State-of-the-art nitrogen removal methods from Air Products for liquefaction plants

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As the LNG industry continues to grow and new feed gas supplies from unconventional sources are considered, many natural gas liquefaction projects require more effective nitrogen removal options.

This presents challenges for effective and efficient LNG plant design. Historically it has been relatively easy to remove nitrogen from LNG to the fuel system.

Sophisticated

This is particularly true when nitrogen content in the feed is low and the fuel is going to boilers for steam turbines or large industrial gas turbines. However, many modern LNG plants require more sophisticated nitrogen removal methods because of increasing nitrogen content in the feed gas, lower autoconsumption (which decreases fuel demand) and/or lower tolerance for nitrogen content in the fuel.

Optimum facility design may require increased integration with the liquefaction unit. These increased requirements may make it difficult to reach the key goals for the nitrogen removal solution: flexible, efficient, and minimal impact on operation of the liquefaction process.

In the following paper several options for nitrogen removal are presented along with the advantages and capabilities of each.

Nitrogen is an inert gas that is a naturally occurring component of natural gas. Nitrogen sometimes needs to be removed when producing LNG to meet product specifications and to ensure safe storage of the product.

Introduction

Typically, nitrogen content in LNG is maintained below 1 mole% to prevent tank rollover and maximize the heating value of LNG that is being shipped. Historically, due to relatively low feed nitrogen content and large fuel demands, nitrogen is removed during the simple endflash step, which produces fuel. With the recent trend to new compressor driver options for the LNG industry such as electric motors and fuel efficient aeroderivative gas turbines, this former home for nitrogen has been greatly curtailed or eliminated all together. This has led to the need for innovative processing schemes to remove nitrogen from the natural gas.

Need for removal

LNG product requirements typically include a Higher Heating Value (HHV) specification. Nitrogen makes no contribution to HHV and often needs to be removed to meet the product requirement, particularly with lean feed gases, which have lower C2+ content.

Also, since natural gas is sold on a heat content basis rather than by weight, nitrogen takes up valuable space in the natural gas composition. Typical pipeline tariffs in the United States limit nitrogen to a maximum of 3% for this reason.

As a multi-component cryogenic liquid, LNG presents some unique storage problems. One dangerous phenomenon is called “roll-over”. As the liquid sits in the tank for extended periods, the lighter components, such as nitrogen, boil off preferentially from the upper layers of the tank, increasing its density.

This stratifies the liquid layers, with the denser liquid on top of the lighter layer. If the lighter layer and the heavier layer suddenly switch position, the lighter layer will suddenly rise in the tank. The less dense fluid suddenly sees a lower pressure, due to the decrease in static head, and vapor flashes off.

The amount of released vapor can be very large, and can overwhelm the relief systems on the tank, leading to a loss of containment scenario. It has been found that keeping the nitrogen content of the produced LNG below 1% can essentially eliminate the likelihood of this occurring.

Sinks for Nitrogen

In addition to any nitrogen that exits the plant in the LNG product, there are typically two additional sinks for nitrogen removed from natural gas – the atmosphere or fuel gas. Venting nitrogen to the atmosphere requires a high purity of nitrogen for both environmental and economic reasons.

Methane is a greenhouse gas and its release to the atmosphere can be highly regulated. Additionally, methane is a flammable gas so it must be flared to prevent the formation of flammable mixtures in the air.

Finally, any methane that is released to the atmosphere is lost product. Alternatively, sending nitrogen to the fuel system gets rid of the nitrogen without loss of valuable methane product.

To better define the options for nitrogen removal, it is helpful to perform a mass balance around the nitrogen in the system.

Nitrogen_{fuel} = Nitrogen_{LNG} + Nitrogen_{vent} + (Nitrogen_{soil})

The nitrogen in the LNG is limited by the LNG product quality specification and the nitrogen in the fuel is limited by the maximum amount of nitrogen allowed in the fuel for the particular fuel user.

