Air Products meets requirements of full range of Floating LNG concepts

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It has been over 30 years since the LNG industry first considered the construction of a liquefaction facility on a floating platform as a means to commercialize offshore gas reserves.

Although the idea itself is not new, interest in the concept has been heightened in recent years as on-shore and near-shore gas fields amenable to LNG project development become increasingly scarce.

With floating LNG now being examined by almost every major oil company, shipbuilder and EPC firm, plans for floating LNG production, storage and offloading facilities (FLNG) and other offshore plants (such as on gravity-based structures) are now closer to reality than ever before.

Investment

After many years and millions of dollars of engineering and development invested by the industry, it currently appears that the first commercial FLNG project may finally achieve final investment decision some time this year.

But the fact that it has taken as long as it has to reach this point is evidence of the many complex technical and commercial challenges confronting FLNG project developers.

Selecting and designing the optimum liquefaction process is only one of the technical challenges FLNG plant developers must face.

Projects currently in the front-end engineering and design stage include floating plants with capacities ranging from less than 1 million tonnes per annum to around 4 MTPA, with numerous project-specific factors to be considered, including gas feeds with compositions ranging from lean to rich.

It seems unlikely that a single liquefaction process can meet the needs of the wide range of plant requirements equally well; rather, the selection of the optimum liquefaction process requires consideration of the unique set of parameters of each offshore opportunity.

The cycle selected for a particular project will depend on the feed-gas characteristics, Train capacity, driver selection, project specific economics and owner preference, along with the typical considerations of safety, flexibility and efficiency.

In addition, factors unique to an offshore facility, such as limited availability of deck space, equipment weight and height limitations, and the robustness of equipment in the offshore environment must be taken into account.

Importance

Finally, because many offshore plants may be a single Train, reliability and ease of maintenance have increased importance.

Because it is impossible to address all of the factors that enter into the proper liquefaction process selection in the confines of a short paper, the following will concentrate on the single parameter of plant scale as an example of just one of the considerations that are important to proper process and equipment selection.

	CASE 1		CASE 2	
Liquefaction Process	Nitrogen Recycle	DMR	Nitrogen Recycle	DMR
Number of Gas Turbine Drivers	2	2	3	3
Number of liquefaction trains	1	1	2	1
Nominal LNG Production	100%	125%	167%	200%

Table 1: Comparing LNG production from two liquefaction projects. Each entry is based on multiple identical aeroderivative gas turbine drivers

Legacy

Although the design considerations and evaluation criteria are somewhat different from land-based facilities, the fundamental factors for land-based success can help point the direction towards choosing the optimal cycle and key equipment for FLNG.

Air Products has a proven history of successfully implementing new process and equipment technology for land-based facilities. Using this same methodology, Air Products evaluated many liquefaction process cycles for FLNG applications.

Much of the world's LNG is liquefied using the propane pre-cooled mixed refrigerant (C3MR) Process with a coil wound main cryogenic heat exchanger, as shown in Figure 1.

In the last decade, the AP-X® LNG Process was developed to increase plant capacity by more than 50 percent, leveraging the success of C3MR technology.

Like the C3MR Process, the AP-X Process utilizes propane for pre-cooling and a mixed refrigerant for liquefaction. The single Train capacity is increased by adding a nitrogen refrigeration loop for sub-cooling, as shown in Figure 2.

This debottlenecks the C3MR portion of the liquefaction area, allowing for the increased capacity. This new technology is now proven in the six AP-X trains currently operating in Qatar.

Air Products has built on the successes and advantages of both the C3MR and AP-X processes in developing efficient and robust processes and equipment for FLNG.

Dual mixed refrigerant (DMR), single mixed refrigerant (SMR), and nitrogen refrigeration processes have been developed which share many of the attractive features of the processes that have been well proven in numerous land-based projects.

Process options

Many offshore operators prefer to minimize propane inventory for safety reasons, which makes the traditional mixed refrigerant and cascade cycles less desirable.

