

# TANKER SAFETY GUIDE LIQUEFIED

Second edition 1995



## International Chamber of Shipping

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## PURPOSE AND SCOPE

The purpose of this publication is to provide those serving on ships carrying liquefied gases in bulk with up-to-date information on recognised good practice. While the recommendations given may not fully cover every possible situation, they do provide the best general guidance currently available on safe procedures in such situations.

For the purpose of promoting consistent and uniform safe working practices it is recommended that a copy of this Guide be kept - and used - on board all gas carriers.

This is a revision of the first edition of the ICS Tanker Safety Guide (Liquefied Gas) and is intended to be a companion to the ICS Tanker Safety Guide (Chemicals). Where a gas carrier is also certified to carry chemicals the more stringent recommendations should be followed.

The Guide deals primarily with operational matters and good safety practices. It does not make recommendations on the construction of gas ships or their equipment; such standards are set by the International Maritime Organisation (IMO), National Administrations and Classification Societies. The Guide does not address the operation of specific items of equipment, repairs or navigational equipment, although some references are made to these matters.

It should be borne in mind that in all cases the advice given in this Guide is subject to any local or national regulations that may be applicable. In addition, terminal operators have their own safety procedures which could affect the cargo handling operations and procedures to be adopted in emergencies. It is necessary for the Master and all personnel to be aware of, and to comply with, these regulations and procedures. They will be highlighted by the use of the Ship/Shore Safety Checklist.

The data sheets contained in this Guide outline the main characteristics of individual cargoes, and the action to be taken in an emergency. Matters relating solely to maintenance of the purity of individual cargoes and their condition during carriage have not been included.

## ACKNOWLEDGEMENT

The Tanker Safety Guide (Liquefied Gas) is a consolidation of experience and good operating practice in many companies. The production of this second edition would not have been possible without the contribution of many individuals and organisations who have given their time and expertise.

Particular thanks are due to:

- the members of the ICS Gas-Carriers Sub-Committee, in particular its Chairman, Mr Ulf Tveita (Norway), Captain John Glover (UK) and Mr Carl Salicath Mortensen (Denmark);
- the directors and staff of the Centre for Advanced Maritime Studies, Edinburgh;
- the Secretariat of the Society of International Gas Tanker and Terminal Operators (SIGTTO);
- the Warsash Campus of the Southampton Institute of Higher Education;

A special acknowledgement is made to the late Captain Alberto Allievi (Italy) a past member of the ICS Gas Carrier Sub-Committee and Director of the Centre for Advanced Maritime Studies in Edinburgh, for his personal contribution to the compilation of the data sheets.

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## DEFINITIONS

For the purpose of this Guide the following interpretations apply; other definitions of more limited application are given in Appendix 3.

**Absolute vapour density** The mass of a unit volume of gas\* under stated conditions of temperature and pressure.

[\*For the purpose of this Guide the term 'gas' is regarded as being synonymous with 'vapour'.]

**Adiabatic** Without transfer of heat. Adiabatic expansion is volume change in a liquid or gas with no heat loss or gain involved (see Appendix 3).

**Administration (Flag State)** The Government of the country in which the ship is registered. This is the authority that issues all certificates related to the operation of a ship, and is responsible for inspections to ensure compliance with appropriate standards.

**Administration (Port State)** The Government of the country in which a port is situated.

**Air lock** A separation area used to maintain adjacent areas at a pressure differential, e.g. an electric motor room air-lock is used to maintain pressure segregation between a gas-dangerous zone on the open weather deck and the pressurised gas-safe motor room.

**Approved equipment** Equipment of a design that has been tested, approved and certified by an appropriate authority, such as an Administration or Classification Society, as safe for use in a specified hazardous atmosphere.

**Anti-freeze** An agent which lowers the freezing point of water, e.g. alcohol, ethanol, methanol.

**Asphyxia** The condition arising when the blood is deprived of an adequate supply of oxygen so that loss of consciousness may follow.

