

Offshore LNG industry developments

Recent developments in the LNG industry have improved the economic viability of offshore liquefaction processing, making it competitive with onshore processing plants. Three LNG experts focus on future developments in the offshore LNG industry

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The potential to unlock offshore gas reserves (Figure 1) without investment in capital-intensive pipeline infrastructure, infield platforms and onshore infrastructure, while minimising exposure to geopolitical and security risks, makes offshore gas liquefaction options worthy of close scrutiny. Increased project costs for onshore liquefaction plants, coupled with important developments in liquefied natural gas (LNG) ship-to-ship transfer and LNG storage, have made offshore liquefaction economically viable.

The authors address new developments in the offshore LNG industry, giving a more thorough understanding of the pros and cons of the various decision options for offshore LNG facilities.

Selecting offshore liquefaction technology

Recent developments in liquefaction process technology specific to the requirements of offshore facilities have brought offshore liquefaction closer to technical and commercial viability. Developers are rightly focusing on process simplicity, a low weight and small footprint. In this respect, some technologies already deployed and proven for onshore peak-shaving applications are attractive. Considering that all process technologies are dealing with the thermodynamic constraints imposed by natural gas compositions, technologies that make use of proven machinery are those most likely to succeed commercially.

Three generic types of refrigeration cycle can be considered for offshore natural gas liquefaction: the cascade, mixed refrigerant and expander cycles. Each has its own merits, and there are variants of each cycle, with some common features between them. For example, in both the mixed refrigerant and expander cycles, the feed gas may be pre-cooled by a conventional propane vapour compression cycle. This is also a feature of the cascade



Figure 1 Giant natural gas and condensate fields, such as this facility in UK's central North Sea, jointly operated by ConocoPhillips and Chevron, include significant liquefaction infrastructures

cycle, but the main disadvantage here is the relatively high capital cost due to each refrigeration circuit having its own compressor (with associated suction drums and interstage coolers) and refrigerant storage. The requirement for multiple hydrocarbon refrigerants as well as a large number of equipment items and a large plot space mean this cycle is unlikely to be either technically or economically viable for offshore applications, unless at very large capacities.

Mixed refrigerant technology has been assessed for offshore liquefaction based on both single mixed refrigerant

and dual mixed refrigerant (DMR) cycles. The number of storage tanks, separators, valve manifolds, and instruments and controls required to maintain the refrigerant charge and composition in the mixed refrigerant processes is high. In addition, a good distribution of two-phase streams can be difficult due to vessel movement, which could limit the use of mixed refrigerant technology to only calm seas. Mixed refrigerant process plants take longer to start up and stabilise than plants using other refrigerant cycles because of the need for precise blending of the refrigerant mix. This is a significant

consideration in an environment where frequent start-ups and shutdowns are to be expected.

Expander cycles using nitrogen as the refrigerant may be ideal for offshore applications, and one of the obvious advantages is a reduction in the size of the plants, as there is no need for refrigerant storage. In addition, the non-flammability of the refrigerant would reduce the distance between process equipment. Turbo-expander refrigeration cycles are well proven for cryogenic liquefaction, including LNG peak shaving and large-scale industrial gas liquefiers. Compression and work expansion of a suitable fluid, typically nitrogen, generates refrigeration. A major benefit of using nitrogen as the cycle fluid is that it is inherently safe. The cycle gas is boosted in the brake end of the expander. While this process has been used to liquefy natural gas, it has a relatively low efficiency, because a single component gas with a uniform flow rate through the cycle cannot closely match the cooling requirements of the process gas. However, expander-based processes are steadily improving, with advances in plate fin heat exchangers, turbomachinery and process configuration. If only one stage of work expansion is employed, power consumption is excessive and justifiable for only small plant capacities. Low efficiency and high power consumption (compared with the propane mixed refrigerant and optimised cascade cycles) are the only serious disadvantages with the turbo-expander cycle, and this limits capacity to about 3 mtpa, but does not outweigh the other advantages.

