Enabling safe and reliable offshore LNG transfer operations
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Executive Summary
Moving liquefied natural gas (LNG) production to an offshore setting certainly presents a serious set of challenges for the offshore oil and gas industry, particularly when it comes to the design and construction of a floating offshore gas liquefaction plant (FLNG). This is because FLNG facilities need to maintain the utmost levels of safety and give increased flexibility to LNG production while withstanding the effects of winds, waves and currents in the open seas.

However, with the first FLNG plants now in production, it is safe to say that over the past few years these challenges have been overcome and these facilities have well and truly demonstrated their economic and technical viability to the industry. But while some challenges have certainly been met, others remain.

The environmental conditions of the current FLNG locations are at present quite mild and only require the use of the most straightforward technology for the unloading of the LNG, i.e. marine loading arms. But, with prospective new FLNG locations moving away from these 'mild' areas, to sites where sea states, wind and currents can be much more severe, is this straightforward equipment enough?

This white paper will discuss why in these cases, where conditions are much more demanding, conventional marine loading arms will simply not cut it and could result in the shut-down of the liquefaction plant due to bad weather conditions. The paper will outline why tandem offloading solutions, which rely on the use of flexible hoses, are a viable alternative for the industry - not only limiting downtime, but also improving safety.

Demanding Configurations
Not surprisingly, moving LNG production to an offshore setting has presented a demanding set of challenges. However, as well as the design and construction challenges of developing FLNG facilities, extra thought has had to be given to the transfer of the product; LNG transfer must now battle with the effects of winds, waves and currents in the open seas.
Many solutions which could reduce the effect of motion and weather have been considered, however primarily, traditional LNG loading arms have been adapted to enable LNG ship-to-ship transfers in open water through side-by-side configuration. While loading arms can handle both liquids and gases, in a wide range of viscosities and temperatures, environmental constraints, such as the range of tide, wind conditions, and earthquake tolerance can have a significant effect on performance; compared to hoses, loading arms are seen as having a lack of flexibility.

Furthermore, with future FLNG sites being proposed for areas where conditions can be even more extreme, thought has had to be given to more flexible solutions. As such, hose-based solutions for both side-by-side transfers in calmer seas and tandem transfers in rougher conditions are now coming to the forefront as viable alternatives.

Tandem offloading, where vessels line up stern to bow, would allow vessels to keep more distance between them (328 feet / 100 meters distance between FLNG and LNG carriers or more) and more easily cope with greater wave heights. This highly limits the risk of collision between the two vessels, enhancing safety, but also greatly simplifying naval operations in approach, berthing and residence.

A Question of Safety
The main objective of tandem offloading systems is to be able to transfer LNG at a similar flow rate compared to traditional ship-to-shore offloading operations performed along jetties equipped with LNG loading arms, and to enable LNG transfer operations to take place in difficult environmental conditions.

Systems and their associated floating hoses must be designed to operate in sea states with significant wave heights, of up to 11.5 feet / 3.5 meters at connection and 13 feet / 4 meters during transfer and disconnection, even with non collinear wind or current directions. These figures guarantee very good offloading availability in almost any location in the world.

Safety has driven the design of the tandem offloading system through a number of considerations designed to limit risk of personnel exposure and damage to the equipment and facilities. For example, the use of floating hoses in tandem configuration enables the LNG carrier (LNGC) to be almost as far away from the FLNG as requested by the operator; a configuration which brings a clear safety benefit compared to side-by-side loading or tandem loading with aerial hoses.
In addition, in exposed conditions the less time the LNGC stays connected, the safer the transfer operation will be. Limiting the duration of the LNG transfer operation improves offloading availability; degradation in weather conditions is less likely to occur if the offloading window is shortened. Therefore, one of the targets when designing suitable systems has been to minimize duration of all operations.

**Innovative Solutions**

So, in the absence of any mature tandem offloading solutions using floating hoses, leading manufacturers have initiated the development of their own. As a key technical component of any proposed tandem offloading solution, the cryogenic floating hose is a technology which has seen a rapid increase in innovation and development to keep up with this new demand and help address the wants and needs of the offshore oil & gas industry.

