Reprinted from
LNG INDUSTRY
A supplement to Hydrocarbon Engineering

ON A smaller scale

James C. Bronfenbrenner and Warren R. Miller, Air Products and Chemicals, present coil wound heat exchangers for mid sized LNG plants.

Mid sized LNG plants producing from 0.5 - 2.5 million tpy are being promoted as the way to monetise stranded gas reserves at reduced cost. The LNG industry trend in recent years has been toward larger plants, but it is often forgotten that approximately half of the operating LNG plants are in the capacity range of 0.5 - 2.5 million tpy, what is today called the mid size LNG market. Coil wound heat exchangers in these mid sized operating plants have demonstrated high reliability, operability, and productivity for more than 35 years. The coil wound heat exchanger is most suitable for liquefying natural gas for several reasons, the most notable of which is its robust design and resultant ability to withstand the stresses inherent in the operation of a liquefaction process.

Liquefaction heat exchanger process requirements

LNG liquefaction processes have independent natural gas and refrigeration streams. To complicate matters, the multi component natural gas feed stream changes phase continuously from vapour to liquid. This makes it difficult for the control system or the operator to equalise the heat load of the natural gas (warm) and refrigerant (cold) streams. For example, when the refrigerant is a single phase fluid (e.g. N_2 vapour) the heat load of the single phase vapour must be matched to the heat load of the multi component, two phase feed. During startups and major upsets, there is no way to measure the phase change rate of the natural gas, and therefore to directly match the refrigerant heat load to that of the feed. When the refrigerant is a multi component refrigerant, it goes through the same phase changes as the feed. While this provides greater efficiency, it introduces an additional challenge in matching the heat loads of the warm and cold streams during startup and upsets. When the heat loads are not matched, the temperature difference between the warm and cold streams can easily exceed 30˚C, the generally accepted alarm point for aluminium heat exchangers due to thermal stress.[1] In the years that Air Products has been providing coil wound heat exchangers for natural gas liquefaction service, none have ever reported a complete failure due to the thermal stresses resulting from large temperature differences, which can occur during every startup and upset. In contrast, there are documented failures of brazed aluminium heat exchanger (BAHX) cores in similar services.

As a leading industrial gas and cryogenic engineering firm, Air Products is one of the largest buyers and users of BAHX cores in the world. BAHX cores are well suited for processes with single phase, inherently balanced feed and refrigeration streams, i.e. where the heat loads of the hot and cold streams are inherently matched. Examples of this are cryogenic air separation and NGL extraction where predominantly all of the feed is returned as vapour products. BAHX cores in these processes do not experience the large temperature differences and hence thermal stresses that LNG heat exchangers do. Pure component propane and ethylene evaporators used in liquefaction processes are also inherently balanced as long as the pure component level controller works and there have been no documented problems with BAHX cores in this service.

However, when BAHX cores are used in processes with independent, multi component, phase changing streams, the risk of failure is increased due to thermal stresses if/when large temperature differences between the warm and cold streams occur. Reports of problematic applications of BAHX cores in the LNG industry can be found for LNG end flash exchangers, multi component liquefaction heat exchangers, and reboilers where hot and cold heat loads are independently set.[2]

In addition to the thermal stress issue, liquefaction main heat exchangers are occasionally exposed to water and mercury (Hg) when adsorption systems break through. The coil wound heat exchanger with its relatively large smooth tube surface provides few crevices where the contaminants can build up and cause damage, whereas BAHX cores have many small crevices between the heat exchanger parting sheets and the heat transfer fins which can collect water and mercury. Water can cause leaks due to expansion on freezing; and mercury, when exposed to moisture, can cause leaks due to corrosion of aluminium.

The mechanical structure of a coil wound heat exchanger provides an additional benefit in that if a hydrocarbon leak in the natural gas circuit were to occur, the hydrocarbon would be contained within the pressure shell. The heat exchanger can be operated with leaks for a long period of time with minimal process effect; and the leak can be repaired during a scheduled shutdown in conjunction with other plant maintenance activities. Hydrocarbon leaks in a BAHX core tend to be at the side bar and manifold joints where the thermal stresses are highest. Hydrocarbon leaks in these locations are to the atmosphere (since the cold box is not a pressure vessel) requiring immediate shutdown of the BAHX core system.

