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Innovations in Small to Mid-Scale LNG Plants

Success Story from Hanas LNG Plant

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Background

Located 1600 km from the nearest port in the industrial zone of Yinchuan City, Ningxia, China, the Hanas LNG plant comprises two LNG trains each producing nominally 0.4MTPA of LNG using the AP-SMR™ Liquefaction Process. The plant is air cooled and electrically driven from an external power source. The feed gas is sourced from the pipeline grid. The LNG product is stored in a 50 000 m^3 full containment tank before export across China by road tankers. It successfully started up in 2012 and has demonstrated excellent performance ever since. This paper describes the solutions that contributed to the successful start-up and operation of the Hanas facility as well as other innovations that address the unique characteristics of small to mid-scale LNG plants.

Feedstock Compositions

Many small to mid-scale LNG plants have feed gas that originates from domestic pipelines or unconventional sources such as coal beds methane (CBM), tight sands, or shale. In many cases, these feed streams contain much less C_2 through C_5 components when compared to conventional LNG plant feeds, yet may still contain unusually high levels of heavy alkanes and aromatics (Heavy Hydrocarbons, or HHC's) that introduce operating challenges in cryogenic liquefaction plants. A key issue in addressing these challenges is the removal of the heavy hydrocarbons in the feed gas (typically with content <1000ppmV) down to below detectable limits (0.5 to 1ppmV) before the gas is sent for liquefaction – i.e. ultra-purification of the feed gas – that can otherwise result in crystallization at the cold end or the cryogenic sections of the plant leading to potential plugging of equipment and/or formation of cryogenic sludge or wax in storage tanks.

Another unique characteristic of such feed gas is that the pipelines have multiple sources. As these sources come on and off, the gas composition entering the LNG plant can vary significantly over a relatively short period of time. It is therefore crucial to design a process that can accommodate the various and changing feed gas compositions.

As an example, the feedstock for an LNG plant can vary across the compositions given in Table 1.

%mol	Composition A Lean	Composition B Average	Composition C Rich
N2	0.3%mol	1.5%mol	0%mol
C1	99.57%mol	94.1%mol	93.1%mol
C2	0.07%mol	3.0%mol	5.2%mol
C3	0.02%mol	0.82%mol	1.0%mol
i-C4	0%mol	0.20%mol	0.18%mol
n-C4	0%mol	0.15%mol	0.17%mol
i-C5	0.02%mol	0.01%mol	0.08%mol
n-C5	0.01%mol	0.1%mol	0.04%mol
C6+	0.01%mol	0.1%mol	0.2%mol
Benzene	Trace	300ppm	400ppm
Toluene	Trace	35ppm	50ppm
Xylene	Trace	Trace	15ppm

Table 1: Example of feedstock composition

As it can be seen from Table 1, the relative content of NGL and Heavy Hydrocarbon (HHC) can be widely different.

Removing HHC's from the feedstock with varying and unpredictable compositions was one of the most challenging aspects of designing the Hanas LNG plant, particularly the liquefaction process.

For base load LNG plants, an integrated scrub column is widely used to remove HHC's. For this method, the natural gas is pre-cooled and then fed to a distillation (scrub) column to remove the HHC's. The overhead from the scrub column, containing natural gas without HHC's, is then liquefied. Thus the HHC removal is "integrated" with the liquefaction process. The scrub column must operate below the critical pressure of the feed gas in order to provide adequate HHC removal. Depending on the gas composition, the critical pressure may be as low as 40 barg, as is the case for Gas Composition A, for which the phase envelope is given in Figure 1.

