Thinking in CIRCLES

Lars Odeskaug, Sevan Marine, and Tom Haylock, KANFA Aragon, Norway, discuss cylindrical hull technology in FLNG operations.

A 3700 year old clay tablet from Babylon has recently been translated into English. On it is a detailed explanation of how to build an enormous round ship for saving man and beast from an expected huge flood. Until this recent discovery, nobody knew that Noah's Ark actually was round. So the circular hull concept is older than one may think!

In 2001, the ark was reinvented, patents were filed and design and analysis of a cylindrical hull for use in the oil and gas industry began. There was great scepticism, with many experts claiming that this had been tried before without success. But model testing continued, and

Figure 1. Sevan FLNG with HiLoad offloading.

eventually the successful combination for a cylindrical design with the necessary load carrying capacity and stability was found. An order for the first floating, production, storage and offloading (FPSO) unit (the *Piranema Spirit*) was placed with Yantai Raffles in China, and a contract was secured with Petrobras for operations offshore Brazil. The *Piranema Spirit* has been under operation for Petrobras since 2007.

Following the *Piranema,* two more FPSOs (the *Hummingbird* and the *Voyageur*) were built, and both are currently in operation in the UK sector of the North Sea. A further two FPSOs are under construction: the *Goliat* at Hyundai Heavy Industries, which will be the first FPSO in the Barents Sea, operated by ENI; and the *Western Isles*, under construction at Cosco's yard in Qidong, to be owned and operated by Dana Petroleum in the UK sector of the North Sea.

Four drilling rigs have also been built with cylindrical hulls: the *Sevan Driller* and *Brazil* are both operating for Petrobras offshore Brazil, the *Sevan Louisiana* is chartered to LLOG for drilling in the Gulf of Mexico, and the last drilling unit, the *Sevan Developer*, is due to be delivered from Cosco Qidong in Q3 2014.

Lastly, two accommodation units with cylindrical Sevan hulls are also under construction at Cosco Nantong, with delivery due in 2015.

Figure 2. FPSO *Piranema Spirit.*

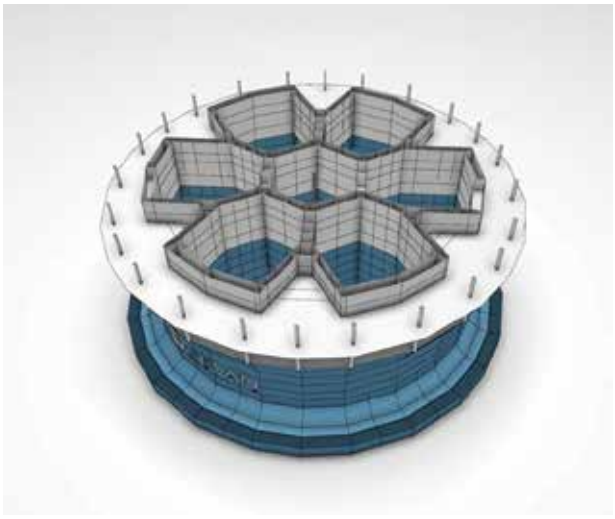

Figure 3. Hull design.

With 11 circular hulls in operation or under construction, this concept has evidently been accepted in offshore oil and gas.

Why cylindrical FLNG?

Natural gas is the cleanest of all fossil fuels, and, for the foreseeable future, will probably also be the cheapest. The oil and gas industry has been talking about floating gas liquefaction plants for decades, but it was only after Shell made the final investment decision on its *Prelude* project that the race for floating LNG (FLNG) began. There are now more than 30 FLNG projects around the world in various stages of development. However, most of these only consider traditional hull shapes. Sevan's proprietary cylindrical hull concept offers several advantages over ship shaped vessels and it is now being offered to developers to enhance their FLNG project development and operations.

