With an abundance of low cost unconventional gas in regions such as North America and Australia, and a thirst for imported and cleaner energy resources across the globe, the demand for LNG is expected to continue to rise for years to come. There are a large number of LNG production projects in various stages of development, engineering or construction, including onshore baseload, mid scale, small scale and floating LNG (FLNG). These projects are intended to export LNG for power generation and heating, or, in the case of small scale, to supply LNG locally as a substitute for fuel oil and diesel in high horsepower applications.

Flexible and cost-effective LNG pretreatment solutions will facilitate large baseload, mid scale, and smaller scale liquefaction projects. While conventional pretreatment technologies are established, the increasing use of lean gas as feed poses new risks and serious technical challenges for engineering, procurement and construction (EPC) contractors.

Trevor Smith and Shain Doong, Honeywell UOP, USA, present a highly selective multilayer adsorbent process to remove C₅⁺ hydrocarbons.
and LNG plant owner-operators. In North America, for example, pipeline feed gas often does not have the natural gas liquid (NGL) content necessary to make deep cut recovery economically viable. However, the level of heavy hydrocarbons present is still sufficient to cause freezing and plugging in the main heat exchanger.

When feed gas is lean, meaning less than 2 gal. of C₂, NGLs per million ft³ (GPM), traditional hydrocarbon removal methods, such as scrub columns, expansion and condensation, tend to be either non-economic or difficult to operate. Their drawbacks include a lack of selectivity in the removal of specific hydrocarbon species, a reduction in plant capacity, more complicated operations by requiring external NGL imports into the plant, or more downtime due to frequent derining.

In response to these challenges, Honeywell UOP has developed a flexible LNG pretreatment solution for projects utilising lean gas as feed. SeparSIV™ is an adsorbent-based Thermal Swing Adsorption (TSA) system that will remove the C₅⁺ fraction, which may otherwise freeze in the heat exchangers, while leaving behind the C₄ fraction in the LNG product for Btu heating value. The process is based on the principle that adsorbents are capable of selectively removing impurities through a unique combination of materials and a comprehensive control system. The impurities are adsorbed at low temperatures in a fixed-bed adsorber and desorbed by ‘swinging’ the adsorbers from feed gas temperature (low) to regeneration temperatures (high) with hot regeneration gas, similar in flow scheme to a dehydration unit.

For lean feed gas, the SeparSIV adsorption system provides significantly lower Economic Lifecycle Cost (ELC) and is designed as an easier and more robust system to operate. For mid scale LNG projects (~50 – 400 million ft³/d capacity), the system can provide up to 35% lower ELC compared to an integrated scrub column. For large baseload LNG projects (1 billion ft³/d), lifecycle savings can be up to 50% against a cryogenic solution.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Feed composition</th>
<th>Specification</th>
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<tbody>
<tr>
<td>C₅⁺</td>
<td>800 ppmv</td>
<td>&lt; 1000 ppmv</td>
</tr>
<tr>
<td>C₄</td>
<td>100 ppmv</td>
<td>&lt; 100 ppmv</td>
</tr>
<tr>
<td>C₃</td>
<td>60 ppmv</td>
<td>&lt; 10 ppmv</td>
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<tr>
<td>C₂</td>
<td>50 ppmv</td>
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<tr>
<td>C₁</td>
<td>10 ppmv</td>
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</tr>
<tr>
<td>BTEX</td>
<td>30 ppmv</td>
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</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
| Turbo-expansion or JT valve followed by recovery tower | • Proven technology for large LNG systems.  
• Ability to handle wide feed concentration range.  
• Excellent removal of NGLs. | • Highest CAPEX and OPEX. Requires more pieces of equipment, including booster compressor.  
• Rotating equipment can impact plant availability.  
• Only economical at high levels of NGL recovery. |
| Scrub column integrated with mechanical refrigeration or mid-point cooling from the cold box | • Lower CAPEX than turbo-expansion with recovery tower.  
• Simpler to operate than turbo-expansion.  
• Good removal of NGLs at rich feed gas levels. | • Column requires small to moderate pressure drop to operate below critical pressure. Results in lower LNG yield, or the need for larger refrigeration horsepower or recompression (additional CAPEX and OPEX) to meet desired production rate.  
• Performance and operability challenged with lean gas (insufficient C₅ – C₄ reflux to remove heavy components effectively or efficiently; potentially benzene slip). Results in greater downtime, more frequent derining of the heat exchanger.  
• C₅ – C₄ removed with the heavy components; lowers LNG heating value and yield. |
| Separator drum integrated with mid-point cooling from the cold box | • Simple to operate.  
• Low CAPEX. No column or reflux needed.  
• Good for intermittent LNG production applications. | • Inefficient removal of C₅ components, including benzene.  
• Condenser pressure needs to operate below critical point; results in lower LNG yield or higher refrigeration horsepower or recompression requirements (CAPEX and OPEX).  
• Very low temperatures needed to remove compounds, such as benzene, reducing liquefaction capacity and increasing products losses (C₅) to fuel gas. |

