UK P&I CLUB

# Gas matters

*A focus on some of the issues surrounding gas tanker fleets in the P&I world*

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## Introduction

The renewed interest in gas, which started in the 1990s due to its excellent environmental credentials, has seen an increase in the order book for LNG carriers – LNG carriers being the leviathans of the gas carrier fleet. Yet, while attracting great interest, the gas trade still employs relatively few ships in comparison to oil tankers, and hence its inner workings are little known except to a specialist group of companies and mariners.

Considering the fleet of gas carriers of over 1,000m$^3$ capacity, the total of over 1,500 ships can be divided into 5 major types according to the following table:

**The gas carrier fleet**

| | Pressurised LPG carriers | Semi-pressurised LPG carriers | Ethylene carriers | Fully refrigerated LPG carriers | LNG carriers |
|---|---|---|---|---|---|
| Ship numbers | 673 | 313 | 140 | 261 | 372 |
| Total capacity (m$^3$) | 1,812,823 | 2,849,355 | 1,234,029 | 10,725,479 | 29,059,620 |

By contrast, the world oil tanker fleet for a similar size range is over 12,000 ships!

Given the relative paucity of knowledge on gas tankers in comparison to oil tankers, the purpose of this article is to describe the gas carrier genre, its particularities within each type and its comparison with other tankers. The aim is to provide basic knowledge about gas carriers and an overview of their strengths and weaknesses, both from design and operational viewpoints.

The article on page 11 describes the liquefied natural gas (LNG) carrier in more detail. The introduction of a tanker designed to carry compressed natural gas (CNG) is anticipated in the near future. A number of designs have been produced but, due to the relatively low deadweight and high cost of these ships, the first commercial application of this technology cannot be predicted.

The gas carrier is often portrayed in the media as a potential floating bomb, but accident statistics do not bear this out. Indeed, the sealed nature of liquefied gas cargoes, in tanks completely segregated from oxygen or air, virtually excludes any possibility of a tank explosion. However, the image of the unsafe ship lingers, with some administrations and port state control organisations tending to target such ships for special inspection whenever they enter harbour. The truth is that serious accidents related to gas carrier cargoes have been few, and the gas carrier's safety record is acknowledged as an industry leader. As an illustration of the robustness of gas carriers, when the *Gaz Fountain* was hit by rockets in the first Gulf War, despite penetration of the containment system with huge jet fires, the fires were successfully extinguished and the ship, together with most cargo, salved.

The relative safety of the gas carrier is due to a number of features. One such, almost unique to the class, is that cargo tanks are always kept under positive pressure (sometimes just a small overpressure) and this prevents air entering the cargo system. (Of course special procedures apply when stemmed for drydock). This means that only liquid cargo or vapour can be present and, accordingly, a flammable atmosphere cannot exist in the cargo system. Moreover all large gas carriers utilise a closed loading system with no venting to atmosphere, and a vapour return pipeline to the shore is often fitted and used where required. The oxygen-free nature of the cargo system and the very serious limitation of cargo escape to atmosphere combine to make for a very safe design concept.

## The liquefied gases

First let us consider some definitions in the gas trade. According to the IMO, a liquefied gas is a gaseous substance at ambient temperature and pressure, but liquefied by pressurisation or refrigeration – sometimes a combination of both. Virtually all liquefied gases are hydrocarbons and flammable in nature. Liquefaction itself packages the gas into volumes well suited to international carriage – freight rates for a gas in its non-liquefied form would be normally far too costly. The principal gas cargoes are LNG, LPG and a variety of petrochemical gases. All have their specific hazards. LNG is liquefied natural gas and is methane naturally occurring within the earth, or in association with oil fields. It is carried in its liquefied form at its boiling point of -162°C. Depending on the standard of production at the loading port, the quality of LNG can vary but it usually contains fractions of some heavier ends such as ethane (up to 5%) and traces of propane.

The second main cargo type is LPG (liquefied petroleum gas). This grade covers both butane and propane, or a mix of the two. The main use for these products varies from country to country but sizeable volumes go as power station or refinery fuels. However LPG is also sought after as a bottled cooking gas and it can form a feedstock at chemical plants. It is also used as an aerosol propellant (with the demise of CFCs) and is added to gasoline as a vapour pressure enhancer. Whereas methane is always carried cold, both types of LPG may be carried in either the pressurised or refrigerated state. Occasionally they may be carried in a special type of carrier known as the semi-pressurised ship. When fully refrigerated, butane is carried at -5°C, with propane at -42°C, this latter temperature already introducing the need for special steels.

Ammonia is one of the most common chemical gases and is carried worldwide in large volumes, mainly for agricultural purposes. It does however have particularly toxic qualities and requires great care during handling and carriage. By regulation, all liquefied gases when carried in bulk must be carried on a gas carrier, as defined by the IMO. IMO's Gas Codes (see next section – *Design of gas carriers*) provide a list of safety precautions and design features required for each product.

A specialist sector within the trade is the ethylene market, moving around one million tonnes by sea annually, and very sophisticated ships are available for this carriage. Temperatures here are down to -104°C and onboard systems require perhaps the highest degree of expertise within what is already a highly specialised and automated industry. Within this group a sub-set of highly specialised ships is able to carry multi-grades simultaneously.

Significant in the design and operation of gas carriers is that methane vapour is lighter than air while LPG vapours are heavier than air. For this reason the gas carrier regulations allow only methane to be used as a propulsion fuel – any minor gas seepage in engine spaces being naturally ventilated. The principal hydrocarbon gases such as butane, propane and methane are non-toxic in nature and a comparison of the relative hazards from oils and gases is provided in the table below.

