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TRANSACTIONS (TM)

COMBINED LIQUEFIED GAS AND CHEMICAL TANKERS

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Combined Liquefied Gas and Chemical Tankers

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SYNOPSIS

The last fifteen years has seen the introduction of a new type of tanker. They are basically gas tankers, but the materials and arrangements for cargo containment and cargo handling systems are also designed for the transportation of highly corrosive products such as acids and other chemicals. So far ten liquefied gas tankers, with a total capacity of 72 572 m^3, have been built with independent pressurized cargo tanks made of stainless steel. Five more ships, with a total capacity of 32 200 m^3, are on order or under construction. This paper describes the ships and their uses, the Rules applicable to them, and some of the typical arrangements and technological features.

PURPOSE OF COMBINED LIQUEFIED GAS AND CHEMICAL TANKERS

Background

The LPG market is changing with typical charters now not exceeding one or two years. However, the costs of building and maintaining gas tankers are quite high, and for such a vessel to be laid up is a major problem for the owner. To cater for this, such tankers should have as many uses as possible in order to provide the maximum number of opportunities for chartering.

Depending on their size, the uses will be different: for vessels under 30 000 m^3 capacity the first option will be to use pressure vessels with full reliquefaction facilities to suit the requirements of land storage which is at either atmospheric pressure or ambient temperature. For reasons of size and cost, this cannot be done for large tankers (30 000 to 70 000 m^3), and would not in fact add to the flexibility of such vessels, as because of their size they cannot enter most of the ports where liquefied gas is stored.

For these large tankers greater usage is achieved by adapting the vessels for the carriage of clean products or light cuts. Most such vessels are currently chartered for carrying naphtha.

Considerable flexibility may therefore be contemplated for smaller vessels, the smallest size being dictated by the need to achieve a balance between the length of the loaded voyage and the time spent adapting the vessel for different cargoes. This latter time is more or less fixed and the smaller the ship the more important this time becomes in comparison with the maximum length of the loaded voyage.

The full effectiveness of a flexible ship may be limited to a range of vessels with a cargo capacity of 6000 to 30 000 m^3.

Type of product

The liquid cargoes commonly transported in bulk by these ships are classified as follows.

Liquefied gases

These are included in Chapter 19 of the 'International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk' (IMO IGC Code). They can be grouped into three categories, depending on the minimum design temperature needed:

1. Methane (LNG) at −163 °C.
2. Ethylene at −104 °C.
3. Propene, propane, butane, ammonia, butene, butadiene and VCM at above −50 °C.

The minimum design temperature and the specific gravity of the liquefied gas will influence the design and the materials needed for the construction of the cargo tanks.

Oil products

These are the refined or clean products produced by the processing of crude oil and consist of naphthas, light refined products, gasolines, lube oil, kerosene, diesel oil, gas oil and turbo fuels.

No special problems arise from either the temperature requirements or the specific gravity of the oils, and the ship is considered to be an oil tanker for the purposes of safety (SOLAS Convention Chapter II.2 E) and MARPOL 73/78 Annex I must be complied with (apart from any exceptions agreed by the Flag Administration).

The equipment required includes a means of cleaning and stripping the tanks. These products, since they are not corrosive, do not require the cargo tanks to be coated.

Easy chemicals

These products are those judged by IMO to be low-hazard chemicals. This judgement is based on the chemical's flammability, toxicity, corrosiveness, reactivity with water and possible pollution risks.

The chemicals are listed in either IMO Resolution A212 (Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk) Chapter 7 or in the IBC Code (International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk) Chapter 18.

These chemicals are usually non-corrosive and so no coating or special tankage material is required. Nevertheless some of

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them, if used for special applications, may require a coating in order to avoid pollution or deterioration of the product (eg methanol when not used for bulk industrial purposes).

Attention must be paid to the specific gravity of the chemical, the heating requirements and the effectiveness of cleaning. Special fire-fighting equipment using foam which is suitable for polar chemicals is to be provided (a polar chemical is defined as one whose molecular arrangement destroys standard foams).

Edible liquids

Cargoes such as wine, edible alcohols and vegetable oils are required to be carried in tanks which have been approved for the transportation of products for human consumption. Therefore special tank coatings are required. Heating of the cargo may be necessary and special attention must be paid to accurate temperature control as some cargoes (eg vegetable oils) can be damaged by slight overheating. In addition, some alcohols, depending on the flash point (ie pure alcohol content), are treated as cargoes having a flash point of less than 60 °C, and in such cases a foam fire-fighting system suitable for polar chemicals must be provided.

Chemicals

These are listed in Resolution A212 Chapter 6 or the IBC Code Chapter 17, and are classified by IMO as hazardous chemicals. When transporting such a chemical, attention must be paid to its compliance with either A212 or the IBC Code, specific gravity, heating capability, cleaning efficiency (the system must comply with MARPOL 73/78 Annex II) and corrosiveness.

Special products such as acids require a special containment system and only a thick lining or stainless steel can be used. If the vessel is to carry a large number of chemicals or liquefied gases, only stainless steel should be used.

Design

The decision to build a combined LPG and chemical tanker is linked to possible different uses of the vessel. This is based upon the ability of the ship to carry different cargoes, which increases the chances of the ship being chartered. Taking into account the present chartering rates for LPG ships, which are unstable and weak, it is preferable to carry other liquid cargoes rather than have the ship lying idle.

Another aspect to be considered is the ability of the ship to accept a charter whilst carrying another cargo to the new loading port. This will allow the ship to sail to a new loading port with a cargo instead of sea-water ballast. Considering the turn round time and the time spent adapting the ship for the new cargo, the cargo capacity should be at least 6000 m^3.

However, such a tanker cannot be built, for technological and practical reasons, fully optimized for several cargoes. Thus a compromise, based on a lead product, has to be considered. Today, the most profitable liquefied gas cargo is ethylene. Bearing in mind the fact that the ship may be used only on a restricted range of products, the lead product should be the most profitable one.

A ship which has been designed to carry ethylene is built to operate with a minimum service temperature of −104 °C. This requires a high alloy steel, the minimum acceptable material being a 5% nickel steel. The use of a corrosion resistant material increases the flexibility of the ship.

The difference in the price of tanks built in a material suitable for chemicals (316 grade stainless steel) is therefore reduced. Stainless steel will also be suitable for corrosive chemicals such as acids. The increase in price of the ship, depending on the flexibility required, is summarized in Table I.

Table I: Comparison of prices for different cargoes and tank materials

Cargo	Tank material	Price
Propene, LPG and isoprene	Carbon manganese steel	N
Propene to isoprene and clean products	Carbon manganese steel	1.05 × N
Propene and ethylene	5% Ni steel	1.17 × N
Propane, ethylene and chemicals	316 LN steel	1.25 × N

Consideration should also be given to the maximum size of the vessel. As ethylene is the lead product, the maximum capacity will depend on the most profitable size required for ethylene.

Following the increase over the last 10 years of land storage capacity for ethylene from 6000 to 12 000 m^3, the maximum size for such a ship is 12 000 m^3, which also meets most of the size limitations in possible ports of call.

Finally, the design has to suit the various specific gravities to be handled (from 0.58 to 2.2 t/m^3). This is basically a problem of adjusting the maximum deadweight for a chosen specific gravity. The choice of the maximum specific gravity for 100% loading will decide the volume of the hull. The gross tonnage will be limited by the maximum draught of the vessel, the breadth and length being dictated by a compromise between cost-effective building and economic fuel consumption.

The present practice is to design the ship for a maximum deadweight with a relative density of 1.4, which seems to be the most efficient compromise.

APPLICABLE RULES

1974 SOLAS Convention and Amendments

The 1974 SOLAS Convention has been modified by two sets of Amendments. The first of these entered into force on 1 September 1984 and the second will enter into force on 1 July 1986.

The 'International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk' (IGC) and the 'International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk' (IBC) will be made mandatory by Regulations 9 and 12 of Chapter VII of the 1974 SOLAS Convention, as amended by the second set of amendments. These requirements will not apply retrospectively.

The 1973/78 MARPOL Convention, Annex II

Regulation 13 of Annex II of MARPOL 73/78 refers to Resolution A212 (VII) (BCH Code) and also the IBC Code. Annex II will enter into force in April 1987 and will cover both new and existing ships.

Specific requirements for chemical carriers

Existing ships

A ship whose building contract was signed prior to 2 November 1973 will be covered by Resolution A212 (VII) or the BCH code and its Amendments when Annex II of MARPOL 73/78 enters into force, subject to the requirements of paragraph 1.7.3 of the BCH Code. This will apply to ships carrying category A, B or C substances in bulk regardless of the ship's size.

A ship whose building contract was signed on or later than 2 November 1973 or whose keel is laid prior to 1 July 1986 will be covered by the BCH Code and its Amendments when Annex II of MARPOL 73/78 enters into force. This will be applied to all ships carrying category A, B or C substances in bulk.

As specified above, and subject to the agreement of the Administration, the IBC Code rather than the BCH Code can be applied to ships built during the intermediate period from June 1983 to June 1986. Compliance with the BCH Code is sometimes required at an earlier date because of National or Port Regulations.

New ships

The IBC Code will be mandatory for all ships whose keel is laid on or later than 1 July 1986.

Specific requirements for liquefied gas carriers

Existing ships

Depending on the date of construction of the ship, one of the following three Codes, together with their Amendments, is applicable, either on a voluntary basis or through National or Port requirements:

1. Code for Existing Gas Carriers.
2. Resolution A328 (IX) (GC Code).
3. Resolution A328 (IX) and Resolution A329 (IX).

For ships under construction whose keel is laid prior to 1 July 1986, the IGC Code can be applied in lieu of the GC Code, subject to the agreement of the Administration.

New ships

For ships whose keel is laid on or later than 1 July 1986, the IGC Code is mandatory regardless of their size.