**LNG specifications and traditional hydrocarbon removal methods**

Pipelines, particularly in North America and Australia, are increasingly carrying lean unconventional gas. The feed gas is considered lean if it has high methane content naturally, or when the majority of the ethane, propane and butane components have been recovered in an upstream or midstream gas processing plant. The C₂ hydrocarbons in the feed, however, often remain near the same levels as when the natural gas was produced at the well head.¹

Table 1 provides information regarding typical levels of C₂, in pipeline gas and the maximum allowable limits to avoid freezing in the downstream LNG plant. The allowable limits of heavy hydrocarbons to the LNG plant vary depending on the liquefaction technology and

Table 2. Comparison of traditional heavy hydrocarbon removal methods for lean LNG plants

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
</table>
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• Ability to handle wide feed concentration range.  
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• Rotating equipment can impact plant availability.  
• Only economical at high levels of NGL recovery. |
| Scrub column integrated with mechanical refrigeration or mid-point cooling from the cold box | • Lower CAPEX than turbo-expansion with recovery tower.  
• Simpler to operate than turbo-expansion.  
• Good removal of NGLs at rich feed gas levels. | • Column requires small to moderate pressure drop to operate below critical pressure. Results in lower LNG yield, or the need for larger refrigeration horsepower or recompression (additional CAPEX and OPEX) to meet desired production rate.  
• Performance and operability challenged with lean gas (insufficient C₅ – C₄ reflux to remove heavy components effectively or efficiently; potentially benzene slip). Results in greater downtime, more frequent derining of the heat exchanger.  
• C₅ – C₄ removed with the heavy components; lowers LNG heating value and yield. |
| Separator drum integrated with mid-point cooling from the cold box | • Simple to operate.  
• Low CAPEX. No column or reflux needed.  
• Good for intermittent LNG production applications. | • Inefficient removal of C₅ components, including benzene.  
• Condenser pressure needs to operate below critical point; results in lower LNG yield or higher refrigeration horsepower or recompression requirements (CAPEX and OPEX).  
• Very low temperatures needed to remove compounds, such as benzene, reducing liquefaction capacity and increasing products losses (C₅) to fuel gas. |
process conditions. Since most of the NGLs have already been extracted from pipeline gas, the primary purpose of removing heavy hydrocarbons is to prevent freezing in the downstream heat exchangers.

Table 2 compares the various traditional hydrocarbon removal methods for LNG plants. Selection of the appropriate heavy hydrocarbons extraction technology can greatly influence the cost and operability of an LNG plant. Using cryogenic technology is unlikely to be the most cost-effective method to remove C5+ hydrocarbons in a lean gas situation, due to high capital and operating costs associated with expanders, columns and compressors. In addition to this, there are also process challenges. Pressure drop associated with the stable operation of a scrub column is often required, and due to the gas being lean, there may not be sufficient NGLs to provide the necessary reflux to maintain that stability. Such instability can result in heavy hydrocarbon slip and greater downtime associated with frequent deriming (defrosting) of the heat exchanger.

For lean gases where the primary purpose is removal of C5+ hydrocarbons and not NGL production, adsorption technology can offer significant advantages.

**Heavy hydrocarbon removal from lean gas with adsorbents**

Adsorption systems are commercially proven for removal of water and heavy hydrocarbons (C7+) to protect equipment and meet pipeline specifications. However, the typical hydrocarbon removal unit using a single adsorbent, such as silica gel, cannot efficiently remove heavy hydrocarbons to the levels required for LNG pretreatment (Table I). Efficiently removing hydrocarbons to tight LNG specifications requires a combination of high performance adsorbents. The SeparSIV process utilises a multi-layer system of adsorbents to target and optimise adsorption of C5+ to less than 0.1 mol% and BTEX to less than 1 ppmv from lean gas. The process technology is combined with an advanced control system that enables the process to flexibly adjust to varying dew point requirements.

A process flow diagram of the SeparSIV process is provided in Figure 1. Hydrocarbons are adsorbed at near ambient temperatures in a fixed-bed adsorber and desorbed by heated regeneration gas, much like the flow scheme of a dehydration unit. The pressure of the treated gas remains close to that of the feed gas and the hydrocarbons are recovered as a liquid during regeneration.