Mid sized LNG process cycle considerations

When a plant is designed for continuous operation, downtime is costly, and reliability commands a premium. Onstream time is directly associated with revenue. A mid sized LNG plant must minimise downtime, maintenance, and lost production just like a large plant; and if the mid sized plant is on a floating production, storage and offloading (FPSO) vessel, it is even more critical that the plant is robust and reliable.

In hopes of reducing costs, many new LNG plant promoters are considering small N_2 expander cycles because they are perceived to be 'simple, easy to operate, and reliable'. This may sound attractive, but it pays to understand the details. The largest N_2 expander, single LNG train operating today is smaller than the 'mid size' range. The majority of these plants are <0.1 million tpy, and are used in interruptible service. These are very simple plants, usually consisting of one compressor, one compressor loaded expander (compander), and one cold box with at most two brazed aluminium heat exchanger (BAHX) cores. Air Products has designed and built several of these plants around the world. Because these plants are much less efficient than mixed refrigerant plants operating today, their practical size is limited. To make up for inefficiencies, more expander refrigeration is required. However, commercially available expanders are limited in size, and a 0.5 million tpy N_2 expander liquefier uses the largest ones commercially available. To produce more LNG, parallel companders and BAHX cold boxes can be used, but the increased plant complexity is no longer as simple or easy to operate. The alternative is building several small, 'simple' plant trains in parallel resulting in a larger footprint, more pieces of equipment, and generally more maintenance costs and downtime. Experience has also shown that commercially available compander reliability is lower than mid sized LNG plant compressors used in mixed refrigerant cycles. This requires multiple parallel units to ensure availability of the liquefier. Finally, the BAHX cores must handle the thermal stresses inherent with liquefying the multi component natural gas.

While single mixed refrigerant (SMR) LNG processes are more efficient than N_2 expander cycles, they are still significantly less efficient than pre-cooled, mixed refrigerant cycles. Again, this inefficiency limits the practical size of a single train before parallel compression trains and liquefaction heat exchangers are required. Almost all SMR LNG processes operating today are
< 1 million tpy size range. They use both BAHX cores and coil wound heat exchangers. The BAHX cores have been problematic in this service due to thermal stresses and poor two phase flow distribution; coil wound heat exchanger SMR plants have been more successful.

The propane precooled, mixed refrigerant processes (C3MR) that are the workhorse of the baseload LNG industry have all been built with coil wound heat exchangers since 1970; and as noted above, more than half of these are in the 'mid sized' range, some with less than 1 million tpy capacity. They are very efficient plants with high onstream factors using single compressor trains. There has been no need for parallel compression trains to achieve high reliability.

Efficiency is important when producing LNG from any gas resource, and stranded gas is no exception. Poor efficiency is the lost opportunity to produce more LNG from the stranded reserve. High efficiency can be the difference that makes a project economically attractive, and the resulting capacity will almost always justify the costs. With higher efficiency the rotating machinery power can be lower to produce the desired LNG, or with a given set of machinery, more LNG can be produced. Coil wound heat exchangers have a demonstrated, winning reputation in projects with very high returns. Figure 1 compares the well known LNG process cycle 'thermodynamic' efficiencies (power per tonne of LNG) on a relative basis. The precooled, mixed refrigerant cycles are highest, followed by the cascade, single MR, and N2 expander cycles in that order. Engineering choices (e.g. compressor efficiency, ratio of heat exchanger surface area to power, etc.) can change these relative relationships, but when all things are equal, the relative relationships shown are accepted by the industry. High 'thermal' efficiency (auto-consumption) is also valuable, as this measures how efficiently the required power is produced. Gas turbine firing rate, waste heat recovery, and boil off gas recovery among other things determine 'thermal' efficiency rather than the thermodynamics of the chosen process cycle.