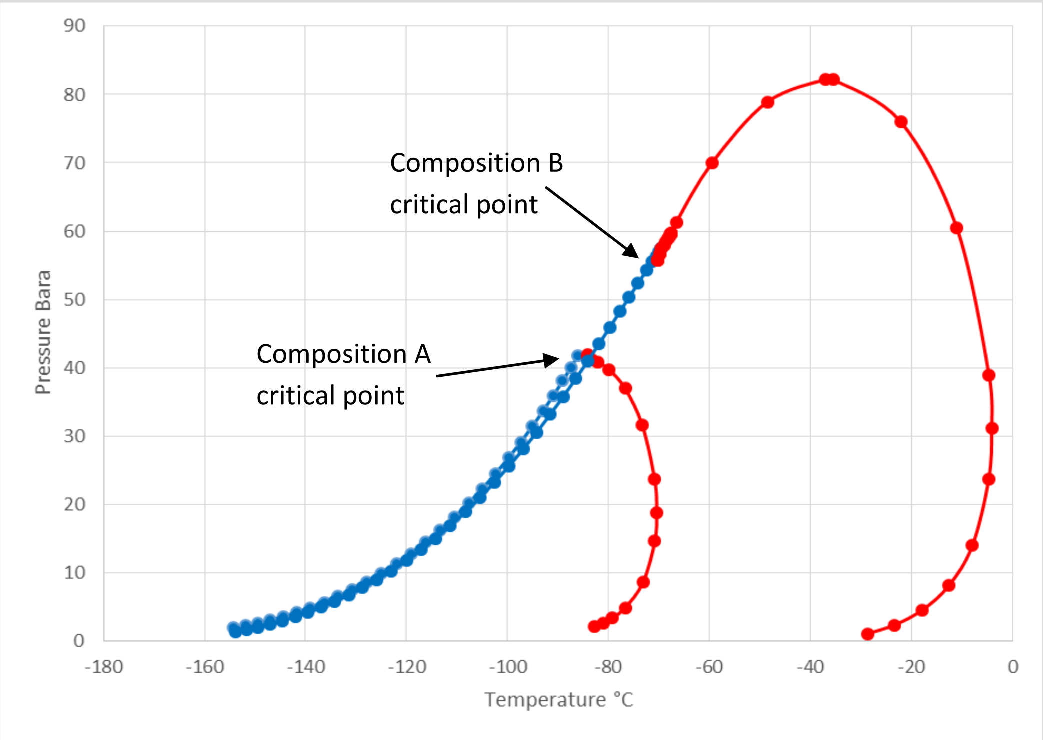

Figure 1: Phase envelope for Gas composition A and B

Note: Phase envelope for composition C is very close to composition B and is not presented not to overload the figure

Since the liquefaction efficiency improves as the feed pressure increases, a scrub column used for a plant processing a feed gas with a low critical pressure would be a burden for the plant performance, and would negatively impact the plant CAPEX and OPEX.

One possibility to mitigate this efficiency loss while ensuring a proper HHC removal is to use a turbo-expander based NGL extraction unit. This lowers the feed pressure and sends the feed to a distillation column, where the HHC's are removed. The treated natural gas is then recompressed to the optimum liquefaction pressure. This arrangement has implemented in some base load plants [1].

However, in a small capacity plant processing very lean gas such as Composition A, a front-end NGL extraction unit is often not feasible for several reasons, including associated capital cost and process complexity.

Another possibility is to use a Temperature Swing Adsorption (TSA) process with adsorbents that selectively remove the aromatics and linear alkane HHC's. Adsorption processes are widely used in the natural gas industry to reduce the hydrocarbon and water dew points to meet pipeline specifications. However, at the design stage of Hanas LNG plant, no adsorbent supplier was ready to offer guarantees for the ultra-purification process of removal of aromatics and HHC's to the required levels (typically, less than 1ppm for C_8 and Benzene).

Technip and Air Products and Chemicals, Inc. (APCI) decided to implement a Temperature Swing Absorption (TSA) system designed according to a predictive model developed by APCI. During the initial plant design, the anticipated feed gas composition included a modest level of nC_8 and aromatics that required complete removal (which was the basis for bed sizing), but relatively lower levels of nC_6 and nC_7 that would have been acceptable if not completely removed.

The TSA proved very successful, and performance tests completed during the first months of operation demonstrated that the model accurately predicted the actual performance of the TSA.

After the plant was designed, new information indicated that the plant would also need to process a heavier feedstock that was not originally anticipated. This feedstock contained a much higher amount of heavy alkanes, particularly nC_6 and nC_7. The TSA by itself, as manufactured and installed, could no longer effectively remove all HHCs below their allowable concentration. After reviewing several options, Technip and APCI decided to implement an integrated stripping column downstream of the TSA to remove residual heavy alkanes (primarily nC_6 and nC_7). This integration effectively incorporates each unit operation at what it does best: TSA for C_8 and aromatics, and the stripping column for nC_6 and nC_7 removal. A simplified scheme of this arrangement is presented in Figure 2.

