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Safety of Cargo Handling and Transport Liquefied Natural Gas by Sea. Dangerous Properties of LNG and Actual Situation of LNG Fleet

A. Starosta
Gdynia Maritime University, Gdynia, Poland

ABSTRACT: Natural gas becomes very important source of energy. There is only one economical solution of transport natural gas to distant destination – LNG – Liquefied Natural Gas. The LNG fleet is growing very fast and fleet characteristic is changing. Very popular is myth that gas carriers are sailing bombs – is it true? Properties of LNG compare with other liquid cargos show the true.

1 LNG FLEET

Nowadays, when deposits of traditional sources of energy like coal and crude oil are close to end and additional the Meddle East region is political unstable, have people started to think about other energetic medium – a natural gas. The natural gas is produced from oil fields and natural gas fields. The largest gas fields are probably in Russia and Iran. Russia exports gas to West Europe countries by pipelines. Other sources are placed for example in Indonesia, Algeria and Malaysia, many miles from countries which need natural gas for their industries. There are no possibilities to transfer gas by pipelines and only one economical solution is transport it by sea as liquefied natural gas LNG.

1.1 *History of transport LNG by see*

Liquefaction of natural gas is not modern technology. British physicist and chemist Michael Faraday liquefied methane in 1854 and the first practical compressor refrigeration machine was build in Munich in 1873 by German engineer Karl von Linde.

The first LNG plant was built in the USA at the beginning of XX century and began operation in 1917. Establishing of first commercial liquefaction plant in Cleveland, Ohio, in 1941 gave the possibility of transport natural gas to distant destinations.

The first transport by sea was made in 1959. Converted "liberty" freighter was the first LNG carrier named "Methane Pioneer". This experiment demonstrated that large quantities of liquefied natural gas can be transported safety. Commercial transport of LNG started in 1964. The British Gas imported natural gas from Algeria to United Kingdom. They used two carriers "Methane Progress" and "Methane Princess" which had Conch tanks of capacity 27 400 m^3 each. These vessels were used till half of the nineties of XX century. "Methane Progress" made 467 voyages and was scrapped in 1992 and "Methane Princess" before scrapping in 1998 had made over 500 voyages.

1.2 *Evolution of LNG fleet*

1.2.1 *Number of LNG carriers*

LNG fleet is in the midst of an unprecedented expansion. At December 2000 there was 119 vessels of summary tanks capacity 12 003 MSCM (Thousands Cubic Meters). New ships were ordered to replace the old ones. A lot of vessels were 15 or more years old. The prediction was that in 2005 would be 148 LNG carriers and 172 ships in 2010.

Nobody predicted that LNG market would start develop so quickly. Figure 1 shows how many new vessels was build from 1970 till now each year. Till 2003 only few ships were built each year, but at the beginning of XXI century some new players entered LNG market. They ordered a lot of ships to serve their new LNG projects. These ships started to be delivered in 2003 – 17 new vessels, in 2004 – 20 and in 2005 -29. At the end of 2005 LNG fleet comprised 195 ships (47 more then was predicted in 2000) of summary tanks capacity 23 143 MSCM.

224 LNG carriers were sailed across the oceans on 1st March 2007 and they were able to carry 27 279,5 MSCM liquefied natural gas. Ship yards worldwide had 145 new builds on their order books with cumulative tank capacity 25 280,7 MSCM.

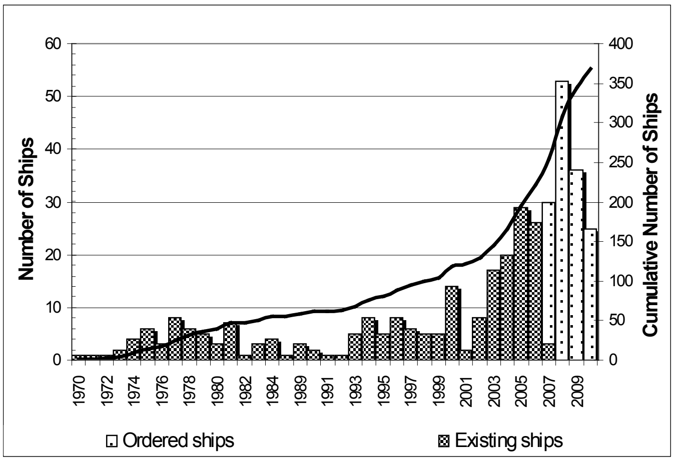

Fig. 1. Age of LNG fleet

Those new orders will boost the global LNG fleet to over 300 vessels in 2008. (That year will enter to service record number of 53 new LNG carriers.) Ordered ships will raise this number to 369 at the end of 2010. There is a big probability that it could be over 400 vessels, because only during two first months of 2007 shipyards got 14 new build orders.

