Smooth Sailing

Christopher Ott, Joanne Trimpi, and Dr Annemarie Weist, Air Products, USA, describe considerations for planning a floating LNG facility.

There are a lot of choices to be made when planning an LNG facility, and there are many additional decisions when developing a floating LNG (FLNG) facility. First off, for an FLNG facility, the weight of these decisions literally affects the cost of the entire vessel. Once the LNG production target has been determined from commercial considerations, the work begins. Determining the optimal number of trains and train size is very important to the overall equipment weight and layout. The compressor drivers and machinery arrangement decisions are often made in parallel to train size and number of trains.

This article will compare two mixed refrigerant (MR) process options frequently considered for FLNG applications, along with train sizes and machinery arrangements. The impact of these options on the overall equipment count relative to equipment weight and train availability will be discussed.

In all options discussed in this paper, the liquefaction cryogenic heat exchangers that will be considered are coil wound heat exchangers (CWHE). CWHEs provide a significantly smaller footprint and are inherently robust and safe to operate with dual containment, which allows for continued operation even in the unlikely event of a tube leak until a scheduled turnaround. They also provide the ability to economically scale up in capacity without requiring parallel configurations vs the alternative, brazed aluminium heat exchangers (BAHX). Air Products has done extensive marinisation testing and development over many years to meet both the mechanical and process design requirements to account for the effects of motion on CWHEs caused by sea states and continues to improve the

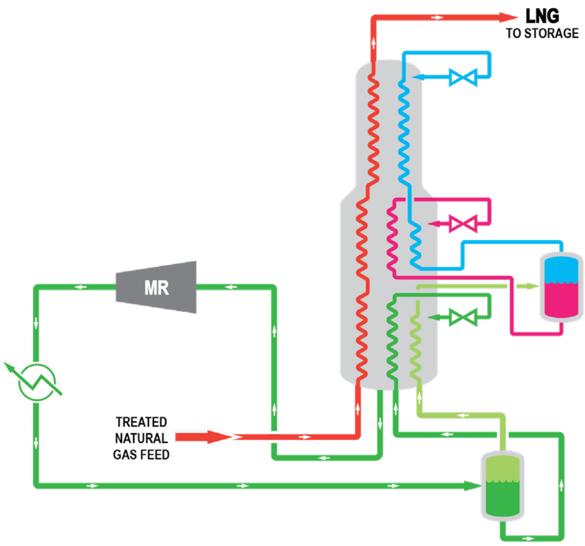

Figure 1. AP-SMR™ LNG Process.

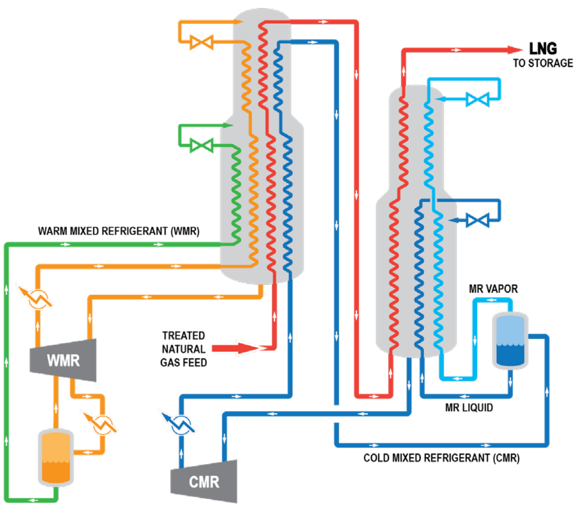

Figure 2. AP-DMR™ LNG Process.

equipment design. That has been covered in other papers and will not be discussed here, but is also an important factor for FLNG applications.[1,2,3]

The very nature of an FLNG facility means that all equipment is modularised. The number and weight of the modules required for the facility are directly influenced by the count and weight of the bare equipment. Liquefaction processes using MR are the most efficient. Since MR processes use the latent and sensible heat of the refrigerant to remove enthalpy from the natural gas, the relative flow rate of these refrigerants compared to gas expansion processes is much less. Therefore, the refrigeration equipment including the cryogenic heat exchanger(s) and refrigerant compressors are much smaller than those in a gas expansion refrigeration process for the same LNG production.

Two MR processes will be highlighted in this article. The AP-SMR™ LNG Process has been proposed for many floating opportunities. The AP-DMR™ LNG Process is currently in operation off the coast of Mozambique on the Coral Sul FLNG vessel. Both processes are proven and take advantage of the compact, robust, and safe features of CWHEs.