The primary differences between a molecular sieve dehydration unit and an adsorbent-based hydrocarbon removal unit are that hydrocarbon removal units generally have a shorter adsorption time and use different adsorbents. It is also possible to remove low levels of CO2, water and hydrocarbons with a single adsorption system. This solution improves plant economics by eliminating the need for a separate amine acid gas removal unit and molecular sieve dehydration unit.

As a general guide, Figure 2 shows where SeparSIV is a strong fit for lean gas applications compared to a cryogenic solution. When NGL GPM levels in the feed gas are approximately two or less, the process can be the fit-for-purpose solution. At GPM levels of approximately two or above, a cryogenic solution may be the better option. Actual selection of the most appropriate process will be influenced by the specific gas composition and product specifications of the project.

For lean gas, SeparSIV provides the following benefits:

- Simpler to operate than a turbo-expander or scrub column.
- ‘Surgical’ removal of heavy components (C5+) without removing lighter hydrocarbons (C2 – C4), maintaining the Btu heating value of the LNG.
- Operates at high pressure with little pressure drop, maintaining high operating efficiency and high LNG production rate while eliminating the CAPEX and OPEX associated with recompression.
- Unlike a scrub column, SeparSIV does not require reflux to operate, which eliminates the cost and complexity of having to import NGLs into the plant.
- Less downtime and cost of deriming.
- The process has the turndown capability and the flexibility to handle changes in feed gas composition by adjusting the cycle times of adsorption, the temperature of the regeneration gas, and the flowrate of the regeneration gas.
Technical solution and verification

The SeparSIV process has a unique design of layered adsorbent configuration, where C\textsubscript{8+} and BTEX are removed by the top layer, designated as SS3, and lighter hydrocarbons C\textsubscript{7-} are removed by the bottom layer, SS7. This innovation is also based on a fundamental adsorption principle, as illustrated in Figure 3, showing the adsorption isotherms of C\textsubscript{8} and C\textsubscript{5} for both adsorbents. SS3 has a higher adsorption capacity for heavier components, such as C\textsubscript{8}, and SS7 shows a higher capacity for lighter components, such as C\textsubscript{5}. The two layers of adsorbents, working complementarily, remove a wide spectrum of hydrocarbons to meet the stringent requirement of LNG pretreatment specification.

Honeywell UOP conducted comprehensive pilot plant testing, acquiring key design information, such as dynamic adsorption capacities, mass transfer parameters, cycle time, regenerability, etc. A rigorous dynamic adsorption process simulator based on fundamental adsorption data and pilot plant results was also developed. Figure 4 shows a comparison of the model predictions with the pilot plant data.

The model has been validated by commercial plant data from several of Honeywell UOP’s MemGuard\textsuperscript{TM} units in gas processing operation globally and also from peak shaver plants, thereby providing an operating basis for the SeparSIV design tool.

The company designed and commissioned more than 10 TSA-based adsorption units (Table 3), which go by the name of MemGuard, for heavy hydrocarbon removal starting in the late 1990s. These adsorption units remove primarily C\textsubscript{8+} hydrocarbons, including BTEX upstream of Separex\textsuperscript{TM} membrane systems, which are also sensitive to heavy hydrocarbons, due to the potential for hydrocarbon condensation. It has also designed many peak shaver molecular sieve units for removal of CO\textsubscript{2} and water from pipeline quality gas. While not specifically designed for hydrocarbon removal, these molecular sieve units typically remove hydrocarbons, such as C\textsubscript{5}, C\textsubscript{6} and C\textsubscript{7}, to less than 1 ppmv. The SeparSIV process has been enabled by this experience.

Conclusion

As the demand for LNG continues to grow globally, a greater share of feed gas is anticipated to be lean in NGLs. In response to these conditions, EPC contractors, modular plant suppliers, and LNG owner-operators require a cost-effective process technology to remove nuisance levels of higher hydrocarbons. The process described in this article aims to consistently protect the main heat exchanger from heavy hydrocarbon damage and is based on commercially proven TSA technology. A flexible process solution for heavy hydrocarbon removal can be more fit-for-purpose, easier to operate, and more cost-effective than traditional heavy hydrocarbon removal methods.

References


<table>
<thead>
<tr>
<th>Location</th>
<th>Million ft\textsuperscript{3}/d</th>
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<th>Start-up</th>
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<tr>
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<td>2-bed</td>
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<tr>
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<td>2000</td>
</tr>
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<td>4-bed</td>
<td>2000</td>
</tr>
<tr>
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<td>550 + 450</td>
<td>5 + 4-bed</td>
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</tr>
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<tr>
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