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Review Article

A Review on Floating Liquefied Natural Gas Carriers

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Abstract

Goods transportation from one place to another is an activity that has carried out from the time of Stone Age. We require some commodities in large quantities, while some commodities are such that their absence is rarely matters to us. One such commodity is the LNG. Liquefied Natural Gas is now, such a fuel which though might have issues with storage size but their Output parameters are fantastic. Thus to maximize its use with minimum wastage of time and extra terrestrial space, the concept of FLNGs has been introduced. FLNGs have quite an edge over the terrestrial processing plants which have further been stated.

Keywords: *Liquefied Natural Gas (LNG), Floating LNG (FLNG), Transport, Ships*

1. Introduction

The FLNG concept is amalgamation of technology from LNG industry, offshore oil & gas and marine transport industry. Rules and regulations based on respective field can become too conservative or not conservative enough when applied to a offshore unit of floating LNG. According to Det Norske Veritas (DNV) an LNG FPSO could be considered as an offshore installation and would hence follow offshore classification practice. An FSRU could follow classification according to offshore or ship classification practice depending on the mode of operation. Alignment with rules for conventional LNG carriers would be an advantage as this would increase the transparency and possibility for standardization in the building of floating LNG production vessel. The risk of gas treatment and it is being stationary, either offshore or berthed close to shore, compared to the risk on board an LNG carrier may be significant.. FLNGs are expected to provide these on-board facilities. Floating production platforms and re-gasification platforms, collectively referred to as FLNG. Regulations and rules based on experience from these applications could become too conservative or not conservative enough when applied to a FLNG unit.

2. Floating Liquefied Natural Gas

FLNG refers to water-based LNG operations employing technologies designed to enable the development of offshore natural gas resources. Right now, no FLNG facilities exist currently, a facility is being development by Royal Dutch Shell, and scheduled to be completed by 2017. Floating above an offshore natural gas field, the FLNG facility will produce, liquefy, store and transfer LNG at sea. Studies into offshore LNG production have been conducted since the early 1970s. In 1997, Mobil developed a FLNG production concept based on a large, square structure with a moon-pool, commonly known as The Doughnut. In 1999, a major study was commissioned by Chevron Corporation and other oil and gas companies. This was followed by the 'Azure' research project, conducted by the EU and other oil and gas companies. Both projects made great progress in steel concrete hull design, topside development and LNG transfer systems. Since the mid-1990s Royal Dutch Shell has been working on its own FLNG technology. This includes engineering and the optimization of its concept related to specific potential project developments in Namibia, Australia, and Nigeria. In July 2009, Royal Dutch Shell signed an agreement with Technip and Samsung,for the design, construction and installation of multiple Shell FLNG facilities.

3. Current Projects

A number of major gas and oil companies are still researching FLNG developments.The world's first development of FLNG is Shell's Au$12bn Prelude FLNG project, 200 kilometers offshore Western Australia. Royal Dutch Shell announced their investment in FLNG on 20 May 2011 and construction began in October 2012. In April 2010 Shell's FLNG technology was selected as the Sunrise Joint Venture's preferred option for developing the Greater Sunrise gas fields in the Timor Sea. This followed an extensive and rigorous concept-evaluation process during which the merits of the project were weighed up against alternative onshore solutions. The JV is now looking to engage regulators on the concept selection process. The Sunrise project will be the second deployment of

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Shell's proprietary FLNG design. In February 2011, Petronas awarded a FEED contract for an FLNG unit to a consortium of Technip and Daewoo Ship Building and Marine Engineering. The facility will be located in Malaysia. Petrobras has invited three consortiums to submit proposals for engineering, procurement and construction contracts for FLNG plants in ultra-deep Santos basin waters. Japan's Inpex plans to leverage FLNG to develop the Abadi gas field in the Masela block of the Timor Sea. According to GASTECH 2011, ConocoPhillips aims to startt a facility by 2019, and has completed the quantitative risk analysis of a design that will undergo pre-FEED study during 2011. GDF Suez Bonaparte – has awarded a pre-FEED contract for the Bonaparte FLNG project offshore Northern Australia. The first phase of the project calls for a floating LNG production facility with a capacity of 2 million mt/year. Chevron Corporation is currently considering an FLNG facility to develop offshore discoveries in the Exmouth Plateau of Western Australia, while ExxonMobil is waiting for an appropriate project to launch its FLNG development.

