than the main processing equipment within the NRU.

Helium recovery is often dependent on the required product purity. For a crude helium product, containing roughly 65% helium, typically 98 - 99% recovery of the feed helium is possible.

NRU with liquid nitrogen production

With additional processing equipment, an NRU can be configured to produce small quantities of liquid nitrogen. Since this stream will invariably contain some level of methane contamination, it must be considered as a refrigeration-grade product only. Certain process schemes will permit the production of ultra pure nitrogen; however, this nitrogen will still contain ppm levels of methane.

Given the sensitivity of the overall heat balance for auto-refrigeration, the process is capable of liquefying only a small portion (3 - 5%) of the vent nitrogen from the NRU column. This portion of the overhead nitrogen is typically

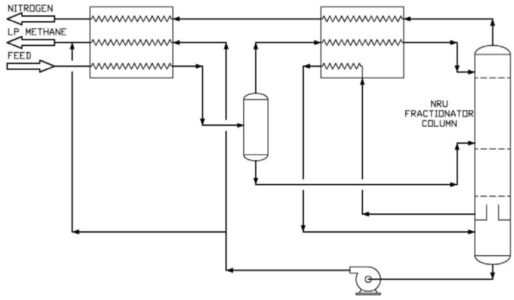

Figure 4. Cold end section NRU.

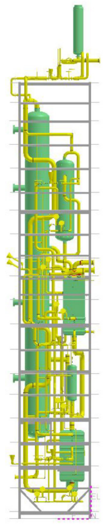

Figure 5. Cold box for NRU cold section.

warmed, compressed to sufficient pressure, and returned to the cold box, where it is condensed and subcooled by heat exchange with the coldest streams within the NRU.

This arrangement requires additional capital expenditure for the compressor and its ancillary equipment, and may require extra staging in the low pressure NRU column.

NRU with partial LNG production

When analysing the heat balance of the NRU, it was recognised that not all of the low pressure column bottoms methane is needed to refrigerate the coldest part of the unit. When this excess amount of high quality LNG methane is extracted as a separate product, the refrigeration shortage usually occurs in the warmer section of the unit. Therefore, the refrigeration of the extracted methane (LNG) may be replaced by a mechanical refrigeration system – typically, propane.

Using this scheme, roughly 5 - 10% of the low pressure liquid methane can be extracted as an LNG product. Additional capital expenditure is required for the mechanical refrigeration package, and some extra surface area may be required within the BAHX exchanger circuit.

NRU with NGL recovery

Depending on site specific economics, it may be advantageous to recover NGL when the feed gas is sufficiently rich in ethane plus components. In addition, NGL recovery is one means to remove heavy ends, which may freeze in the cold section of the unit. When NGL recovery is not desired, the heavy hydrocarbons are typically removed in the warmer section of the unit and re-injected into the re-vapourising methane residue, which is then sent to the pipeline.

Conventional NGL recovery configurations using an expander are integrated with the NRU for NGL recovery. NGL recovery is project specific; however, it is possible to design the NGL/NRU facility for recovery of up to 95% of the feed ethane content, and essentially all of the propane and heavier (C3+) feed hydrocarbons, as a demethanised NGL product. Designs for optional ethane rejection mode are also possible.

The integration of simultaneous NGL recovery and nitrogen rejection typically produces high pressure, intermediate pressure, and low pressure methane residue streams. This process design results in significantly lower energy consumption, compared to the combination of an independent NGL recovery system with a separate nitrogen rejection unit.

NRU integration with LNG units

When demand for LNG is economical, natural gas with high nitrogen content could be considered as feedstock for LNG units; therefore, nitrogen rejection is necessary to meet the LNG product specification.

Depending on the source for the gas and its range of composition variability, the NRU design is either integrated with the LNG unit or is independent of the LNG unit. An independent NRU is often desirable when the variability of gas compositions is such that it is possible to shutdown the NRU, during times when a low nitrogen content feed gas is liquefied.

Configuration of an integrated unit is a function of:

- LNG purity.
- Environmental regulations governing methane emissions.
- Facility demand for fuel.

Gas turbines and other low Btu burners are capable of burning gas with 37% nitrogen, or with a gross heating value of approximately 25 MJ/Nm^3. If fuel demand is sufficient, it may eliminate the need to produce high purity nitrogen.

Cold boxes and insulation of equipment

Cold conservation is important for an auto-refrigerated system. While a design margin is easily applied to a mechanically refrigerated system to compensate for external heat leak, an auto-refrigerate system does not have this option. For the NRU, the bulk of the very low temperature process equipment must be contained in cold boxes. The cold box construction permits a high degree of modularity and allows the use of high efficiency perlite insulation. An internal, dry nitrogen atmosphere maintains the insulating quality for the enclosed equipment – whereas mechanical insulation requires constant maintenance to retain its insulating integrity. In addition, transportation and field construction are simplified with the use of cold boxes.