As the hull is cylindrical, the vessel is geostationary, which eliminates the need for a turret and swivel, and offers substantial savings in investment, operation and maintenance costs. The hull has small pitch and roll motions and thus is a stable platform for the topsides gas treatment and liquefaction plant, resulting in improved production uptime and revenue. A good example of the cylindrical hull's strengths is the large requirement for cooling water – without a turret the seawater intake is much simpler and the capacity for risers is typically larger than with ship shaped turret moored vessels.

The Sevan FLNG concept has been developed using KANFA Aragon's nitrogen expansion liquefaction technology, but the hull is equally suitable for other liquefaction technologies.

The concept

The FLNG concept is a further development of Sevan's proven FPSO design. The hull meets the requirements of the International Gas Code and has been developed to accommodate both SPB and membrane cargo containment systems. With IHI's SPB cargo containment system the storage capacity is 170 - 190 000 m^3, and with GTT's Mark III system the storage capacity is 220 - 240 000 m^3. There is also space for LPG and condensate storage.

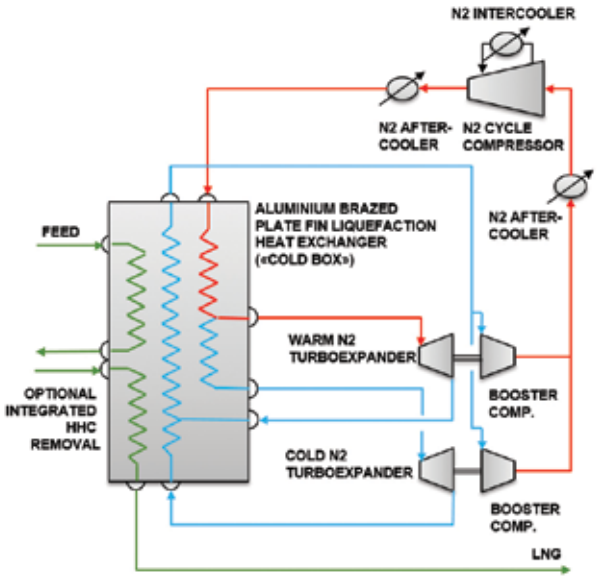

Figure 4. Aragon's Optimised Dual N_2 Expander Cycle.

The hull has double sides and bottom, and the ballast tanks are in the double sides. The double bottom is void space and the condensate tanks are situated along the periphery between the cargo tanks.

There are three decks: the main deck, intermediate deck and the process deck. The cargo tanks extend all the way to the process deck, while the condensate tanks terminate at the main deck. The process deck is supported from the main deck by columns and bulkheads.

Utility and safety equipment, such as lifeboats, watermakers, heat exchangers, etc. are located on the main and intermediate decks. The gas treatment and liquefaction plant along with power generation and living quarters are on the process deck. The living quarters have capacity for 120 beds and there are three cranes for material handling. The total weight of the topside, including utilities and living quarters, is in the range of 32 000 t for a production rate of approximately 2.4 million tpy of LNG.

Offloading

Offloading is a challenge for many FLNG projects. Side-by-side offloading is only possible in benign areas with sea-states below significant wave height (Hs) 2 m. The other alternative, tandem offloading, would increase the operational threshold, but it also means the introduction of dedicated, specially equipped LNG carriers at significant extra cost to the project. A novel development, the 'HiLoad', could resolve the issues with offshore transfer of LNG. The HiLoad unit is a specially designed vessel that attaches to the carrier and guides it during approach and departure, keeping the LNG carrier at a safe distance of 150 m from the FLNG unit during the offloading operation. The first HiLoad is in operation offshore Brazil for offloading of crude oil, and the LNG version will be available with cryogenic floating hoses by the end of 2014. As a result, the offloading challenge can be solved more easily than has been the case until now.

Figure 5. Sevan FLNG.