1.2.2 *Region of LNG shipping*

One of the first LNG importers was Japan. According to geographic location, LNG was the only one solution of natural gas supplies. This is the reason that the main region of LNG shipping has been the Pacific region and the main LNG route leads from Indonesia and Malaysia to Japan.

On 1st March 2007 50% of LNG fleet had long term charters on Pacific region. And only 42% of LNG carriers operated on Atlantic routes. Those number doesn't show clearly the actual situation. The most of new import terminals are being built in USA and Western Europe so new ships are ordered to serve those projects. In the last 3 years over 80% vessels were built for Atlantic region. 74% of ordered vessels are designated to particular long term charters. 52% of new carriers will carry LNG to USA and Europe and only 22% are ordered for Pacific region. The rest, 26% of newbuildings, are still waiting for definitive trading route. Maybe this is the chance to find LNG carriers for planned LNG terminal in Poland.

1.2.3 *Main types of cargo tanks of LNG carriers*

LNG carriers are double-hulled specially designed to prevent leakage or rupture in an accident. The main problem witch had to be solved by designers is extremely low temperature of cargo. The inner hull of tanks and other parts of containment system contacts with liquid gas in temperature -161,5°C. This extremely low temperature forces usage of a special construction materials: stainless steel or invar – 36% nickel steel.

Existing LNG carriers cargo containments systems reflect one of two main designs: spherical design produced by Kvaerner-Moss, and membrane design by two firms: Technigaz and Gaz Transport. There are some other designs of LNG cargo containment systems, for example self-supporting structural prismatic design, but their account for about few percent of all LNG fleet.

Ships with spherical tanks are most characteristic as LNG ships because tank covers are visible above the deck. The figure 2 shows that this design was used by most of LNG ships till 2003. Nowadays there are ordered 21 of 145 new vessels with Moss tanks only and the rest are being built with membrane design. Technigaz technology will be installed in 44% of newbuildings and 41% new LNG carriers will be equipped with Gaz Transport membrane. The membrane ships look more like oil tankers, because their tanks structure is less visible above the deck.

Membrane technology is the most popular because it is cheaper then spherical, but the more important is the fact that gas carriers with spherical tanks have higher Suez Canal Tonnage. New vessels are dedicated on Atlantic region so they will travel through Suez Canal very often. Vessel with membrane tanks of capacity the same as carrier with Moss tanks has 20% less Suez Canal Tonnage.

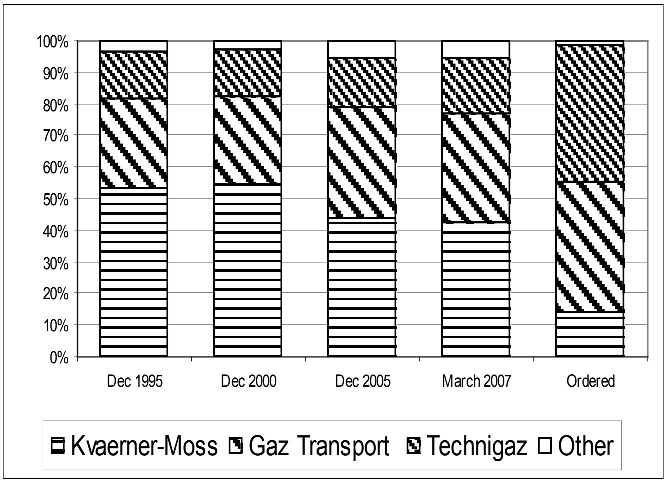

Fig. 2. Changes of LNG cargo tanks types.