Comparison of the International Codes

IMO set two objectives in the preparation of IBC and IGC:

1. The unification of regulations applicable to chemical carriers and liquefied gas carriers.
2. The unification of regulations applicable to chemical carriers and oil tankers.

Both Codes were prepared along the same lines. Table II compares their contents.

Chapter 2: Ship survival capability and cargo tank location

The IBC Code defines the vertical extent of standard bottom damage to be $B/15$ (B being the breadth of the ship) or 6 m, whichever is less, whereas in the IGC Code the latter value is reduced to 2 m. This difference arises from the different basic design of chemical and gas ships.

It is the IBC Code which is in accordance with Regulation 25 of Annex I of MARPOL 73/78. Difficulties may arise for the carriage of petroleum products (eg naphtha) in a liquefied gas carrier.

The maximum angle of heel for asymmetric flooding is 30° in the IGC Code and 25° in the IBC Code (30° if the deck is not submerged).

Chapter 3: Ship arrangements

The IBC Code prohibits, in principle, all closed spaces on open decks in the cargo area (with the exception of pump rooms, spaces intended for the storage of cargo equipment and cargo control stations). The IGC Code, however, authorizes such spaces provided they are properly ventilated gas-safe spaces and are protected against penetration of cargo vapours. The protection of gas-safe spaces by air locks is accepted by the IGC Code but not by the IBC Code.

The compressor room of gas carriers has to be fitted above the deck whereas the cargo pump room of chemical carriers may be located below deck, except on ships carrying certain very noxious products.

Chapters 4, 5 and 6: Pressure vessels and piping arrangements – materials of construction

Requirements covering the design and construction of pressure vessels and cargo piping are far more detailed in the IGC Code than in the IBC Code. It is left to the Classification Societies to provide additional regulations applicable to chemical carriers.

Table II: Comparison of the contents of the international codes

IGC Code	*Chapter*	*IBC Code*	*Chapter*
General	1	General	1
Ship survival capability and cargo tank location	2	Ship survival capability and cargo tank location	2
Ship arrangements	3	Ship arrangements	3
Cargo containment	4	Cargo containment	4
Process pressure vessels and liquid, vapour and pressure piping systems	5	Cargo transfer	5
Materials of construction	6	Materials of construction	6
Cargo pressure and temperature control	7	Cargo temperature control	7
Cargo tank vent systems	8	Cargo tank vent systems	8
Environmental control	9	Environmental control	9
Electrical arrangements	10	Electrical arrangements	10
Fire protection and fire extinguishing	11	Fire protection and fire extinguishing	11
Mechanical ventilation in cargo area	12	Mechanical ventilation in cargo area	12
Instrumentation (gauging) and gas detection	13	Gauging	13
Personnel protection	14	Personnel protection	14
Filling limits for cargo tanks	15		
Use of cargo as fuel	16		
Special requirements	17	Special requirements	15
Operating requirements	18	Operating requirements	16
Summary of minimum requirements	19	Summary of minimum requirements	17
		Lists of chemicals to which the code does not apply	18
		Requirements for ships engaged in the incineration at sea of liquid chemical waste	19
Appendix: Model form of certificate		Appendix: Model form of certificate	

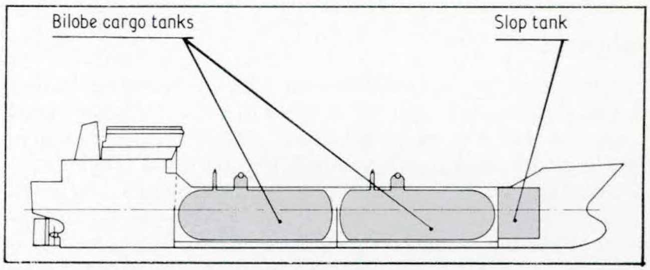

FIG. 1: General arrangement of a combined liquefied gas and chemical tanker

Chapter 7: Cargo pressure and temperature control

The cargo pressure and temperature control requirements are different because of the very different thermodynamic characteristics of the products carried. The IGC Code aims for a cargo storage system designed to prevent cargo from being accidentally discharged into the atmosphere because of faulty cargo pressure or temperature control (cargo heating not balanced by the reliquefaction system, incorrect setting of safety relief valves etc.).

The IBC Code requires that the cargo heating systems necessary for cargo handling are sufficiently safe to prevent the risk of contaminating the atmosphere with noxious, flammable or corrosive cargo.

Chapter 8: Cargo vent systems

The IGC Code requires cargo tanks to be protected against over-pressure by means of two pressure relief valves, which are normally of the pilot-operated type. For certain types of ships these valves have multiple settings. The minimum capacity required is based on the hypothesis of a surrounding fire.

When using a short vapour return connection or when loading or unloading using the reliquefaction plant or a vaporizer connected to the cargo compressors, the valves are closed under normal service conditions and are only provided for emergency use. Usually tank vacuum protection is provided by pressure sensors which trigger auxiliary cargo pumps and compressors.

Taking into consideration the kind of products carried and the operating conditions of chemical carriers, the IBC Code emphasizes the risk of pipes and fittings being blocked by polymerization. There is also a need to provide efficient pipe drainage and protection against flash backs.

Safety relief valves are, on most ships, opened during loading. High-velocity valves may be used, some of which permit the omission of flame screens at the tank vent main discharge.

Chapter 10: Electrical arrangements – dangerous areas

Requirements regarding the electrical equipment fitted in the cargo area will depend on whether it is defined as a gas-dangerous zone. This concept may be misunderstood as it concerns not only electrical equipment but also the safety of the ship's personnel.

The IGC Code Chapter 1 defines a gas-dangerous zone with the intention that the definition is applicable to the whole of the ship's design. The IBC Code only explicitly defines gas-dangerous zones in Chapter 10. Consequently, gas-dangerous zones on gas and chemical carriers are only comparable with regard to the electrical equipment that can be fitted in the cargo area, with the following exceptions:

- Submerged electric motor pumps are prohibited in the cargo tanks of chemical carriers.
- Electric motors, even those certified as safe, are prohibited in all enclosed gas-dangerous spaces on chemical carriers.

Chapter 11: Fire protection and fire extinguishing

Apart from chemical carriers intended to carry only phosphoric acid, caustic soda or potassium hydroxide solutions, the structural fire protection of accommodation spaces is to be the same for both gas and chemical carriers. In addition, on gas carriers intended to carry noxious gases, arrangements must be provided to enable accommodation openings to be closed from the inside.

The main differences between the two Codes concern fire-fighting:

- The IGC Code requires the use of dry-powder and water-spray protection for critical areas.
- The IBC Code requires the use of a low-expansion foam extinguishing system suitable for all products, which implies, for a majority of ships, the use of an alcohol-type foam agent.

Additional means are to be provided if the ship carries products for which foam is an inefficient extinguishing medium.

Chapter 12: Mechanical ventilation in the cargo area

The rate of air changes per hour in cargo pump rooms of highly toxic chemical carriers is 45, whereas the normal rate required by the IGC Code is 30.

Chapter 13: Gauging

In addition to the gauging system, the cargo tanks of chemical carriers are to be fitted with a high-level alarm and an overflow control system, depending on the products being carried. These three systems are to be independent of each others. It must be possible to test the level alarms prior to each loading operation.

An automatic overflow control system (automatic closing of filling line valves) may only be fitted if authorized by the Port Authorities. This implies that the system can also be operated manually. Under certain conditions the IGC Code does not require an overflow system. The obligation to test the operation of high-level alarms does not involve the electrical arrangements, except those concerned with mechanical operations inside the tanks.

Chapter 14: Personnel protection

There is little difference between the two Codes regarding the protection of personnel. Particular attention is to be paid to filter-type breathing apparatus provided on chemical carriers. The apparatus must be efficient for all the products to be carried. This requirement generally means prohibiting the use of such apparatus and replacing it by self-contained air-breathing apparatus.

Construction and equipment requirements of MARPOL 73/78 Annex II

Noxious substances are divided into four categories (A, B, C and D) according to their pollution hazard, category A substances being the most hazardous. Annex II gives a list of chemicals (called Appendix III Chemicals) that are not considered to be a pollution hazard and so are not regulated by Annex II.

In addition to the requirement to comply with a Chemical Code (BCH or IBC) for the carriage of substances in categories A, B and C, the hardware requirements of Annex II for new ships (built after 1 July 1986) are:

1. The fitting of efficient stripping systems in each tank for category B and C substances. The systems must be capable of reducing the residue remaining in the pump area and the pipe line to less than 100 and 300 litres respectively, with 50 litres tolerance.
2. The fitting of an underwater outlet to discharge into the sea residue or residue + water mixtures of category A, B and C substances. The outlet is located within the cargo area in the vicinity of the bilge. It is designed so that the discharged mixture will not pass through the ship's boundary layer. In practice, a minimum diameter is fixed which is a function of the distance from the forward perpendicular and of the maximum slop tank discharge rate.

Amendments to the Codes state that category B substances solidifying at temperatures of 15 °C and above may not be carried either in tanks bounding the ship's side or in tanks without heating arrangements.

SPECIAL ARRANGEMENTS AND TECHNOLOGICAL ASPECTS OF COMBINED LIQUEFIED GAS AND CHEMICAL TANKERS

In order to comply with the Codes and the technical and operating requirements involved in the handling of different cargoes, certain arrangements, which are more or less specific to this type of vessel, are necessary.

General arrangement of the ship

The cargo spaces of these vessels (see Fig. 1) are defined as follows:

- Tanks for the carriage of ethylene and heavy chemicals.
- Slop tanks for handling cargo-tank washing water before discharge at sea according to the requirements of MARPOL 73/78. These slop tanks may also be used as cargo tanks and their design must fulfill the requirements for the largest possible range of chemicals.
- Cargo handling systems for fluids with densities ranging from 0.58 to 2.2 t/m^3.