3. Rules and Regulation

Each classification society has its own set of rules for standard ship construction and supplements covering the specific application of different ship types and their equipment. The requirements are formed so that they implicitly describe the hazards. The shipping industry traditionally had a prescriptive approach in implementation of new requirements and regulations. Gas carriers are governed by regulation and class requirements, which is favorable for ship-owners and shipyards as it provides clarity for contracting vessels. A tendency to move from the prescriptive regulations to goal-based regulations with an integration of risk analysis is seen today, and this will facilitate novel technology and novel ship design. To assure that a ship or offshore structure has an acceptable safety level it has to fulfill certain standards.

• Classification Societies issue classification certificates, which certify that safety and rule compliance is fulfilled. The validity is for five years given that annual and intermediate surveys are fulfilled successfully. Several parties have an interest in the safety and quality of a ship and the classification system serves as a verification system to ensure that the requirements of rules and other standards are fulfilled. Such parties could be, among others, insurance companies, ship owner, cargo owners and national authorities under whose flag the ship will sail.
• In Coastal state a foreign ship operates when entering a port or operating in the coastal areas of a country. According to the United Nations Convention on Law of the Sea (UNCLOS), a coastal state has the right to enforce its own laws and regulations considering pollution on foreign ships entering their waters. A country could also act as a port state when a foreign ship enters a port or offshore terminal, and then the state has the right to detain a vessel and require repairs if the ship is not found to be seaworthy.
• Flag state is where a ship or offshore structure is registered in order to identify it for legal and commercial purposes. The object does not have to be registered in the same state as the company and it could be beneficial to register the ship in another flag state for tax reasons. The flag state is responsible for the ship and it complies with the law of the flag state. The most significant flag states have implemented the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from ships (MARPOL) and other IMO conventions into their own laws. UNCLOS states that the flag is responsible for the seaworthiness of a vessel flying its flag and that laws and regulations targeted at preventing and controlling pollution are followed.
• The United Nations set up the broad framework of the law of the sea, UNCLOS, and to date 162 states or entities have signed the convention. The IMO and the International Labour Organization (ILO) are the two agencies that they operate through.

4. Existing rules & regulations for LNG carriers

DNV rules for the classification of LNG carriers are in Rules for Classification of Ships Liquefied Gas Carriers. In its general form, the Classification of ships is described as: The classification concept consists of the development and application of rules with respect to design, construction and survey of vessels. In general, the rules cover: - the structural strength and integrity of essential parts of the vessel's hull and its appendages, and - the safety and availability of the main functions in order to maintain essential services.
Class is maintained in the service period provided applicable rules are observed and surveys carried out. Ships carrying Liquefied Gases have set of requirements in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC), which has been specified by the IMO in cooperation with the International Association of Classification Societies (IACS). The IGC addresses:

• Flammability.
• Toxicity.
• Corrosivity.
• Reactivity.
• Collisions and strandings.
• Cryogenic release.

The IGC code is not mandatory, but most flag states require that the code is fulfilled if the ship is to sail under their flag. If an LNG carrier is classified according to DNV rules it is also fulfilling the IGC code: The requirements are considered to meet the requirements of the International Code for the

Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, IGC Code, Res. MSC.5 (48). The following amendments to the IGC Code are included in this edition of the rules: Res. MSC.30(61) (1992 amendments), Res. MSC.32(63) (1994 amendments), Res. MSC.59(67) (1996 amendments) and Res. MSC.103(73) (2000 amendments).

5. Existing rules & regulations for FLNG carriers

DNV have gathered their experience of classification rules for oil and gas carriers and Oil FPSOs into classification rules of Gas FPSOs. The result is DNV-OSS-103, Rules for Classification of LNG/LPG Floating Production and Storage Units or Installations. In addition to the class rules, class notation PROD (LNG) will also supplement rules for the gas treatment and liquefaction plant. DNV-OSS-103 contains references to the appropriate offshore standard applicable for the different areas of the unit. Future rule development could benefit from alignment possibilities from the classification rules for LNG carriers. However, it is important that the rules allow novel technology so that future development of technology is not restricted for use due to regulations.