Conclusion

Chart is synonymous with cryogenic technology. Its nitrogen rejection technology leverages its brazed aluminum heat exchangers and expertise in cold box design and fabrication to provide companies with a customised NRU, meeting their specific needs. The efficient designs allow companies to maximise the value of their natural gas resources. HE

Reference

1. O'BRIEN, J. V. and MALONEY, J. J., 'Continuous Improvement in Nitrogen Rejection Unit Design', Hydrocarbon Engineering, September 1997.

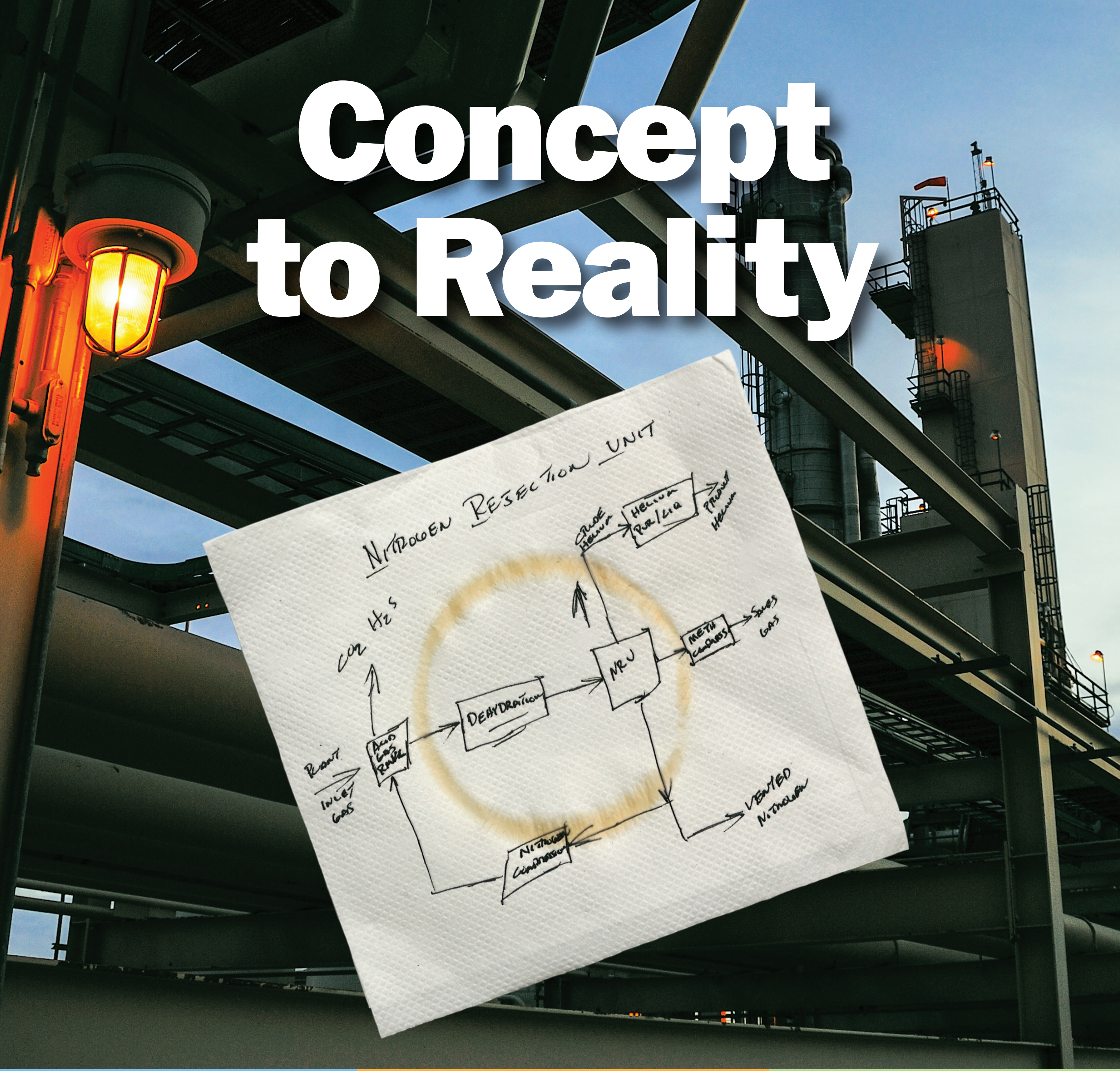

Chart cryogenic nitrogen rejection units enable monetization of low BTU gas reserves

- **Solutions from 15MM SCFD to >900 MM SCFD**
- **Inlet nitrogen concentrations from 1% to >70%**
- **Integrated process technology – maximum revenue opportunities through NGL extraction, helium recovery, LNG and LIN production**
- **Experience with variable N2 content in feed gas for nitrogen injection EOR fields**
- **Flange to flange solutions including process technology and Chart proprietary brazed aluminum heat exchangers**
- **Modular construction**

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