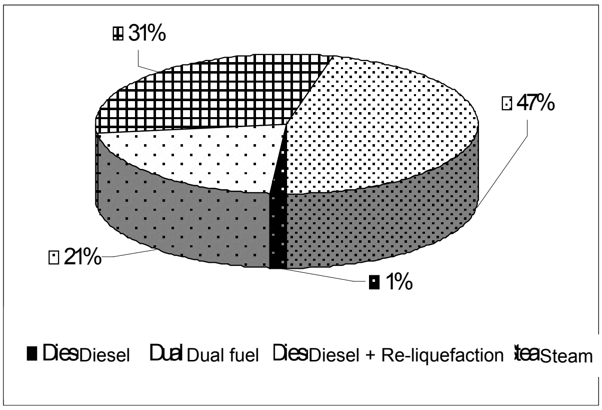

Fig. 3. Propulsion system of ordered LNG carriers

1.2.4 *Types of propulsion machinery*

Until now, steam turbines have dominated as propulsion machinery for LNG carriers. 97% of existing ships are burning the boil-off gas from the ship's cargo tanks to power two boilers supplying steam to steam turbine plant driving a propeller. This solution is very old and was used on firsts LNG carriers in 1964, but it is a simple and reliable solution for these ships. However the relatively low efficiency of this kind of propulsion system (<30%) and increasing size of new ships has motivated investigations into utilizing alternative propulsion systems.

New propulsion systems are used on modern LNG vessels. Figure 3 presents propulsion system of ordered ships. Only 47% will have traditional steam turbine. 31% will have option employs conventional low speed diesel engine technology for propulsion purposes and a reliquefaction plant to turn the boil-off gas back to liquid and return to the cargo tanks. That concept is similar to the practice for fully refrigerated LPG vessels, but till now there were technical problems to construct economical LNG reliquefaction plant.

The other concept is to use dual fuel medium speed diesel generators to provide all the vessel's power requirements. The electricity will be used for main propulsion and a "power station" principle. Development of Dual Fuel engines, which can operate both on gas and diesel oil, electric propulsion has become very attractive solution. Boil-off gas is used directly in the medium speed engines, which will be used in 21% of ordered vessels.

2 PROPERITIES OF LNG

The natural gas is a mixture of gases that is produced with oil in gas or gas fields and consists mainly of methane. Composition of natural gas depends on production area. (For example natural gas from Alaska contains: Methane 99,5%, Ethane 0,1%, Nitrogen 0,4%; and natural gas from North Sea contains: Methane 85,9%, Ethane 8,1%, Propane 2,7%, Butane 0,9%, Pentane 0,3%, Nitrogen 0,5%, CO_2 1,0%.) To achieve liquefied natural gas the methane is cooled down to below minus 160°C under normal atmospheric pressure. Process of liquefaction eliminates some of natural gas components, so in general LNG is more reach of methane than the its original natural gas. Standard LNG contain Methane 91-92%, Ethane 6-7% and others hydrocarbons 2%. Natural gas in liquid form is about 600-620 times less in volume then its gaseous equivalent, and that is the economical reason to transport LNG.

LNG is clear, non-corrosive, non-toxic, cryogenic liquid. It is odourless and well known odour of gas from our kitchens is obtained by adding special odorants to enable detection of gas leaks by end users. LNG specific gravity is one half of water specific gravity. In case of spillage LNG floats on water and vaporised very fast. Vapours at low temperatures are heavier than air and make visible white cloud. The cloud is white because the water in the air is frozen by cold vapours. The cloud disperses quite quickly, because vapour of methane is heated and at the temperature of about minus 100°C it has the same weight of air. At higher temperature vapour becomes lither than air.

The very high percentage of methane in LNG (natural gas) may permit us to assume the methane characteristic also valid for LNG, at least as first approximation. The followings are its main physical characteristics:

- Chemical composition: CH_4
- Boiling point at atmospheric pressure -161.5°C
- Specific gravity of liquid at -160°C 458 kg/m^3
- Specific gravity of gas at 30°C 0.67 kg/m^3
- Critical pressure 44.7 bar
- Critical temperature - 82.5°C
- Heat of vaporization at boiling point 121 kcal/kg

3 HAZARDS OF LNG

The main hazard of LNG is flammability of liquid gas vapours. However the health effect of transport substance is also very important. The health hazards of substances are their toxicity, carcinogenic, oxygen deficiency and other specific characteristic. In case of liquefied gases, LNG specially, the problem is extremely low temperature. Comparison, in table 1, LNG with other substances, like LPG, VCM and gasoline, transported in bulk by see, shows if LNG is very dangerous cargo.