6. The Working Principle: FPSO

LNG FPSOs are offshore floating production units that contain both gas processing and liquefaction equipment as well as storage for the produced LNG. The unit could have a fixed mooring or be equipped with a turret, external or internal, that will allow the unit to weathervane. On top of the main deck, a supporting structure, called the topside, is installed, which contains the gas processing and liquefaction equipment.

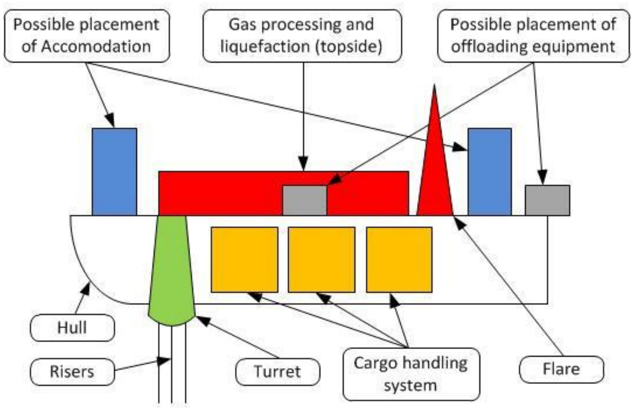

Fig.1 Conceptual Layout of LNG FPSO

The raw natural gas is transferred from the wells in risers and diverted to the topside through a turret, if equipped with a connection along the side of the hull. The produced LNG is then transferred from the topside to cargo tanks situated below deck. The stored LNG is frequently transferred to arriving LNG carriers via offloading equipment, which could be located amidships or in the aft of the unit. To provide the crew with living quarters, control room, etc., an accommodation block is needed, and this could be situated on the deck in front or aft of the topside. FIG. 1 shows a possible layout of an LNG FPSO The different building blocks and their difference compared to an LNG carrier are presented further according to the following list:

• Structure (Hull.
• Gas processing and LNG production (Topside, Flare).
• Cargo handling.
•Transfer systems (Risers, Turret, Offloading equipment).
• Additional systems (Accommodation).[10-14]

- *Structure*

The main structure of LNG FPSOs will be similar in design as oil FPSOs and oil tankers and follow the principles of the design of steel ships. Due to similarities to tankers with regard to structural arrangement, many reliability formulations developed for ships could be applied to LNG FPSOs. The design of an offshore structure will have additional requirements compared to a ship. Due to continuous operation and the absence of regular docking, additional attention needs to be drawn to corrosion prevention. To ensure the structural integrity, corrosion-protective coating and cathodic protection could be used. For critical structural members, corrosion allowance should be used as a safety factor in design. Additional loads on the hull structure from the topside and mooring equipment need to be accounted for in the design. Depending on the capacity of the LNG FPSO the weight of the topside could exceed 70000 tonnes for a large production unit producing between 3-5 million tons per annum (MTPA).There are two different mooring systems in use for permanently moored offshore structures: spread mooring and turret mooring. The additional load will affect internal major load-carrying structural elements, such as longitudinal and transverse bulkheads, and, depending on the system used, the load will be taken up by different areas on the hull. Spread mooring constrains the vessel in one direction and is equipped with chain stoppers distributed along the main deck of the hull. A turret mooring system could be fitted externally or internally of the structure and will affect the structure in its vicinity.

- *Gas processing and LNG production*

Raw natural gas can have a variety of compositions. Natural gas is often found together with oil. First step in the process is to examine which contaminates are present. Therefore, an LNG process plant can differ between locations depending on the technique used to process the gas to reach a pure state. A typical processing scheme of an LNG process plant is presented in DNV Offshore Technical Guidance OTG-02. The sub-systems are presented in more detail below.