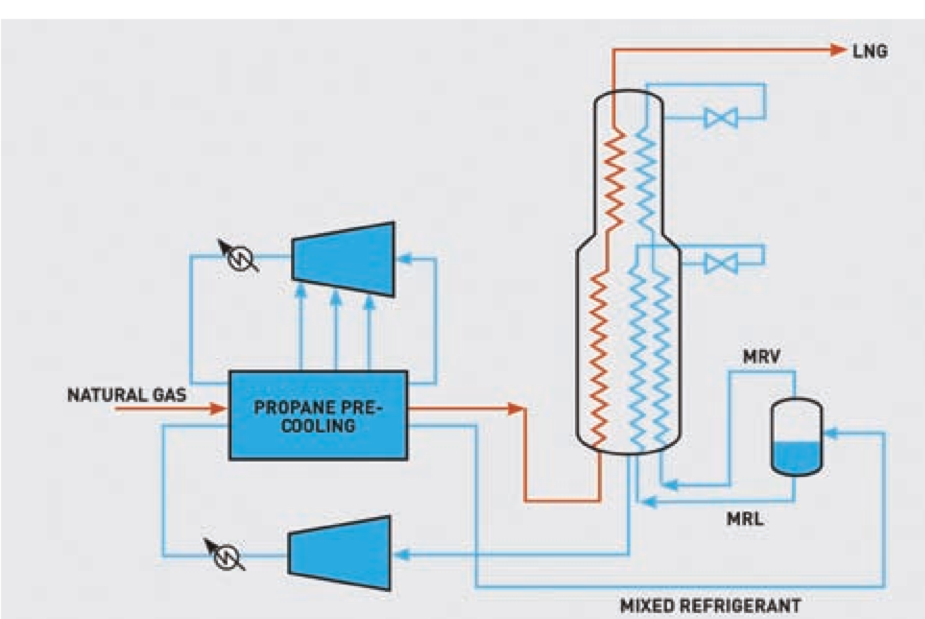

Figure 1: Much of the world's LNG is liquefied using the propane pre-cooled mixed refrigerant (C3MR) Process

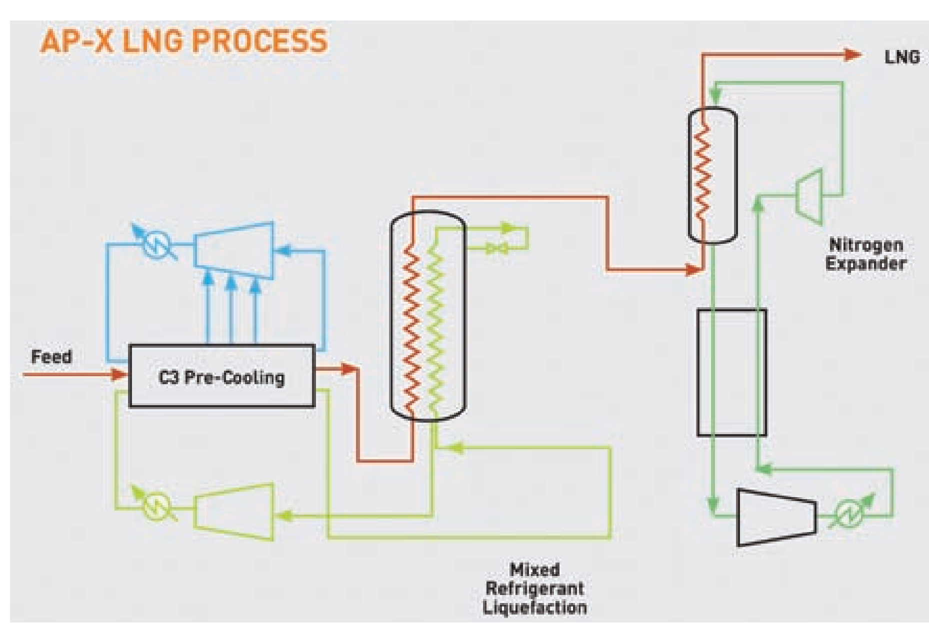

Figure 2: the AP-X® LNG Process was developed to increase plant capacity by more than 50 percent

For offshore applications, mixed refrigerants can be formulated without propane while maintaining process efficiency.

Additionally, years of mixed-refrigerant process experience has led to the attainment of efficiencies and availabilities that make a single Train FLNG plant practical, saving space over two 50 percent parallel Trains.

For plant sizes up to about 1 MTPA, a simple single mixed refrigerant (SMR) system with a single driver, as shown in Figure 3, may be a reasonable option.

