Safety and Environmental Concern Analysis for LNG Carriers

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ABSTRACT: The main attempt of this study is to overview and to discuss occupational safety and environmental conciseness for the transportation of LNG with gas carriers. LNG is transported by a fleet of 157 LNG tankers of varying sizes from 18,500 m^3 to 140,000 m^3. This study investigates the technological development and innovation in LNG transportation while considering safety and environmental standards and regulations for LNG shipping. It is also originally contributing the process safety for decision making process for the MET institutions while planning the further needs of LNG industry during the planning of their related curricula. The further research activities could also be concentrated on quantitative risk evaluations of LNG equipment, based on risk maintenance and reliability concepts.

1 INTRODUCTION

1.1 *LNG Definition*

LNG is the common acronym for "Liquefied Natural Gas". Natural gas is a mixture of gases that is produced with or without oil in gas and/or oil fields and consists primarily of methane. Liquefaction of methane is achieved by cooling the gas to below minus 160°C under normal atmospheric pressure. Natural gas in liquid form is some 600-620 times less in volume than its gaseous equivalent. The actual percentage of methane in the natural gas depends on the characteristics of the oil field where it is produced.

1.2 *World Energy Demand and Supply*

World energy production relative with the demand and supply intention has a great significance on the determination of usage and transportation. Therefore Figure 1 illustrates the world energy production in 2005 to give an idea on the change of energy supply-demand and how the LNG takes a significant portion in the world total energy production (BP, 2006). When the world energy production in 1990's analyzed, similar distribution among the different kinds of energy production still remains with only slight differences and increase in: oil 40%, gas 23%, coal 28%, nuclear 7% and hydroelectric 2% (U.S. Energy Information Administration, 2005).

It would seem that production share changes in 15 years have been quite insignificant. However, considering the very large figures involved in the total world produced energy, even a variation of 1 % percent is noticeable. The above data clearly indicate that there is a clear trend of increase of the "clean" sources of energy (gas and water) and a decrease of the "dirty" sources (oil and coal), while the nuclear remains almost constant (U.S. Energy Information Administration, 2005). This trend appears more evident comparing the rate of increase of the world energy consumption with the rate of increase of the various types of fuels for the 15 years period between 1991 and 2005 (BP, 2006).

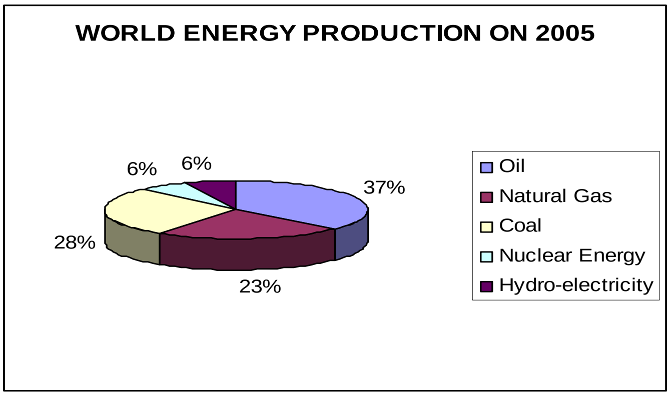

Fig. 1. Energy source production rates (BP, 2006)

1.3 *LNG Supply and Demand*

Up to 1970, almost all natural gas was transported from the producing countries to the consuming countries via pipelines. Pipelines are still used to transport the majority of natural gas today, particularly in Europe and United States. Figure 2 respectively illustrates LNG Trade by Exporting Country (BP, 2006). This figure is also useful to give an idea of the dimensions, the trends, the routes of gas and LNG in the world.