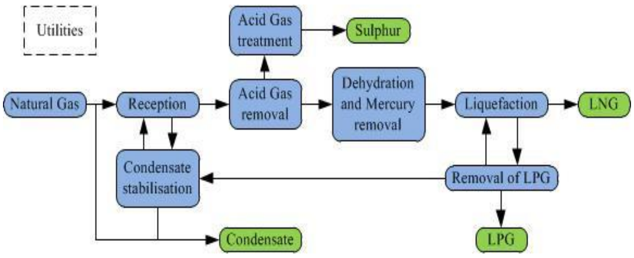

Fig. 2 Example of process layout for an LNG FPSO

- *Reception*

When the raw natural gas is brought up from the wells the first step is to separate erosive solids, water and condensate. Erosive solids, for example sand, could damage or tear piping and components. The separation could be achieved by three principles; momentum, gravity settling or coalescing. The technology used is dependent on the composition of the raw natural gas. Condensate is separated from the gas stream and routed to the condensate stabilizer. Heavy hydrocarbon components are normally found to some extent in all gas reservoirs in its liquid state. In underground pressure they exist in a liquid state and will become gaseous at normal atmospheric pressure. In liquid state, these hydrocarbons are called hydrocarbon condensates consist of lighter components. When brought up to atmospheric pressure these lighter components will flash off and therefore there is a need to stabilize the recovered hydrocarbon condensate to avoid flashing in storage tanks. Flashing occurs when a liquid immediately evaporates to vapour undergoing reduction in pressure. Stabilization could be achieved either through Flash vaporization of Fractionation.

• Flash vaporization: To allow flashing of lighter components, such as methane-ethanepropane, from the condensate, the pressure is lowered progressively through several stages. The flashing could be done in 2 to 4 stages. The vapour is injected back into the natural gas stream after recompression or could be used as fuel to on board power generation. The remaining heavy hydrocarbons are sent to a storage tank.

• Stabilization by fractionation: Fractionation removes and recovers the light components such as methane-ethane-propane and most of the butanes from the condensate. The liquid hydrocarbon from the inlet separation is either preheated or flashed down into a stabilizer feed drum and then further fed into the stabilization tower. The stabilization tower separates the lighter components, which are sent to a low-pressure fuel line. The technique allows the condensate liquid to keep a certain quality, which generates greater revenue since the condensate could be sold at a higher price.

- *Acid gas removal*

To avoid damages on the equipment, sour gases such as CO2 and H2S are removed from the flow. This is done with various processes depending on concentrations of contaminants in the gas and the degree of removal desired, temperature, pressure, volume and composition of the gas, etc. There are two general processes are used for removal; adsorption or absorption. Adsorption concentrates the impurities on the surface of an absorbing medium, usually granular carbon solid, while absorption relies on physical solubility of the impurities into an absorption medium. The collected CO2 could be released into the atmosphere, but this may not be desired due to environmental policies of the operator or not permitted by regulations of the site of operation

- *Dehydration and mercury removal*

To avoid freezing damages to pipes and equipment due to the formation of hydrates, water is eliminated from the flow. The most common techniques to dehydrate gas is by injection of a solid or liquid desiccant or by refrigeration. The technique most preferable for offshore use is solid bed dehydration due to a relatively small footprint and being unaffected by vessel motions. If mercury is present in the gas flow it can cause corrosion of aluminum, therefore, it is also removed to avoid damages. The removal of mercury can be achieved by adsorption or by a bed filter.

- *Removal of liquefied petroleum gas (LPG)*

LPG is a flammable mixture which consists of mostly propane and butane. For offshore use the preferred method for removal of LPG is fractionation. The amount of LPG presence in the gas flow will be an important factor. A large amount of LPG products can be produced for sale or used as fuel for power generation on board. A small amount of LPG in the raw gas is expensive to remove and could not fulfill the fuel consumption on board or is unprofitable to sell. The fractionation train normally, depending on the composition of the raw natural gas, consists of three stages where the lighter product is boiled of in each stage.

• De-ethanizer: In the first step ethane and propane is separated, the ethane goes overhead and propane and heavier components are extracted from the bottom and sent to the depropanizer.