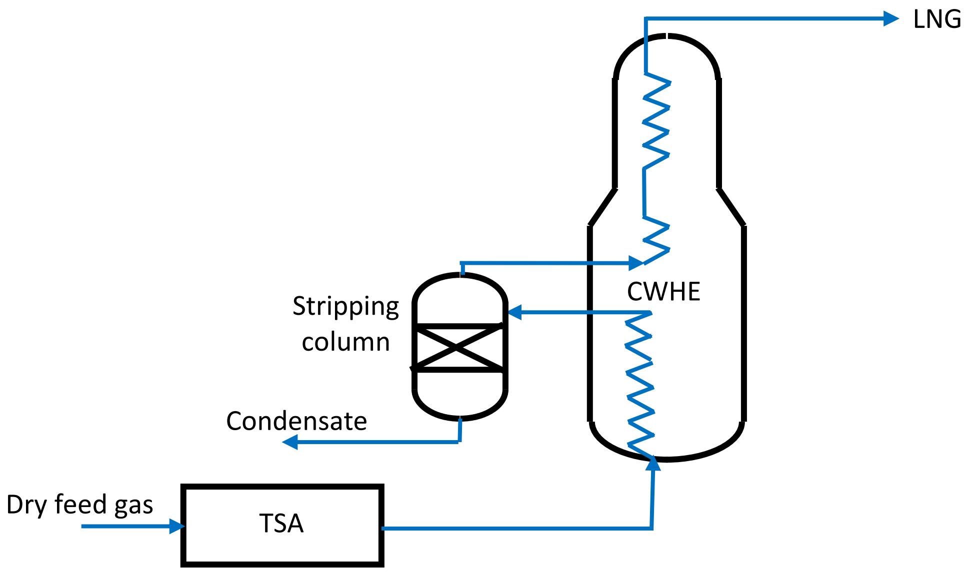

Figure 2: Simplified HHC removal process scheme

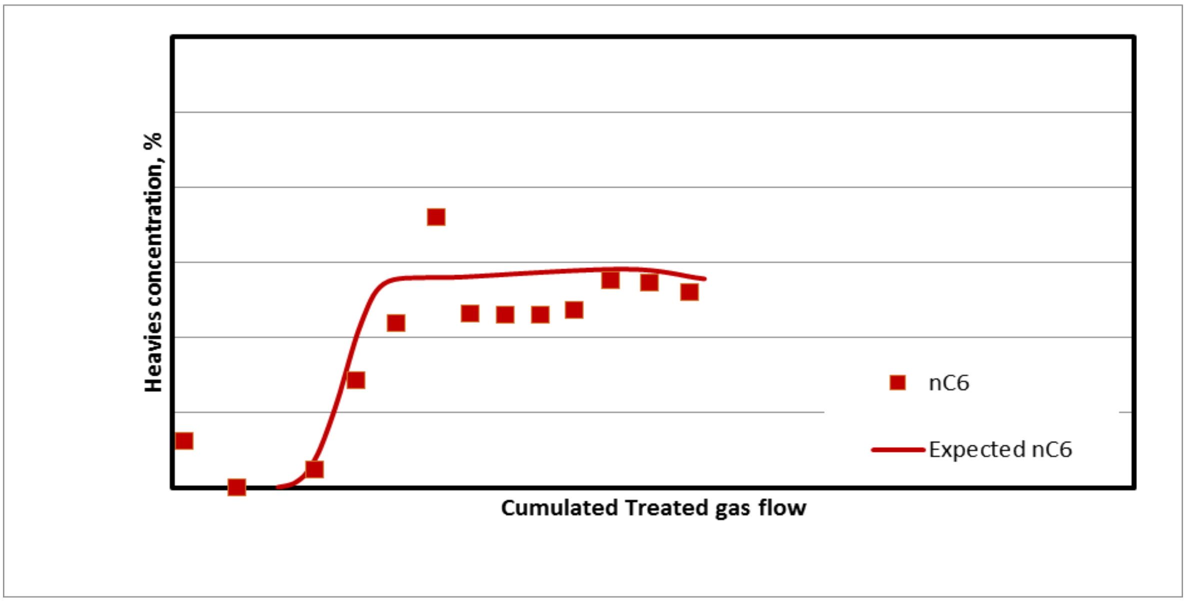

Figure 3: nC_6 content at adsorber outlet vs. treated gas flow, over a cycle.