For these small sizes, the SMR process provides some attraction due to its flexibility, relatively simple operation and efficiency which exceeds single component refrigeration systems.

However, performing all of the liquefaction with a single exchanger and compressor string limits the practical size of a single SMR Train.

Efficiency

In addition, the SMR process has a lower efficiency than pre-cooled mixed refrigerant processes, and as the plant size increases this efficiency difference becomes more important.

For plant sizes above about 1 MTPA, a more viable option is the higher efficiency dual mixed-refrigerant (DMR) process, which reduces the liquefaction unit equipment and plot sizes.

A typical DMR configuration is shown in Figure 4. The process is very similar to the well proven land-based C3MR process, but instead of pure propane, the DMR process utilizes a second mixed component refrigerant (which can be formulated with no propane) for pre-cooling.

This system can achieve an efficiency which rivals the largest land-based process, and has emerged as the process of choice for FLNG developers considering larger capacities.

This progression from SMR to DMR reflects the experience of land-based plants. Some of the very early onshore plants were based on SMR processes.

But as the industry matured, project developers soon came to appreciate that pre-cooling improved efficiency and reduced equipment size, and as a result,

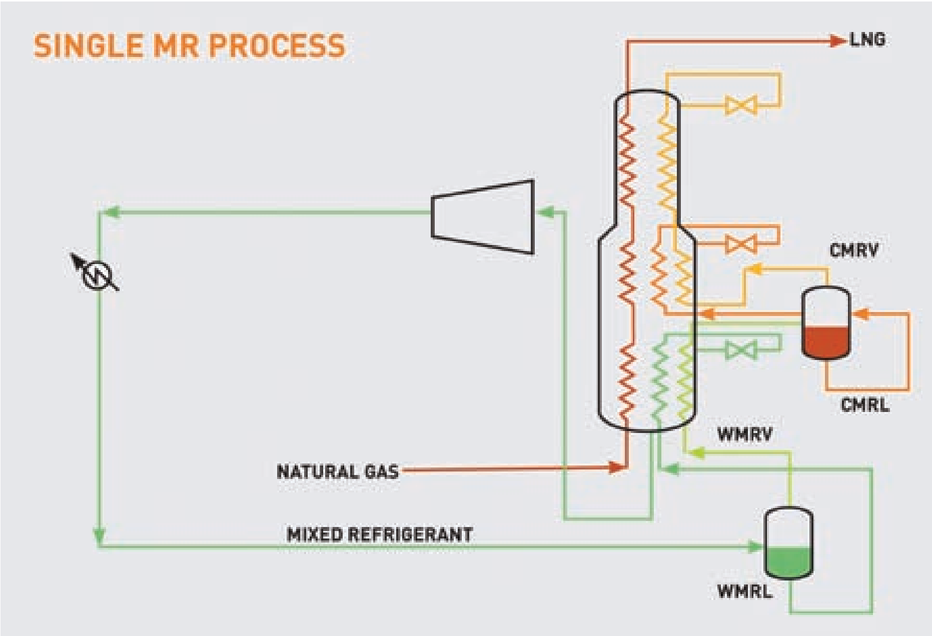

Figure 3: The Single MR Process is suitable for plant sizes up to 1 MTPA

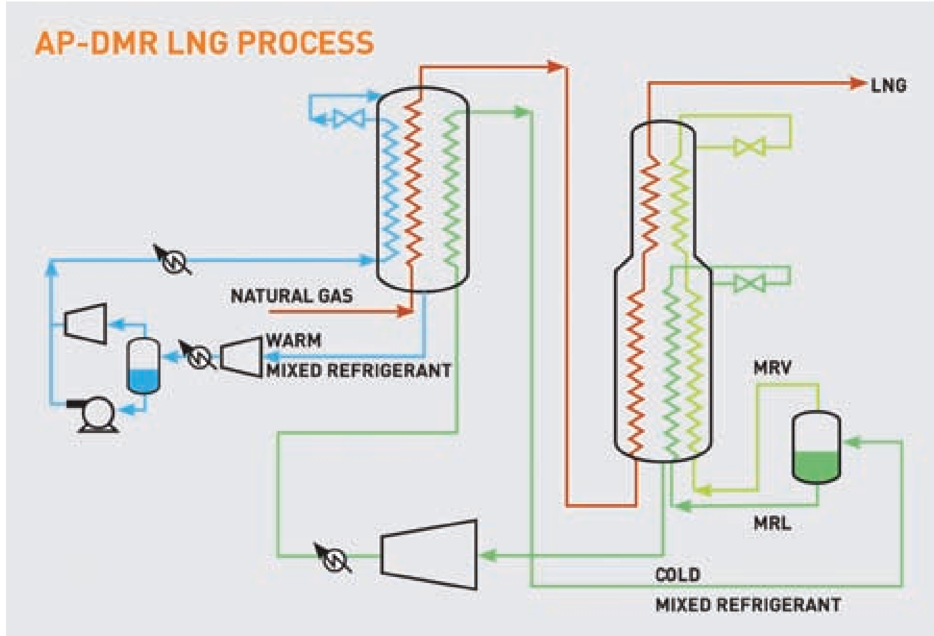

Figure 4: A typical DMR Process configuration is shown above

pre-cooled processes became almost universally selected as plant scale increased.

The logic that led to that widespread technology change translates to FLNG as well.

Certain offshore operators have expressed the desire to avoid hydrocarbon refrigerants entirely which also eliminates the need for generating, importing and storing them on board.

Tested

In this case, although lower in efficiency, a N2 refrigeration process can be considered, such as the one pictured in Figure 5.

Nitrogen recycle refrigeration systems have been applied to LNG production for many years, but most of these systems are peak shaver sized plants with capacities measured in hundreds of tonnes per day.

By comparison, the nitrogen refrigeration sub-cooling portion of the 7.8 MTA AP-X Trains in Qatar is roughly equivalent to a 1-2 MTPA all- nitrogen refrigeration cycle in which nitrogen is used to pre-cool, liquefy, and sub-cool the natural gas.

Success

The success of the AP-X nitrogen refrigeration sub-cooling section has proven that Air Products' large scale nitrogen-based refrigeration processes and proprietary equipment are reliable and efficient for LNG liquefaction.