Liquefaction process selection and design are influenced by site location, deck space and ambient conditions, as well as specific feed gas quality and conditions. Key criteria that influence process selection and plant optimisation for offshore liquefaction lead unavoidably to some trade-offs and compromises between efficiency and simplicity. In the meantime, the capital cost of the processing facilities is only a fraction of the total project cost, so technology selection and process design must be considered in the context of total, full-cycle project economics. The selection of liquefaction technology must consider all aspects of the process and plant design, including storage and offloading in a floating environment.

FPSO production at lower cost than onshore LNG

Over the past 20 years, floating production, storage and offloading (FPSO) facilities have become conventional for recovering and processing oil and gas from remote deep-water fields. They reduce production costs by avoiding the need

for pipelines to shore and onshore infrastructure. LNG production offshore has been considered for years, but it has taken the development and realisation of hydrocarbon FPSOs (and the relevant engineering capability) to promote real interest in offshore liquefaction. Key technical challenges, such as LNG storage systems that accommodate sloshing due to vessel movement and the transfer of LNG from the storage system to a carrier vessel, have been solved. As a result, for the first time, offshore LNG production could now be practical at a lower cost than onshore LNG production, especially as there are many remote offshore gas fields that could provide the gas for liquefaction.

Costain Oil, Gas and Process (COGAP) has undertaken a number of front-end conceptual design and basic engineering studies for floating LNG (FLNG) plants since it carried out an initial study for the UK Department of Energy and published the findings at the Offshore Technology Conference (OTC) in Houston, Texas, in 1981. The main conclusion of this study was that turbo-expanders, proven for smaller-scale LNG facilities, had considerable merit for offshore LNG production. This conclusion differed from accepted wisdom, which considered that offshore LNG production should use the same process technology as used onshore for base-load LNG facilities.

Cost-effective and efficient liquefaction plant designs have been based on generating refrigeration by gas compression and subsequent work expansion in turbo-expanders. This provides:

- Inherent safety by avoiding the need for any hazardous liquid hydrocarbon refrigerants
- Insensitivity to vessel movement, as the refrigerant is always in the gaseous phase
- Simplicity of operation and flexibility to feed gas changes
- Ease of start-up and shutdown
- A small number of equipment items, small area and low weight
- Ease of modularisation and fabrication
- Use of conventional well-proven equipment that maximises the opportunity for competition among suppliers and means lower cost equipment.

By 1990, COGAP was basing process designs on the dual expander process utilised by the company on cryogenic liquefiers for industrial gas and LNG. This provides approximately 25% more LNG for no additional power consumption compared to a single expander plant.

Several studies have shown that expander-based technology gives the

lowest overall LNG production cost for LNG plant capacities of up to about 3.0 million tonnes per annum. As the initial FLNG projects under consideration are of 1.0–2.0 million tonnes per annum capacity, the acquired engineering experience and project management capability becomes very relevant, which is why a number of prospects are under consideration for energy majors, FPSO leasing companies, and large engineering and construction companies that need specialist cryogenic plant know-how and experience.

The first LNG FPSOs will need to utilise well-proven equipment and design concepts to ensure technical and commercial success. There are several engineering challenges associated with the marination of gas processing and liquefaction technology, and the utilisation of large nitrogen cycle compressors, whether driven by electric motor or aero-derivative gas turbine. Establishing a reliable, efficient and operable plant design in a limited space sets some novel engineering challenges, requiring plant designers skilled in LNG and modular plant design.

Different challenges for floating LNG liquefaction facilities

Various companies have taken initiatives in floating LNG liquefaction. LNG liquefaction technology has been proven but in a different operating environment. Design of the facility on land compared to a marine-based floating facility presents different challenges. These challenges require not only the process technology knowledge, but also a great deal of multidisciplinary experience and a disciplined approach in dealing with the marination of such facilities.