The cargo tanks, which are designed as pressure vessels to provide greater flexibility and remove the need for a secondary barrier, can be longitudinal cylindrical tanks, transverse cylindrical tanks, bilobe longitudinal tanks or spherical tanks. All these designs have some advantages and disadvantages:

1. Longitudinal cylindrical tanks: ease of construction and cleaning but uneconomical in the use of space in the ship's hull with the possibility of sloshing problems.

2. Transverse cylindrical tanks: economic in the use of space in the ship's hull with the possibility of a greater number of tanks, which can be used for different cargoes, but stability problems and thus a reduced rate of loading.
3. Bilobe longitudinal tanks: economic in the use of space in the ship's hull but reduced efficiency of cleaning of the stiffened longitudinal bulkhead.
4. Spherical tanks: excellent cleaning efficiency, no sloshing problems but uneconomic on space in the ship's hull with building difficulties and stability problems.

As the cost effectiveness of the overall ship design becomes more and more important, the bilobe tank arrangement, which permits a decrease in the length-to-breadth ratio, seems to be preferred.

The slop tanks may be either independent deck tanks or integral forward tanks. The advantage of deck tanks is that they do not affect the design of the forward part of the vessel.

However, there is not a lot of deck space for fitting such tanks, especially if good access to all parts of the cargo piping is required. In addition stability problems could be encountered.

An integrated gravity tank has the advantage of not requiring any space on the deck except for associated piping and equipment, but the design of the forward part of the vessel may be affected.

Cofferdams are to be provided between this tank (or tanks) and ballast or fuel oil tanks if there is to be no restriction on the products to be carried. A cofferdam will always be required at the forward end of the tank.

Slop tanks, depending on the cargoes to be transported, may be built of either normal steel with a suitable coating or lining or stainless steel if acids are to be carried. A solution to the problem, especially for integrated tanks, may be the use of austeno-ferritic steel (ASTM A 240 UNS 31 803) which combines very good corrosion resistance (especially for crevice or stress corrosion and when chlorinated fluids like residual washing waters after sea-water cleaning are present) with mechanical characteristics similar to those of structural steels.

Another major problem is the large range of densities of the liquids to be carried. It is necessary to decide which density to use when calculating the maximum deadweight of the vessel associated with complete filling of the tanks. This density is normally taken as between 1.4 and 1.6 t/m^3, which permits efficient use of the vessel for low-density substances without much reduction in the filling ratio for liquids of higher densities.

This leads to the following additional needs:
1. Large ballast capacity.
2. Ability to adjust the trim of the vessel for economic propulsion with a range of cargoes.
3. Economic fuel consumption with significantly different draughts.

Point 1 requires that sufficient space is left in the hull for ballasting purposes, with efficient arrangements for controlling the trim.

Point 3 requires a controllable-pitch propeller and a low-profile bulbous bow with a large vertical part to the stem.

The hull structure will not need to be specially modified, except for some increase in scantlings to compensate for the bending moments induced by alternate loaded and unloaded states and for heavier loads in way of tank supports.

No major problem is likely with operational or post-damage stability, except in the case of transverse tanks or open longitudinal bulkheads in bilobe tanks. The stability after damage, although involving the IBC Code, does not present difficulties for gas-loaded ships as the freeboard is significantly greater than when the ship is loaded with heavy chemicals.

Cargo tanks

The design of the cargo tanks must conform to the requirements of the IGC Code for independent type C tanks. The requirement defines, depending on the density of the cargo, a minimum vapour pressure for which the tank is to be designed:

$$P_0 = 2 + AC\rho^{3/2}$$

where

$$A = 0.0185 \left(\frac{\sigma_m}{\Delta\sigma_a}\right)^2$$

σ_m is the design primary membrane stress, $\Delta\sigma_a$ is the allowable dynamic membrane stress, which is 55 MPa for steel, C is the height of the tank, 0.75 times the width of the tank or 0.45 times the length of the tank, whichever is the greater, and ρ is the relative density of the cargo compared with fresh water.

The basic philosophy behind this requirement is to ensure that no defect becomes a through crack in the tank shell during the anticipated 25 year life of the ship. The allowable dynamic stress is the stress level at which a crack will grow fom 0.2 times the thickness of the plating to 0.5 times this thickness during 25 years operation in the North Atlantic sea state (10^{-8} wave occurrences).

In the case of combined tankers the formula given by the IGC Code is used for cargoes with a relative density of less than 1.0. For heavier cargoes the dynamic stresses are calculated directly from acceleration formulae associated with the filling ratio. They are then checked either for being less than the allowed value or if an increase in plating thickness is required.

For the range of design temperatures, which may be up to 80 or 90 °C (temperatures at which steel has poor characteristics), the stiffening rings in way of tank supports are designed on the basis of the mechanical characteristics of the steel at the maximum design temperature. The following points must be considered when selecting the material for the cargo tanks:

- Toughness at the minimum design temperature of −104 °C.
- Corrosion resistance.
- Mechanical characteristics.
- Cost effectiveness.

Table III: Composition and characteristics of 316 LN

Composition (%)	*Mechanical characteristics at 20 °C*	
$C < 0.030$	UTS	500 to 800 MPa
$Mn < 2$		
$Si < 1$	YS (0.2)	290 MPa
$P < 0.040$		
$S < 0.030$	Strain	43%
$16 < Cr < 18$		
$11.5 < Ni < 13.5$		
$2.5 < Mo < 3$		
$0.1 < N_2 < 0.2$		

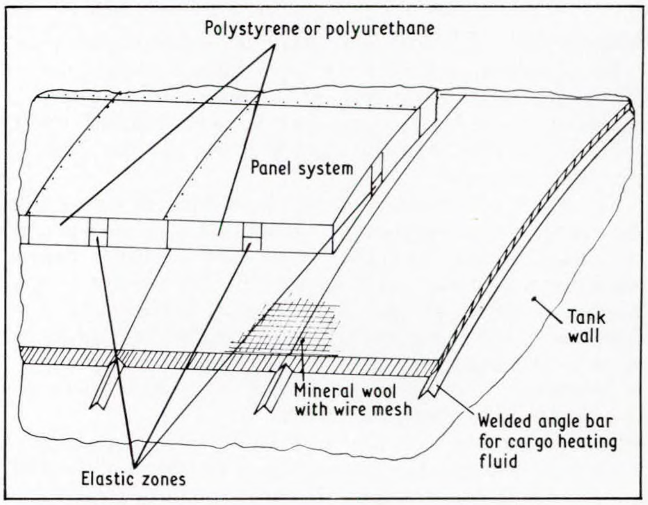

FIG. 2: Arrangement of cargo tank insulation

The material which best fulfills these requirements is austenitic stainless steel ASTM A 316 LN, which has good toughness characteristics down to 0 K, good corrosion resistance to a large range of chemicals, mechanical characteristics not significantly worse than those of the carbon manganese steel used for pressure vessels and a price similar to that of the nickel alloy steel normally used for ethylene tanks. The composition and characteristics of the steel are given in Table III.

One problem with the use of austenitic stainless steel for bilobe tanks is in the welding of the longitudinal bulkhead to the cylindrical shells. This weld cannot, because of its shape, be examined by X-ray techniques. For carbon manganese steel ultrasonic examination is possible.

In the case of austenitic steel the metallurgical structure of the heat-affected zone creates some difficulties in the interpretation of ultrasonic measurements. This means that special procedures, including precise calibration of the defects, are necessary.

However, this problem is also encountered in ethylene tanks built of nickel alloys and welded with austenitic welding rods.

Cargo tank insulation

In order to limit the ingress of heat into tanks containing low-temperature cargoes, they must be efficiently insulated. This reduces the time that the refrigeration plant has to be operated and avoids the hull being cooled to dangerous levels.

In the case of tankers used for ethylene, LPG or chemicals, the insulation has to be efficient for temperatures in the range from −104 to +90 °C. The low-temperature insulation is normally polyurethane or polystyrene foam, which is not suitable for higher temperatures. It is therefore necessary to combine high-temperature insulation such as mineral wool with a low-temperature insulation (see Fig. 2).

The inside layer is made of mineral-wool slabs within a galvanized wire mesh and the outside layer consists of polystyrene or polyurethane foam panels which have elastic zones to take up the expansion and contraction. The panels are glued to each other and clad with metal sheets for mechanical protection. This type of insulation is suitable for use with external heating coils.

The insulation must be able to withstand thermal cycling between minimum and maximum design temperatures. In order to achieve good performance under thermal fatigue, the foam insulation should not be bonded to the tank shell and should preferably be fitted with elastic zones.

Piping system

The piping system of a combined tanker must be designed for the minimum expected temperature, be resistant to corrosion and easily drained and cleaned. The first two requirements lead to the same type of material as used for the cargo tanks, ie austenitic stainless steel containing molybdenum (grade 316).

The need to drain and clean the piping system is not a new requirement, as it is also necessary in LPG tankers handling butadiene or VCM. Nevertheless, because of the high viscosity of some chemicals and the possibility of crystallization in others, the design of the piping system must ensure that it is self-draining and can be cleaned.

The self-draining pipes from the cross-overs lead to the tanks where stripping facilities are provided. The piping aft of the cross-over is arranged with a slight downward slope (about 1.5°) to the stern and the piping forward of the loading manifolds is led with a greater slope (about 3°) to the stem to allow for the trim of the ship.

Numerous drain cocks should be fitted to the piping and connected to the stripping lines. All dead ends are to be avoided, and branch pipes fitted with blind flanges are to be as short as possible and mounted horizontally for more efficient self-draining and cleaning.

Pipe valves in the piping must be suitable for both liquefied gases and chemicals. Apart from the strength and corrosion characteristics required for all components in low-temperature areas or in contact with corrosive products, the valves must also be gas tight and easy to clean. This leads to the use of butterfly valves with resilient seats (eg PTFE) or plug valves of the top entry type with easy access to the plug for cleaning purposes.

