LNG TANDEM OFFLOADING – A KEY ENABLING TECHNOLOGY TO MAKE LNG PRODUCTION OFFSHORE HAPPEN

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Keywords: 1. LNG; 2. Offshore; 3. Offloading; 4. Tandem.

1 Introduction

Offloading operations of liquid natural gas (LNG) are critical for the feasibility of Floating Production Storage and Offloading (FPSO) system for fields at weather-exposed locations subject to medium or harsh environmental conditions. The offloading technology is key for the commercial evaluation of the associated gas in these fields. In the oil industry, tandem offloading operations are routinely performed using flexible marine hoses in various transfer configurations. These systems are operated in relatively severe sea-states.

SBM Offshore has developed a LNG tandem transfer concept based on the proven principle of an offshore loading platform that supports flexible cryogenic flow lines. The base case envisioned is a tandem offloading system located on the stern of the LNG-FPSO connected to dedicated bow manifolds on the LNG carrier (LNGC). For the safety of operations and to increase the operability weather window, this system is designed to be operated without line handling vessels or tugboats.

2 Objectives

The paper will describe the system and its key components developed in house by SBM Offshore, system behaviour and operational aspects, and will demonstrate deployment in harsher environment and higher availability side by side offloading arrangements.

3 Development

A - System description

An artistic view of the proposed LNG offloading system arrangement is shown below. The vessels are moored in tandem with two hawsers in a crowfoot mooring arrangement. The cryogenic transfer lines are freely hanging in a catenary configuration from a fixed structure sitting on the LNG-FPSO to the LNGC bow manifolds.

Within the LNG offloading system the only true novel elements are the LNG hose and the LNG connector. SBM has been developing both and refers to these typically as COOL™ Hose and COOL™ Connector, respectively. The design is compliant with relevant applicable international standards in force or under development. The following components are shown in Figure 1 below:

A LNG-FPSO  G COOL™ Hose
B Fixed offloading structure H COOL™ Connector
C Fluid transfer hard pipe I Hinge articulation connector support
D Cryogenic pipe swivels J Hammerhead carrier bow structure
E Rotating Boom structure K Backup mooring hawser
F Mechanical hinge for hanging hose L LNGC
The fixed offloading structure sitting on the LNG-FPSO stern is designed to support the hoses during the offloading and to store the hoses when not in service. The dimensions of the structure are constrained primarily by the separation distance required between the vessels and by the air gap between the COOL™ connector and the sea surface required during connection and disconnection.

In the proposed scenario, the LNG transfer line arrangement is made of three 18” inner diameter lines, one liquid, one hybrid usable as a spare and one for vapor return. Each flow line is an assembly of COOL™ 35’ hoses. The use of only 35’ COOL™ hose sections for the flow lines facilitates the transport, enables partial replacement and provides adjustable length of the line. A different assembly with longer flow line sections can also be envisaged.

A rotating boom is located on top of the offloading structure to ensure the clearance of the COOL™ Connector from the sea surface during connection and disconnection at sea. Prior to LNG transfer, the boom is raised to vertical position; the elevation of the hose connection point is increased to ensure a suitable minimum air gap above the sea surface in any vessel loading condition.

To minimize the fatigue of the hoses and optimize the LNG-FPSO deck layout, the hoses are stored and supported inside the main structure between each offloading operation. Access for testing, repair and maintenance of the different components of the system is thus guaranteed.
B - Key components

SBM is developing in house the Cryogenic Offshore Offloading and Loading (COOLTM) hose. The design is based on a hose-in-hose concept, and uses essentially existing field-proven components and technologies. The inner hose is a composite hose. The outer hose is a single carcass traditional marine loading hose produced by Veyance Technologies Inc. The end fittings, the insulation and the hose centering system are developed by SBM Offshore.

The LNG FPSO project is envisioned to have a 25 year operating life time. The nominal design life of the cryogenic hose is 5 years. The hose sections are inspectable and replaceable.

An extensive qualification program is underway for the COOL™ hose following EN1474 guidelines including mechanical, thermal and flow tests. Flow tests with a variety of liquids (naphtha, water), and recently with LNG were successfully carried out to assess the pressure losses in a hose section and calculate the maximum flow rate for the configuration envisaged.

Under an exclusive cooperation agreement a single wall COOL™ Connector is being jointly developed with FMC Technologies for offshore applications in accordance with EN 1474 standard.