If it is not feasible to satisfy the nitrogen mass balance with only nitrogen in the LNG and nitrogen in the fuel, it will be necessary to reject nitrogen to atmosphere using a nitrogen rejection unit.

In early vintage LNG plants, the compressors were driven by steam turbines and the fuel necessary to raise the steam had very few requirements other than the ability to burn. As such, the fuel gas from the LNG plant could contain a fairly high percentage of nitrogen.

A simple flash or series of flashes was sufficient to remove the nitrogen from the LNG and produce the fuel gas.

As the technology has evolved, gas turbines have been introduced as compressor drivers. Gas turbines have an upper limit on the amount of nitrogen that can be contained in the fuel gas. This can often still be met by flashing off the nitrogen, especially for gases with low feed nitrogen content.

However, if too much methane is lost to fuel, adding a nitrogen stripping column to the process improves the efficiency of the nitrogen removal step. It should be noted that this improvement in the nitrogen removal efficiency increases the nitrogen content in fuel, which may present challenges for the fuel system as noted above.

More recent LNG plants are looking at implementing aeroderivative gas turbines and electric motors as refrigerant compressor drivers. These plants have lower fuel demand due to the higher efficiency of aeroderivative gas turbines and little or no fuel demand in the case of electric motor drives.
Flash needed for the plant fuel demand is nitrogen content feeds the amount of the plant fuel requirement. The resulting flash plus LNG tank boil-off gas exchanger is adjusted such that the main cryogenic heat exchanger is satisfied to meet the plant fuel requirement. As is the case with the simple flash drum, the temperature of the LNG exiting the main cryogenic heat exchanger is adjusted to meet the plant fuel requirement, putting a constraint on the amount of nitrogen that can be removed without exceeding the plant fuel demand. If it is necessary to remove more nitrogen from the process, further improvement in the efficiency of the separation is required. However, this requires the addition of a rectifying section and reflux to this column. This will also increase the nitrogen concentration in the fuel stream which may cause complications for the downstream fuel users. Rather than simply add reflux to the column, it is often preferable to vent nitrogen to the atmosphere.

Removal solutions

There are many solutions for removing nitrogen from the LNG product. As nitrogen removal solutions become more flexible, they tend to become more sophisticated.

Figure 1 on the previous page shows a simple flash drum. LNG exits the main cryogenic heat exchanger and is flashed down to a low pressure, with the resulting nitrogen enriched vapor is warmed in an endflash exchanger and compressed to high pressure before being sent to fuel.

Typically, the temperature of the LNG exiting the main cryogenic heat exchanger is adjusted such that the resulting flash plus LNG tank boil-off gas and fuel taken from the feed gas matches the plant fuel requirement.

This approach is typically suitable for low nitrogen content feeds. For higher nitrogen content feeds the amount of flash needed for the plant fuel demand is insufficient to reduce the nitrogen content of the LNG to an acceptable level, which is typically below 1 mole%.

Figure 2 above shows the simple flash drum of figure 1 replaced by a nitrogen stripping column. This configuration improves the separation of nitrogen from the LNG by reducing the nitrogen in the LNG and increasing the nitrogen content of the fuel.

It uses the relatively warm LNG exiting the main cryogenic heat exchanger to provide reboiling duty in the column. The stripping vapor generated by this duty removes nitrogen contained in the LNG as it descends the column.

The nitrogen stripping column process of figure 2 is limited in the ability to reduce the nitrogen content of the LNG because the amount of reboiling duty that can be provided to the stripping column is directly related to amount of methane that can be sent to fuel. As is the case with the simple flash drum, the temperature of the LNG exiting the main cryogenic heat exchanger is adjusted to meet the plant fuel requirement, putting a constraint on the amount of nitrogen that can be removed without exceeding the plant fuel demand. If it is necessary to remove more nitrogen from the process, further improvement in the efficiency of the separation is required. However, this requires the addition of a rectifying section and reflux to this column. This will also increase the nitrogen concentration in the fuel stream which may cause complications for the downstream fuel users. Rather than simply add reflux to the column, it is often preferable to vent nitrogen to the atmosphere.