Table 1. Comparison of properties of liquid cargos

Properties	LNG	LPG	VCM	Gasoline
Toxic	-	-	+	+
Carcinogenic	-	-	+	+
Narcotic	-	-	+	+
Irritant	-	-	+	+
Asphyxiant	+	+	+	+
Frostbite	+	+/-	+	-
Flash point °C	-175	-105	-78	-40
Boiling point °C	-162	-40	-14	60
LFL % (in air)	5	2	3,5	1,5
UFL % (in air)	15	9	33	7,5

3.1 *Flammability and explosions hazard*

Flammability is the main hazard of transport natural gas. LNG as a liquid is not flammable. Only vapours released from LNG, as it returns to a gas phase, can become flammable, but explosive only under specific conditions.

Flammable vapours can ignite and will burn only when mixed with air in certain proportions. For LNG lower flammability limit (LFL) is 5% by volume and upper flammability limit (UFL) is 15% by volume. When vapour concentration exceeds its UFL, it cannot burn because too little oxygen is present. This situation exists in cargo tanks where the vapour concentration is approximately 100% methane. When fuel concentrate is lower then LFL there is too little methane to burn. An example is leakage of small quantities of LNG in well-ventilated area, for example deck. The LNG vapour will rapidly mix with air and dissipate to less then 5% concentration. Comparison LNG with other liquid cargos shows that its LFL is generally higher, which means that more LNG vapours is needed to ignite as compared to gasoline or LPG. Additionally vapour of LNG is lighter than air and it disperses quickly so is not easy to ignite. LNG fire is smokeless and leaves no residue. However LPG when spilled forms an explosive vapour cloud because it is heavier than air and does not disperse. LPG and gasoline burn very hot and black. In consequence fire-fighters consider LPG and gasoline fires more dangerous than LNG fire.

3.2 *Health hazards*

Liquefied gases and their vapours displace air from cargo tanks and enclosed spaces. Human body requires air containing about 21% oxygen by volume for normal breathing. Effects of oxygen deficiency are loss of muscle movement, mental confusion, unconsciousness and finally respiratory arrest. This effects may occur when oxygen concentration decreases below 19,5% by volume at normal atmospheric pressure. A lot of liquid cargos carried by sea have poison, narcotic, irritation or toxic properties additionally.

LNG in comparison with other substances transported by sea is quite safe. However natural gas that is vaporized from LNG can cause asphyxiation due to lack of oxygen if a concentration of gas develops in an unventilated, confined area, but other cargo may do the same. Very important is fact that methane is non-toxic and non-irritant and for example gasoline, transported every day by numerous tankers, is toxic, irritant and have carcinogenic properties.

Extremely low temperature is one of the main hazards specific connected with the transportation of LNG. Direct contact with liquid cargo, cold vapour or non-insulated pipes or equipment may cause a cold burn. Cold burn, frostbite, causes damages similar to those when skin contact with hot materials of similar temperature difference. The symptoms are extreme pain in the affected area and may cause even fainting of victim

4 CONCLUSIONS

LNG is not as dangerous as people think. LNG carriers are not sailing bombs, and the best argument is that LNG has been safety delivered across the oceans for over 40 years. In that time there have been over 40 000 LNG carriers voyages. In all of those voyages and associated cargo transfer operations no fatality has been recorded for a member of any LNG ship's crew. This excellent safety record is a result of several factors:

- physical and chemical properties of LNG are well understood,
- industry has technically and operationally evolved to ensure safe and secure operation,

– the standards, codes and regulations that apply to the LNG business further ensure safety,
– crews of LNG carriers are experienced and good educated.

The fleet of LNG carriers are changing and growing up. New ships are bigger, have new types of propulsion and usually membrane cargo tanks. Technology is well understood but very short constructions time may bring some little mistakes and errors. The last two accidents involving LNG carriers were connected with inaccuracy of tank isolations performance.

The bigger problem is lack of experienced crew to operate complicated cargo handling system of LNG carriers. To keep excellent safety record good educated and experienced crew members are need. The estimations shows that LNG ship owners need about 2300 deck officers, 1200 engineers, 1200 steam engineers and about 4500 ratings. It is essential to prepare special syllabus for LNG crews and start educates new officers and ratings especially for this kind of ships as soon as possible. Otherwise when ships would had uneducated crews without necessary experience the LNG carriers might become “sailing bombs”.

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