• De-propanizer: In the second step the propane is separated, the propane now goes
overhead and isobutene and heavier components are extracted from the bottom and sent further to the debutanizer.

• Debutanizer: In the last step butanes are separated from the flow leaving natural gasoline from the fractionation train.

- Liquefaction: The liquefaction cools the clean feed gas in normally three steps down to its storage temperature of -160 to -163 °C. When liquefied the natural gas is equivalent to 1/600 of its volume in a gaseous state. There are three main technologies, mixed refrigerant processes, cascade refrigerant processes and expander processes.
- Mixed refrigerant process: A single mixture of nitrogen and hydrocarbons is used as refrigerant to cool the natural gas. The mixture is composed to match the cooling curve of the natural gas.
- Cascade refrigerant process: The natural gas is cooled in three steps using different refrigerants for each step. Propane is used in the first step to pre-cool the gas, secondly ethylene or ethane is used to bring the gas down to its liquefaction temperature. In the final sub-cooling step methane is used to cool the gas.
- Expander processes: The natural gas is cooled in a heat exchanger process with either methane or nitrogen as refrigerant gas. The refrigerant gas is cooled in a compression-expansion cycle. For offshore application, an expander process utilizing Nitrogen as cooling medium would be preferable due to its small form factor and to its being less sensitive to motion than the other techniques. Other advantages of the technology are higher safety and that it is easier to operate.

Power generation

The power demand of an LNG FPSO is large mainly due to the large amount of compressors involved in the process. Proposed LNG FPSOs have a power demand between 100 to 250 MW.. Electrical motors would most likely be the choice for powering the compressors and pumps, which offers more flexibility in the power supply. Several solutions for power supply have been proposed. Due to its small form factor and high power output, gas turbines would be a good choice for powering electrical generators. The gas turbine could be equipped with a waste heat recovery system utilizing the exhaust heat from the gas turbines. The recovered waste heat could also be used to generate steam used for powering equipment and/or used in the pre-heat process.

- *Cooling water*

The different processes on board require a large amount of cooling. Sea water would likely be used for cooling the medium of a closed loop cooling system. To prevent marine growth and corrosion, substances such as biocides need to be added to the water. To prevent pollution of the marine environment around the FLNG the residual of these substances have to be held at a low level. The amount of cooling water needed for the FLNG can be 50,000 m3 per hour.

7. Cargo handling

In marine transportation of LNG the IGC code designates a number of tank types. These can be divided into two main types, membrane tanks and independent tank.

Membrane tanks: The membrane tanks are non-self-supported and rely on the double hull surrounding the tank for structural strength. The tank consists of a cryogenic liner composed of primary and secondary membrane separated by insulation, which is designed to compensate for thermal and other expansion. The benefits of the tank system are the high utilization of space available and the disadvantages are large impact loads due to sloshing when partially filled. To reduce the influence of sloshing, large tanks can be replaced by smaller tanks arranged in parallel rows. Independent tanks: Independent tanks are divided into three types:

- Type A – Full secondary barrier.
- Type B – Reduced secondary barrier.
- Type C – No secondary barrier.

Type B tanks are common on existing LNG carriers and often proposed for use on FLNG, therefore type A and type C will not be described further. Type B can be divided into Prismatic and Spherical types.

Prismatic type: The tanks, are built up of a single primary barrier and have an internal structure with typical ship hull structural elements in a plate – stiffener - girder system. The tank system has a partial secondary barrier in the form of an insulation system surrounding the tank, and drop trays covering the bottom and side of the tank. The internal structure will reduce liquid motions and consequently the effects of sloshing, and this, however, could be significant if not designed properly.

Spherical tank: The spherical tank, consists of a primary barrier of aluminum and a partial secondary barrier made from insulation surrounding the entire sphere and drip trays beneath. A cargo pump tower is installed reaching from the bottom to the top of the sphere. Sloshing can be significant but the impact pressure is insignificant due to the spherical design of the tank. Low utilization of hull space and the absence of deck space for process equipment makes this tank solution unlikely for use on an LNG FPSO.