There are several methods for rejecting nitrogen to the atmosphere, but solutions typically fall into two main categories: integrated or stand-alone. Stand-alone nitrogen rejection units offer several benefits over integrated units. Stand-alone units are typically more flexible and can handle a wider range of feed gas compositions.

The stand-alone rejection units also only need to process the endflash gas from the LNG plant and can therefore be much smaller than integrated units that need to process all of the feed gas to the LNG plant. Stand-alone units are typically more efficient as the operating conditions can be optimized to maximize the efficiency of the nitrogen rejection units without impacting the liquefaction unit.

A nitrogen rejection unit that is integrated with the liquefaction requires a compromise of operating conditions that must meet the requirements of both the liquefaction unit and the nitrogen rejection equipment.

One advantage of an integrated NRU is that the distillation column has both a stripping section and a rectifying section, allowing a more complete separation of methane and nitrogen. The NRU separates the methane-nitrogen mixture into a purified nitrogen stream which can be vented, and a methane stream.

By employing an NRU, it is possible to adjust the outlet temperature of the main
Figure 5: Nitrogen Rectifier

For plants employing gas turbines for refrigerant compressor drivers and power generation, the plant fuel requirement is dominated by the fuel demand of the gas turbines. In some cases with high nitrogen content feeds, employing an NRU may be necessary to reduce the nitrogen content in the fuel to within acceptable limits.

In figure 5, LNG is withdrawn between bundles in the main cryogenic heat exchanger before final subcooling. The LNG is flashed in the bottom of a rectifier column and the resulting nitrogen rich vapor is purified in the column to the point where it can be vented.

The condenser for the column is refrigerated by vaporizing LNG in the endflash drum. LNG from the bottom of the rectifier is subcooled in the cold bundle of the main cryogenic heat exchanger.

Figure 6 summarizes the applicability of different types of nitrogen removal schemes. For high fuel demands, an LNG flash drum is the simplest option. As fuel demand decreases, a nitrogen stripping column must be considered. As fuel demand continues to decrease, the ability to reject nitrogen to the atmosphere and send the methane product from the NRU to fuel must be considered.

This includes options such as a nitrogen rectifier column or a stand-alone NRU with an LNG flash drum or a nitrogen stripping column. As fuel demands approach zero, the ability to reject nitrogen to the atmosphere and recycle methane products from the NRU to the feed must be considered. Again, this includes options such as a nitrogen rectifier column or a stand-alone NRU with an LNG flash drum or a nitrogen stripping column.

Note that figure 6 assumes there are no limits on nitrogen content in the fuel for the particular fuel user.

Figure 7 summarizes the applicability of the different nitrogen removal schemes when nitrogen content in fuel is limited to approximately 10 mole% or less. At higher nitrogen concentrations in the feed gas, an LNG flash drum or a nitrogen stripping column would produce fuel containing more than 10 mole% nitrogen. To reduce the nitrogen content in the fuel, it is necessary to reject nitrogen to the atmosphere.

A summary of the key parameters for the nitrogen removal options covered in this paper are shown in table 1 below.