A single MR process

The AP-SMR liquefaction process (Figure 1) is a simple process that combines all the required refrigeration into a single refrigeration compressor and main cryogenic heat exchanger (MCHE), which has the benefit of minimising the total equipment count. However, this low equipment count comes at a cost. All refrigeration duty for the train is accomplished in a single CWHE. As a result, the maximum train size is limited to approximately 1.4 – 1.7 million tpy by the practical limits of refrigerant compression, gas turbine or motor drives for the refrigerant compressor, or construction and shipping of the MCHE. Train sizes greater than approximately 1.7 million tpy are expected to require parallel equipment of one of those three items, which is feasible, but limits the benefits of a compact AP-SMR LNG train. At this train capacity, the refrigerant compressor aerodynamic efficiency is best matched with the high output shaft speeds of aeroderivative gas turbines. If, however, the compressor is driven by a motor, then a gear box or super synchronous motor is needed to increase the rotational speed of the compressor to optimise aerodynamic efficiency, adding to the equipment count and required plot space of the train.

In single MR processes, the refrigerant must contain refrigerant components needed for all three duties: precooling, liquefaction, and subcooling. Although the AP-SMR process has three separators to optimise the refrigerant in each section of the MCHE, the individual duties of the process are still constrained because the entire temperature profile cannot be optimised for a specific cooling curve. This reduces the liquefaction efficiency and increases the power consumption compared to precooled MR processes.

A dual MR process

In general, for a single train, adding independent refrigeration loops increases process efficiency and maximises LNG capacity. This allows each refrigeration loop to be optimised for its specific purpose, either precooling or liquefaction/subcooling. The AP-DMR liquefaction process, shown in Figure 2, utilises a separate mixed refrigerant to precool the feed and MR in a single vertical CWHE to minimise plot space and size of the module. This precooled process increases the maximum single train LNG capacity by as much as three times and improves process efficiency by approximately 10 – 12% compared to the AP-SMR process. This allows the AP-DMR process to utilise smaller drivers and compressors for the same LNG production or increase LNG production for the same installed power. Either path improves the overall economics of the project.

Determining optimal train size for an FLNG facility

The largest practical train size using the AP-SMR liquefaction process is approximately 1.5 million tpy. The AP-DMR process can have train sizes above 6 million tpy. Therefore, for total production above 1.5 million tpy, is it more economical to have multiple SMR trains or one DMR train? Is the availability greater with multiple trains or can the same availability, or perhaps even greater, be gained by employing larger trains with parallel refrigerant compression?

In general, there are two advantages to having multiple smaller size trains. For an onshore facility, where it may be practical to have phased investment, the first smaller train could be installed and commissioned quicker for earlier revenue. For floating facilities, however, it is not practical or cost effective to have this type of phased development as construction on all LNG trains would need to be completed before the FLNG vessel is deployed or each train would require its own vessel.

The second advantage of having multiple smaller trains is the availability of LNG production. With multiple trains, there is a higher probability that at least one train is down but when a train is down, there is production from the other trains mitigating how much LNG production is lost for the entire facility.

Figure 3. Galileo's square-cube law.

However, the availability of single trains can be improved by using parallel refrigerant compression. There are several baseload LNG trains and three FLNG facilities that have proven the increase in train availability by using parallel compression.

One important consideration of train size for an FLNG plant is the added weight of the replicated equipment. Galileo's square-cube law is applicable in illustrating this effect. For example, consider having two trains of 1 million tpy each for a total FLNG production of 2 million tpy compared to one train of 2 million tpy. Each train will have the same equipment count, but for the two-train vessel, there will be two of each count, while the one train vessel will have one count but of a larger size. What is the effect on total weight? Consider a simple vessel as shown in Figure 3. This vessel can be a separator or even a CWHE. To process the same flow, the volume of the larger train size will be approximately 70% larger than its corresponding piece in the smaller train. For a typical vessel thickness, it will have approximately 40% more metal – in order to maintain the same design pressure, the metal thickness of the larger vessel is greater.

The overall result is less metal for the single larger vessel than for two of the smaller vessels. This scaling can be applied to most process equipment including pipes, valves and other process vessels. There may also be additional metal used to construct two smaller modules than one larger module for the larger train size. Most importantly, for a floating vessel this additional weight has cascading costs to the floating vessel itself. A rule of thumb for offshore vessel design for estimating module weight is that the topsides weight is approximately four times the equipment weight. This magnifies the impact of the equipment weight as it cascades into the overall module weight. Additionally, any added weight caused by liquefaction plant selection means the vessel displacement required for buoyancy purposes must be larger to keep the vessel afloat.

Conclusions

Train size and liquefaction process selection are key decisions that influence the overall capacity and size of an FLNG vessel. Taking advantage of economies of scale can be used to maximise LNG production in the smallest footprint and lowest module weight. In addition, using the highest efficiency liquefaction process will maximise the LNG production for a fixed gas turbine or motor size, with low carbon emissions. Considerations such as these should be reviewed early in project development to maximise the economics of an FLNG project. **LNG**

References

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