The different arrangements of liquefied gas and chemical loading and discharge terminals may require the ship to be fitted with two types of transfer manifold, one to meet the chemical standard and the other to meet the liquefied gas standard. In addition a stripping manifold for purging is to be fitted. This requires a minimum of three liquid cross-over connections for each cargo system.

Cargo transfer facilities

The cargo pumps of a combined tanker are designed for temperatures between −104 and +90 °C, densities in the range from 0.58 to 2.2 t/m^3 an viscosities up to 2000 cSt. The pumps are of the deep-well type with a double-sealing system. The first seal is for liquid at the discharge pressure with a drain return to the cargo tank, and the second seal is both gas- and liquid-tight at a pressure greater than the tank pressure.

The materials used in the pump must be able to withstand the temperatures encountered and the corrosiveness of the product. Thus austenitic stainless steel with a low carbon and molybdenum content is used. However the material is not the best solution for highly corrosive products containing solid particles (eg phosphoric acid). Nevertheless, a compromise has to be made and as ethylene is the lead product, chemicals such as phosphoric acid are likely to be handled for only a short part of the lifetime of the vessel.

The pump, in order to be able to handle products within the range of densities and viscosities, must be capable of operation at two or more speeds. Different types of prime mover may be used to provide variable speed.

Electric motors

With electric motors, the speed can be controlled by frequency converters, by an autotransformer or by using a multiple pole motor.

The autotransformer is not a realistic solution if the pump is in frequent use. Excessive reductions in voltage for lower speeds cause instability and this method is very inefficient.

The frequency converter is a possible solution as the motor is run efficiently. In addition, the cost of such equipment has been significantly reduced in recent years. The only disadvantage is the maintenance of sophisticated electronic equipment, which cannot be undertaken by the crew and requires specialists.

The multiple pole motor may only reasonably be used at two different speeds and so no flexibility is available. The complexity of the pole-changing stator windings makes such motors very expensive.

Hydraulic motors

A hydraulic prime mover for pumps permits a full range of speed and torque with flow and pressure control. Either mechanical/electric/hydraulic or mechanical/hydraulic systems can be used. The latter set-up offers higher efficiency as no electrical loss occurs, but speed control is required when driven from an internal combustion engine. This is provided in the mechanical/electric/hydraulic system.

For this reason an efficient hydraulic system should be fitted with:

1. Variable displacement, pressure compensated hydraulic pumps to provide a constant pressure to the ring main independent of load. The pressure can be set at any level up to the maximum allowable.
2. Variable displacement, individually adjustable hydraulic

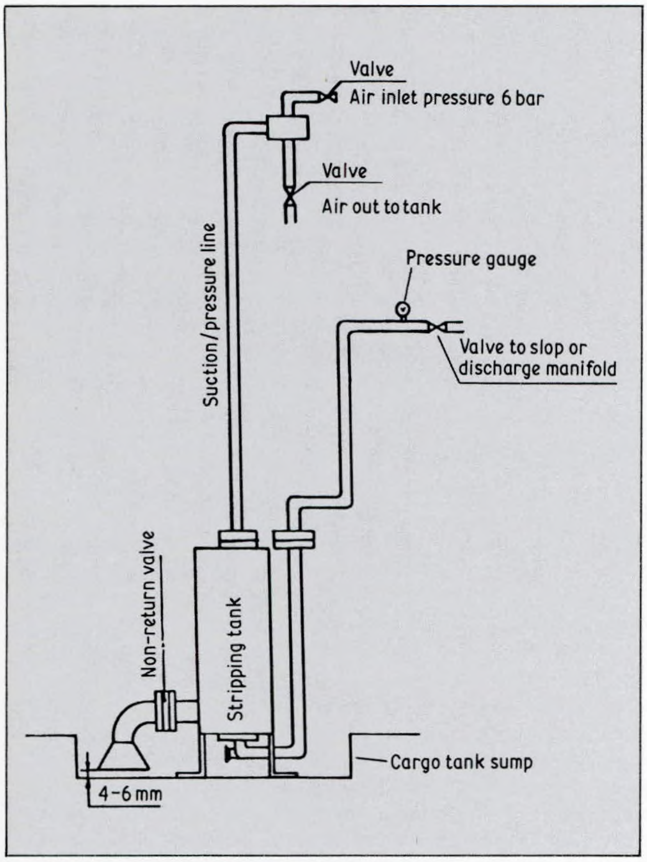

FIG. 3: Arrangement of a stripping box in a cargo tank

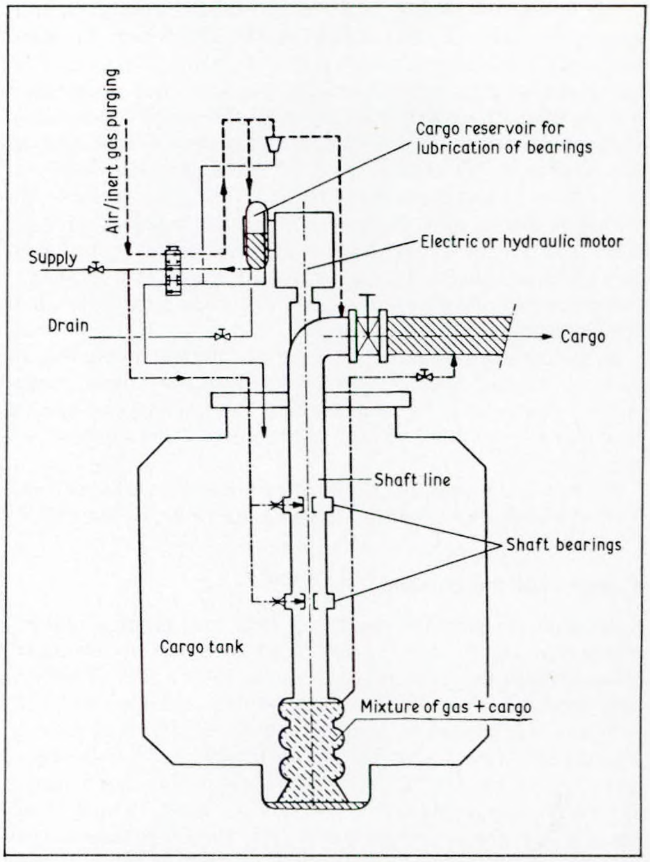

FIG. 4: Arrangement of a cargo pump for efficient stripping

motors to enable the cargo pumps to operate at maximum efficiency.

The cargo pumps may also have to operate at low flow rates when passing the cargo through a heat exchanger for heating or cooling purposes, or for recirculating products such as phosphoric acid, which may contain solid deposits. This requires an additional connection to the cargo pump system and greater flexibility from the pump.

Stripping

The stripping of the cargo tanks, in accordance with MARPOL 73/78 Annex II, may be achieved using one of three systems.

The first system involves pressurizing the cargo tank and stripping it via a small diameter line led down to the bottom of the sump with the cargo tank relief valves set to not less than 3 bar. The operation is slow and may require a large quantity of inert gas or nitrogen to fill the tank.

The second system involves a stripping box in the tank. This box is connected to the stripping line and another line which is pressurized with either inert gas or nitrogen or under vacuum from an air ejector. A suction line is led down to the bottom of the sump and fitted with a non-return valve (see Fig. 3).

The stripping operation is performed by cycling alternate pressure and vacuum in the box until a vacuum can no longer be drawn. This arrangement has the advantage of simplicity and does not involve rotating machines, but the non-return valve may be a problem if crystallization occurs.

The third system involves a pump operating against a closed discharge valve and top pressurization of the column with nitrogen. The stripping line is led from the discharge manifold of the pump to the discharge side of the shut cargo discharge valve. This system requires the pump to operate for long periods with a closed discharge valve and without lubricating liquid for the long shaft bearings. A reservoir of pressurized cargo liquid is therefore provided to lubricate the bearings (see Fig. 4).

Temperature control

A standard reliquefaction plant for handling boil-off gas is provided. This is normally a cascade plant using an R22 cycle with an evaporator for ethylene and a sea-water condenser for LPG or ammonia.

In addition to the conventional system, another system is required to handle chemical cargoes with either a high melting point or a high viscosity.

External heat exchanger

An external heat exchanger [see Fig. 5(a)] is fitted to the cargo pump system. This arrangement is used with phosphoric acid, which requires recirculation.

External heat transfer

In this arrangement [see Fig. 5(b)] channels made by angle bar stiffeners are welded directly to the external shell of the tank. Owing to the difficulties of venting these spiral channels, the heating/cooling fluid must remain liquid over the entire range of operating temperatures (from −104 to +90 °C).

There is a risk of fluid leakage into the insulation and possible damage to it. This is because non-destructive testing of the welds of the angle bar channels is not easy and in-service survey is not possible as the channels are located under the insulation of the cargo tanks.

Electric strip heating

The electric strip heating system [see Fig. 5(c)] consists of self-regulating tape laid directly on the outer surface of the tank shell under the insulation. This tape is made of two conductors linked by a semi-conductive core, which regulates the heating power in the tape.