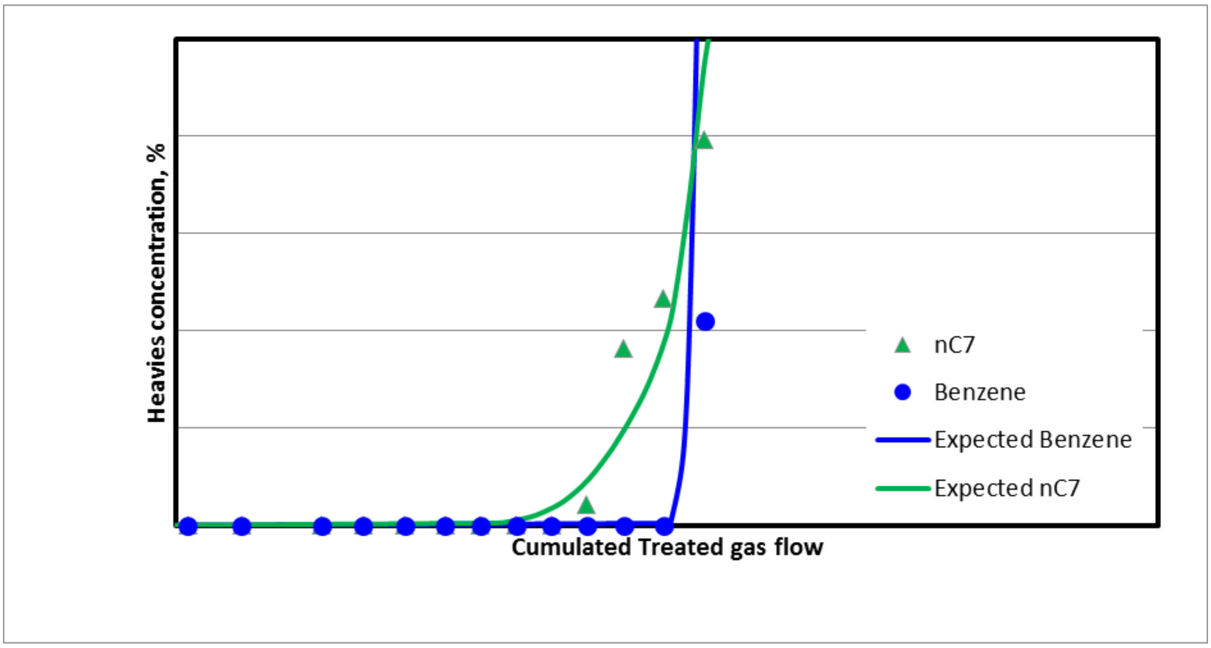

Figure 4: nC_7 and Benzene content at adsorber outlet vs. treated gas flow, over a cycle.

Figure 3 and Figure 4 show that the model developed by APCI accurately predicts the breakthrough curves of the HHC's, and the adsorbent beds are effective to remove benzene and HHC's that are heavier than nC_7, as proven by the fact that these components did not breakthrough for the duration of the test.

Then, when feed gas composition changes, the operating pressure of the stripping column can be adjusted to ensure that residual heavy alkanes are removed down to their allowable concentration in LNG. This operation flexibility minimizes the time-averaged impact of feed gas composition change on liquefaction capacity and specific power.

As demonstrated at the Hanas LNG plant, combining a TSA with a stripping column effectively removes HHCs even though the feed has low C_2-C_5 components and the feed gas composition changes rapidly.

Other HHC removal schemes have been developed by APCI [2, 3] that can effectively reduce the level of HHCs in lean natural gas prior to liquefaction.

High efficiency

The Hanas plant buys electricity from the grid and process efficiency gains quickly improve OPEX. Hence, from the proposal stage, APCI and Technip closely coordinated with the

Mixed Refrigerant (MR) compressor supplier to optimize the compressor design with the AP-SMR™ Liquefaction Process, providing a cost effective, highly efficient plant.

APCI first ran its simulation with a three stage refrigerant compressor. Based on the resulting process data the MR compressor supplier (Dresser-Rand) optimised the design of its machine and proposed a two stage compressor, however with a slightly lower than expected efficiency. Technip then suggested further optimization by increasing the speed of the machine. This improved the compressor polytropic efficiency but also resulted in a smaller compressor frame. Overall, this coordination between the three parties, namely APCI, Technip and Dresser-Rand resulted in a more efficient process, and in a lower capital investment.