In designing any facility, there are tradeoffs between initial capital investment (CAPEX) and efficiency, which are highly dependent on specific site conditions. The underlying justification for many of these projects tends to be driven more by the cost of gas and LNG price. Recognising that the liquefier tends to be a smaller percent of the overall investment for a greenfield project, an LNG developer may want to be careful and not take risks with operability and reliability, which can directly affect the revenue stream. While mid sized plants on the surface may be viewed as smaller investments than the mega trains being built today, investors are still putting hundreds of millions, or even billions of dollars at risk.[3]

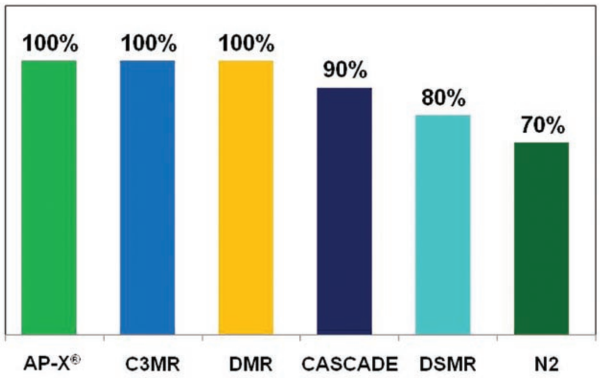

Figure 1. LNG process cycle efficiency comparison.

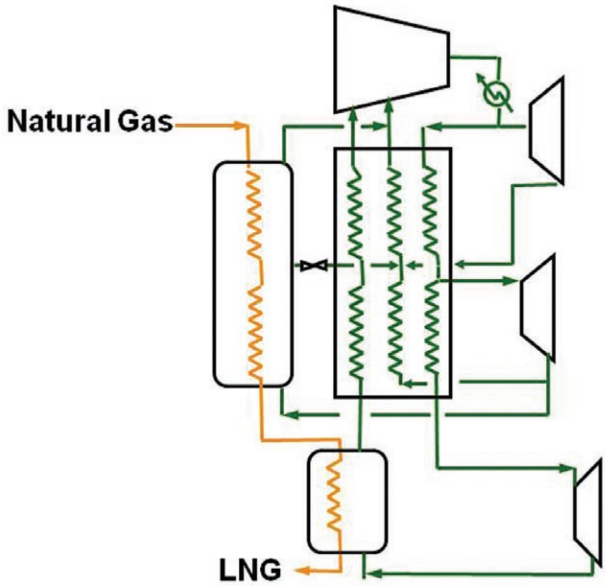

Figure 2. N_2 expander LNG process.

Mid sized LNG applications

N_2 expander LNG facility

The N_2 expander LNG cycle shown in Figure 2 has three expanders, a coil wound heat exchanger to liquefy the natural gas, and BAHX cores for precooling the N_2 refrigerant. This is an efficient N_2 expander cycle compared to the 'simple' N_2 expander liquefiers mentioned above and it is comparable to the single mixed refrigerant process. It uses commercially available companders to make 0.5 - 1.0 million tpy LNG. It might take five to ten 'simple' N_2 cycle trains to produce the same LNG as one to two LNG trains using this cycle. This more complex N_2 expander cycle will reduce footprint and pieces of equipment while increasing efficiency.

This N_2 expander cycle coupled with the reliability of a coil wound heat exchanger for liquefaction makes it attractive for an FPSO LNG plant as well as land based plants. As with all N_2 cycles, a nitrogen source is required, possibly from a dedicated nitrogen generator.

Single MR LNG facility

For the 0.5 -1.0 million tpy size LNG facility the single mixed refrigerant (SMR) LNG process with dual pressure coil wound heat exchangers (Figure 3) can provide an attractive solution with enhanced performance and reliability. The dual pressure cycle is more efficient than a single pressure cycle and therefore the heat exchangers and compressor are smaller. The coil wound heat exchanger can be fully modularised to minimise fieldwork. If required, the mixed refrigerant can be formulated without propane without affecting efficiency, making it appropriate for FPSO plants as well as land based plants. Parallel trains may increase availability, but will also increase maintenance costs due to increased pieces of machinery/equipment. The SMR cycle with coil wound heat exchanger benefits from years of experience and 'know how' learned in the LNG industry because it uses the same compression equipment and heat exchangers.

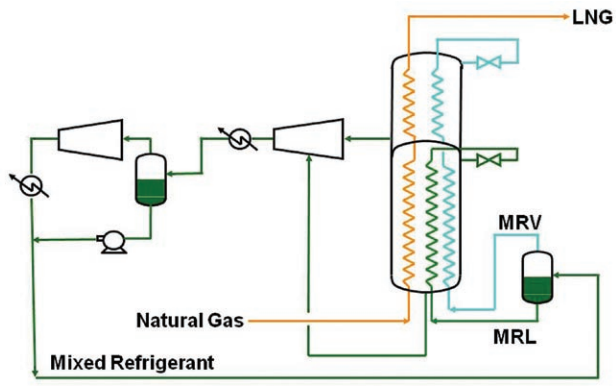

Figure 3. Single mixed refrigerant LNG process.