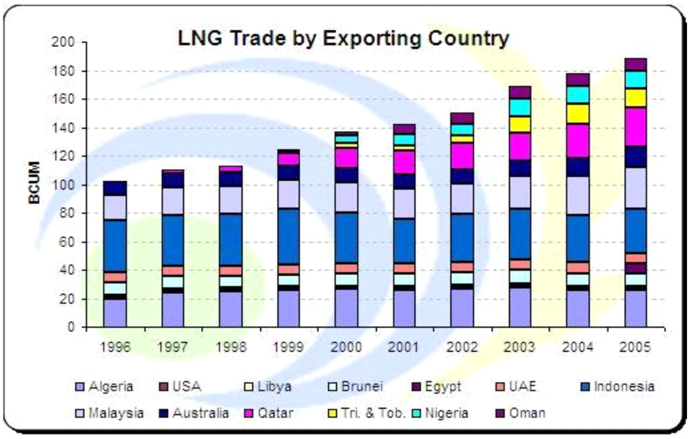

Fig. 2. LNG trade depending upon the demand of exporting countries

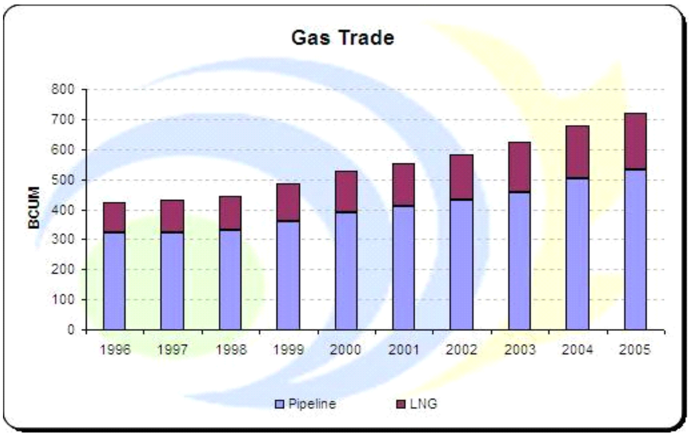

Fig. 3. World LNG trade expansion

Figure 3 indicates how the transportation of LNG has increased for the last ten years, since 1996 and continuing up to the end of 2006 comparing with the existing pipelines and the maritime transportation (BP, 2006).

2 WORLD LNG SHIPPING CAPACITY

According to LNG Shipping Solutions, number of LNG tankers were in operation worldwide as of End 2006 shown in Figure 4,: 16 ships with a capacity of less than 50,000 cubic meters, 21 in the 50,000 to 120,000 cubic meters range, and 120 larger than 120,000 cubic meters (BP, 2006). Fifty-five ships are under construction, of which 46 are designed to carry at least 138,000 cubic meters of LNG (equivalent to 2.9 Bcf of natural gas). Much larger ships with 250,000 cubic meters of capacity (equivalent to 5.3 Bcf of natural gas) are under consideration, but may not be compatible with all existing LNG terminals. The addition of new ships to the fleet will raise total fleet capacity 44 percent from 17.4 million cubic meters of liquid (equivalent to 366 Bcf of natural gas) in October 2003 to 25.1 million cubic meters of liquid (equivalent to 527 Bcf of natural gas) in 2006.

Shipping accounts for 10 to 30 percent of the delivered value of LNG (depending on the distance from the reserves to the market), compared with less than 10 percent for oil, because of the relatively high cost of manufacturing LNG tankers. Tankers currently cost $150 to $160 million for a 138,000-cubic-meter ship, more than double the price of a very large crude oil tanker which carries 4 to 5 times as much energy. One reason for this high cost is that LNG ships require expensive, insulated cryogenic containment for the cargo.

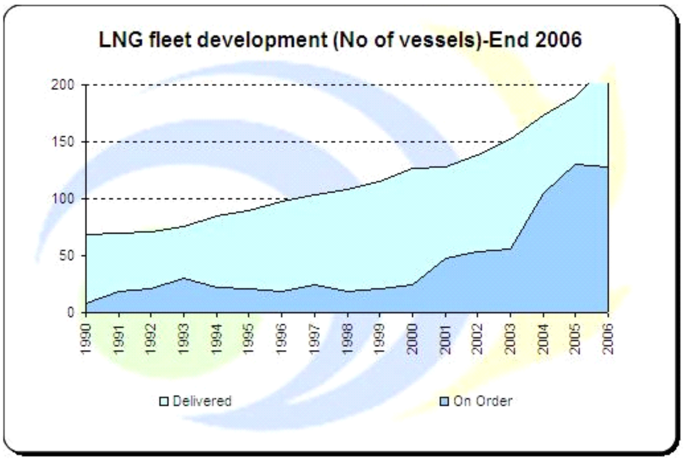

Fig. 4. LNG fleet expansion statistics

Only thirteen shipyards in the world currently build LNG tankers: five in Japan; four in Korea, three in Europe and one in China. However, India, and Poland are planning to develop LNG tanker construction capabilities in their shipyards (U.S. Energy Information Administration, 2005).

3 SAFETY AND ENVIRONMENTAL PROTECTION FOR LNG OPERATIONS

3.1 *LNG Hazardous and Mitigation*

The potential hazards of most concern to operators of LNG facilities and surrounding communities flow from the basic properties of natural gas. LNG hazardous and its consequences to assure safety and to prevent environmental pollution are subdivided into four categories. These are the primary containment; secondary containment, safeguard systems, and separation distance provide multiple layers of protection (American Bureau of

Shipping, 2000). These measures provide protection against most hazards associated with LNG.