In an example of this initiative, leading manufacturers, Trelleborg and Saipem have teamed up to develop a new LNG tandem offloading system which utilizes three Cryoline LNG floating hoses, as well as a hose storage system, a connection head with a dedicated storage platform on the LNG terminal and bow loading platform on the LNG carrier.

Since 2009, specialist manufacturers have been developing floating cryogenic hoses which ensure LNG offshore transfer with minimum Boil of Gas (BOG) generation, combine high flexibility, reliability and long service life, and also meet LNG operator and contractor’s offloading requirements related to safety, flowrate capacity and operation availability.

However, to meet the challenging demands required by these new tandem systems, this technology has been further enhanced, with new parameters being put forward for the development of these hoses. For example, the choice of a 20 inch / 50 cm inner diameter LNG hose was required as this enables operators to transfer LNG at least as fast as standard LNG loading arms on traditional jetties, i.e. up to 423,776 ft³/h / 12,000 m³/h.

The end result was an LNG floating hose based on a hose-in-hose concept that consists of a field-proven outer rubber marine hose with an inner LNG composite hose, which is already well established, in particular for use in LNG ship-to-ship transfer.
A Dedicated Design

This new floating cryogenic hose is made up of several key components, including an inner cryogenic hose, an outer protective hose, an efficient insulation layer and an integrated leak monitoring system.

The inner cryogenic hose has been derived from the latest developments in composite hose technology best known for its high flexibility and proven suitability for LNG ship-to-ship transfer in side-by-side configuration. Composite LNG hoses usually consist of multiple unbonded, polymeric film and woven fabric layers, trapped between two stainless steel wire helices which give the hose its convoluted shape, one being internal and one external.

Broadly, the film layers provide a fluid-tight barrier to the conveyed product, while the woven fabric layers provide the mechanical strength of the hose. The number and arrangement of multiple polymeric film and woven fabric layers is specific to the hose size and application. The polymeric film and fabric materials are selected to be compatible with the conveyed product and the extreme operating temperatures. Composite LNG hoses have already proven their suitability for such an application as this technology has been validated through many full scale static and dynamic tests, and many offshore ship-to-ship LNG transfers.

The outer protective hose has been developed based on flexible rubber bonded hose technology best known for its high resistance to fatigue and high ability to comply with harsh environmental conditions. Rubber bonded hoses are usually made of rubber, steel rings, steel cable reinforcement layers and end-fittings and typically come in sections of 39 feet / 12 meters, which are bolted together in situ, either in horizontal or vertical assembly configuration. They might be used for floating or in submarine configurations, and conform with OCIMF or API 17K specifications. Such a technology offers major technical and project execution advantages, making it a very attractive solution, especially from the perspective of overall offloading terminal optimization.

To demonstrate the fatigue life of rubber-bonded hoses, Finite Element Analysis (FEA) tools have been specifically developed during the qualification program in order to compute the stress within any steel wires or the strains within rubber layers. This technology offers high resistance to fatigue as the rubber bonded hoses might include a tapered Integrated Bending Stiffener (IBS) at each end, progressively decreasing the stress concentration in the flange’s connection.
Also, as the steel parts of the flange are fully integrated within the rubber, the system is corrosion free, and due to the high insulation performance of rubber (thermal conductivity about 0.3 W/m.K), rubber bonded hoses inherently show high thermal insulation properties.

**Integrated Systems**
The annular space between the inner and outer hose is filled with innovative and efficient insulation materials which have excellent properties over the full range of temperatures (from ambient to cryogenic temperatures). As long as external environmental conditions are above +41 °F/ +5° C, the insulation layer is designed so that no ice will form on the outer cover of the cryogenic hose.

These materials have been designed to reduce heat loss within the structure, to protect the outer rubber bonded hose from cryogenic temperatures and to ensure LNG hose buoyancy. Derived from advanced technologies, they consist of an open structure, which enables the operator to inert the annular space with nitrogen, between each offloading operation. Moreover, they also have excellent resistance properties to dynamic loads (fatigue) generated by the application.