Table 1 compares an LNG flash drum (option 1), a nitrogen stripping column (option 2), an LNG flash drum combined with a Nitrogen Rejection Unit (option 3),
minimizing equipment count and capital investment is a goal. Five nitrogen removal options will be considered: an LNG flash drum (option 1), a nitrogen stripping column (option 2), an LNG flash drum combined with a Nitrogen Rejection Unit (option 3), a nitrogen stripping column combined with a Nitrogen Rejection Unit (option 4), and finally an integrated nitrogen rectifier column (option 5). A summary of the key results are shown in table 2 above. An LNG flash drum (option 1) and a nitrogen stripping column (option 2) are capable of producing LNG that meets the LNG product quality specification. However both these options must produce significantly more fuel than is capable of being consumed by the facility. Recycling the excess fuel to the feed gas compressor is not an option as the nitrogen will accumulate in the process. Adding a stand-alone Nitrogen Rejection Unit to a process with an LNG flash drum (option 3) solves the problem of nitrogen accumulation as low methane content nitrogen can be vented from the Nitrogen Rejection Unit while the methane product from the Nitrogen Rejection Unit is recycled to the feed gas compressor. Adding a stand-alone Nitrogen Rejection Unit to a process with a nitrogen stripping column (option 4) also solves the problem of nitrogen accumulation as low methane content nitrogen can be vented from the Nitrogen Rejection Unit while the methane product from the Nitrogen Rejection Unit is recycled to the feed gas compressor. Option 4 is slightly more efficient than option 3 and has a simpler Nitrogen Rejection Unit as the nitrogen content in the endflash gas supplied to the Nitrogen Rejection Unit is higher. An integrated nitrogen rectifier column (option 5) produces a nitrogen rich fuel stream that can be burned for fuel, rather than vented to the atmosphere. In this option, no nitrogen is vented to the atmosphere as all the nitrogen exits the process in the fuel stream. The process is not as efficient as the stand-alone Nitrogen Rejection Unit options, but this arrangement has the benefit of a reduced equipment count.

Table 1: Comparison of Nitrogen Removal Solutions

<table>
<thead>
<tr>
<th></th>
<th>LNG Flash Drum</th>
<th>Nitrogen Stripping Column</th>
<th>LNG Flash Drum + Nitrogen Stripping Column</th>
<th>Nitrogen Rectifier Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Process Efficiency</td>
<td>Better</td>
<td>Best</td>
<td>Best</td>
<td>Good</td>
</tr>
<tr>
<td>Equipment Count</td>
<td>Lowest</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Fuel Production</td>
<td>Highest</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Nitrogen Content in Fuel</td>
<td>High</td>
<td>Highest</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Methane Content in Nitrogen Vent</td>
<td>N/A</td>
<td>&lt;1%</td>
<td>1%</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

Case Study #1

To help illustrate the various nitrogen removal options and understand how project requirements can impact the optimal solution, two case studies will be reviewed. Case Study #1 will review an optimal nitrogen removal solution for one LNG plant opportunity. The example opportunity is for a 0.5 mtpa LNG plant with a feed gas containing 3 mole% nitrogen. Air Products’ C3MR technology was selected as the liquefaction process. The refrigerant compressors will be driven by electric motors, so there is only a small fuel requirement of 7 MW to supply a limited amount of process heating. To meet the LNG product quality specification of 1 mole% nitrogen in the LNG, nitrogen must be removed. In addition, any nitrogen vented must contain less than 1 mole% methane. This is a relatively small facility, so minimizing equipment count and capital investment is a goal. Five nitrogen removal options will be considered: an LNG flash drum (option 1), a nitrogen stripping column (option 2), an LNG flash drum combined with a Nitrogen Rejection Unit (option 3), a nitrogen stripping column combined with a Nitrogen Rejection Unit (option 4), and finally an integrated nitrogen rectifier column (option 5). A summary of the key results are shown in table 2 above.

