



Carefully to Carry

The carriage of liquefied gases

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 1,000 m³ capacity, the total of nearly 1,000 ships can be divided into 5 major types according to the following table:

The gas carrier fleet (end 2004)					
	Pressurised LPG carriers	Semi-pressurised LPG carriers	Ethylene carriers	Fully refrigerated LPG carriers	LNG carriers
Ship numbers	336	189	103	185	175
Total capacity (m ³)	1,045,970	1,378,690	755,620	11,171,705	20,683,798

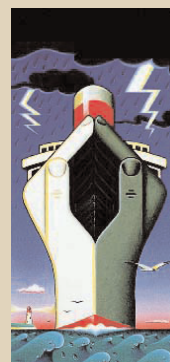
Source: Braemar Seascope Gas (all information given in good faith but without guarantee)

By contrast, the world oil tanker fleet for a similar size range is over 16,000 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.

A second article, on page 8, describes the liquefied natural gas (LNG) carrier in more detail and a third article, to be published later, will describe the liquefied petroleum gas (LPG) carrier.

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



"The carrier shall properly and carefully load, handle, stow, carry, keep, care for and discharge the goods carried."

Hague Rules, Articles iii, Rule 2

Carefully to Carry Advisory Committee

This report was produced by the Carefully to Carry Committee – the UK P&I Club's advisory committee on cargo matters. The aim of the Carefully to Carry Committee is to reduce claims through contemporaneous advice to the Club's Members through the most efficient means available.

The committee was established in 1961 and has produced many articles on cargoes that cause claims and other cargo related issues such as hold washing, cargo securing, and ventilation.

The quality of advice given has established Carefully to Carry as a key source of guidance for shipowners and ships' officers. In addition, the articles have frequently been the source of expertise in negotiations over the settlement of claims and have also been relied on in court hearings.

In 2002 all articles were revised and published in book form as well as on disk. All articles are also available to Members on the Club website. Visit the Carefully to Carry section in the Loss Prevention area of the Club website www.ukpandi.com for more information, or contact the Loss Prevention Department.

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, salvaged.

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 about 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:

Comparative hazards of some liquefied gases and oils				
Hazard	GASES		OILS	
	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

Design of gas carriers

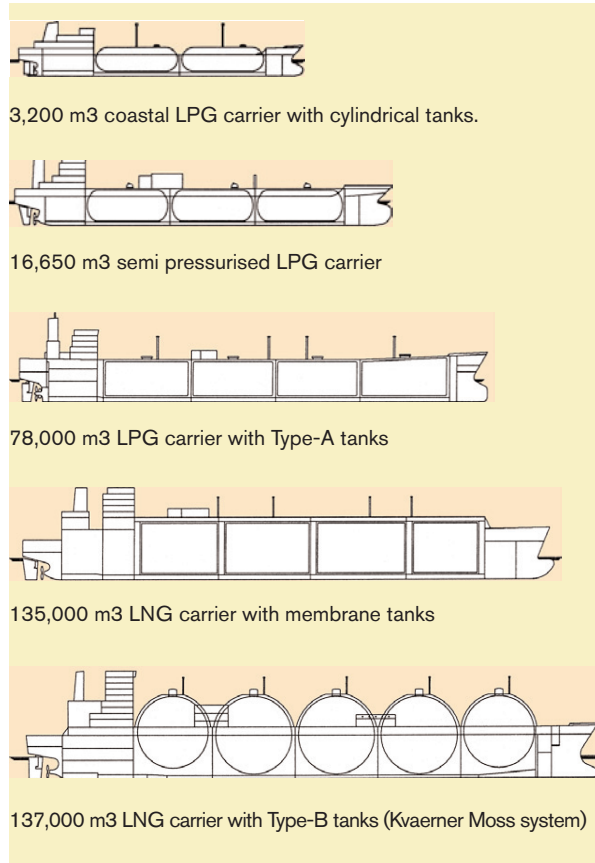
The regulations for the design and construction of gas carriers stem from practical ship designs codified by the International Maritime Organization (IMO). This was a seminal piece of work and drew upon the knowledge of many experts in the field – people who had already been designing and building such 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 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; i.e. 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 boxshaped or prismatic tanks (i.e. 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, above and the photograph on the next page, 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 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



Pressurised LPG carrier with cylindrical tanks.

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.

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 20,000 m³. 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 2,000 m³ to 15,000 m³ 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

Semi-pressurised LPG carrier.





Fully refrigerated LPG carrier.

inerting and for the dehydration of the cargo system as well as the interbarrier 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.

The fully refrigerated fleet

These are generally large ships, up to about 100,000 m³ cargo capacity, those above 70,000 m³ being designated as VLGCs. Many in the intermediate range (say 30,000 m³ to 60,000 m³) 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 75,000m³ to 150,000m³ capacity, with ships of up to 265,000 m³ expected by the end of the decade. The cargo tanks are thermally insulated and the cargo carried at atmospheric pressure. Cargo tanks may be free standing spherical, of the membrane 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. Existing LNG carriers do not reliquefy boil-off gases, they are steam ships and the gas is used as fuel for the ship's boilers. The first ships to burn this gas in medium speed diesel engines will be delivered in 2005/6, and ships with reliquefaction plant and conventional slow speed diesel engines will enter service late in 2007. It is likely that gas turbine propelled ships may appear soon after this.

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



LNG carrier with membrane tanks.



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.

Hard arms at cargo manifold, including vapour return line (below, centre arm).



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 60,000 m³ 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 , page 13).

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 opposite) 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.

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

Hard arm quick connect/disconnect coupler (QCDC).



Translation Error.

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

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 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 photo above).

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?