The process can also be operated with the TSA only (no stripper) for certain feed gas compositions. Use of the TSA for HHC removal, allowing liquefaction of the treated gas at high pressure, is a major contributor to the efficiency whenever the feed gas is lean enough to run on the TSA alone.

Figure 5 plots the relative specific liquefaction power vs. feed pressure at the liquefaction inlet. It shows the reduction in specific power (or gain in efficiency) from 40 to 70 barg of an AP-SMR™ liquefaction process.

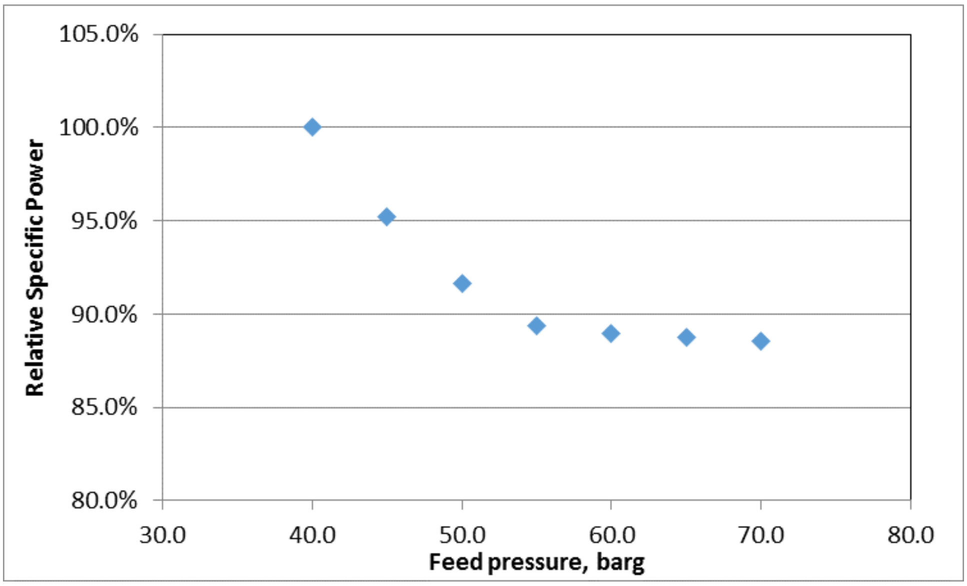

Figure 5: Relative specific liquefaction power vs. feed pressure

Note: The specific power is defined as (MR Compressor power + Feed Compressor power + BOG Compressor power)/(LNG rundown).

This graph shows the advantage of operating the liquefier at a pressure higher than the critical pressure (approximately 45 barg), which can be achieved only if HHC removal is performed through a TSA, or a turbo-expander based front-end NGL recovery unit.

Turndown Flexibility

Since small to mid-scale LNG plants usually draw their feedstock from pipelines supplying domestic and commercial users, the plants are prone to changes in gas supply availability. For example, feed gas availability during winter may be reduced as gas is prioritised toward domestic usage in northern Region. In summer, increased power demand from air conditioning may reduce the gas available for liquefaction in the southern regions. Also, in contrast to base load plants which usually rely on long term take-or-pay agreements, mid-scale plant adjust their production to meet the market demand, which is influenced by several parameters such as seasonal variation or economic fluctuation in their area of delivery. All of these may require the LNG plants to operate at reduced capacity more often than typical base-load plants. At the same time, to maintain the profitability of the plant, it is of crucial importance to maintain low operating costs even at reduced capacity, or to maintain a satisfactory efficiency and low power consumption at turndown.

The robustness and flexibility of equipment are important to consider when designing an LNG facility with frequent turndown operation. During transition between full capacity and reduced capacity, matching the refrigerant flow with the required heat load is necessary to prevent rapid and large thermal stress in the liquefaction equipment. The robustness of the Coil Wound Heat Exchanger (CWHE) during transient temperature changes (start-up, upset and turndown) has been proven in over 85 operating base-load LNG plants in the past 40 years. When properly engineered, utilizing high performance internals, CWHEs can operate stably over a very wide range of LNG production, covering greater flow regimes than other heat exchanger types. All of these features make CWHEs the best fit for Hanas and similar plants where frequent turndown may be foreseen.

One of the key features of the AP-SMR™ technology is that the circulating MR composition adjusts itself with the plant capacity, without having to dispose or make-up refrigerant during capacity swings. This is because at turndown, the liquid MR inventory is reduced in the CWHE and piping. The refrigerant is then stored in the MR separators, which prevents having to vent MR. This is important, because if MR were vented, it would have to be purchased and made-up to the refrigeration loop when production is increased.