Key components proven in the AP-X Trains in Qatar are the large Air Products compressor-loaded expanders (companders).

With the mixed refrigerants, the natural gas is liquefied with BOILING mixed refrigerant. With N2 cycles, the natural gas is liquefied by WARMING gaseous N2.

It takes much more gas to provide the same cooling duty - evaporation provides much more heat per unit of flow.

Therefore, larger Train capacities using N2 refrigeration require very large pipe sizes and parallel rotating machinery translating into a more complex plot plan and the need for increased deck space.

For this reason the applicability of the N2-recycle system is limited to smaller capacity, around 1 MTPA or smaller.

In conjunction with selecting the optimum process configuration, project developers must carefully select proven, robust equipment which will provide the reliability demanded by offshore operations.

Air Products has completed extensive research and development programs to understand what is required to marinize heat exchange equipment to both mitigate the effect of ship motion on the process and to confirm structural integrity for expected sea states.

Both Air Products' mixed refrigerant and nitrogen based processes for FLNG service use coil wound heat exchangers (CWHE).

Decades of experience have proven these to be safe, reliable and more robust than any other type of heat exchangers for natural gas liquefaction service.

Aluminum is the optimum material for land based CWHEs for both shells and internals. Aluminum saves weight and cost, has excellent heat transfer properties, while providing the necessary strength.

To stand up to the rigors of the marine environments however, the FLNG CWHEs utilize stainless steel shells instead of aluminum.

Weight reduction

The internals continue to be aluminum, providing efficient heat transfer and reducing exchanger weight.

Stainless steel shells with aluminum internals have been successfully implemented in the nitrogen sub-cooling system of the AP-X Trains, proving the interface between the aluminum internals and stainless shells, which takes into account the different coefficients of thermal expansion between stainless steel and aluminum.

Ten year ago, Air Products analyzed the structural integrity of CWHEs in an FLNG environment through the following steps:

- Established a basis for evaluating the structural integrity of the heat exchanger
- Defined the mechanical design criteria for FLNG service
- Determined the effects of the wave motion forces on the pressure vessel and the internal bundle support system.

Working with Moss Maritime (part of the Kvaerner Group at the time and now part of Saipem), the analysis assumed a conventional, steel-hulled ship, and wave motions based on North Sea storm conditions.

