Designed for stormy seas

Andy Foreman, Amarinth Ltd, UK, discusses the challenges of designing pumps for FLNG vessels stationed in some of the world's most hostile environments.

Despite the short-term reduction in energy demand caused by the COVID-19 pandemic, the US Energy Information Administration (EIA) predicts that global energy demand will rebound to its pre-crisis level in early 2023 whilst also taking advantage of cleaner technologies than traditional coal and oil. As the global demand for energy grows again, natural gas, the cleanest burning fossil fuel, will play a vital role in balancing economic growth and environmental responsibilities, with a projected growth in demand for LNG of 30% by 2040.

However, the economics of onshore LNG plants is becoming increasingly challenged as suitable gas fields have become more remote and project infrastructure has become difficult to construct, resulting in high costs and high risk. A huge proportion of the world's natural gas reserves are also located offshore in under-developed or remote regions of the globe. In recent years, with the global demand for LNG continuing to increase, floating LNG (FLNG) facilities have been commissioned enabling companies to start to take advantage of previously unreachable gas fields.

A self-contained LNG plant on a ship

FLNG vessels are entire facilities that handle the offshore storage, processing, and transport of LNG. Using the same systems as land-based LNG plants, these vessels can process gas closer to the source, treating and liquefying it (which involves supercooling the gas to -160˚C to turn it into a liquid), without needing miles of pipelines to transport the gas to the nearest coastal facility. The liquefied gas is stored in tanks on the vessel until it is transferred to LNG carriers for transport to processing plants. FLNGs open the potential to exploit gas fields that can be miles out to sea and which would previously have been too difficult or costly to take advantage of.

Designing and building FLNG vessels raises numerous challenges. For the system to be viable, the vessel must include all the same facilities as a land-based LNG plant. Although the vessels are some of the largest in the world, this requires packaging the plant and equipment into a space one-quarter of the size of land-based plants. To operate in the harsh environment of the open sea, the process modules aboard the vessels require reliable, robust pumping solutions to maximise the efficiency and safety of the vessel, its equipment, and the LNG processes.

Figure 1. Amarinth API 610 VS4 vertical pump used on several topside processes.

Figure 2. Bespoke strengthened pump casings from Amarinth.

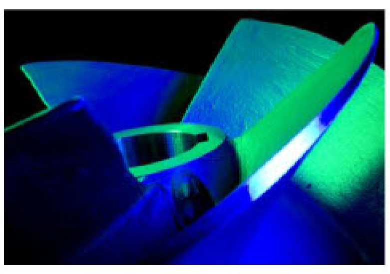

Figure 3. Amarinth pump impeller designed for low NPSH(A) duties.

Amarinth is at the forefront of the design and manufacture of centrifugal pumps for the oil and gas industry, including for many of the world's FPSO vessels. The company has also established itself as one of the industry's go-to experts for centrifugal pumps that can deliver the duties demanded by the LNG industry, both onshore and offshore. The company is now using all its experience and expertise to equip the latest generation of FLNG vessels with robust, reliable pumping solutions.

Harsh environment and limited space

The pumps onboard a FLNG vessel must withstand an extremely harsh environment, from the composition of the fluids, extremely low temperatures, corrosive seawater, highly abrasive sand, and all aboard a vessel that is constantly in motion from wind and waves. Moreover, the pumps must operate reliably 24 hours a day, requiring minimal downtime for scheduled maintenance.

With space at a premium aboard a FLNG vessel, particularly headroom, one of the key challenges is that pumps must be designed to operate in a low net positive suction head (NPSH) available environment otherwise they will be prone to cavitation, seriously shortening their working life.

Many of the pumps must also work reliably despite being placed under significant and unusual loadings due to the motion of the ship and space constraints, and it is not unusual to have specifications that are above and beyond that set out in API 610. However, being aboard a vessel, any bespoke design must be achieved whilst keeping the weight of the pumps to a minimum.

Furthermore, despite these considerable design challenges, the target time to fit out a vessel is often less than 52 weeks from start to finish, with the time given over to the procurement of equipment as little as 20 weeks. This places immense pressure on the pump manufacturer to align the design and delivery of the pumps to meet the critical build schedule of the FLNG and its process packages as any delay would prove extremely costly.