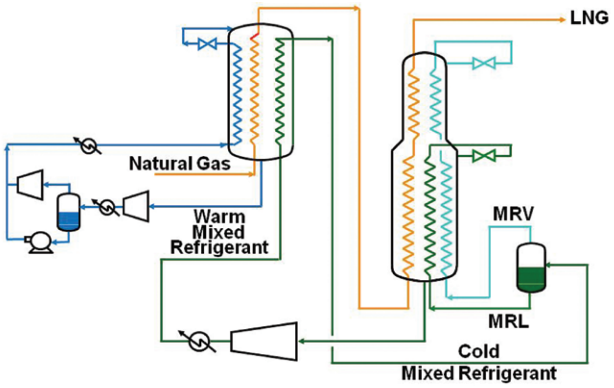

Figure 4. Dual mixed refrigerant LNG process.

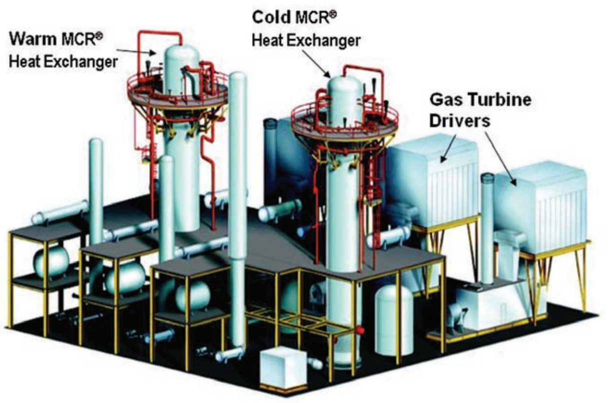

Figure 5. Artist's rendition of dual MR FPSO LNG plant layout.

Larger FPSO LNG facility

Air Products has proposed a dual mixed refrigerant (DMR) LNG process (Figure 4) for mid sized FPSO applications for reliability, efficiency, and maintainability. It is designed to provide a single train capacity of greater than 1.0 million tpy. The DMR cycle has a compact footprint, can eliminate propane from the mixed refrigerants when required for safety, uses two coil wound heat exchangers (less than 50 m tall) that can be provided in a modular package, and compression equipment proven in the LNG industry. A single pressure, warm mixed refrigerant with a liquid refrigerant pump is shown; a dual pressure, warm mixed refrigerant without the liquid pump has also been proposed. An artist's rendition of major equipment layout is shown in Figure 5 for the DMR process on an FPSO vessel. This process benefits from years of mixed refrigerant process experience and should achieve availabilities that can make a single train FPSO plant practical.

The propane precooled, mixed refrigerant (C3MR) LNG process that is used in liquefying more than 80% of the world's LNG today is also fit for FPSO service as long as propane or a non hydrocarbon precooling refrigerant is acceptable.

Coil wound heat exchangers for FPSO service

Starting in 1997, Air Products has carried out research to prove the performance of coil wound exchangers in a floating environment. This work has included small scale fluid flow and heat transfer experiments at the Institute of Thermal Physics in Siberia, pilot scale static and dynamic fluid flow experiments with a coil wound heat exchanger at Heriot Watt University, and fluid flow modelling and dynamic simulation carried out by Air Products. With this work, Air Products has gained insight into the performance of the coil wound heat exchangers, which has resulted in design improvements that have been demonstrated in operating heat exchangers.

Conclusion

In conclusion, the coil wound heat exchanger's robustness and operability help to ensure that the LNG liquefier will produce LNG as designed and achieve the project economics projected. Reliability is the key to economic success of a project, and experience and 'know how' of the process licensor and contractor can help ensure reliability.[2] The LNG plant does not produce LNG while it is down for maintenance and repairs. When making a technology decision, project developers must continue to investigate all of the options available and ask whether their choice carries with it undue operational risks. **LNG**

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230-09-001-GLB