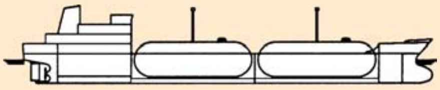
## Design of gas carriers

The regulations for the design and construction of gas carriers stem from practical ship designs codified by the International Maritime Organization (IMO). This was a seminal piece of work and drew upon the knowledge of many experts in the field – people who had already been designing and building such ships. This work resulted in several rules and a number of recommendations. However all new ships (from June 1986) are built to the *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the *IGC Code*). This code also defines cargo properties and documentation, provided to the ship (the *Certificate of Fitness for the Carriage of Liquefied Gases in Bulk*), shows the cargo grades the ship can carry. In particular this takes into account temperature limitations imposed by the metallurgical properties of the materials making up the containment and piping systems. It also takes into account the reactions between various gases and the elements of construction not only on tanks but also related to pipeline and valve fittings.

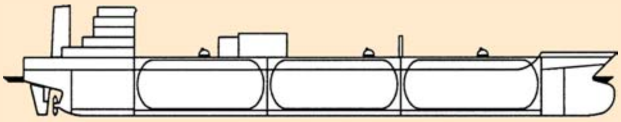
When the *IGC Code* was produced an intermediate

**Comparative hazards of some liquefied gases and oils**

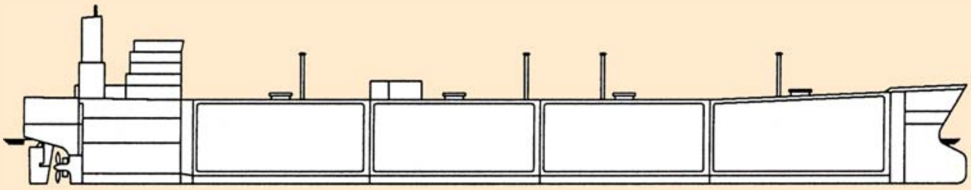
| | GASES | | OILS | |
|---|---|---|---|---|
| **HAZARD** | **LNG** | **LPG** | **GASOLINE** | **FUEL OIL** |
| Toxic | No | No | Yes | Yes |
| Carcinogenic | No | No | Yes | Yes |
| Asphyxiant | Yes (in confined spaces) | Yes (in confined spaces) | No | No |
| Others | Low temperature | Moderately low temperature | Eye irritant, narcotic, nausea | Eye irritant, narcotic, nausea |
| Flammability limits in air (%) | 5-15 | 2-10 | 1-6 | Not applicable |
| Storage pressure | Atmospheric | Often pressurised | Atmospheric | Atmospheric |
| Behaviour if spilt | Evaporates forming a visible 'cloud' that disperses readily and is non-explosive, unless contained | Evaporates forming an explosive vapour cloud | Forms a flammable pool which if ignited would burn with explosive force, environmental clean-up may be required | Forms a flammable pool, environmental clean-up is required |



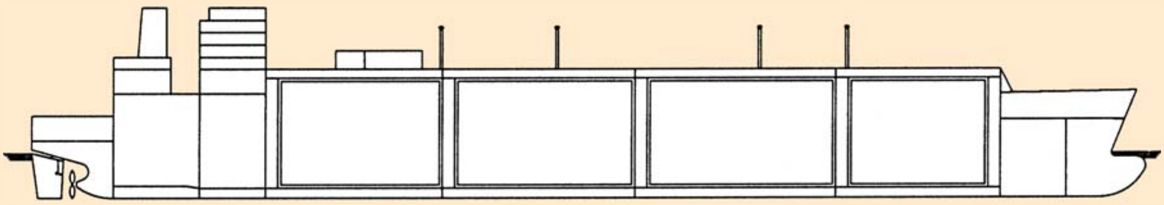
**3,200 $m^3$ coastal LPG carrier with cylindrical tanks**



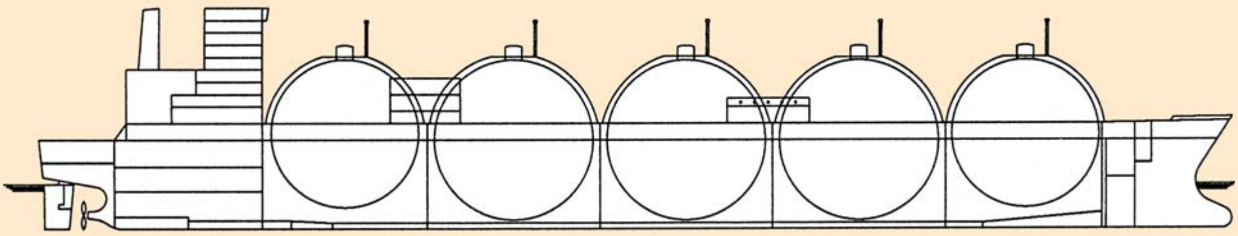
**16,650 $m^3$ semi pressurised LPG carrier**



**78,000 $m^3$ LPG carrier with Type-A tanks**



**135,000 $m^3$ LNG carrier with membrane tanks**



**137,000 $m^3$ LNG carrier with Type-B tanks (Kvaerner Moss system)**

code was also developed by the IMO – the *Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk* (the *GC Code*). This covers ships built between 1977 and 1986.

As alluded to above, gas carriers were in existence before IMO codification and ships built before 1977 are defined as 'existing ships' within the meaning of the rules. To cover these ships a voluntary code was devised, again by the IMO – the *Code for Existing Ships Carrying Liquefied Gases in Bulk* (the *Existing Ship Code*). Despite its voluntary status, virtually all ships remaining in the fleet of this age – and because of longevity programmes there are still quite a number – have certification in accordance with the *Existing Ship Code* as otherwise international chartering opportunities would be severely restricted.