Primary containment is the first and most important requirement for containing the LNG product. This first layer of protection involves the use of appropriate materials for LNG facilities as well as proper engineering design of LNG containers onshore, offshore, and on LNG ships. LNG storage containers are specially designed, constructed, installed, and tested to minimize the potential for failure. The containers are designed to: safely contain the liquid at cryogenic temperatures, permit the safe filling and removal of LNG, permit boil-off gas to be safely removed, prevent the ingress of air, reduce the rate of heat input consistent with operational requirements, and prevent frost heave, withstand the damage leading to loss of containment arising from credible factors, operate safely between the design maximum and minimum pressures, withstand the number of filling and emptying cycles and the number of cool-down and warming operations that are planned during the design life (ABSG Consulting Inc., 2004).

Secondary containment ensures that if leaks or spills occur at the LNG facility, the LNG can be fully contained and isolated. In many installations, a second tank is used to surround the LNG container and serves as the secondary containment. Secondary containment systems are designed to exceed the volume of the LNG container for onshore installations; dikes surround the LNG container to capture the product in case of a spill. Secondary containment should be designed to minimize the possibility of accidental spills and leaks endangering structures, equipment, adjoining property, or adjacent waterways. NFPA 59A requires that LNG containers be provided with a natural barrier, dike impounding wall, or combination to contain a leak or spill of LNG (National Federal Protection Agency, 2001). Additionally, a drainage system can be used to remove the LNG to a holding area where the LNG can vaporize safely. NFPA 59A provides guidance on the location and sitting of LNG containers from adjacent property lines, equipment, and other facilities at terminals. EN 1473 is performance based in its approach to sitting and location. The outcomes of a risk assessment can be used to justify the distance and locations specified (EN 1473, 1996). On offshore facilities, trenches are used to channel LNG flow to a safe location where the LNG can vaporize under controlled conditions.

Safeguards' goal is to minimize the frequency and size of LNG releases both onshore and offshore and prevent harm from potential associated hazards, such as fire. For this level of safety protection, LNG operations use technologies such as high level alarms and multiple backup safety systems, which include Emergency Shutdown (ESD) systems. Fire and gas detection and fire fighting systems all combine to limit effects if there is a release. The LNG facility or ship operator then takes action by establishing necessary operating procedures, training, emergency response systems, and regular maintenance to protect people, property, and the environment from any release (SIGTTO, 2003).

There are many safeguards required by regulations. These can be summarized in terms of detection, emergency shutdown and fire protection. The ability to detect a leak of LNG or natural gas is important for emergency response actions to begin. Hydrocarbon gas detectors can be used to detect a natural gas leak if properly located. Hydrocarbon detectors need to be located higher than suspected leak points and placed where natural gas can be expected. Hydrocarbon detectors are generally located over vaporizers, in metering stations, and in cargo tanks where natural gas is stored and processed. Hydrocarbon detectors will not detect a LNG spill because vapors are insufficient. Temperature detection is used to sense a spill of LNG. The set point for the alarm is set low enough that ambient freezing conditions do not cause a fault trip. Temperature detection is located where spills can occur. In some instances, the temperature detection is used to activate a high expansion foam system that helps control vaporization.

ESD Systems are required to shut off operations in the event certain specified fault conditions or equipment failures occur. They should be designed to prevent or limit significantly the amount of LNG and natural gas that could be released. The ESD systems should be designed such that a spill or leak does not add to or sustain an emergency condition. The ESD systems should fail to a safe condition. NFPA 59A is pseudo–performance based when it comes to fire protection. Because of the wide range in size, design, and location of LNG facilities, NFPA 59A does not identify specific details of fire protection. The extent of fire protection should be determined by an evaluation based on sound fire protection engineering principles, analysis of local conditions, hazards within the facility, and exposure to or from other property. The evaluation should, as a minimum, consider (Mizner & Eyer, 1983):

- The type, quantity, and location of equipment necessary for the detection and control of fires, leaks, and spills of LNG, flammable refrigerants, or flammable gases.
- The type, quantity, and location of equipment necessary for the detection and control of potential non-process and electrical fires.
- The methods necessary for protection of the equipment and structures from the effects of fire exposure.
- Fire protection water systems.

- Fire extinguishing and other fire control equipment.