When used in the hold space of a tanker, which is designated a hazardous area, the tape has to be certified as safe. The tape is fitted with a protective jacket and, being located under the

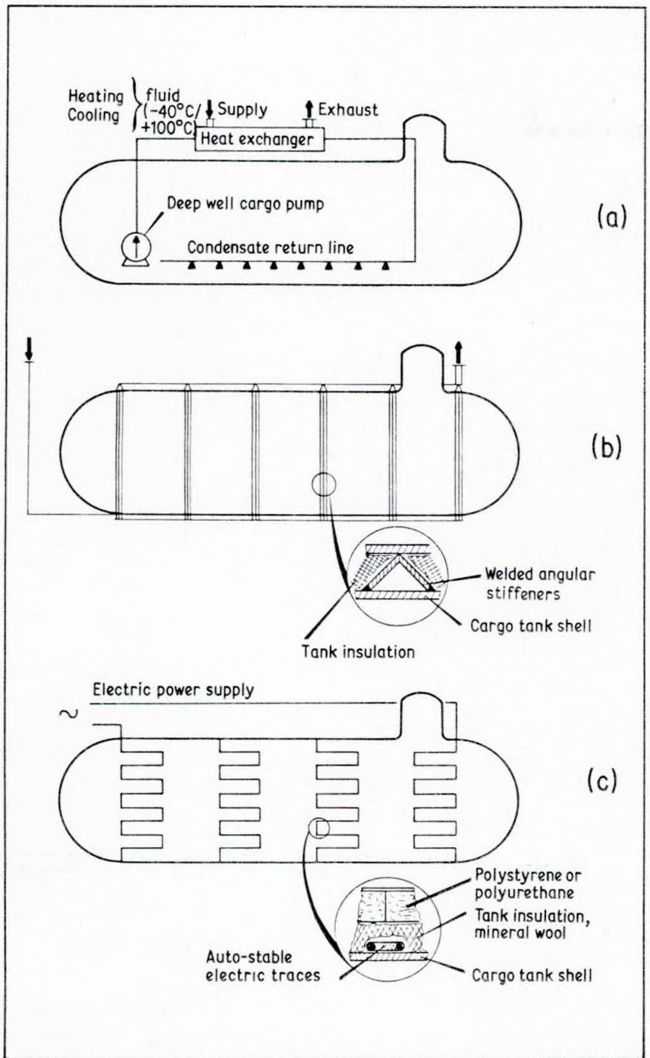

FIG. 5: Arrangements for heating and cooling cargoes: (a) external heat exchanger, (b) external heat transfer and (c) electric strip heating

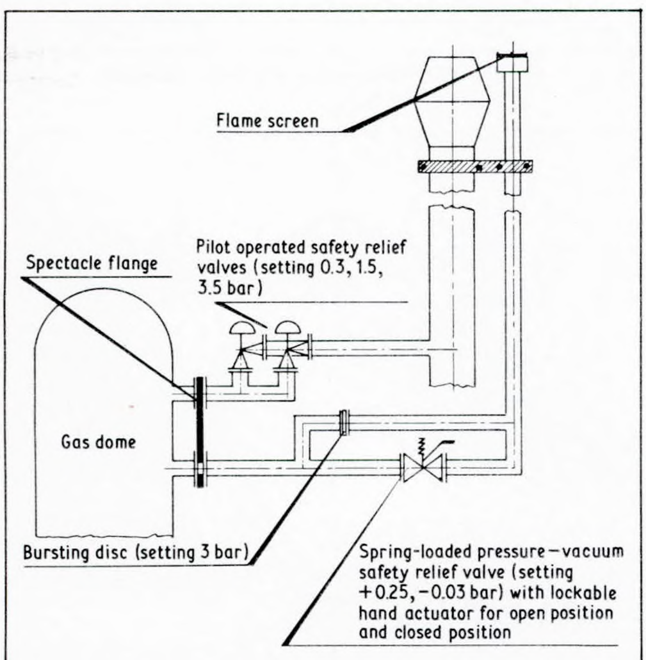

FIG. 6: Arrangement of venting in a cargo tank

insulation, is protected by the steel cladding provided for mechanical protection of the insulation.

Under these conditions, and provided the junction boxes are certified as safe, this system may be considered as meeting the requirements of the regulations for either liquefied gas carriers or chemical tankers. The advantages of this arrangement are that no heating fluid is required and the external heating coils are efficient.

On the other hand this arrangement, being an interpretation of the IGC and IBC Codes, requires the agreement of the Flag Administration. It also increases the electrical power needed by the vessel as the heating system will be used simultaneously with cargo handling equipment when the pumps may be discharging a high viscosity product.

Finally, this system cannot be used for indirect cooling, which is required for cargoes such as propylene oxide in order to avoid the possibility of an explosive autopolymerization reaction occurring under the effects of pressure and temperature. However, these products have a low vapour pressure under ambient conditions up to 45 °C and can be transported in a fully pressurized condition. Therefore the need for cooling is not a major design consideration.

Venting system

As described in the rules applicable to these vessels, the venting systems (see Fig. 6) for liquefied gases and chemicals have different purposes. The venting system of a chemical tanker is designed to keep the tank pressure within the working range (normally −30 to +200 mbar) and allow vapour displacement during loading or unloading of the tank. Normal practice is to use weight- or spring-loaded pressure/vacuum relief valves which are lockable in the open position.

The venting arrangement of the liquefied gas containment system is for emergency use only in the case of a fire. The system is pressure-tight under normal conditions and is designed for high flows associated with the heavy vaporization that would be caused when the cargo tank is surrounded by fire.

The relief valves are of the pilot-operated type and are activated immediately the setting pressure is reached and close immediately the pressure drops below the set value. Pilot-operated valves are not suitable for use with chemicals which crystallize as they may clog the valve and so render it inoperable.

The chemical system is fitted with a combined pressure/vacuum relief valve which is not susceptible to clogging. This valve is lockable in the open position for loading, unloading or gas freeing. It may also be locked in the closed position for use when the tank is pressurized for stripping. In this case a by-pass with a bursting disc set below the maximum working pressure of the tank must be fitted.

Because of the different relief systems required for gas and chemical cargoes, two systems have to be fitted. These systems are connected to the tank dome by a common spectacle flange, which acts as an interlock and prevents the gas and chemical relief valves from being disconnected simultaneously. When changing from a gas to a chemical cargo the flange is moved into the chemical cargo position, activating the chemical cargo venting system. Separate gas and chemical exhaust pipes are fitted up the vent mast with flame screens at their exits.

Instrumentation

Cargo instrumentation is provided for level, pressure and temperature, and must be able to withstand a wide range of temperatures, pressures and densities.

Temperature sensors must be able to give readings from −104 to +90 °C or should be duplicated. The level gauging system must comply with the Code requirements for all cargoes, and each tank should include a level gauge measuring 0 to 100%, a high-level alarm and a second high-level alarm for overflow control. The three systems are to be independent of each other.

With chemical cargoes some designs of level gauges do not work satisfactorily and should not be used. Float systems are usually fitted and have proved to be satisfactory. The float can be either in a wire tube or be wire guided. The former allows for better protection of the float while the latter suffers less blockages and is easier to clean. Washing arrangements should be fitted to tube float gauges.

Fire fighting

The fire-fighting installations should comply with the applicable regulations for both chemical and gas cargoes. The requirements of the codes are different, which again leads to two separate systems and raises problems of compatibility and operational procedures.

The dry powder of the gas system should be compatible with the foam of the chemical system, but this does not generally cause difficulties (except with some fluoroproteinic foams). Of greater concern is the possibility of the foam blanket of the chemical system being destroyed by the water spray of the gas system.

The aim of the water spray is to cool the liquefied gas containment system (domes, deck tanks, control valves and manifolds). A low-expansion foam can, to some extent, also achieve this cooling effect. Loading and unloading operations present a high fire risk and the manifold zone is considered to be a critical area.

Four possible situations are envisaged:

1. Gas carriage and gas handling, which implies use of the gas fire-fighting system.
2. Chemical carriage and chemical handling, which implies the use of the chemical fire-fighting system.
3. Combined gas and chemical carriage and gas handling. In this case a gas fire is expected and the dry powder should be used in conjunction with the cooling water spray to protect the cargo containment and piping systems.
4. Combined gas and chemical carriage and chemical handling. In this case foam should be used for fire fighting, but water spray should be used for cooling in 'remote' locations. The compatibility of the foam and water spray needs to be considered. The systems may be divided into sections throughout the cargo area and there may be physical separation by the cargo area coamings on deck.

The use of AFFF foam, which is efficient even at a very low expansion ratio, permits the water spray to be doped and so avoid compatibility problems.

The foam system, in accordance with the regulations, is sized on the basis of the cargo tank area, the width between two monitors or the largest tank area. On combined liquefied gas and chemical ships, which have large tanks (compared with chemical tankers), the rate of delivery of foam will be high. This implies large storage tanks and copious supplies of water, which must be allowed for when designing the ship's sea-water service system.

Foam may be more efficient than either powder or water spray on liquid IGC Code cargoes such as acetaldehyde, which, being a very polar liquid, requires a very efficient foam.

Operation

The combined tankers, in addition to the operational requirements of transporting either liquefied gas or chemicals, are designed to carry both types of cargo. The transportation of chemicals emphasizes the problems of stripping and draining the cargo piping and tankage. It must be possible to clean and dry the tanks when the cargo is changed. The operations involved when changing the cargo of a multipurpose tanker are summarized in Fig. 7.