APCI developed a rigorous dynamic simulation that uses the Hanas specific CWHE design information, proprietary thermodynamic package, and as-tested machinery information. This was used to design a robust control scheme that ensures optimal operation for wide diurnal temperature swings and rapid production changes without the needs for venting or draining of the refrigerants, saving the associated cost of refrigerant replacement.

Figure 6 shows how the level in the MR separator varies with the plant production, reflecting that less MR is held up in the CWHE and piping and is transferred to the MR separator. This demonstrates the effectiveness and ease of control of the AP-SMR^{TM} technology. In addition, the theoretical prediction of the MR separator inventory, calculated from the APCI optimized dynamic simulations compares very well with the actual inventory measured during plant operation.

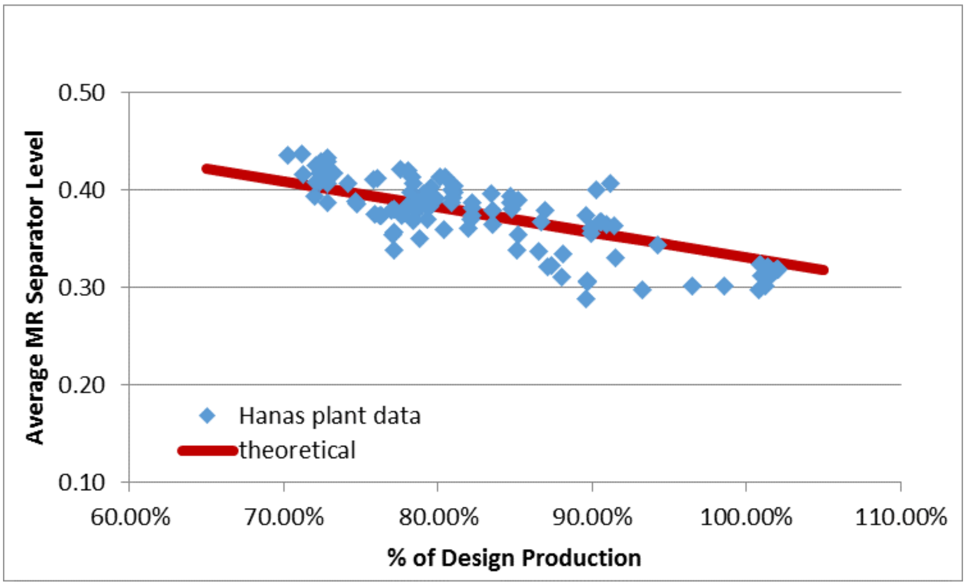

Figure 6: MR separator hold-up vs. plant production rate

In addition, the refrigerant compressor in the HANAS LNG plant, as is often the case in a mid-scale LNG plant, uses an electric motor drive, and is fitted with a variable speed drive system primarily to accommodate the MR compressor start-up from settle-out conditions, without putting excessive burden onto the public electrical grid. However, the variable speed drive system provides additional benefit, allowing the plant to maintain relatively high efficiency even at reduced capacity, by adjusting the MR compressor speed with the plant throughput. As the plant production rate decreases, the MR speed can be reduced so that the MR machine stays away from the surge line while maintaining optimal compressor efficiency at reduced throughput.

Figure 7 shows how the MR compressor rotating speed can be adjusted to meet the optimum operating point when the plant production changes.