Finally, an integrated leak monitoring system based on optical fiber technology for gas leak detection has been included in the design in the annular space between the inner and outer hoses. The two optical fibers – for redundancy purpose – are wound around the composite LNG hose in order to check the evolution of temperature within the structure and prevent any abnormal activity during the offloading operation. The operator will benefit from a fast, effective and reliable control system to monitor the offloading conditions.

**Precise Design**
A compact and specific connection system has specifically been designed for the application. This new technology will typically consist of 39 feet/ 12 meter long sections, which will be connected together – either onshore or offshore – with threaded rods and nuts, in the same way as conventional flexible bonded hoses for oil application.

As such, leading manufacturers have also developed a new concept of end fitting in order to ensure load transfer and leak tightness, and to minimize heat loss within the offloading lines. The design of the connection system includes dedicated seals for cryogenic application which are used for static and dynamic applications, exhibit excellent sealing integrity in gas and fluid applications, and withstand rapid changes in temperature.
The concept of the end fittings has been developed through Finite Element Analysis (FEA) to take into account coupled thermal and mechanical loads at the very first steps of the design process. In a second step, the calculations have been validated through full scale tests performed on a dedicated test bench so as to validate the design of the connection system, to demonstrate the tightness of the connection design at room and cryogenic temperatures, and to endorse the choice of the cryogenic sealing technology. For example, cyclic compression loads up to 200 tons have been applied on a full scale connection, highlighting a safety factor of 10 in service conditions on the key components.

**Qualifying Technology**

The main challenge for this LNG tandem offloading system qualification was to qualify the floating hose according to the EN1474-2 standard, which requires a complete set of full-scale tests.

Based on flexible bonded hose technology, which is suitable as an external hose for the floating LNG hose-in-hose concept, the cryogenic hose development program has been focused at an early stage on key elements such as composite hose suitable for transfer in cryogenic conditions and dedicated end fittings for such application. Subsequently, those elements have to be integrated within the flexible bonded hose in order to design a homogeneous, safe and reliable cryogenic hose able to meet the operators’ offloading requirements.

Several reduced scale prototypes have been manufactured and tested since 2009 at ambient and cryogenic conditions in order to validate theories and demonstrate feasibilities. The design has already been validated by numerous characterization tests and qualification tests on 4 inch, 12 inch and 20 inch / 10 cm / 30 cm and 50 cm internal diameter hoses, including:

- Material testing at ambient and cryogenic temperatures, leading to a definitive selection of stainless steel grade, high performance polymers and insulation materials.
- Fatigue tests on reduced scale composite hose prototypes at cryogenic temperature in order to check the ability of materials to withstand a large number of bending cycles, simulating the fatigue loads the cryogenic hose will face in service condition.
- Characterization test, mainly tensile and bending tests, on 12 inch and 20 inch / 30 cm and 50 cm composite hose prototypes at ambient and cryogenic temperature to validate the analytical model developed to anticipate the behavior of the cryogenic hose under pressure.
- Specific hydrostatic tests to validate the end fitting design and to qualify the tightness of the cryogenic hose connection.
- Extreme thermal tests to check the temperature cycling fatigue life.
Since September 2012, an extensive qualification program has been underway for the new 20 inch / 50 cm LNG hose according to EN 1474-2 standard’s requirements including mechanical, thermal and flow tests. More than 20 tests will be performed, either destructive or non-destructive, at ambient and cryogenic temperature in order to qualify the technology, under survey of Bureau Veritas.

Several 20 inch / 50 cm prototypes will hence be tested in both static and dynamic conditions to demonstrate the suitability of a bonded flexible hose for LNG transfer applications. In particular, a fatigue test will be completed on full scale prototypes to prove that Cryoline LNG hose withstands recurrent dynamic loads for long service life.

The qualification of the 20 inch / 50 cm LNG hose is expected to be completed in 2013.

**Conclusion**

Derived from existing and proven technologies, the latest development in cryogenic LNG floating hoses will become a key component in offloading systems for future offshore FLNG projects. By enabling offshore transfer of LNG in tandem configuration, the cryogenic floating hose will pioneer a step change in the safety of this critical operation. This innovative system will also allow FLNG projects to be considered for harsher conditions, without excessive downtime due to offloading system availability, and with significantly reduced risk.

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