All LNG terminals are required to be provided with a fire water system. The amount of water will be determined by the number of fire protection systems and demand for these systems. The duration of water supply is typically not a problem because LNG terminals are generally located next to water. Fire protection systems for LNG facilities consist of water spray, high expansion foam, dry chemical, or a combination of these. Water spray is used to control radiant heat exposure on equipment and structures. LNG pool fires are neither controlled nor extinguished by water. In fact, the application of water on the LNG surface will increase the vaporization rate, and thus there is the potential to increase burning rate with negative consequences on fire control. The use of water spray systems should be carefully considered in the design. High expansion foam can be used to control the vaporization rate on the surface of an LNG spill. The foam works by warming the LNG vapors and reducing the fire thermal radiation back to the LNG pool, thereby reducing the LNG burning rate. High expansion foam is generally provided for impounding areas or where a LNG pool can form. Dry chemical extinguishing systems are used to extinguish an LNG fire. The dry chemical should be applied such that the surface is not agitated, which will allow additional vaporization. Dry chemical systems have been installed at unloading area, LNG pumps, boil-off compressors, and LNG vaporizers.

Separation (Safety Excursion Zones) LNG facility designs are required to maintain separation distances to separate land-based facilities from communities and other public areas. National regulations have always required that LNG facilities be sited at a safe distance from adjacent industries, communities, and other public areas. Also, safety zones are established around LNG ships while underway in territorial waters of a nation and while moored. The safe distances or exclusion zones are based on LNG *vapor dispersion* data, thermal radiation contours, and other considerations as specified in regulations (Paik et al. 2001). Most hazard analyses for LNG terminals and shipping depend on computer models to approximate the effects of hypothetical accidents. Regardless of the cause, the formation of a methane/ air mixture and its movement depends on the quantity of the spill, whether on land or water, atmospheric stability, wind direction and velocity, and temperature of the atmosphere and water.

3.2 *Emergency Procedures for Low Temperature Effects and Pressure*

Spillage of LNG may lead to the following dangers: Fire starting from the vapor, which is generated during the spillage, brittle fractures of the ship structures, which are in contact with the spilled LNG, accidental contact of LNG or its vapor with ship personnel. However, should a spillage be detected on a LNG ship the measures to be taken are the following: Stopping the flow, avoiding contacts with liquid and vapor, extinguish all possible sources of ignition, flooding the area where the spillage happened with a large amount of water in order to disperse the spilled LNG and to prevent the risk of brittle fracture.

As liquefied gas cargoes are often shipped at low temperatures it is important that temperature sensing equipment is well maintained and accurately calibrated. Hazards associated with low temperatures include (Bainbridge, 2003):

Brittle Fracture: Most metals and alloys become stronger but less ductile at low temperatures (i.e. the tensile and yield strengths increase but the material becomes brittle and the impact resistance decreases) because the reduction in temperature changes the material's crystal structure. Normal ship building steels rapidly lose their ductility and impact-strength below 0°C. For this reason, care should be taken to prevent cold cargo from coming into contact with such steels, as the resultant rapid cooling would make the metal brittle and would cause stress due to contraction. In this condition the metal would be liable to crack. The phenomenon occurs suddenly and is called 'brittle fracture'. However, the ductility and impact resistance of materials such as aluminum, austenitic and special alloy steels and nickel improve at low temperatures and these metals are used where direct contact with cargoes at temperatures below -55° C is involved.

Spillage: Care should be taken to prevent spillage of low temperature cargo because of the hazard to personnel and the danger of brittle fracture. If spillage does occur, the source should first be isolated and the spilt liquid then dispersed. (The presence of vapor may necessitate the use of breathing apparatus). If there is a danger of brittle fracture, a water hose may be used both to vaporize the liquid and to keep the steel warm. If the spillage is contained in a drip tray the contents should be covered or protected to prevent accidental contact and allowed to evaporate. Liquefied gases quickly reach equilibrium and visible boiling ceases, this quiescent liquid could be mistaken for water and carelessness could be dangerous. Suitable drip trays are arranged beneath manifold connections to control any spillage when transferring cargo or draining lines and connections. Care should be taken to ensure that unused manifold connections are isolated and that if blanks are to be fitted the flange surface is clean and free from frost. Accidents have occurred because cargo escaped past incorrectly fitted blanks. Liquefied gas spilt onto the sea will generate large quantities of vapor by the heating effect of the water. This vapor may create a fire or health hazard, or both. Great care should be taken to avoid such spillage, especially when disconnecting cargo hoses (International Tanker Owners Pollution Federation, 2007).