Cargo carriage in the pressurised fleet comprises double cargo containment – hull and tank. All other gas carriers are built with a double hull structure and the distance of the inner hull from the outer is defined in the gas codes. This spacing introduces a vital safety feature to mitigate the consequences of collision and grounding. Investigation of a number of actual collisions at the time the gas codes were developed drew conclusions on appropriate hull separations which were then incorporated in the codes. Collisions do occur within the class and, to date, the codes' recommendations have stood the test of time, with no penetrations of cargo containment having been reported from this cause. The double hull concept includes the bottom areas as a protection against grounding and, again, the designer's foresight has proven of great value in several serious grounding incidents, saving the crew and surrounding populations from the consequences of a ruptured containment system.

So a principal feature of gas carrier design is double containment and an internal hold. The cargo tanks, more generally referred to as the 'cargo containment system', are installed in the hold, often as a completely separate entity from the ship; ie. not part of the ship's structure or its strength members. Herein lies a distinctive difference between gas carriers and their sisters, the oil tankers and chemical carriers.

Cargo tanks may be of the independent self-supporting type or of a membrane design. The self-supporting tanks are defined in the *IGC Code* as being of Type-A, Type-B or Type-C. Type-A containment comprises box-shaped or prismatic tanks (ie. shaped to fit the hold).

Type-B comprises tanks where fatigue life and crack propagation analyses have shown improved characteristics. Such tanks are usually spherical but occasionally may be of prismatic types. Type-C tanks are the pure pressure vessels, often spherical or cylindrical, but sometimes bi-lobe in shape to minimise broken stowage.

The fitting of one system in preference to another tends towards particular trades. For example, Type-C tanks are suited to small volume carriage. They are therefore found most often on coastal or regional craft. The large international LPG carrier will normally be fitted with Type-A Tanks. Type-B tanks and tanks following membrane principles are found mainly within the LNG fleet.

## The pressurised fleet

The first diagram, on the previous page, and the photograph above show a small fully pressurised carrier. Regional and coastal cargoes are often carried in such craft with the cargo fully pressurised at ambient temperature. Accordingly, the tanks are built as pure

**Pressurised LPG carrier with cylindrical tanks**

pressure vessels without the need for any extra metallurgical consideration appropriate to colder temperatures. Design pressures are usually for propane (about 20 bar) as this form of LPG gives the highest vapour pressure at ambient temperature. As described above, ship design comprises outer hull and an inner hold containing the pressure vessels. These rest in saddles built into the ship's structure. Double bottoms and other spaces act as water ballast tanks and if problems are to develop with age then the ballast tanks are prime candidates. These ships are the most numerous class, comprising approximately 40% of the fleet. They are nevertheless relatively simple in design yet strong of construction.

Cargo operations that accompany such ships include cargo transfer by flexible hose and in certain areas, such as China, ship-to-ship transfer operations from larger refrigerated ships operating internationally are commonplace.

Records show that several ships in this class have been lost at sea because of collision or grounding, but penetration of the cargo system has never been proven. In one case, a ship sank off Italy and several years later refloated naturally, to the surprise of all, as the cargo had slowly vaporised adding back lost buoyancy.

**Semi-pressurised LPG carrier**

## The semi-pressurised fleet

In these ships, sometimes referred to as 'semi-refrigerated', the cargo is carried in pressure vessels usually bi-lobe in cross-section, designed for operating pressures of up to 7 bars. The tanks are constructed of special grade steel suitable for the cargo carriage temperature. The tanks are insulated to minimise heat input to the cargo. The cargo boils off causing generation of vapour, which is reliquefied by refrigeration and returned to the cargo tanks. The required cargo temperature and pressure is maintained by the reliquefaction plant.

These ships are usually larger than the fully pressurised types and have cargo capacities up to about 20,000m$^3$. As with the fully pressurised ship, the cargo tanks are of pressure vessel construction and similarly located well inboard of the ship's side and also protected by double bottom ballast tanks. This arrangement again results in a very robust and inherently buoyant ship.

## The ethylene fleet

Ethylene, one of the chemical gases, is the premier building block of the petrochemicals industry. It is used in the production of polyethylene, ethylene dichloride, ethanol, styrene, glycols and many other products. Storage is usually as a fully refrigerated liquid at -104°C.

Ships designed for ethylene carriage also fall into the semi-pressurised class. They are relatively few in number but are among the most sophisticated ships afloat. In the more advanced designs they have the ability to carry several grades. Typically this range can extend to ethane, LPG, ammonia, propylene butadiene and vinyl chloride monomer (VCM), all featuring on their certificate of fitness. To aid in this process several independent cargo systems co-exist onboard to avoid cross contamination of the cargoes, especially for the reliquefaction process.

The ships range in size from about 2,000m$^3$ to 15,000m$^3$ although several larger ships now trade in ethylene. Ship design usually includes independent cargo tanks (Type-C), and these may be cylindrical or bi-lobe in shape constructed from stainless steel. An inert gas generator is provided to produce dry inert gas or dry air. The generator is used for inerting and for the dehydration of the cargo system as well as the inter-barrier spaces during voyage. For these condensation occurs on cold surfaces with unwanted build-ups of ice. Deck tanks are normally provided for changeover of cargoes.

The hazards associated with the cargoes involved are obvious from temperature, toxic and flammable concerns. Accordingly, the safety of all such craft is critical with good management and serious personnel training remaining paramount.

**Fully refrigerated LPG carrier**

## The fully refrigerated fleet

These are generally large ships, up to about 100,000m$^3$ cargo capacity, those above 70,000m$^3$ being designated as VLGCs. Many in the intermediate range (say 30,000m$^3$ to 60,000m$^3$) are suitable for carrying the full range of hydrocarbon liquid gas from butane to propylene and may be equipped to carry chemical liquid gases such as ammonia. Cargoes are carried at near ambient pressure and at temperatures down to -48°C. Reliquefaction plants are fitted, with substantial reserve plant capacity provided. The cargo tanks do not have to withstand high pressures and are therefore generally of the free standing prismatic type. The tanks are robustly stiffened internally and constructed of special low temperature resistant steel.