Aker Solutions has designed many floating production and gravity-based structures over the past three decades in oil and gas production, involving many first-of-a-kind facilities, where a multitude of challenges existed. Floating LNG liquefaction facilities have similar challenges when bringing the gas from a subsea surface to the floater, including gas feed pretreatment, LNG liquefaction, LNG storage, condensate or liquefied petroleum gas (LPG) storage, LNG transfer and loading in the marine atmosphere. These challenges are not new to the industry, but it requires a disciplined approach, keeping in mind that it is still a new concept utilising some proven technologies in a different environment.

Some elements in the floating LNG liquefaction facility chain previously described have been recently developed or tested. The industry has already developed flexible risers for the inlet fluid transport from the subsea surface

to the floating facility. Recently, the transfer of LNG through flex hoses has been tested and additional development is ongoing in this area for further optimisation and cost reduction. A specific design for floating storage tanks associated with LNG liquefaction facilities has recently been developed. The LNG storage tank is designed to help reduce the overall cost in this area, as well as addressing some of the safety issues associated with liquid sloshing in the marine atmosphere with partially filled LNG tanks.

Aker Solutions has gone through concept developments and studies in the marinisation of floating LNG liquefaction facilities, which have involved various refrigeration cycle configurations employed commercially to liquefy natural gas. Each cycle has its own advantages and disadvantages when evaluated for the specific marine application. The selection of the LNG liquefaction process is a balance between the safety, operational flexibility and capacity or train size for the specific application. Liquefaction cycles vary between the sophisticated mixed refrigerant system that is energy efficient to certain cascade refrigeration and nitrogen systems that may have lower energy efficiencies. The mindset for the floating facility design requires various considerations that differ from the onshore base load facilities. Some of the factors influencing the design of the offshore floater-based facility include, but are not limited to, plot density, train size configuration, reduction of hydrocarbon inventory, operational flexibility, machinery configuration, integration of process with floater utilities, site location and impact on the floater, gas reserve/quality, and availability of skilled operators for the offshore location.

The increased size of a single train also magnifies the complexity of design, as well as the risks associated with the operational reliability in the offshore environment. The changes in feedstock (characteristic and flow rates), process sophistication employed for energy conservation and increased inventory of hydrocarbon fluids in the larger trains may lead to underperformance of the asset and operational safety risks.

The specific liquefaction technology considerations in the floater-based liquefaction plants may favour multiple compact modularised trains in the mixed refrigerant or cascade hydrocarbon-based technology, where a system design approach of plug and play may be best suited. The standard small-scale, modularised approach, which is efficient and expandable based on the available ship space, can determine the specific capacity (based on the feed pretreatment requirements)

for a given ship, and it can provide optimum cost and risk reduction. The process must still be marinised to ensure it is flexible and easy to operate in the offshore environment.

The single larger train with lower energy efficiency nitrogen refrigeration-based technology can be employed for higher safety-related considerations, but will require higher energy consumption. There are ways to integrate the process and ship configurations and utilities to better accommodate the process to provide cost optimisation. The maximum capacity of the single train for a specific floater will still depend on the feed pretreatment for the available ship space. The advantage of the nitrogen refrigeration cycle is its process simplification and ease of operation.

The capacity for the floater-based processes can vary from less than 1.0 million metric tonnes per annum (mmtpa) to as much as 3.0 mmtpa. Achieving higher capacities in the floating liquefaction plants reaching up to 3.0 mmtpa are dependent on the deck space driven by the hull design, which is affected by the hydrodynamics of the offshore location. In addition, the site ambient conditions, available gas reserve and inlet feed characteristics also affect the ultimate capacity of the floating liquefaction facility. While not mentioned previously, other non-hydrocarbon-based refrigerants can be utilised in a cascade arrangement. These technologies do not have a track record in the industry, but may provide advantages in certain applications.

Major project developments

Significant advancement has occurred in the design of floating LNG plants in recent years. Floating LNG is being considered seriously for several major project developments around the world. LNG liquefaction technology that is simple, provides reasonable efficiency and flexibility in operation is best suited to the offshore floating facility.

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