8. Transfer systems

The wellheads are either placed sub-sea directly on the well or on the LNG FPSO. If placed sub-sea, a flow line transports the raw gas from the wellhead to the LNG FPSO via risers. The FPSO is usually tied to multiple sub-sea wells. Depending on the harshness of environment of the intended location and the need to disconnect from the risers, the LNG FPSO could be equipped with a turret which the risers are connected to. The offloading is an important part of the LNG FPSO. The produced LNG must be offloaded onto an LNG carrier arriving periodically. The design of an offloading system can be divided into two main categories, side by side and tandem.

Side-by-side transfer: Side-by-side transfer, is carried out by a shuttle tanker temporarily moored alongside the FLNG. The transfer of the LNG is performed via rigid connection arms located on the side of the FLNG. The operation is normally supported by tugboats. Up to four tugboats could be required to get the carrier alongside the FLNG. Calm weather is required for this offloading system since the loading arms do not allow for a wide range of relative motion, and this limits the window of offloading for many locations. The advantage of this solution is that conventional LNG carriers could use their standard amidships manifold without modification, which minimizes the cost. A novel technology, HiLoad DP, originally developed by Remora, utilizes a self-propelled unit that attaches itself to the carrier. The unit is always connected to an FLNG or pipeline. Since the unit maneuvers itself alongside the LNG carrier and attaches itself using suction, the relative motion between carrier and platform is absent.

Tandem transfer: Tandem transfer, is performed from the stern of the FLNG to the bow of the shuttle tanker. There are several different technologies available. The benefits of tandem transfer are less influence from relative motion between the FLNG and the shuttle tanker. The tandem transfer technique allows for a more severe sea state than side-by-side transfer, which makes it preferable if the location of the FLNG is under the influence of harsh weather.

9. Additional systems

There is a need for several different utility systems on board. Some different utility systems are briefly described below.

Accommodation: Accommodation is needed to provide the personnel on board with living quarters, a control room, and medical facilities, etc. The location of the accommodation needs to be as far away as possible from the most hazardous process plant areas as well as the flare.

Fire fighting system: The required amount of water spray capacity would be larger than for an LNG carrier since the gas treatment and processing plant need to be covered as well. If the FLNG store condensates and in addition to LNG, there is a need for different measures for fighting potential fires. The redundancy of the system must be kept high.

Flare and venting systems: During operation, the need for the disposal of gas arises several times. This could be done by release of the gas directly into the atmosphere, called venting, or burned in a controlled manner, called flaring. Flaring requires a flaring tower on board the platform. Both options have advantages and disadvantages and studies need to be carried out for each case. The location of the flare will have to take the placement of living quarters and process plant into account.

Control and safety systems: To further increase safety on board the vessel, several control systems would need to be implemented aboard. The complex environment of an FLNG with processing and simultaneous transfer to shuttle tankers makes an integrated control system necessary.

Normally, the control and safety systems consist of systems controlling the following: normal process control, interlock and shutdown, fire and gas detection, heating-ventilation-air-conditioning (HVAC) and emergency shutdown (ESD). It is crucial that the software is designed and meets the requirements of safety, functionality, and reliability.

10. Risk Evaluation of Flng During Operation

The first step of the FSA methodology is to perform a risk assessment. This section presents some of the hazards due to the physical properties of LNG and LNG vapour.

Hazards due to the physical properties of LNG and LNG vapour: According to the IMO, LNG is a colourless, odourless, non-corrosive, non-toxic and cryogenic liquid, but when vaporized it forms a visible cloud that can become flammable if the gas-to-air mixture is between 5 – 15 %. LNG will behave differently if spilled over water compared to land. When spilled over land, the vaporization will be rapid but decreases as the ground underneath is cooled down, and therefore the evaporation of the created LNG pool can proceed during a long period of time. If spilled over water, LNG will float on the surface due to lower density. In contrast to when spilled on ground, heat will be transmitted through the water causing the LNG pool to boil and rapidly vaporize. A gas-to-air mixture of 10 % LNG vapour has an auto-ignition temperature of 540 °C, and hence the vapour cloud is highly unlikely to self-ignite and will dissipate into the atmosphere unless it encounters any source of ignition. According to the IMO, the main hazards of LNG in liquid or vapour form are:

• Pool fires: If the spilled LNG is ignited the mixture of evaporated gas and air will burn above the LNG pool. The fire cannot be easily extinguished. The heat from the fire may injure people or property at a significant distance from the fire.