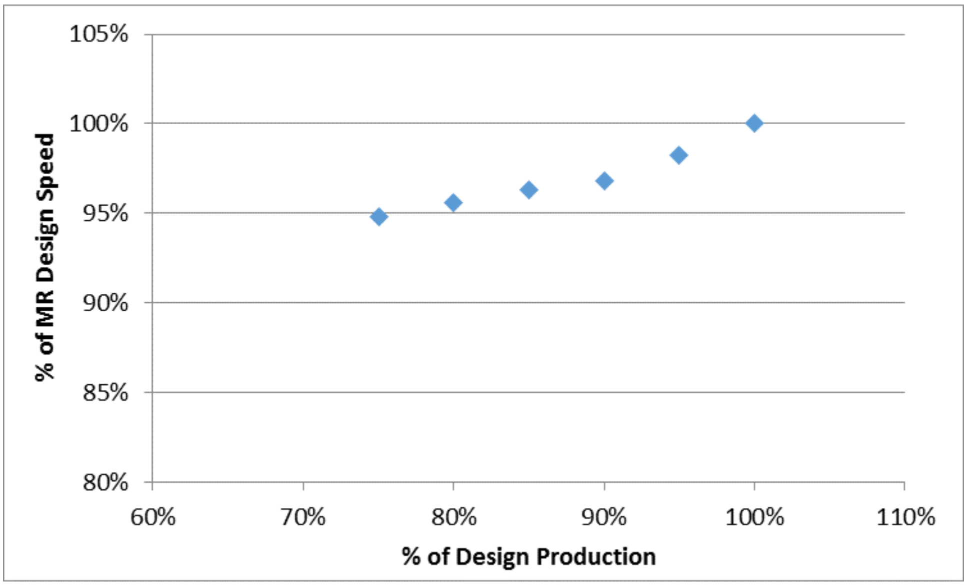

Figure 7: MR compressor speed vs plant throughput.

Figure 8 shows the benefit of the combining the AP-SMR™ process intrinsic flexibility with variable speed compressor with respect to overall efficiency.

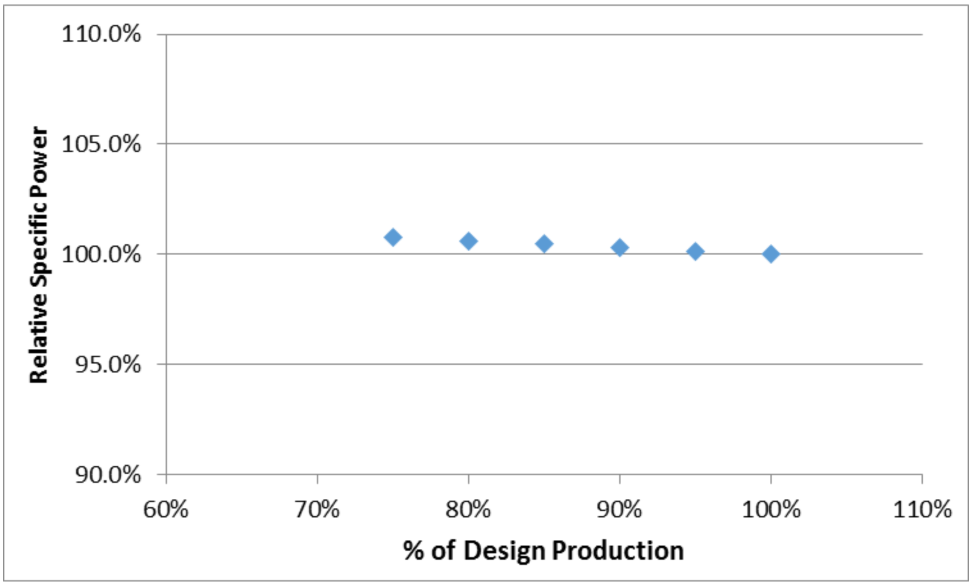

Figure 8: Specific power vs plant throughput.

The Hanas LNG plant has been operated efficiently over a very wide range of capacity, from less than 10% of the design rate when feed gas availability was low, to over 100% when customer demand was high. It is important to point out that Hanas LNG plant was able to operate at an impressive 30% turndown rate without having to open refrigerant compressor recycle valves (therefore the liquefaction could be maintained with relatively high efficiency). Furthermore stable production has been demonstrated at only 10 to 15% of the throughput, with MR compressor recycle valves only partially opened.

Imported Refrigerant

Like many small to mid-scale LNG plants, the refrigerant components are imported rather than produced at site due to the "lean" nature of the feed gas and the capital cost associated with additional extraction processes. As it turns out, the savings from not having to install refrigerant fractionation is offset by the cost of importing these refrigerants. It is therefore extremely important to reduce the refrigerant consumption. In a base load plant, refrigerant are typically disposed to the flare when the refrigerant inventory has to be reduced to:

a) accommodate lower plant production,

b) reduce the compressor torque required to move the refrigerant inventory held in the system when starting a refrigerant compressor

As we have seen earlier, the MR separator vessels installed in the Hanas LNG AP-SMR™ process naturally serve as "storage" for refrigerant components, each at different pressure and temperature, allowing a decrease in the active inventory of the system without having to vent refrigerants during period of low production.