The main functional requirements of the COOL™ Connector are to:

- Provide a cryogenic Quick Connect / DisConnect system (QC/DC).
- Provide an Emergency Release System (ERS) with minimum LNG spillage and in accordance with LNG industry practices and standards.
- Provide pick up, guiding and alignment devices for handling and connection of the COOL hose in dynamic environment.
- Withstand the offloading design loads, design pressure and temperature, climatic exposure and marine environment.
- Provide local leak test facilities for normal connection operation.
- Ensure maintenance and inspection of the LNGC manifolds and of the COOL™ Connector.
Emergency contingency plans are developed describing steps to be taken for any potential emergency:

- An Emergency Shutdown (ESD) can be automatically initiated by pre-agreed events or manually operated from a number of control points. Allowances shall be made to avoid surge pressures developing during the ESD valves closing.
- An Emergency Release Procedure 1 (ERP1) is carried out after completion of an ESD only when normal disconnection cannot be achieved. This utilises the Emergency Release System (ERS). The ERS is either automatically activated by the green line system or manually operated from a number of control points.
- An Emergency Release Procedure 2 (ERP2) is carried out before an ESD initiation. This procedure protects the LNG FPSO, in the case of a mooring hawser failure leading to a drift of the LNGC outside of the operating envelope or in other emergency situations. An ERP2 can be manually operated or automatically initiated.

![Figure 5: COOL™ Connector](image)

The fixed part of the connector is connected below a hinge articulation. The hinged articulated unit is rotated by means of hydraulic jacks to align the connector with the hose. Between offloading operations the connector will be stored back to allow inspection and maintenance. A hammerhead structure at the bow of the LNGC will support the three hinge connections and the winch equipment to pull and connect the flow lines.

SBM developed its own cryogenic pipe swivel and toroidal swivel. Since 1998 SBM has permanently worked on the development of cryogenic swivels until the final test program was completed in January 2006.

![Figure 6: Swivel test rig within BHR Solutions LNG testing facility](image)
**C - Marine operation**

The following marine operations are carried out during a LNG cargo transfer:
- Tandem mooring equipment, dynamic positioning and bow loading system check prior to arrival
- Tanker approach
- Hawser(s) connection
- Transfer system connection
- Green line connection
- Cargo transfer
- Disconnection
- Hawser(s) disconnection
- Sail-away

**D - System analysis**

The LNG FPSO is typically moored by an external turret in deep water. The turret mooring lines are typically made of two chain segments at the top and bottom and of one polyester rope segment. The tandem mooring arrangement is typically made of a single or twin arrangement depending on the coastal weather conditions.

A mooring analysis is carried out using a diffraction/radiation panel model of the two vessels. The model is built to calculate the hydrodynamic forces applied on the two vessels and to derive the motion RAO’s and, the mean and slowly varying drift forces. The wind and current loads on the two vessels are taken from the OCIMF specifications.

Time domain simulations accounting for current, wind and different wave components are performed with rigid body dynamic software to derive the resulting hawser tension, the bow manifold motion envelope and the heading between LNGC and LNG-FPSO in the design operational conditions.

A model of the aerial flow lines configuration is built in flexible dynamic software using the vessel’s RAO and the hose mechanical characteristics. The vessels are set in the extreme positions derived from the mooring analysis and the resulting loads and motions along the transfer line are calculated in the design operational conditions.

Flow assurance and thermal transient analysis are carried out to assess the lines cool down duration and the boil off rate during the different phases of the transfer.

Based on the system analysis and in-house marine expertise a comprehensive scenario of the operational procedure is built. The typical duration of each phase is established from the project requirements and the system physical characteristics. The weather threshold for each specific marine operation is derived from the vessels type, the mooring and transfer system characteristics and the equipment available on board the units (LNG-FPSO heading control capacity, LNGC DP capacity).

The overall offloading availability is computed at a specific location considering a long term time history of metocean conditions.
4 Conclusion

The tandem offloading solution is inherently safer compared to side by side approaches from an operational perspective in severe offshore conditions. For LNG transfer, it requires the development of key components such as cryogenic flexible and specific connector. SBM COOL™ Hose and COOL™ Connector developments enable safe and reliable LNG offloading. The analysis performed for different offshore case studies shows that tandem mooring of a LNGC and LNG offloading is feasible in the environmental conditions required for project viability. The availability figures are in the right direction for economic feasibility of the project. The uptime will be achieved by using the right combination of technologies together with the adapted marine procedures.