• Vapour clouds: The vapour cloud can travel some distance from the spill site before encountering any source of ignition - the vapour cloud is normally expected to burn back to its source of spill and continue to burn as a pool fire.

• Cryogenic temperature: LNG is held at a temperature of -160°C, if human skin is exposed to this temperature the damage effect will be similar to a thermal burn. If structural elements and equipment are exposed to LNG and have not been designed to withstand the low temperature they will most likely become brittle and failure will occur.

• Asphyxiation: LNG is non-toxic but can cause death by replacing breathable air if spilled and could be of significant risk in enclosed or confined spaces.

• Rollover: When loading LNG with different compositions, these might not mix at once but form layers with different density within the tank. After a period of time the LNG may rollover to stabilize the liquid in the tank. The rollover causes the liquid to give off a large amount of vapour, which creates an overpressure in the tank.

• Rapid phase transition (RPT): When large enough quantities are rapidly spilled over water the LNG could change phase at such a fast rate that a cold explosion occurs. No combustion occurs but a large amount of energy is transferred in the form of heat from the water to the LNG.

• Explosion: LNG is not explosive in a liquid state and the vapour is only flammable at gas-to-air mixture of 5-15%. The only way for LNG to cause an explosion is if being ignited in an enclosed or semi-enclosed space and at the same time being in the flammable region.

- Identification of hazards

The identification of hazards was established by a brainstorming event and followed the guidelines of IMO for FSA. The study was limited to the first step of the FSA, risk identification. A schematic model of the process of an LNG FPSO can be seen in FIG. 3 and a schematic model of the process in a FSRU.The consequence of a hazard is normally calculated on computational models of the actual problem. IMOs severity index, was used to give a rough estimate of the consequence of a hazard. The frequency of an event can be predicted from similar onshore plants or historical data, in this study the frequency index proposed by IMO, have been used to estimate a rough value.

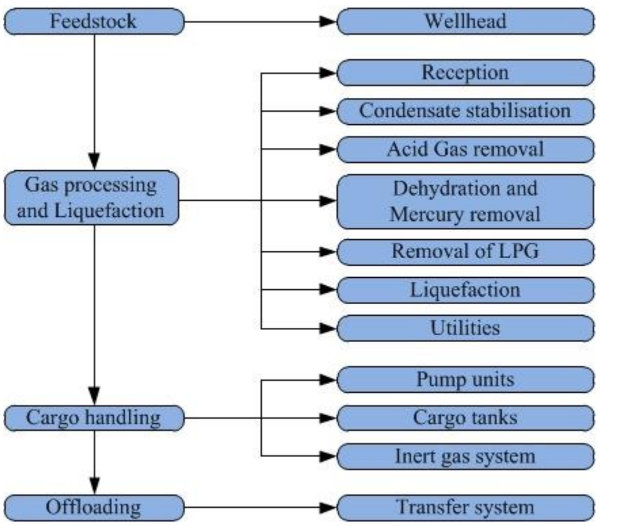

Fig.3 Schematic overview of an LNG FPSO

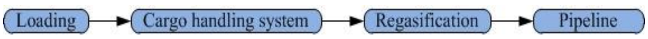

Fig. 4 Schematic overview of an FSRU

Table 1 lists the different hazards which were found in the brainstorming event. All hazards listed in Table will affect an LNG FPSO. An FSRU will be not be influenced by hazards 1 and 2.