The variable speed drive provides a high start-up torque, even at low speed, and allow the MR compressor to be started from the settle-out pressure, thus removing the need to depressurize the MR system.

Hence these features clearly are keys in reducing the OPEX associated with refrigerant import.

Variable speed electric drives

Most mid-scale LNG plants take advantage of a reliable local grid and use electric drives for the rotating machinery. However, due the large power draw required to start a large electrical motor, variable speed drives are often required to decrease the power surge during motor loading and to stay within the grid capacity.

The advantage of variable speed drive coupled to the MR compressor has been extensively described in the previous section of this article, and is summarized below:

- Because of the fairly frequent swings in capacity, a variable speed drive translates not only into ease of operation but also lower operating costs. In turndown conditions, the compressor can stay out of recycle (up to a certain point) while maintaining optimal compressor efficiency.
- The compressor can be restarted from settle-out pressure, preventing large amount of refrigerant to be wasted.
- Finally, adjustment to production capacity changes can be done without the need to purge costly refrigerants.

Speed variation can be achieved using one of several available technologies: Several types of electronic frequency variation (VFD) or a variable ratio hydraulically coupled gear associated with a fixed speed motor. Specifically in Hanas, a variable speed hydraulic coupling with planetary gear had been selected for this purpose and has been successfully operating since start-up.

Both technologies have their place in the mid-scale LNG field, and selection shall be made carefully, taking into account parameters such has electrical power grid strength, available footprint, shaft dynamics, compressor/driver interface, ease of maintenance and operator preferences.

Low fuel gas demand in e-LNG

Another particularity of small to mid-scale LNG plants lies in the extremely low fuel gas demand due to the use of electric drives. Thus, boil off gas from the tank and other gaseous effluents cannot be used as fuel as it is commonly the case in base load plants. In addition, as opposed to a base-load plant, mid-scale plants often ship LNG by tanker truck, which are loaded during daytime, loading operation being stopped during night-time. This causes the boil-off gas, and subsequently the fuel gas, to vary between day and night. Although boil-off gas could be theoretically suppressed by producing deeply subcooled LNG, this would have significantly reduced liquefaction efficiency. Also, since more LNG boils off during truck loading, this would require close operator attention. Therefore, to reduce operating complexity and increase efficiency, the boil-off gas is recycled to the front of the plant for liquefaction. To achieve the optimum operating conditions, the LNG rundown temperature is adjusted to balance the boil-off compression duty with the MR compressor duty. This operating mode results in stable and efficient operation, quite insensitive to truck loading.

Transportation Limitations

Unlike large base load LNG plants for export where the facility is close to the shoreline, many small and mid-scale LNG plants are built close to local inland markets. The location of Hanas LNG plant is 1600 km away from the nearest port. This poses unique challenges to inland transportation as the equipment size and weight have to stay within limitations imposed by bridges, tunnels, and toll stations. To overcome this challenge, the Hanas CWHEs were designed to be split into three separate vessels and were shipped separately to the site.

The three separate bundles were then installed in a steel structure, along with instrumentation and interconnecting piping. Technip applied its cryogenic plant experience to design a modular structure which accommodates thermal contraction, requires limited space, and provides sufficient access.

Schedule

As for any other oil and gas project, after safety and plant performance, on time completion is highly important. This was the case for Hanas LNG, for which an aggressive schedule was followed to meet the owner's objectives.

The competitive business environment, the contracting strategies employed and the dynamic construction sector in China facilitated a very short design and construction schedule.

Despite the harsh weather conditions in the Ningxia region, where outside works have to be stopped during the winter season, the 50 000 m^3 full containment LNG tank was completed in less than 28 months, the CWHEs arrived on-site within 17 months, and the plant was Ready-for-Start-up 30 months after award.

Conclusion

Small to mid-size LNG plants have their unique characteristics and pose new challenges. As described above, the Hanas LNG plant successfully addressed these challenges.

Lean but variable feedstock, capacity swings, electrical driver requirements, logistic issues, a challenging schedule had to be accommodated into the design, while meeting the ultimate aim of any plant owner: efficiency, profitability, and adaptability, combined with ever higher safety and environment standards.

The strong interaction and experience of the various participants to the Hanas LNG project (owner, engineering contractor, process licensors, and equipment suppliers) allowed all challenges to be overcome, resulting in a successful, innovative, efficient, and robust plant.

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