Cool down: Cargo systems are designed to withstand a certain service temperature; if this is below ambient temperature the system has to be cooled down to the temperature of the cargo before cargo transfer. For LNG and ethylene the stress and thermal shock caused by an over-rapid cool down of the system could cause brittle fracture. If tanks are fitted with spray equipment it should be used, and the liquid distributed around the inside of the tank as evenly as possible to avoid thermal stresses. Pressure build-up in the tanks will restrict the rate at which liquid is introduced. The use of a vapor return line is recommended to avoid cool down and loading rates being dictated by the capacity of the re-liquefaction plant. Cargo pipe-work and equipment should be cooled down by circulating liquid at a controlled rate. The system should reach liquid temperature sufficiently slowly to prevent undue thermal stresses in materials or expansion / contraction fittings. The temperature sensors will indicate when liquid is present on the tank bottom, but the liquid should be introduced slowly until the bottom is completely covered. The cool down of tanks may cause a pressure reduction in sealed hold or inter-barrier spaces, and dry air, inert gas or dry nitrogen should be introduced in order to maintain a positive pressure. This is usually done by automatic equipment. Pressure gauges should be observed regularly during cool down to ensure that acceptable pressures are maintained.

Ice Formation: Low cargo temperatures can freeze water in the system leading to blockage of, and damage to, pumps, valves, sensor lines, spray lines etc. Ice can be formed from moisture in the system, purge vapor with incorrect dew point, or water in the cargo. The effects of ice formation are similar to those of hydrates, and anti-freeze can be used to prevent them.

Rollover: Rollover is a spontaneous rapid mixing process which occurs in large tanks as a result of a density inversion. Stratification develops when the liquid layer adjacent to a liquid surface becomes denser than the layers beneath, due to boil-off lighter fractions from the cargo. This obviously unstable situation relieves itself with a sudden mixing, which the name ‘rollover’ aptly describes. Liquid hydrocarbons are most prone to rollover, especially cryogenic liquids. LNG is the most likely by virtue of the impurities it contains, and the extreme conditions of temperature under which it is stored, close to the saturation temperatures at storage pressures. If the cargo is stored for any length of time and the boil-off is removed, evaporation can cause a slight increase in density and a reduction of temperature near the surface. The liquid at the top of the tank is therefore marginally heavier than the liquid in the lower levels. Once stratification has developed rollover can occur (Pitblado et al. 2004).

No external intervention such as vibration, stirring or introducing new liquid is required to initiate rollover. The response to a small temperature difference within the liquid (which will inevitably occur in the shipboard environment) is sufficient to provide the kinetic energy to start rollover, and release the gravitational driving forces which will invert the tank contents. The inversion will be accompanied by violent evolution of large quantities of vapor and a very real risk of tank over-pressure. Rollover has been experienced ashore, and may happen on a ship that has been anchored for some time. If such circumstances are foreseen the tank contents should be circulated daily by the cargo pumps to prevent rollover occurring. Rollover in a ship on passage is most unlikely. Essentially, stratification and the subsequent rollover process are confined to shore LNG storage. However, if the use of LNG carriers for floating storage were to be introduced, personnel manning such vessels would need to be as aware of the problem and as vigilant to avoid rollover as their counterparts managing shore based storage.

4 CONCLUSION

LNG is an extremely cold, nontoxic, non-corrosive substance that is stored at atmospheric pressure. It is refrigerated, rather than pressurized, which enables LNG to be an effective, economical method of transporting large volumes of natural gas over long distances. LNG itself poses little danger as long as it is contained within storage tanks, piping, and equipment designed for use at LNG cryogenic conditions.

This study is mainly concentrated on safety and environmental awareness issues for LNG carriers taking into account the expanding tendency of world LNG shipping capacity. This would enable the not only the industry itself but the Maritime Training and Education (MET) institutions that are providing relevant training on LNG safety management system. Therefore due to its nature and the core activity of LNG shipping, the overview of methodology on LNG hazardous and their mitigation is discussed firstly to clarify the major concern on the assurance of safety and the protection of environment. Then the emergency procedures for low temperature effects and pressure are discussed in advanced signifying the brittle fracture, spillage, cool down, ice formation and roll over which are only applicable for the transportation of LNG with their probable consequences. These interpretations could be utilized during the planning of training needs of LNG ship operators which could be designed in terms of basic and specific familiarization in accordance with STCW convention and for MET institutions for the enhancement of their curricula related with LNG operations.

Consequently the LNG industry has an excellent safety record. This strong safety record is a result of several factors. First, the industry has technically and operationally evolved to ensure safe and secure operations. Technical and operational advances include everything from the engineering that underlies LNG facilities to operational procedures to technical competency of personnel. Second, the physical and chemical properties of LNG are such that risks and hazards are incorporated into technology and operations. Third, the standards, codes, and regulations that apply to the LNG industry further ensure safety.

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