11. Risk acceptance criteria

There are several different standards for establishing risk criteria. Most of the criteria normally place the risk in one of the three categories; unacceptable, tolerable and broadly acceptable. For offshore applications the ALARP, short for 'as low as reasonably possible', is often used and refers to the cost-effectiveness and benefits of the solution. The term is derived from the UK Health and Safety at Work Act 1974. The risks of the intolerable and tolerable should be ALARP and have proved to be so. In the risk assessment the individual, societal and the environmental risks should all be taken into account. For risks in the ALARP area a criterion is needed to determine when a risk is reasonably practicable. According to Skjong, this is often given in terms of the cost of averting a fatality normally referred to as Net Cost of Averting a Fatality (NCAF) or Gross Cost of B5 Averting a Fatality (GCAF). Quantitative values must be set for the optimum/maximum of the cost of averting a fatality, and the definitions of NCAF and GCAF are:

GCAF = ΔCost/ΔPLL

NCAF = (ΔCost - ΔEconomic-Benefits)/ ΔPLL

With the parameters:

ΔCost = Marginal cost of the Risk Control Option

ΔPLL = the reduced number of fatalities

ΔEconomic Benefits = the economic benefits of implementing the RCO

According to Skjong, the IMO proposed values for the individual risk to be used as risk acceptance criteria. For a large project exposing a large number of people to risks, the societal risk criteria is preferable. This criteria is expressed in frequency versus number of fatalities, but the risks are not as straightforward to develop as the individual risk criteria. In some cases both societal and individual risk criteria must be complied with. For example, with a passenger ferry that carries a large number of passengers the risk should be expressed in societal risk. However, the crew is exposed to additional hazards related to their work and this should be expressed as individual risk. A technique for presenting risk is FN curves, see FIG. 5

Different models exist on the inclination angle of the boundary between the ALARP region and the intolerable. The FN diagram shows the relationship between the frequency F and accidents with N or more fatalities. The FN curve gives a good overview over accidents which span from a single to multiple fatalities.

Table 1 List of hazards to LNG FPSO

Area	Hazard No	Hazard	Frequency	Consequence	Risk level
Feedstock	Hazard 1	Blowout	3	1	4
	Hazard 1	Hydrocarbon release from the turret	2	3	5
Gas processing and Liquefaction /Regasification	Hazard 3	Hydrocarbon release in process area	2	3	5
	Hazard 4	Cryogenic spill in liquefaction area (regasification plant in case of FSRU)	1	3	4
	Hazard 5	Spill of hazardous substance	2	1	3
	Hazard 6	Fire/explosion in process area	2	3	5
Cargo handling	Hazard 7	Fire/explosion in containment area	2	4	6
	Hazard 8	Inert gas release in containment area	2	1	3
	Hazard 7	Sloshing in cargo tanks	4	1	5
Offloading And vessel overall	Hazard 10	Ship collision	1	2	3
	Hazard 11	Cryogenic leak during offloading (loading in case of FSRU)	1	3	4

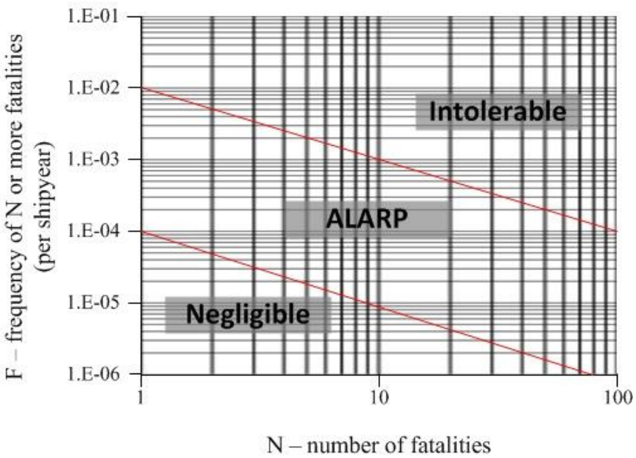

Fig. 5 FN-curve

Conclusion

The conclusion that arises is that we, India, need to develop units like the FLNG. A country ranking among the top 3 for population density and being among the top 10 consumers of non-renewable resources, economising our processing techniques of LNG can help save time and thus is a major step towards faster economic development. In addiion to economic development, more utilization of water resources for the betterment of human life by fascilitating faster and more feasible availbility of the LNG(for eg.), a fuel required for the most needy tool of the century: an automobile.

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