The analysis confirmed that exchanger design was acceptable for both strength and fatigue.

Over the span of the last 15 years, Air Products completed rigorous analysis of the effect of tilt and oscillatory motion on CWHE performance.

Research work

The analysis focused on liquid distribution on the shell-side of the exchangers and the effect on heat transfer performance.

This work included fundamentally-based experiments, pilot scale test units, and dynamic simulation. The fundamentally-based experiments used hydrocarbons to characterize the fluid flow in CWHEs and quantified the flow behavior under various motion conditions.

The results were used to develop a proprietary model which predicts the shell side liquid distribution as a function of heat exchanger geometry, motion conditions, elevation of the heat exchanger above the pivot point, and process conditions.

The model was validated in a pilot scale wound coil exchanger bundle. This data was collected under various motion conditions, including both oscillations and permanent tilt. Flow distributions predicted by the model agree very well with the pilot scale data. The final step incorporates the effects of shell side flow distribution into Air Products' well established heat exchanger design methods.

This allows Air Products to assess the

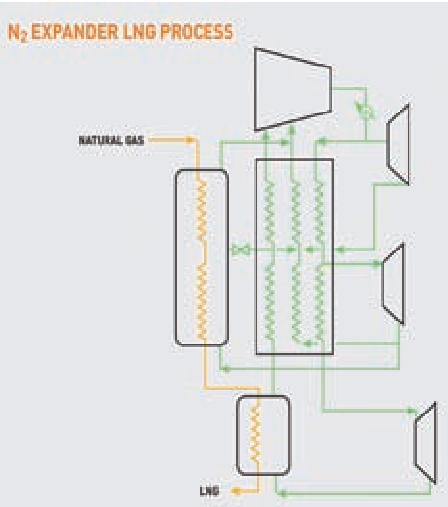

Figure 5: Three-stage AP-N Process

impact of ship motion on heat exchanger performance and to develop heat exchanger designs which mitigate the effects of motion.

Air Products uses computational fluid dynamics (CFD) to assess the impact of motion on the hydraulic behavior of the internal distributors and separators in CWHEs.

CFD was used to model the sloshing dynamics and to assess the force amplification that may occur in areas where the resonant frequency is close to the motion frequency.

Study results

Recent engineering design studies have shown that the process efficiency of the nitrogen recycle process can approach that of the SMR process when using the Air Products proprietary heat exchangers and companders.

For this reason, the nitrogen recycle process may be favored over SMR for capacities at or below 1 MTPA especially when its other benefits (e.g. no hydrocarbons in the refrigerant) are considered.

In fact, at LNG production capacities approaching 1 MTPA, any of the above described process cycles can be configured into a single liquefaction Train, and each may be viable depending on the project specifics.

However, at LNG production capacities approaching and exceeding 2 MTPA, the higher efficiency and better economies of scale favor the DMR LNG process compared to the other two processes.

For example, a nominal 2 MTPA FLNG facility will require two liquefaction Trains for the nitrogen recycle and SMR LNG processes while only a single Train for the DMR LNG process.

Examples

And if one considers a fixed aero-derivative gas turbine driver selection, the DMR LNG Process produces significantly more LNG, as shown in the examples.

Table 1 compares LNG production from two projects. The basis for Case 1 is that power will be delivered from two identical pre-selected gas turbine drivers.

In this case the DMR Process can produce 25 percent more LNG given the same available gas turbine power, assuming the same availability for each process.

For Case 2, three identical aeroderivative gas turbines are selected as refrigeration compressor drivers.

For this Case, equipment size limitations necessitate the nitrogen recycle system to be split into two parallel Trains.

For this configuration the DMR system remains a single Train and produces 100 percent more LNG than the two-driver nitrogen recycle case, with only 50 percent more available power.

Of course the actual LNG productions and breakpoint between the DMR Process and the other two processes will depend on the specifics of a particular FLNG project.

Commercialization

In summary, Air Products has developed efficient liquefaction processes and robust equipment which have been proven through decades of successful land-based operation.

Numerous scientists and engineers knowledgeable in LNG technology have identified the key needs to marinize processes and equipment for ship-board use.

Through their extensive testing and modeling, this proven technology has been extended for FLNG applications and is now ready for successful implementation. ■