With a lifespan of over 20 years, it is planned that FLNG vessels will be redeployed to other fields once they have depleted a gas source, reducing the need for further construction, and so all equipment must continue to operate reliably and optimally over this lifetime regardless of the vessel's location.

Although many of the challenges apply to all FLNG vessels, to highlight some of the solutions in more detail, two FLNG projects Amarinth has recently supplied pumps to – Coral South and Tortue Ahmeyim – are detailed next.

Coral South FLNG

Amarinth engineers tackled several of the FLNG challenges head-on for the Coral South field, the first ultra-deepwater FLNG facility in the world. This is the first project in the development of the considerable gas resources discovered by Eni in Area 4 of the Rovuma Basin, off the coast of Mozambique, more than 2 km (1.24 miles) beneath the ocean's surface. The Coral field contains approximately 450 billion m³ (16 trillion ft³) of gas and the mammoth FLNG vessel, which has a 432 m long × 66 m wide hull and weighs in at approximately 140 000 t, will have the capacity to process 3.4 million tpy of LNG.

A total of nine API 610 OH2 pumps with Plan 53B seal support systems were required for a MEG regeneration unit and a further four pumps for the desanding unit onboard the FLNG vessel. In both cases, the pumps had to be packaged and designed to operate with very low NPSH available due to the positioning of the skids on the FLNG topsides.

Selecting a pump is always a balance of many factors, including the volumes and properties of the fluid to be pumped, total static lift, pipe size, pipe losses, the efficiency of the pumps, and how frequently the pump will be run. Where space is at a premium however, engineers must deal with the additional and difficult factor of the lack of suction head.

The lack of headroom on Coral South between decks meant that a low suction head was a significant design consideration, and not taking this into account would cause catastrophic cavitation to occur in the pumps. Cavitation occurs when a pump cannot get enough fluid flow into the impeller and the resulting reduction in pressure causes the liquid to vaporise and form bubbles. These bubbles can grow dramatically and choke an inlet, further reducing the flow of liquid and the performance of the pump. In addition, the bubbles can implode with tremendous force, literally tearing away at the metal surface. The resulting increase in stresses, vibration, and noise can lead to downtime and premature component replacement, and in some cases complete pump failure. To avoid this catastrophic situation, the pump designers needed to ensure that the net positive suction head available at the pump, NPSH(A), exceeded that required by the pump to operate without cavitation occurring, NPSH(R).

NPSH(A) is in principle a straightforward calculation taking into account the suction static head, pipe friction losses, atmospheric pressure, and the vapour pressure of the liquid. The first step in designing a system with low NPSH is to review the physical location of the pumps and tanks. Ensuring the pump is as close to the tank as possible will minimise pipe losses. Similarly, reducing the number of bends, valves, and filters in the pipework between the tank and the pump suction will result in greater NPSH(A). The designer must also ensure that the pipework is of the right size for the required flowrates and that the minimum level of liquid is sufficiently above the suction tank outlet, which reduces vortices and potential air entrapment at low levels.

When designing for the extreme challenges of a FLNG vessel, every calculation must be completed fully and accurately. Simply introducing safety margins without due thought to the process would result in a complex engineering solution with large costs and potentially a weight penalty when a simpler solution may be available. For example, API 610 recommends that the pump manufacturer gives serious consideration to the difference between NPSH(A) and NPSH(R) when calculated using the vapour pressure of the lightest fraction in the fluid being pumped. In the case of Coral South, like many other FLNG vessels, the headroom was not available to engineer a solution if the calculations were only based on the lightest fraction, and so the design considered the lightest bulk vapour pressure of the process fluid. This reduced the vapour pressure used in the NPSH calculation, decreasing the static head required, resulting in a pump that could deliver the duty and fit within the available space.