All ships have substantial double bottom spaces and some have side ballast tanks. In all cases the tanks are protectively located inboard. The ship's structure surrounding or adjacent to the cargo tanks is also of special grade steel, in order to form a secondary barrier to safely contain any cold cargo should it leak from the cargo tanks.

All cargo tanks, whether they be of the pressure vessel type or rectangular, are provided with safety relief valves amply sized to relieve boil-off in the absence of reliquefaction and even in conditions of surrounding fire.

## The LNG fleet

Although there are a few exceptions, the principal ships in the LNG fleet range from 75,000m$^3$ to 265,000m$^3$ capacity. The cargo tanks are thermally insulated and the cargo carried at atmospheric pressure. Cargo tanks may be free standing spherical, of the membrane


**LNG carrier with Type-B tanks (Kvaerner Moss system)**


**LNG carrier with membrane tanks**

type, or alternatively, prismatic in design. In the case of membrane tanks, the cargo is contained within thin walled tanks of invar or stainless steel. The tanks are anchored in appropriate locations to the inner hull and the cargo load is transmitted to the inner hull through the intervening thermal insulation.

All LNG carriers have a watertight inner hull and most tank designs are required to have a secondary containment capable of safely holding any leakage for a period of 15 days. Because of the simplicity and reliability of stress analysis of the spherical containment designs, a full secondary barrier is not required but splash barriers and insulated drip trays protect the inner hull from any leakage that might occur in operation.

## Crew training and numbers

As they did for oil tankers and chemical carriers, the IMO has laid down a series of training standards for gas carrier crews which come in addition to normal certification. These dangerous cargo endorsements are spelt out in the STCW Convention.

Courses are divided into the basic course for junior officers and the advanced course for senior officers. IMO rules require a certain amount of onboard gas experience, especially at senior ranks, before taking on the responsible role or before progressing to the next rank. This can introduce checks and balances (say) in the case of a master from the bulk ore trades wanting to convert to the gas trade.

The only way, without previous gas experience, to achieve this switch is to have the candidate complete the requisite course and sail as a supernumerary, understudying the rank for a specified period on a gas carrier. This can be costly for seafarer and company alike. Accordingly, as the switch can be difficult to manage, especially at senior ranks, current requirements tend to maintain a close-knit cadre of ‘gas men or women’ well experienced in the trade.

In addition to the official certification for hazardous cargo endorsements, a number of colleges operate special courses for gas cargo handling. In the UK a leader in the field is the Warsash Maritime Centre. While this situation provides for a well-trained and highly knowledgeable environment the continued growth in the fleet currently strains manpower resources and training schedules and it is possible that short cuts may be taken.

While the small gas carriers normally operate at minimum crew levels, on the larger carriers it is normal to find increased crewing levels over and above the minimum required by the ship’s manning certificate. For example, it is almost universal to carry a cargo engineer onboard a large gas carrier. An electrician is a usual addition and the deck officer complement may well be increased.

## Gas carriers and port operations

As gas carriers have grown in size, so too has a concern over in-port safety. Indeed, the same concerns applied with the growth in tanker sizes when the VLCC came to the drawing board. The solutions are similar; however, in the case of the gas carrier, a higher degree of automation and instrumentation is often apparent controlling the interface between ship and shore.

Terminals are also protected by careful risk analysis at the time of construction so helping to ensure that the location and size of maximum credible spill scenarios are identified, and that suitable precautions including appropriate safety distances are established between operational areas and local populations.

Regarding shipping operations, risk analysis often identifies the cargo manifold as the area likely to produce the maximum credible spill. This should be controlled by a number of measures. Primarily, as for all large oil tankers, gas carriers should be held firmly in position whilst handling cargo, and mooring management should be of a high calibre. Mooring ropes should be well managed throughout loading and discharging. Safe mooring is often the subject of computerised mooring analysis, especially for new ships arriving at new ports, thus helping to ensure a sensible mooring array suited to the harshest conditions. An accident in the UK highlighted the consequences of a lack of such procedures when, in 1993, a 60,000m$^3$ LPG carrier broke out from her berth in storm conditions. This was the subject of an official MCA/HSE inquiry concluding that prior mooring analysis was vital to safe operations.

The safe mooring principles attached to gas carriers are similar to those recommended for oil tankers (they are itemised in *Mooring Equipment Guidelines*, see References, inside back page).

The need for such ships to be held firmly in position during cargo handling is due in part to the use of loading arms (hard arms – see photos) for cargo transfer. Such equipment is of limited reach in comparison to hoses, yet it provides the ultimate in robustness. It also provides simplicity in the connection at the cargo manifold.

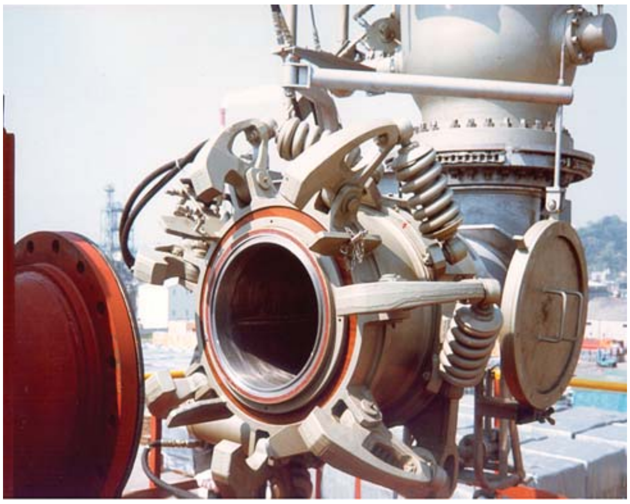
**Hard arm connection to manifold, showing double ball valve safety release**

**Hard arms at cargo manifold, including vapour return line**

The use of loading arms for the large gas carrier is now quite common and, if not a national requirement, is certainly an industry recommendation. The alternative use of hoses is fraught with concerns over hose care and maintenance, and their proper layout and support during operations to prevent kinking and abrasion. Further, accident statistics show that hoses have inferior qualities in comparison to the hard arms.