An LNG flash drum (option 1) and a nitrogen stripping column (option 2) are capable of producing LNG that meets the LNG product quality specification. However both these options must produce significantly more fuel than is capable of being consumed by the facility. Recycling the excess fuel to the feed gas compressor is not an option as the nitrogen will accumulate in the process. Adding a stand-alone Nitrogen Rejection Unit to a process with an LNG flash drum (option 3) solves the problem of nitrogen accumulation as low methane content nitrogen can be vented from the Nitrogen Rejection Unit while the methane product from the Nitrogen Rejection Unit is recycled to the feed gas compressor. Adding a stand-alone Nitrogen Rejection Unit to a process with a nitrogen stripping column (option 4) also solves the problem of nitrogen accumulation as low methane content nitrogen can be vented from the Nitrogen Rejection Unit while the methane product from the Nitrogen Rejection Unit is recycled to the feed gas compressor. Option 4 is slightly more efficient than option 3 and has a simpler Nitrogen Rejection Unit as the nitrogen content in the endflash gas supplied to the Nitrogen Rejection Unit is higher. An integrated nitrogen rectifier column (option 5) produces a nitrogen rich fuel stream that can be burned for fuel, rather than vented to the atmosphere. In this option, no nitrogen is vented to the atmosphere as all the nitrogen exits the process in the fuel stream. The process is not as efficient as the stand-alone Nitrogen Rejection Unit options, but this arrangement has the benefit of a reduced equipment count.

Table 2: Case Study #1 Results

<table>
<thead>
<tr>
<th></th>
<th>LNG Flash Drum</th>
<th>Nitrogen Stripping Column</th>
<th>LNG Flash Drum + Nitrogen Stripping Column</th>
<th>Nitrogen Rectifier Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Production</td>
<td>61.0</td>
<td>61.0</td>
<td>61.0</td>
<td>61.0</td>
</tr>
<tr>
<td>Nitrogen Content in LNG</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
</tr>
<tr>
<td>Fuel</td>
<td>113.1</td>
<td>73.6</td>
<td>7.0</td>
<td>7.0</td>
</tr>
<tr>
<td>Nitrogen Content in Fuel</td>
<td>17.7</td>
<td>24.0</td>
<td>5.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Methane Content in Nitrogen Vent</td>
<td>100%</td>
<td>99%</td>
<td>101%</td>
<td>112%</td>
</tr>
<tr>
<td>Total Power (relative to an LNG Flash Drum)</td>
<td>100%</td>
<td>99%</td>
<td>101%</td>
<td>112%</td>
</tr>
<tr>
<td>Equipment Count</td>
<td>Lowest</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Case Study #2

In Case Study #2, nitrogen removal options for a base-load LNG plant that processes feed gas containing 6 mole% nitrogen and has an LNG capacity of approximately 4 mtpa of LNG will be evaluated. Similar to Case Study #1, Air Products’ C3MR technology was selected for the liquefaction process. The refrigerant compressors are driven by aero-derivative gas turbines and the plant must produce enough endflash gas and B0G to meet the gas turbine fuel demand needed to drive the refrigerant compressors. To meet the heating value specification for the fuel gas supplied to the gas turbines, the fuel gas must contain less than 25% nitrogen. The LNG product quality specification is 1 mole% nitrogen and any nitrogen vented must contain less than 1 mole% methane. Similar to Case Study #1, five nitrogen removal options have been considered.

These are an LNG flash drum (option 1), a nitrogen stripping column (option 2), an LNG flash drum combined with a Nitrogen Rejection Unit (option 3), a nitrogen stripping column combined with a Nitrogen Rejection Unit (option 4), and finally an integrated nitrogen rectifier column (option 5). The key differences between Case Study #1 and Case Study #2 are the higher LNG capacity and feed nitrogen content in Case Study #2 as well as the requirement to produce enough fuel to meet the gas turbine fuel demand in Case Study #2. A summary of the key results are shown in table 3 below.

An LNG flash drum (option 1) leads to higher nitrogen content in the LNG product than is acceptable and is therefore not a viable option. This is due to the fuel requirement and the limited capacity of the flash drum to separate methane and nitrogen. This option also results in high nitrogen content in the fuel stream. A nitrogen stripping column (option 2) improves the nitrogen-methane separation and therefore it is possible to meet the fuel demand and meet the LNG product specification at the same time. However, the nitrogen content in the fuel stream for option 2 is higher than maximum nitrogen content of the fuel for the selected gas turbine. This problem can be addressed by adding a stand-alone Nitrogen Rejection Unit to a process with an LNG flash drum (option 3) or nitrogen stripping column (option 4). In both these cases, low methane content nitrogen will be vented from the Nitrogen Rejection Unit.