The ship is fitted with a cleaning system which can be operated with sea water, fresh water or chemicals. The use of

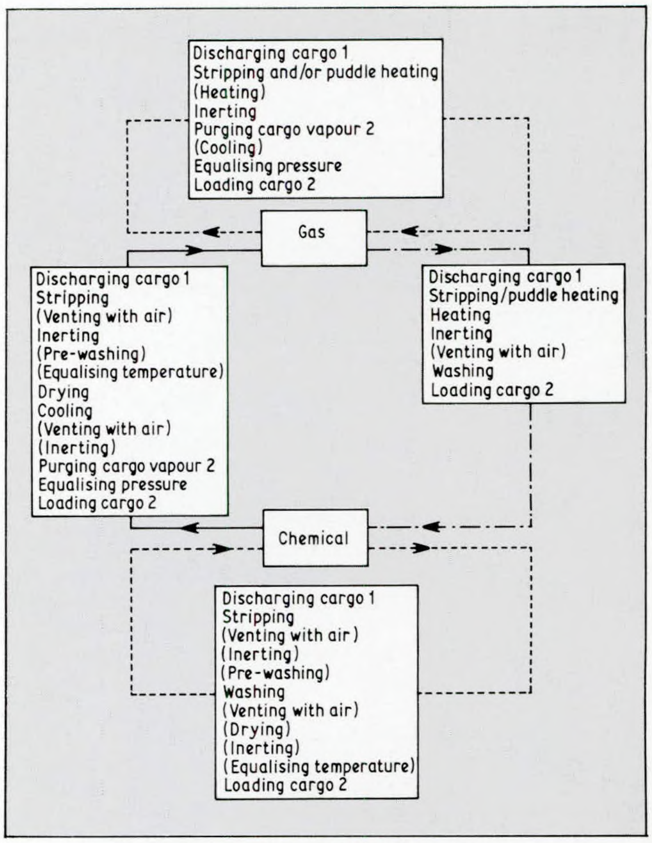

FIG. 7: Operations involved in changing the cargo

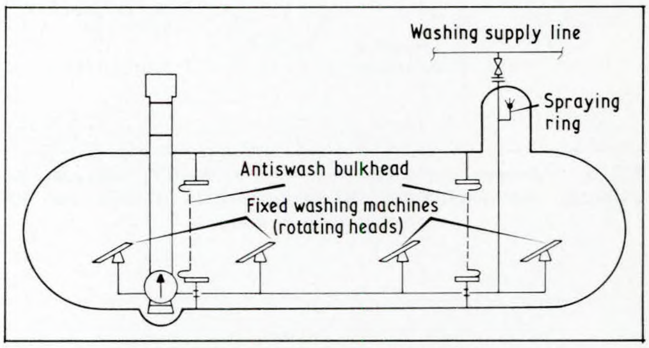

FIG. 8: Arrangement of washing machines

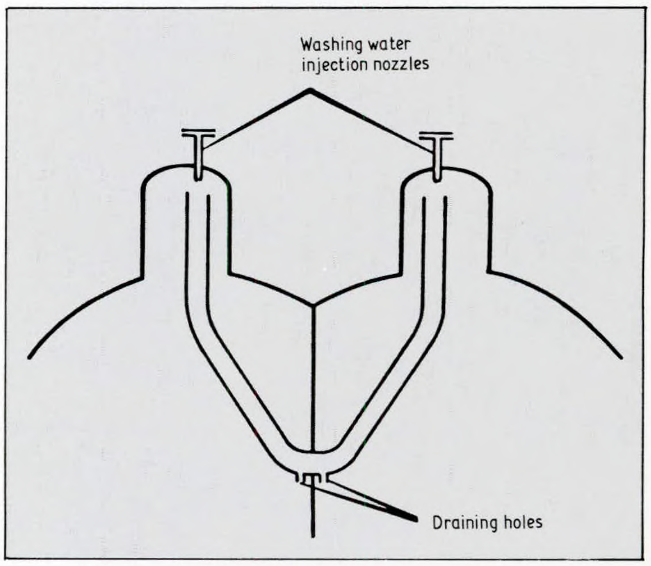

FIG. 9: Arrangement of U tube in a bilobe tank

sea water reduces the required capacity of the industrial fresh-water tanks but it cannot be used alone and is always followed by fresh-water cleaning. Moreover, sea water is not recommended for warm or hot washing as it can react with stainless steel.

Washing water is normally classified as ambient up to 20 °C, warm between 20 to 60 °C and hot above 60 °C. Steaming is not a suitable cleaning method for insulated tanks as steam will not condense on the tank walls.

The washing system consists of an arrangement of pipes, pumps, heaters and valves with cleaning machines located inside the tank. The machines of a chemical tanker are normally removable, but for combined tankers fitted with pressure tanks this is not possible as the machines would need to be fitted beneath the openings.

This would need as many tank domes as washing positions, which would be neither structurally desirable nor economically practical. Moreover, the arrangement on deck of openings to the tank would not be easy, specially in way of the cargo compressor room or electric motor room.

Fixed machines are therefore provided inside the tank. They are made of stainless steel, avoiding the use of brass or other unsuitable material, and lubricated by the washing fluid.

The arrangement of washing machines in the tank is determined by the capacity of the heating system of the washing plant as all machines in a tank are supplied from a common line in order to limit the number of penetrations through the tank walls. The machines are normally fitted near the bottom of the tank for easy maintenance (see Fig. 8).

Special washing arrangements may also be necessary, such as a spray ring in the gas dome or water injection pipes for washing the U tube in the case of bilobe tanks (see Fig. 9).

The major problem on changing from a chemical to liquefied gas cargo is drying the tank. Efficient stripping of water is necessary and requires the crew to enter the tank. The washing is often completed using hand hoses inside of the tank. This need not increase the time in port as often the charterer will carry out an internal cargo tank survey at the same time.

After drying, the tanks are normally vented with air and inert gas before the new cargo vapour is introduced. For a cryogenic cargo, any moisture left in the tank will create problems for the cargo handling equipment.

CONCLUSIONS

The first requirement before designing a combined liquefied gas and chemical tanker is to choose a lead product. Until now ethylene has been chosen because of its profitable charting possibilities. The capacity of the ethylene fleet will remain large, with a total of 267 053 m^3 in 39 ships, and only three of these ships are more than 15 years old. Moreover, the importance of the ethylene trade will decrease as European ethylene crackers at present out of commission come back into service, and so the possibilities of carrying ethylene profitably will decrease. Also the lack of flexibility of LPG ships will become a problem as the market declines.

The design of future combined tankers will be different. Ethylene, to which the current limitation of 12 000 m^3 is linked, will no longer be the lead product and the restriction on the size of the ship will be lifted. An example of this change is the 30 000 m^3 combined LPG and chemical tanker delivered in June 1985 from Meyer Werft. This vessel is fitted with carbon manganese steel trilobe tanks and is not intended to carry ethylene.

ACKNOWLEDGEMENTS

The author thanks those companies which have been kind enough to assist in the research for this paper or have provided information (Liquid Gas Anlagen, Gazocean, Barry Rogliano Salles, Creusot Loire, Thune Eureka, Svanehoj, Kaffer Isoliertechnik, Skarpenord and Tofte & Jorgensen).

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Discussion

J. WHYTE (Liquid Gas Equipment Ltd): First I should like to congratulate Mr Anslot on a very interesting and informative paper which not only deals with the technical details of this comparatively new type of ship but also discusses and questions a number of the commercial assumptions which have influenced their development.

I have to admit to an interest in both the technical and commercial camps as I work for an engineering company that also owns and operates liquefied gas carriers. The freight market today is very depressed and likely to remain that way for some time, and so if new ships are to compete they will have to be cheap to build and efficient to operate. The ship design illustrated in this paper is based on bilobe tanks, and while these undoubtedly give the best utilization of the sectional area of the ship and are ideal for cargoes with specific gravities up to 1, their use with cargoes with specific gravities of 1.4 produces a very deep draughted ship, which makes it difficult to meet the IMO survival capability. Therefore, if you need extra beam to reduce the draught with the high specific gravity cargoes, is it not better to go for cylindrical tanks which are lighter, cheaper and easier to clean?

On the question of the price of tanks, my company has found that tanks made of 316 steel and suitable for LPG, ethylene and hazardous cargoes are about twice the price of tanks made of carbon manganese steel and suitable for LPG only.

My final technical point is on the question of pump motors. There is no doubt that hydraulic drivers are very flexible but expensive in terms of both power and money. It should not be forgotten that ordinary LPG/ethylene carriers cope with specific gravities between 0.5 and 1 with single-speed motors and I believe that the higher specific gravity cargoes could also be handled with two-speed pole-changing motors, which are simple, reliable and comparatively cheap.

If this new class of ship has problems, I am sure they will not be of a technical nature. The ships already in service have proved that they are capable of changing from one type of cargo to the other rapidly and efficiently. But the number of charterers who control a mix of gas and good-paying chemicals or the spot market opportunities is very limited. In other words, these ships have few opportunities to do many of the very clever things for which they have been designed.

I do not wish to sound a negative note but I believe that for most cargoes on the market today a simple gas or chemical carrier will always undercut these technically clever but expensive ships, and I wonder if they have a viable commercial future.

T. A. D. SHARP (Department of Transport): I should like to compliment Mr Anslot on his very interesting paper and for presenting in such a clear manner the different requirements that would have to be met for such a combined carrier. My particular interest at the present time is the implementation of MARPOL Annex II and it is on this aspect of the paper that I should like to comment and ask a question.

On p. 5 under the 'MARPOL Annex II' heading, it is quite rightly stated that for new ships (built after 1 July 1986) the stripping system must be capable of reducing the residue in the pump area and pipeline to less than 100 litres for category B and less than 300 litres for category C substances. This is a very onerous requirement and the tolerance permitted in the required practical water test is in fact 50 litres over the regulation stated limit, that is +50 litres, not ±50 litres as given in the paper.

Because this stripping capability is so important to meet the MARPOL Annex II requirements, I would like to make some comments concerning p. 7 under the heading 'Piping system'. It is stated that the design of the piping system must ensure that it is self-draining and can be cleaned, and goes on to say that 'the self-draining pipes from the cross-overs lead to the tanks where stripping facilities are provided. The piping aft of the cross-over is arranged with slight downward slope to the stern'. This is correct for most pumping systems configurations. However, it continues 'the piping forward of the manifolds are led with a greater slope to the stern to allow for the trim of the ship', which should surely read 'downward slope to the stem or forward'. Would Mr Anslot confirm my assumption or provide an explanation.

The design of the tanks, type C cylindrical or lobe, would appear to be ideal for draining but as with most chemical tankers having to comply with MARPOL Annex II the main amount of residue will be in the pump and piping system. It is the ability to strip these that becomes of paramount importance. Referring to p. 8 under 'Stripping', the first system, pressurizing the cargo tank and the use of small bore lines, means that pipe drainage back to the tank is essential. The second system, involving the use of a stripping tank, would also appear to require drainage of the deck pipeline, manifolds and crossovers back to the tank.