Perhaps the worst case of hose failure occurred in 1985 when a large LPG carrier was loading at Pajaritos, Mexico. Here, the hose burst and, in a short time, the resulting gas cloud ignited. The consequent fire and explosion impinged directly on three other ships in harbour and resulted in four deaths. It was one of those accidents which has led directly to a much increased use of loading arms internationally. The jetty was out of action for approximately six months. Fortunately the berth was in an industrial area and collateral damage to areas outside the refinery was limited.

As ships have grown in size the installation of vapour return lines interconnecting ship and shore vapour systems has become more common. Indeed, in the



**Hard arm quick connect/disconnect coupler (QCDC)**

LNG industry it is required, with the vapour return being an integral part of the loading or discharging system. In the LPG trades, vapour returns are also common, but are only opened in critical situations such as where onboard reliquefaction equipment is unable to cope with the loading rate and boil-off.

A feature common to both ship and shore is that both have emergency shutdown systems. It is now common to interconnect such systems so that, for example, an emergency on the ship will stop shore-based loading pumps. One such problem may be the automatic detection of the ship moving beyond the safe working envelope for the loading arms. A further refinement at some larger terminals is to have the loading arms fitted with emergency release devices, so saving the loading arms from fracture (see top photo, previous page).

Given good moorings and well-designed loading arms, the most likely sources of leakage are identified and controlled.

## Hazards to shore workers and crewmembers at refit

While the gas carrier accident record is very good for normal operations, and exemplary with respect to cargo operations and containment, the same cannot be said for the risks it faces in drydock. Statistics show that the gas carrier in drydock presents a serious risk to personnel, particularly with respect to adequate ventilation through proper inerting and gas-freeing before repairs begin. Most often the risk relates to minor leakage from a cargo tank into the insulation surrounding refrigerated LPG tanks. A massive explosion occurred on the *Nyhammer* at a Korean shipyard in 1993 for this very reason, where considerable loss of life occurred. Although the ship was repaired, it was a massive job.

## Checklist

The following checklist, made available from SIGTTO*, may be used as guidance in a casualty situation involving a disabled gas carrier.

- What cargo is onboard?
- Is specialist advice available in respect of the cargo and its properties?
- Are all parties involved aware of cargo properties?
- Is the cargo containment system intact?
- Is the ship venting gas?
- Is the ship likely to vent gas?
- What will be the vented gas and what are its dispersal characteristics?
- Is a gas dispersion modelling tool available?
- Is the ship damaged?
- Does damage compromise the ship's manoeuvring ability?
- What activities and services are planned to restore a seaworthy condition?
- Is ship-to-ship transfer equipment available if required?
- When is it expected the ship will be seaworthy again?
- Is prevailing shelter (and other dangers) suitable for the intended repairs?
- What contingency plans are required?
- Who will control the operation?
- How will the ship operator and port or public authorities co-operate?
- Will customs and immigration procedures need facilitation for equipment and advisers?

* Society of International Gas Tanker and Terminal Operators – see inside back page

# Liquefied natural gas

## Background

It was as far back as 1959 that the *Methane Pioneer* carried the first experimental LNG cargo and, in 1964, British Gas at Canvey Island received the inaugural cargo from Arzew on the *Methane Princess*. Together with the *Methane Progress* these two ships formed the core of the Algeria to UK project, and the project-based nature of LNG shipping was set to continue until the end of the 20th century. LNG carriers only existed where there were projects, with ships built specifically for employment within the projects. The projects were based on huge joint ventures between cargo buyers, cargo sellers and shippers, all in themselves large companies prepared to do long-term business together.

The projects were self-contained and operated without much need for outside help. They supplied gas using a purpose-built fleet operating like clockwork on a CIF basis. Due to commercial constraints, the need for precisely scheduled deliveries and limited shore tank capacities, spot loadings were not feasible and it is only in recent years that some projects now accept LNG carriers as cross-traders, operating more like their tramping cousins – the oil tankers. Doubtless the trend to spot trading will continue. However, the co-operative nature of LNG's beginnings has led to several operational features unique to the ships. In particular there is the acceptance that LNG carriers burn LNG cargo as a propulsive fuel. They also retain cargo onboard after discharge (the 'heel') as an aid to keeping the ship cooled down and ready to load on arrival at the load port. Thus matters that would be anathema to normal international trades are accepted as normal practice for LNG.

Again, looking back to the early days, there was also great interest in this new fuel in the USA and France. Receiving terminals sprouted. However, gas pricing difficulties in the USA saw an end to early American interest while Gaz de France consolidated rather than expanded. Indeed, the American pricing problems, and the failure of an early US-built shipboard Conch containment system on newbuildings, blanketed any spectacular progress in the Atlantic basin until the regeneration of interest initiated by the Trinidad project in 1999.

At that time, the stifling of European interest was also due to the discovery of natural gas in the North Sea, so quantities to replace town gas were available in sufficient volume on the doorstep without the need for imports. This being so, the first LNG project from Algeria to UK eventually faltered, with the receiving terminal at Canvey Island switching to other interests. The stagnation of LNG in the 70s and 80s applied the world over, with the singular exception of imports to Japan and Korea. Here interest in LNG's potential as an environmentally-friendly fuel stayed vibrant; as it does today.

LNG projects are massive multi-billion dollar investments. Major projects in the Far East included Brunei to Japan, Indonesia to Japan, Malaysia to Japan and Australia to Japan, comprising some 90% of the LNG trade of the day. Consequently, the Japanese defined much of what is seen best today in way of safety standards and procedures. It is worthy of note, however, that some early safety standards and practices are being questioned today in the light of experience in a more mature industry.