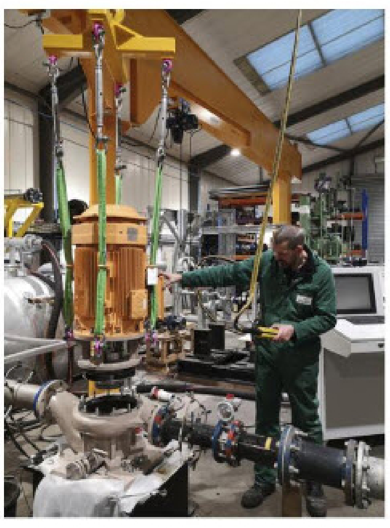

Figure 4. Lowering the motor onto an Amarinth vertical inline pump.

The specification also called for nozzle loading requirements of four times that set by API 610 due to the space constraints. Amarinth used its engineering expertise, business agility, and software solutions to create a bespoke design – strengthening casings and increasing web sizes and thicknesses, and undertaking detailed stress analysis using Finite Element Analysis tools to prove and guarantee the design. Lastly, as the motion of the vessel would starve normal bearings of their lubricating oil, the company developed a bespoke grease lubrication system.

To keep the project on track, the company succeeded in designing and manufacturing these ATEX compliant bespoke pumps on a very tight 28-week deadline.

Tortue Ahmeyim FLNG

FLNG vessels are subject to large fluctuations in loads as they process and then store the liquefied gas until ready to offload and then start again with an empty hull. In addition, to maintain sea worthiness and stability in heavy seas, they have self-contained ballast systems which require pumps that can move large volumes of seawater into and out of the ballast tanks, but which must be compact enough to fit within the available headroom between decks.

Amarinth solved these and other challenges on the FLNG vessel destined for the Greater Tortue Ahmeyim field development project. Located off the coast of Mauritania and Senegal, this field is thought to contain a potential 420 billion m³ (15 trillion ft³) of natural gas and is the deepest offshore project in Africa to date. The FLNG vessel will have the capacity to process 2.5 million tpy of LNG.

Amarinth was commissioned to provide over 65 pump sets for a broad range of duties for both the vessel's topsides and hull applications. The company was selected for its proven expertise and for continuity of supply, spares commonality, and single source commissioning.

To maintain the vessel's stability and equilibrium, large ballast tanks in the hull are filled with seawater and subsequently emptied again as the amount of processed LNG in the vessel's internal hull tanks changes. After careful consideration of the available space within the hull for the ballast pumps, Amarinth designed bespoke compact vertical inline pumps. The bespoke design minimised both the weight and footprint of the pumps and ensured that their height still allowed them to be lifted out for maintenance within the restricted headroom of the decks. The tight space constraints of the vessel also required Amarinth to design complex pipework that would fit within the shape and restrictions of the hull.

The head and flow of the ballast pumps was also not constant and changed according to the tidal conditions. To cover this range of duties, Amarinth supplied the pumps with variable speed drives, enabling them to efficiently move the right amount of seawater at any time and compensate for both slow and rapid changes of volumes in the process tanks.

Other critical duty pumps supplied by Amarinth for Tortue were used in the process of loading the LNG onto waiting transportation ships, where vertically submerged pumps designed for operating with large flow capacities at cryogenic temperatures were required.

In addition, pumps were supplied for several vital topside processes, such as produced water treatment and MEG reclamation. In these cases, the pumps had to handle highly corrosive fluids and so required total containment Plan 53B seal support systems with double mechanical seals. Seal support systems for vertical pumps are usually located some distance from the pump, but with space being so restricted, Amarinth designed bespoke baseplates for the vertical pumps that could accommodate both the pump and its seal support system, minimising the footprint of the whole unit to fit the available space.

Seawater lift duties aboard the vessel required the use of self-priming pumps with substantial MV motors and Plan 53B seal support systems. Amarinth provided its compact vacuum primer units for the pumps and designed a bespoke support frame for the very heavy motor with a footprint to fit the confined space within the hull.

Providing solutions for the growing demands of the LNG industry

Designing pumps for use aboard FLNG vessels is a huge challenge for engineers with each vessel having its own unique requirements. In delivering solutions for these extreme environments however, pump manufacturers such as Amarinth are able to leverage their expertise, skills, and technology acquired in the oil and gas industry, particularly on FPSO vessels, to design and manufacture innovative, robust, reliable, and cost-effective pumps to meet the growing demands of the FLNG industry, now and in the future. LNG