The third system, involving pressurizing the top of the liquid column in the pump stack, has been in use for many years but, I understand, with limited success. The discharge section of cargo piping relating to this third system (shown in Fig. 4, including manifolds and cross-overs) will also need to be stripped, by line blowing, pressurizing or other methods, but whichever method is used design for drainage is necessary. Has Mr Anslot any views as to the best system to adopt to meet the MARPOL stripping requirements?

J. R. J. LEJEUNE (NORMED): I should first like to congratulate Mr Anslot on a very interesting paper.

From what Mr Anslot has told us, not many of these ships seem to be used to carry chemicals, and I wonder how many are being used to carry chemicals classified as type II in the BCH or IBC Codes.

Electric strip heating does not seem to be acceptable to most Flag Administrations, and I would like to ask Mr Anslot if he thinks it is logical to accept electric strip heating and to forbid the use of electric motors (even those certified as safe) in enclosed gas-dangerous spaces.

T. M. C. KELLY (Gerald Geddes and Partners): We now have a combined liquefied gas and chemical tanker in which the prolific use of water becomes the norm for cleaning the cargo tanks, cargo pumps and the associated cargo pipelines when changing cargo grades.

In the liquid gas trade, water, even in the smallest quantities, has always been regarded as the devil responsible for many of the operational problems which occur. The cost of supplying methanol to combat this water, whatever its source, is an additional operating cost to the shipowner and unless an adequate storage and handling system for the methanol is provided there will be an increased workload on the crew.

Mr Anslot discusses the washing and drying of the cargo tanks involving additional manual washing and mopping out by the ship's crew. No doubt the final drying of the cargo tanks could be assisted by the use of the external tank-heating system. However, this cleaning and drying of the cargo tanks will impose a higher workload on the crew, which has been reduced to what is presently considered the bare minimum with further reductions envisaged, and could be to little or no avail unless an adequate means of drying the associated cargo pipelines is available.

Mr Anslot has made little reference to the cargo pipeline system or the means by which the cargo pipelines are cleaned and dried. This is a difficult task, as anyone who has been involved in the hydraulic testing of cargo liquid lines in existing liquid gas vessels will be aware, unless there is a means available by which the cargo pipelines can be heated from without by line heaters or from within by the use of hot air blowers.

The removal of cargo residue and/or water from the deeply corrugated expansion bellows pieces, many of which are incorporated in a cargo pipeline system, could be a special problem in itself and the crew should not be expected to perform a strip-down, clean and replace operation, with its attendant problems, on a short ballast passage solely to remove water. Without an effective arrangement for drying out the cargo pipelines I forsee the possibility of the shipowner being involved in off-hire and/or cargo contamination claims.

I would appreciate Mr Anslot's views on the above comments and would add four questions which, I appreciate, he may not be in a position to answer fully.

1. In the vessel which was delivered to the owner by Meyer Werft in 1985, are there any special arrangements installed for cleaning and drying out the cargo pipelines?
2. What arrangements are installed to ensure that cargo residues and/or water are cleared from the liquid gas vapour rails and purge rails, also spray rails (if fitted) within the cargo tanks?
3. Since the Meyer Werft vessel entered service, and presuming that cargo grade changes from chemical to liquid gas have been involved, have any operational disturbances been experienced as a result of the prolific use of water and/or inadequate drying out of the tanks and pipe systems?
4. Has the consumption of methanol increased significantly and does the vessel have increased storage arrangements and a handling system for methanol?

P. T. D. WILLIAMS (Department of Transport): Cleaning of cargo tanks must entail additional operating problems. Because of spray cooling pipes etc. in tanks for gas carriage, how is it ensured that all product and water is removed? Is it proposed to use copious amounts of methanol? If so, what becomes of the residue of water-contaminated methanol? Is this retained for recovery later or consigned to the slop tank?

It should be pointed out that COF will be mandatory for gas carriers when products listed in both the gas and chemical codes are being carried.

Pump rooms are not forbidden by the gas code. It is for the Flag Administration to decide. Further on in the paper a pump room ventilation rate for gas carriers is mentioned which conflicts with this earlier statement. The gas codes also take polymerization into account.

Relief valves are fitted to gas carriers not only for relief under fire conditions but also to protect the cargo tanks in the event of maloperation of the refrigeration plant. As pressure tanks are being proposed which, it is assumed, will be built to withstand a vacuum in the region of 90%, I would be interested in Mr Anslot's views on the need to provide a vacuum protection (ie pressure/vacuum) valve as a chemical code requirement.

I do not believe that IMO would agree that a low-expansion foam meets the cooling requirements of a water-spray system of gas code standards. The problem of compatability with water-spray and foam systems may not be as great as anticipated. As the area of the gas dome or manifold is comparatively small compared with the deck area to be covered by foam, where chemicals are carried adequate separation from each other with a bund or sill would seem to be the answer. Spray drift, however, may be a problem.

Acetaldehyde, not being a gas but being in the gas code, is a special case. However, the summary of minimum requirements asks for no other fire-protection measures not afforded to the gases.

G. CHAPMAN (Department of Transport): Mr Anslot has stated that the maximum cargo capacity of the vessel is envisaged as 12 000 m^3 and presumably two bilobe tanks (ie four tanks) is the optimum number. Any increase in individual tank size would incur the inert gas penalty when carrying flammable liquid chemicals (3000 m^3 per tank).

Each cargo tank contains an appreciable amount of equipment, piping and instrumentation, as follows:

- Cargo pump with stripping arrangements.
- Tank cleaning equipment.
- Reliquefaction piping.
- Anti-swash bulkheads.
- High level alarms.

The problems of cleaning such tanks have been touched upon but surely such cargo containment arrangements are asking for cargo contamination to take place?

The paper concludes by mentioning a 30 000 m^3 combined LPG and chemical tanker. Can Mr Anslot give any details of the trilobe construction and the tank capacity?

Whilst accepting that the paper is technological in nature, models of operation are referred to in the fire-fighting section, ie the vessel is operated as a combination carrier carrying and handling gas and liquid chemicals simultaneously. Has Mr Anslot any knowledge of how frequently operating in both modes occurs, and have owners reported any difficulties in obtaining dual certificated crews and have the crews proved to be readily adaptable to both modes, each of which is fairly specialized.

R. G. BODDIE (Institute of Marine Engineers): Figure 2 shows the insulation of the cargo tanks with mineral wool next to the tank and polystyrene or polyurethane outside the mineral wool. Could Mr Anslot please explain the reason for selecting this type of insulation and the different insulating properties of mineral wool, polystyrene and polyurethane.

D. StJ. SEIGNE (Department of Transport): I would like to take issue with Mr Anslot on his proposals for the use of electric strip heating. I do not consider this system to be suitable for use in a marine environment. The heating cables are vulnerable to damage, particularly during overhaul and maintenance where confined or awkward spaces are concerned. All too often a pipe or flange is used as a stepping place to gain access to some item due for inspection. If the pipe or flange is fitted with strip heating cable, the likelihood of damage is quite real. There is also a risk of electric shock unless extra low voltage is used. Suitable voltages would severely restrict the choice of strip heating cables.

It is difficult to envisage how an arrangement of electric strip heating as described in the paper could be accepted as an interpretation of the IGC and IBC Codes. The hold spaces where it is proposed to fit the heating system are described in paragraphs 10.2.3.2 and 10.2.3.3 of the codes, respectively. In summary these paragraphs only allow 'through runs of cable' lighting which is certified flameproof (Ex d) and pressurized (Ex p) and certain navigational equipment in gastight enclosures.

Clearly the heating system is neither lighting nor navigational equipment. The only possible interpretation is to regard it as a 'through run of cable'. However, it cannot be regarded as such since it is a power-consuming device and, as Mr Anslot states, requires junction boxes which are themselves not allowed in the space.

There are two further complications. First, the only concept available for certification of electric strip heating systems is to the standards for increased safety (Ex e). This concept is not allowed in these spaces by the codes. Secondly, to meet the increased safety certification, an 'earthed neutral' electrical supply system would be necessary for earth fault trip. 'Earthed neutral' systems are not allowed by the codes.

C. BARCLAY: I would like to compliment Mr Anslot on a very comprehensive paper. As a Maritime Arbitrator, I often see claims relating to trouble with the deck piping of these tankers. This piping is exposed to salt spray and to a large temperature gradient, which in refrigerated chemical carriers cause surface blistering and ultimately corrosion failure.

One is handicapped by the relative inefficiency of crews. The Master, Chief Officer and engine-room staff may be able to sense danger and detect signs of impending failure, but the average seaman is trained inadequately and cannot recognize the areas prone to attack. The deck piping in refrigerated liquid carriers is thousands of feet long and requires constant supervision.

The life of a seaman is hard and the profession does not attract the best individuals. Often they are volunteers from the hinterland who have a sense of adventure but no connection with the sea and because of their ignorance they fear chemicals. Moreover, they do not know what to do in an emergency and are insufficiently trained in fire fighting and damage control. Training should be intensive, but this is difficult where the vessels serve a variety of purposes and the problems change from day to day and from cargo to cargo.

I am delighted to see that Mr Anslot believes in the use of compressed air for stripping, this being a common method of conveying liquid in chemical plants. I note also that he likes hydraulic power for actuating pumps in confined spaces.

Author's reply

In reply to Mr Whyte's question concerning the design, the arrangement of cargo tanks is important for the optimum use of the vessel, but the feasibility of the projected ship must also be considered. The following four factors must be taken into acount:

1. Optimization of survival capability.
2. Optimization of deadweight for various specific gravities.
3. Optimization of building costs.
4. Optimization of operational procedures (cargo changes).

Taking into account the requirements of both the IGC and IBC Codes, the first factor results in sharing the cargo containment system in several hold spaces or arranging a double hull in way of the cargo tanks with a breadth of $B/5$ (B being the moulded breadth of the ship). For new ships this leads to three holds, as no consideration of the limitation of damage in way of the transverse bulkheads may be used since the II PG concept is only relevant for gas tankers.