## LNG as a fuel

Because the ships, terminals and commercial entities were all bound together in the same chain, advantages could be seen in limiting 'unnecessary' shipboard equipment, such as reliquefaction plant, and allowing the boil-off to be burnt as fuel. One way or another the ship would need fuel, be it oil or gas and, if gas, it was only then a matter to quantify usage and to direct the appropriate cost to the appropriate project partner. Interestingly, this concept was recognised in the IMO's *Gas Codes* from the very earliest days, and with the appropriate safety equipment in place the regulations allow methane to be burnt in ships' boilers. This is not the case for LPG, where reliquefaction equipment is a fitment, but specifically because the LPGs are heavier than air gases and use in engine rooms is thereby disallowed.

## LNG quality

LNG is liquefied natural gas. It is sharply clear and colourless. It comprises mainly methane but has a percentage of constituents such as ethane, butane and propane together with nitrogen. It is produced from either gas wells or oil wells. In the case of the latter it is known as associated gas. At the point of production the gas is processed to remove impurities and the degree to which this is achieved depends on the facilities available. Typically this results in LNG with between 80% and 95% methane content. The resulting LNG can therefore vary in quality from loading terminal to loading terminal or from day-to-day.

Other physical qualities that can change significantly are the specific gravity and the calorific value of the

LNG, which depend on the characteristics of the gas field. The specific gravity affects the deadweight of cargo that can be carried in a given volume, and the calorific value affects both the monetary value of the cargo and the energy obtained from the boil-off gas fuel.

These factors have significance in commercial arrangements and gas quality is checked for each cargo, usually in a shore-based laboratory by means of gas chromatography. LNG vapour is flammable in air and, in case of leakage, codes require an exclusion zone to allow natural dispersion and to limit the risk of ignition of a vapour cloud. Fire hazards are further limited by always handling the product within oxygen-free systems. Unlike oil tankers under inert gas, or in some cases air, LNG carriers operate with the vapour space at 100% methane. LNG vapour is non-toxic, although in sufficient concentration it can act as an asphyxiant.

Gas quality is also significant from a shipboard perspective. LNGs high in nitrogen, with an atmospheric boiling point of -196°C, naturally allow nitrogen to boil-off preferentially at voyage start thus lowering the calorific value of the gas as a fuel. Towards the end of a ballast passage, when remaining 'heel' has all but been consumed, the remaining liquids tend to be high on the heavier components such as the LPGs. This raises the boiling point of the remaining cargo and has a detrimental effect on tank cooling capabilities in readiness for the next cargo.

The good combustion qualities attributed to methane make it a great attraction today as a fuel at electric power stations. It is a 'clean' fuel. It burns producing little or no smoke and nitrous oxide and sulphur oxide emissions produce figures far better than can be achieved when burning normal liquids such as low sulphur fuel oil. Natural gas has thus become attractive to industry and governments striving to meet environmental targets set under various international protocols such as the Rio Convention and the Kyoto Protocol. The practice of firing marine boilers on methane provides the further environmental advantage of lesser soot-blowing operations and much fewer carbon deposits.

## Cargo handling

The process of liquefaction is one of refrigeration and, once liquefied, the gas is stored at atmospheric pressure at its boiling point of -162°C. At loading terminals any boil-off from shore tanks can be reliquefied and returned to storage. However, on ships this is almost certainly not the case. According to design, it is onboard practice to burn boil-off gas (often together with fuel oil) in the ship's boilers to provide propulsion. In the general terms of seaborne trade this is an odd way to handle cargo and is reminiscent of old tales of derring-do from the 19th century when a cargo might have been burnt for emergency purposes. It is nevertheless the way in which the LNG trade operates. Boil-off is burnt in the ship's boilers to the extent that it evaporates from its mother liquid. Clearly cargo volumes at the discharge port do not match those loaded.

Accounting however is not overlooked and LNG carriers are outfitted with sophisticated means of cargo measurement. This equipment is commonly referred to as the 'custody transfer system' and is used in preference to shore tank measurements. These systems normally have precise radar measurement of tank ullage while the tanks themselves are specially calibrated by a classification society to a fine degree of accuracy. The system automatically applies corrections for trim and list using equipment self-levelled in drydock. The resulting cargo volumes, corrected for the expansion and contraction of the tanks, are normally computed automatically by the system.

Cargo tank design requires carriage at atmospheric pressure and there is little to spare in tank design for over or under pressures. Indeed, the extent to which pressure build-up can be contained in a ship's tanks is very limited in the case of membrane cargo tanks, although less so for Type-B tanks. Normally this is not a problem, as at sea the ship is burning boil-off as fuel or in port has its vapour header connected to the terminal vapour return system. Clearly, however, there are short periods between these operations when pressure containment is necessary. This can be managed. So taken together, shipboard operations efficiently carried out succeed in averting all possible discharges to atmosphere, apart that is from minor escapes at pipe flanges, etc. Certainly this is part of the design criteria for the class as it is recognised that methane is a greenhouse gas.

Boil-off gas (BOG) is limited by tank insulation and newbuilding contracts specify the efficiency required. Usually this is stated in terms of a volume boil-off per day under set ambient conditions for sea and air temperature. The guaranteed maximum figure for boil-off would normally be about 0.15% of cargo volume per day.