Table 1. Key technology characteristics

Production rate	Up to 2.4 million tpy
Number of liquefaction trains	2
Thermal efficiency	93 - 95%*
Process topsides weight	22 000 t
Refrigerant	Nitrogen
Liquefaction technology	KANFA Aragon Optimised Dual N_2 Cycle
Turndown	20% per train (at least)

* Typical range, actual depending on development specific conditions

Liquefaction technology

Technology and advantages

The FLNG sector currently has two main types of liquefaction technology proposed: mixed refrigerant cycles and nitrogen cycles. FLNG plants have different technical and safety challenges than well established onshore plants. Restrictions concerning space, weight, logistics, operability and potential future re-location present new technical challenges in plant design.

Experience from the offshore oil and gas sector shows that prioritising safety, availability, and flexibility for both changing feed gas composition and more frequent start and stops compared to onshore plants is critical for any offshore process plant's success. Applying this experience to FLNG leads to the use of nitrogen as a refrigerant as it is non-hazardous, single phase, and simple to operate, resulting in optimised availability and, as a result, optimised project net present value (NPV). For any FLNG project, availability and safety are the most important factors, with efficiency a secondary concern.

Due to these considerations, Sevan Marine has partnered with KANFA Aragon AS as topsides engineering and liquefaction technology partner, taking advantage of the company's experience in FLNG. Aragon's Optimised Dual Nitrogen Expander Cycle is utilised by Sevan Marine as its liquefaction technology for the FLNG concept. KANFA Aragon is also responsible for the process topside design including pre-treatment and utility systems.

The tailored solution is a two train facility. Table 1 shows the technology's main characteristics.

Key advantages of the Aragon Optimised Dual N_2 Expander Cycle include the following:

- The base technology is proven and matured.
- Optimised availability.
- It uses equipment proven in offshore oil and gas and on LNG carriers.
- Highly reliable.
- Low complexity and easy to operate.
- Highly safe: non-flammable refrigerant.
- Compact and low weight.
- No liquid or two phase flow into the cryogenic heat exchanger.
- Robust to vessel motions and the marine environment.
- LNG product quality can easily be adjusted.
- Wide feed gas composition and pressure range.
- Turndown to 20% of train capacity with full energy saving.
- Fast start-up.

The technology is developed to a very high level of detail, allowing optimised project execution times and minimised risk.

Layout and safety

Experience over the last 40 years of offshore oil and gas production has highlighted the crucial need for optimal safety in offshore designs. The use of hazardous and flammable refrigerant offshore presents risks and design challenges that result in significant impacts for facility design and project Capex. An inherently safe process using a non-hazardous refrigerant will give the best protection to personnel, assets and production for FLNG. Facility and safety design can be impacted in the following ways depending on the liquefaction technology selected:

- Large safety gap requirements impact hull size (typically from 50 m up to 100 m in hull length for a traditional ship shaped hull).
- More structural reinforcement due to additional hydrocarbons inventory weight and blast loading.
- Propane is flammable and heavier than air.
- Flare requires much higher flow rates.
- Increased requirement for heat shielding.
- Probable requirement to deviate from American Petroleum Institute (API) recommended practices.

Therefore, nitrogen is the safest refrigerant, and also results in an optimised layout.

By keeping the process simple, the equipment count is kept to a minimum, which typically results in lower topsides weight and cost. Simplicity also benefits operations and maintenance as there is a limit to the number of people with the necessary skills, and to the accommodation space offshore.

As a result, by applying Aragon's Optimised Dual N_2 Expander Cycle, the topsides on the Sevan Marine FLNG solution are lightweight and compact and most importantly safe and simple to use.

Conclusion

The Sevan FLNG solution presents an attractive alternative to traditional ship shaped FLNGs. Developments that apply this unit will benefit from a stable platform for production that has been proven in harsh offshore environments and that provides large deck area and a high load carrying capacity. By eliminating the need for a turret and swivel, the mooring arrangement is simple and cost-effective. Together with the use of KANFA Aragon's topside nitrogen liquefaction technology and the HiLoad offloading system, the Sevan FLNG unit is a safe and high availability FLNG production facility that will provide optimal project NPV. **LNG**