The second factor leads to minimization of the volume of cargo tanks compared with the ship's hull volume in order to accommodate cargoes of various specific gravities. The third factor means that simply shaped tanks with thin walls are used but with a limitation on the number of tanks. The fourth factor requires simple shapes, and the cylindrical tank seems to be the best design.

The basic design problem is that the four factors lead to different arrangements. Nevertheless, I agree with Mr Whyte that it seems to be a good solution, up to a certain size, to go for cylindrical tanks.

Regarding his second question, I can confirm that the prices of cargo tanks are effectively in the ratio he mentions. The price coefficients presented in the paper are for a whole ship, where the price of the tank is only a part of the overall price. This is why lower ratios can be found for the ship as some other equipment will remain at a constant price whatever cargo tank material is used.

Mr Whyte's third question is related to the type of prime mover used for the cargo pumps. The double-speed electric motor does not present any technological difficulties as it is basically a cage motor. The difference is in the windings: either the same winding with a change-over switch or two separate windings.

In the first case the powers are in a ratio of 4:1, with power at high speed slightly lower than that of an equivalent single-speed motor. They are suitable when the resisting torque varies as the square of the speed. In the second case, the powers associated with both speeds are almost the same and are comparable to that of a single-speed motor running at the lower speed. I therefore think that this type of motor, even if it has some advantages, lacks flexibility.

Mr Whyte's remark goes to the heart of the problem: is it preferable to choose a cheap and very dedicated ship or an expensive and very flexible vessel. The answer depends on the behaviour of the market and on the volume of freight available.

In a depressed market associated with a serious decrease in the volume of trade, the ratio of the charter price to the building and running costs cannot be considered in isolation; the efficiency of the vessel must also be taken into account (ie the time of unemployment). If the very flexible ship presents a sufficiently lower rate of unemployment there will be a better balance between running costs and profits; moreover, the ship will command a higher second-hand price.

In reply to Mr Sharp, the P and A standards allow for the water test a 'tolerance of 50 litres' which has been theoretically translated as ±50 litres. This is more or less a set clause as the important figure is the maximum allowed quantity of 350 litres. This has been corrected in the paper.

Mr Sharp's second remark is perfectly correct and the paper has been corrected.

It is more difficult to provide a complete answer to the last question covering the theoretical, practical and commercial aspects. The best solution for optimization of the stripping is to combine a mechanical system with full pressurization of the tank and the use of a small-bore line. However, this procedure has disadvantages in terms of the duration of the operation.

Mr Lejeune's remark on the actual use of combined tankers is relevant as most of them do not carry chemicals listed in the BCH or IBC Codes and are used for ethylene or other 'easy' chemicals. The problem is rather whether they fail to be chartered for carrying chemicals or whether they are continuously chartered at a fair price and with a minimum of cargo changing operations. From my own sources I feel that the latter is more likely.

The question Mr Lejeune raised about electric heating for cargo tanks is fully justified as this system has to be accepted by the Flag Administration. This matter, like some others regarding electrical arrangements for gas or chemical tankers, is subject to the interpretation of the regulations by national authorities.

Unfortunately, for a significant number of items, some administrations have different interpretations and levels of acceptance. This is leading to conflicts between the requirements. I think that there is a difference in the reliability of a rotating machine such as an electric motor and fully passive equipment such as strip heating, and it seems logical to differentiate between these two equipments in respect of safety.

Mr Kelly has made some interesting comments on the problems connected with cargo changes for a combined tanker. It is very important to point out that the major operation consists of removing any water in the cargo containment or handling system.

The various possibilities for drying have been summarized by Mr Kelly and there is presently no further development.

What is, I feel, of the greatest importance for further operation of the ship is the arrangement of the cargo piping. The problems encountered with bellows would seem to be a design matter. For combined tankers expansion bellows should be avoided as far as possible. If, in some places, there is an absolute need for such equipment, the only way to install it is vertically so that the corrugations strip by gravity. It is also necessary to avoid deep corrugations.

Concerning the Meyer Werft ship, I can only supply the following information:

1. The ship is not fitted with special equipment for cleaning and drying out the cargo lines. Cleaning is done by pumping through and drying by circulation of warm dry air.
2. No special arrangement is made to ensure that the piping inside the cargo tanks is cleared from cargo residues or water.
3. I have not heard about any operational problems with this ship, and it seems that the charterer is very satisfied with the effectiveness of the cleaning and drying.
4. I have no information about the methanol consumption.

The cleaning and drying of the cargo tanks when changing from liquid cargo to liquefied gas is a major operational problem, as Mr Williams assumes. The drying is performed by warm dry air or nitrogen in order to achieve a correct moisture content. Methanol should not normally be used except when a problem occurs (eg blocking of a cargo pump). In this case, the ship is loaded with LPG and the methanol is mixed with the cargo.

Combined tankers are designed and built for carriage of gases, products common to the gas and chemical codes and pure chemicals; therefore, the ship must have both gas and chemical certificates of fitness.

Regarding conflicts between the gas and chemical codes, I agree that the location of the pump room must be to the satisfaction of the Flag Administration, but the requirements for the position of pipe penetrations in the cargo tanks, which have to be above the weather deck, are a restriction by the standards of the chemical code. I agree that the gas code takes polymerization into account for some products such as butadiene.

I do not agree with Mr Williams' statement that the relief valves fitted on gas carriers protect the cargo tanks in the event of maloperation as this interpretation would lead to a conflict with the requirement for an additional pressure-relieving system, such a system being required to switch on only in the case of fire.

If the tank is to be protected in case of maloperation of the reliquefaction plant, then a filling level based upon the additional setting valve should not be accepted and this system would not appear in the code. Maloperation of the plant is taken into account by the high-pressure alarm required by the code, activated at a pressure slightly under the setting pressure of the relief valves.

As regards the question about vacuum, I think that for a combined tanker vacuum relief valves are not necessary, provided the vacuum capability of the tank is sufficient to withstand pumping out of a product far from its boiling point without opening the vapour space.

Regarding the use of a low-expansion foam, I do not feel that this contradicts the code which considers that the cooling effect of the water spray system is achieved by water being applied at a specified rate of application. I do not expect any difficulty in achieving the same cooling effect with a system using low-expansion foam provided that the rate of application is comparable, since the solution will contain only 5% foam concentrate and 95% water.

The locations where water spray is required are also those where the risk of fire is the greatest because of the possibility of leaking valves. Therefore these locations are also those where foam may be used for fire fighting and could be destroyed by a non-segmented water spray system.

As Mr Williams points out, acetaldehyde is a special case for the gas code, but as a combined tanker is fitted with both dry powder and foam, it may be of interest, in the case of a fire, to use foam on acetaldehyde, although it would not be required on a pure gas tanker.

In reply to Mr Chapman, the consideration of a capacity of 12 000 m^3 is based on a three bilobe tank vessel, which is necessary for damage survival capability. The number of tanks for consideration of the inert gas requirement is then six and the basic capacity is around 2000 m^3, which allows a margin up to the size where inert gas becomes mandatory.

Mr Chapman is right in stating the importance of cargo contamination since the cleaning operation is carried out principally to avoid any such contamination, which would lead to a claim from the charterer. The cleaning system and the arrangement of the equipment are designed for accurate cleaning, always bearing this in mind.

Thge Meyer Werft ship mentioned in the paper is a 30 000 m^3 combined tanker. She is fitted with four hold spaces and four tanks:

- Tank 1: bilobe, 5970 m^3 (100%).
- Tank 2: trilobe, 10 745 m^3 (100%).
- Tank 3: trilobe, 10 420 m^3 (100%).
- Tank 4: transverse cylindrical, 3000 m^3 (100%).

The trilobe tanks are horizontal and built with two longitudinal bulkheads. Each one forms a three-tank system with two side tanks and one control tank communicating only by U tubes which connect the gas domes internally. The diameter of the lobes is 13.20 m. The tanks are made of carbon manganese steel suitable for a minimum temperature of −48 °C. The maximum pressure according to IMO is 6.7 bars (4.8 bars for USCG). They are designed for a 50% vacuum.

Mr Chapman's question about crew training and certification highlights a very important problem, but I regret that I am unable to provide an answer.

In reply to Mr Boddie, the reason for using both mineral wool and polyurethane or polystyrene results from the different properties of those materials.

Mineral wool is a poor insulator for low-temperature tanks but is good for temperatures around 100 °C. Polyurethane and polystyrene are good insulators for low temperatures but are not suitable for temperatures around 100 °C.

The combination of both provides the good insulation properties of polyurethane or polystyrene with protection against high-temperatures achieved by a layer of mineral wool between the insulation and the tank shell.

I disagree with Mr Seigne as I do not believe that the use of electric heating contradicts the regulations, nor does it present a significant source of hazard. The electric heating strip would be located between the tank shell and the insulation and would be protected by the mechanical protection fitted on the outer surface of the insulation.

The safety certification is carried out on the basis of regulations for increased safety equipment (Ex e). The surface temperature of the strip is then lower than the self-ignition temperature of the loaded cargoes in normal or abnormal service.

On the other hand, for the supply of energy to lighting equipment the IGC and IBC Codes do not forbid the use of Pyrotenax-type cables (mineral insulated cables), the operating temperature of which is 100 °C. So there is no real difference, in terms of the source of hazards, between this light supply system, which is allowed by the code, and the electric heating system.

I thank Mr Barclay for his comments and I appreciate his support for some of the opinions expressed in the paper.

Regarding his point about piping failures caused by corrosion, I think that the combined tankers are in a good position. The material used for ethylene and chemicals is solid stainless steel A316 grade, which has good resistance to corrosion caused by seawater. The problem he described would not occur on such a tanker.

I agree with Mr Barclay's statement on the importance of training for crews sailing on ships of this type.

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