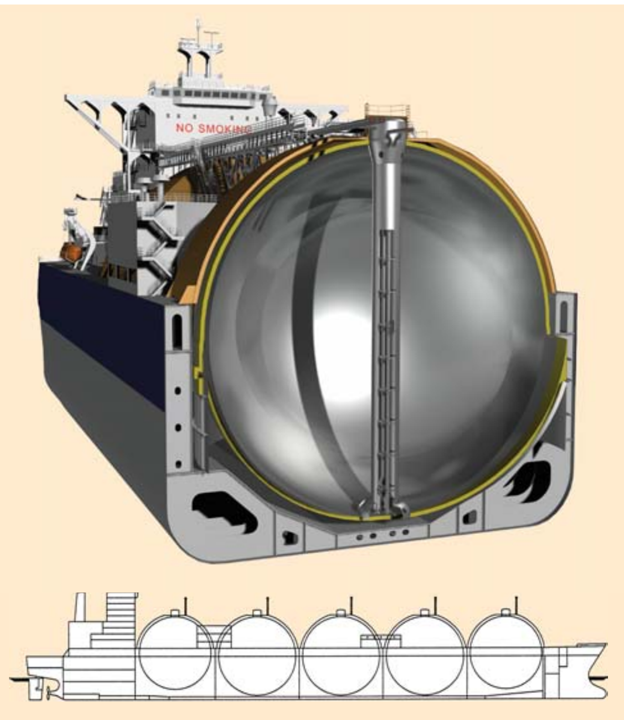
While at sea, vapours bound for the boilers must be boosted to the engine room by a low-duty compressor via a vapour heater. The heater raises the temperature of the boil-off to a level suited for combustion and to a point where cryogenic materials are no longer required in construction. The boil-off then enters the engine room suitably warmed but first passes an automatically controlled master gas valve before reaching an array of control and shutoff valves for direction to each burner.

As a safety feature, the gas pipeline through the engine room is of annular construction, with the outer pipe purged and constantly checked for methane ingress. In this area, operational safety is paramount and sensors cause shutdown of the master gas valve in alarm conditions. A vital procedure in the case of a boiler flameout is to purge all gas from the boilers before attempting re-ignition. Without such care boiler explosions are possible and occasional accidents of this type have occurred.

## Cargo care

The majority of LNG shippers and receivers have a legitimate concern over foreign bodies getting into tanks and pipelines. The main concern is the risk of valve blockage if (say) an old welding rod becomes lodged in a valve seat. Such occurrences are not unknown with a ship discharging first cargoes after newbuilding or recently having come from drydock.

**LNG carrier with Type-B tanks (Kvaerner Moss system)**




Courtesy of Moss Maritime

**Moss design**

Accordingly, and despite discharge time diseconomies, it is common practice to fit filters at the ship's liquid manifold connections to stop any such material from entering the shore system. The ship normally supplies filters fitting neatly into the manifold piping.

In a similar vein, even small particulate matter can cause concerns. The carry-over of silica gel dust from inert gas driers is one such example. Another possible cause of contamination is poor combustion at inert gas plants and ships tanks becoming coated with soot and carbon deposits during gas freeing and gassing up operations. Subsequently, the contaminants may be washed into gas mains and, accordingly, cargoes may be rejected if unfit. Tank cleanliness is vital and, especially after drydock, tanks must be thoroughly vacuumed and dusted.

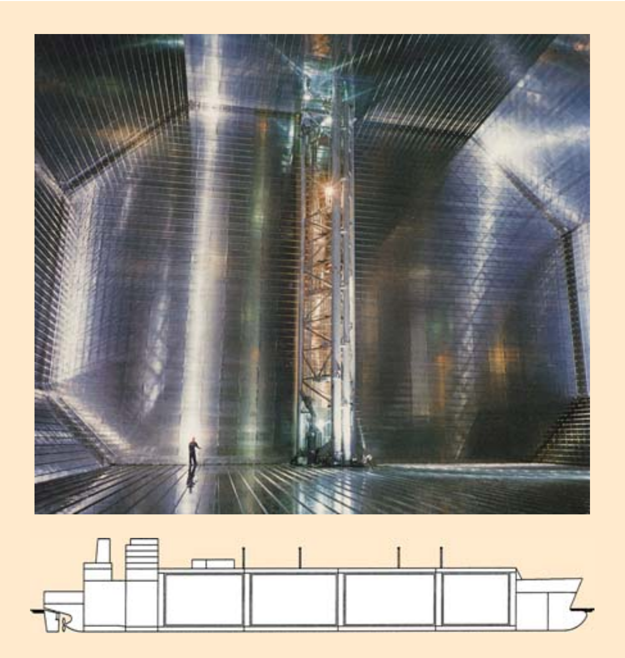
A cargo was once rejected in Japan when, resulting from a misoperation, steam was accidentally applied to the main turbine with the ship secured alongside the berth. The ship broke out from the berth, but fortunately the loading arms had not been connected. This action was sufficient however for cargo receivers to reject the ship, and the cargo could only be delivered after a specialised ship-to-ship transfer operation had been accomplished. The ship-to-ship transfer of LNG has only ever been carried out on a few occasions and is an operation requiring perfect weather, great care and specialist equipment.

Another case of cargo rejection, this time resulting in a distressed sale, involved a shipment to Cove Point in the USA, where the strict requirements which prevail on in-tank pressures on arrival at the berth were not adhered to. The ship had previously been ordered to reduce pressure for arrival. This is a difficult job to perform satisfactorily and, if it is to be successful, the pressure reduction operation must progress with diligence throughout the loaded voyage by forcing additional cargo evaporation to the boilers. This cools the cargo and hence reduces vapour space pressure. The process of drawing vapour from the vapour space at the last moment is ineffective, because the cargo itself is not in balance with that pressure and once gas burning stops the vapour space will return to its high equilibrium pressure. This process is known in the trade as 'cargo conditioning'.