Table 3: Case Study #2 Results

<table>
<thead>
<tr>
<th></th>
<th>LNG Flash Drum</th>
<th>Nitrogen Stripping Column</th>
<th>LNG Flash Drum + Nitrogen Stripping Column</th>
<th>Nitrogen Rectifier Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG Production</td>
<td>500.0</td>
<td>500.0</td>
<td>500.0</td>
<td>500.0</td>
</tr>
<tr>
<td>Nitrogen Content in LNG</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
<td>&lt;1.0%</td>
</tr>
<tr>
<td>Fuel</td>
<td>45.0</td>
<td>45.0</td>
<td>7.6</td>
<td>25.0</td>
</tr>
<tr>
<td>Nitrogen Content in Fuel</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Methane Content in Nitrogen Vent</td>
<td>100%</td>
<td>99%</td>
<td>101%</td>
<td>115%</td>
</tr>
<tr>
<td>Total Power (relative to an LNG Flash Drum)</td>
<td>100%</td>
<td>99%</td>
<td>101%</td>
<td>115%</td>
</tr>
<tr>
<td>Equipment Count</td>
<td>Lowest</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

For Air Products•LNG 3  21/10/2015  14:11  Page 5

PRODUCTION
Unit while methane product from the Nitrogen Rejection Unit is sent to fuel. Any excess methane from the Nitrogen Rejection Unit that exceeds the fuel demand can be recycled to the feed gas compressor. The product and vent nitrogen specifications are satisfied in both options and the nitrogen content in the fuel stream is significantly lower than for option 2. Both options 3 and 4 have a higher equipment count and lower efficiency that option 2, but are viable options when low nitrogen content fuel is required. The final option (option 5) is a nitrogen rectifier column integrated with the liquefaction unit which produces a nitrogen rich vent stream. The nitrogen content in the fuel stream for option 5 is higher than that for options 3 and 4 and but meets than maximum nitrogen content of the fuel for the selected gas turbine. The process is not as efficient as the other options while the equipment count is comparable to option 2.

In summary, an LNG flash drum (option 1) is not a viable option to meet the LNG product specification. A nitrogen stripping column (option 2) has the lowest power requirement, low equipment count, but is not a viable option due to the high nitrogen content in the fuel stream. It should be noted that a nitrogen stripping column (option 2) would likely be a suitable option to supply fuel to industrial gas turbines that have historically been used in baseload LNG plants. An LNG flash drum combined with a Nitrogen Rejection Unit (option 3) and a nitrogen stripping column combined with a Nitrogen Rejection Unit (option 4) both lead to acceptable nitrogen content in the fuel stream with the addition of extra equipment. An integrated nitrogen rectifier column (option 5) results in a higher power requirement compared to the other options and is not a favorable option for this case study. In this example a nitrogen stripping column combined with a Nitrogen Rejection Unit offers the better overall project value due to exceptional efficiency while meeting all of the project requirements for LNG product, fuel and nitrogen vent quality.

**Conclusion**

Effective nitrogen removal options are needed as the LNG industry continues to expand. Fortunately, there are several options for nitrogen removal from LNG with each offering unique benefits. There is no single answer as each feed gas presents different challenges and each project will have different requirements. As was shown in the two case studies above, the options for nitrogen removal primarily depend on the amount of nitrogen in the feed, the amount of fuel that can be consumed by the process and the maximum nitrogen content of the fuel. It is important to select a nitrogen removal option that fits the needs of a particular project while offering a robust and reliable design. These options should be investigated early on in the project to prevent costly re-design and ensure project success.