## Ship care

A temperature of -162°C is astonishingly cold. Most standard materials brought into contact with LNG


**LNG carrier with membrane tanks**



**Membrane design (GTT)**

become highly brittle and fracture. For this reason pipelines and containment systems are built from specially chosen material that do not have these drawbacks. The preferred materials of construction are aluminium and stainless steel. However these materials do not commonly feature over the ship's weatherdecks, tank weather covers or hull. These areas are constructed from traditional carbon steel. Accordingly, every care is taken to ensure that LNG is not spilt. A spill of LNG will cause irrevocable damage to the decks or hull normally necessitating emergency drydocking. Accidents of this nature have occurred, fortunately none reporting serious personal injury, but resulting, nevertheless, in extended periods off-hire.

LNG carriers are double-hulled ships specially designed and insulated to prevent leakage and rupture in the event of accident such as grounding or collision. That aside, though sophisticated in control and expensive in materials, they are simple in concept. Mostly they carry LNG in just four, five or six centreline tanks. Only a few have certification and equipment for cross trading in LPG. The cargo boils on passage and is not reliquefied onboard – it is carried at atmospheric pressure. Although there are four current methods to construct seaborne LNG tanks, only two are in majority usage. There are the spherical tanks of Moss design and the membrane tanks from Gaz Transport or Technigaz (two French companies, now amalgamated as GTT). Each is contained within the double hull where the water ballast tanks reside. The world fleet divides approximately 50/50 between the two systems.

Regarding spherical tanks, a very limited number were constructed from 9% nickel steel, the majority are constructed from aluminium. A disadvantage of the spherical system is that the tanks do not fit the contours of a ship's hull and the consequent 'broken-stowage' is a serious diseconomy. In general terms, for two LNG ships of the same carrying capacity, a ship of Moss design will be about 10% longer. It will also have its navigating bridge set at a higher level to allow good viewing for safe navigation. On the other hand the spherical tanks are simple in design and simple to install in comparison to the membrane system, with its complication of twin barriers and laminated-type construction.

Tank designs are often a controlling factor in building an LNG carrier. Shipyards usually specialise in one type or the other. Where a yard specialises in the Moss system, giant cranes are required to lift the tanks into the ships and limits on crane outreach and construction tooling facilities currently restrict such tanks to a diameter of about 40 metres.

Early LNG carriers had carrying capacities of about 25,00m$^3$. This swiftly rose to about 75,000m$^3$ for the Brunei project and later ships settled on 125,000m$^3$. For some years this remained the norm, giving a loaded draught of about 11.5 metres, thus stretching the port facilities of most discharge terminals to their limits. Since then, however, there have been some incremental increases in size, usually maintaining draft but increasing beam, resulting in ship sizes now of about 145,000m$^3$. That said, one of the newest in class is the *Pioneer Knudsen,* trading at only 1,100m$^3$ capacity from a facility near Bergen to customers on the Norwegian west coast.

Large, modern LNG carriers have dimensions approximately as follows:

| Capacity (m$^3$) | 145,000 | 215,000 | 265,000 |
|---|---|---|---|
| Length | 295m | 315m | 345m |
| Beam | 48m | 50m | 54m |
| Loaded draft | 12m | 12m | 12m |

LNG having a typical density of only 420kg/m$^3$ allows the ships, even when fully laden, to ride with a high freeboard. They never appear very low in the water as a fully laden oil tanker may do. Ballast drafts are maintained close to laden drafts and, for a ship having a laden draft of 12 metres, a ballast draft of 11 metres is likely. This means that for manoeuvring in port in windy conditions the ships are always susceptible to being blown to one side of the channel, and restrictions on port manoeuvring usually apply with extra tug power commonly specified.

Another salient feature of the LNG class is the propensity to fit steam turbine propulsion. This is an anachronism brought about by a reluctance to change over the years, together with a fear that a system as yet untried on LNG carriers may not find favour with the principal charterers – the Japanese. Most other ship types of this size have diesel engines and the engineers to run diesel equipment are plentiful and suitably trained. On the other hand, engineers knowledgeable in steam matters are few and their training base is the ship itself. This situation is changing though, with both diesel electric dual fuel systems and slow speed diesels now finding favour. With slow speed diesel propulsion, reliquefaction plants will be required onboard to handle boil-off gas, and all diesel systems will require back-up gas disposal facilities – also known as 'gas combustion units' (GCUs) – for when either the reliquefaction plants or the duel fuel diesel engines are not available to process boil-off gas.

LNG ships are expensive to build. They comprise very valuable assets: generally far too good to let rust away. Shipowners and ship managers alike recognise this and, together with inspection regimes, the overall quality of LNG tonnage is kept to a high standard. Age for age, they are probably the best maintained ships in the world. Of course some of these ships are now old and only a few have ever been scrapped; some are over 40 years old. This is very old for a large tanker trading all its life in salt water, when 25 years is already considered by many as a cut-off date.

On termination of their original projects we are now seeing many of the older ships as surplus to requirements. Sometimes the project wishes to continue but only with new ships. So the older ships are laid-off. In the past this would have been their death knell but today this is not necessarily the case. The slow development of a spot market has allowed the shipowner to consider life extension programmes of considerable cost; all this set against the value of a very expensive newbuilding. Today life extension programmes are common with old ships making handsome profits in the spot market.

## SIGTTO

Valuable assistance in the preparation of these articles has come from the Society of International Gas Tanker and Terminal Operators (SIGTTO).

SIGTTO is the leading trade body in this field and has over 120 members covering nearly 95% of the world's LNG fleet and 60% of the LPG fleet. SIGTTO members also control most of the terminals that handle these products.

The Society's stated aim is to encourage the safe and responsible operation of liquefied gas tankers and marine terminals handling liquefied gas; to develop advice and guidance for best industry practice among its members and to promote criteria for best practice to all who have responsibilities for, or an interest in, the continuing safety of gas tankers and terminals.

The Society operates from its London office at 17 St. Helens Place EC3. Further details on activities and membership is available at www.sigtto.org

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The aforementioned publications are available from Witherby & Company Ltd, London.

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