**Asphyxiant** A gas or vapour, which may or may not have toxic properties, which when present in sufficient concentrations, excludes oxygen and leads to asphyxia.

**Auto-ignition temperature** The lowest temperature to which a solid, liquid or gas requires to be raised to (Autogenous ignition cause self-sustaining combustion without initiation by a spark or flame or temperature) other source of ignition.

**B.L.E.V.E.** Boiling Liquid Expanding Vapour Explosion. Associated with the rupture under fire conditions of a pressure vessel containing liquefied gas.

**Boil-off** Vapour produced above a cargo liquid surface due to evaporation, caused by heat ingress or a drop in pressure.

**Boiling point** The temperature at which the vapour pressure of a liquid equals that of the atmosphere above its surface; this temperature varies with pressure (see data sheets).

**Bonding (electrical)** The connecting together of electricity conducting metallic objects to ensure electrical continuity.

**Brittle fracture** Fracture of a material caused by lack of ductility in the crystal structure resulting from low temperature.

**Bulk** The term 'in bulk' refers to carriage of cargo in tanks or pressure vessels which are constructed as part of the



ship, the contents being loaded and discharged by the ship's installed handling system.

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**Cargo area** That part of the ship which contains the whole cargo system, cargo pump rooms and compressor rooms, and includes the full beam deck area over the length of the ship above the cargo containment system. Where fitted, the cofferdams, ballast or void spaces at the after end of the aftermost cargo space or the forward end of the forwardmost cargo space are excluded from the cargo area.

**Cargo containment system** The arrangement for containment of cargo including, where fitted, a primary and secondary barrier, associated insulation and any intervening spaces, and adjacent structure, if necessary for the support of these elements. If the secondary barrier is part of the hull structure it may be a boundary of the hold space.

**Cargo operations** Any operations on board a gas carrier involving the handling of cargo liquid or vapour, e.g. cargo transfer, reliquefaction, venting etc.

**Cargo tank** The liquid-tight shell designed to be the primary container of the cargo, and other liquid-tight containers whether or not associated with insulation or secondary barriers or both.

**Cargo transfer** The transfer of cargo liquid and/or vapour to or from the ship.

**Cavitation** Uneven flow caused by vapour pockets within a liquid. In a pump impeller casing this can occur even if the pump suction is flooded.

**Certificate of fitness** A certificate issued by the flag administration confirming that the structure, equipment, fittings, arrangements and materials used in the construction of a gas carrier are in compliance with the relevant IMO Gas Codes. Such certification may be issued on behalf of the Administration by approved Classification Societies.

**Certified gas-free** A term signifying that a tank, compartment or container has been tested by an (see also Gas-free) authorised person (usually a chemist from shore) using an approved testing instrument, and found to be in a suitable condition - i.e. not deficient in oxygen and sufficiently free from toxic and chemical gases - for a specified activity, such as hot work, and that a certificate to this effect has been issued.

**Certified safe electrical** (See Approved Equipment) **equipment**

**Chemical absorption** An instrument used for the detection of gases or vapours which works on the **detector** principle of a reaction between the gas and a chemical agent in the apparatus; the gas discolours the agent or the agent dissolves some of the gas (see

Appendix 6).

**Closed gauging system** A system in which the contents of a tank can be measured by means of a (**closed ullaging**) device which penetrates the tank, but which is part of a closed system preventing the release of tank contents. Examples are float-type systems, electronic probe, magnetic probe and bubbler tubes (see Appendix 6).

**Cofferdam** The isolating space between two adjacent steel bulkheads or decks; it may be a void or ballast space.

**Combustible gas detector** An instrument for detecting a flammable gas/air mixture and usually (**'Explosimeter'**) measuring the concentration of gas in terms of its Lower Flammable Limit (LFL). No single instrument is reliable for all combustible vapours (see Appendix 6).

**Coefficient of cubical expansion** The fractional increase in volume for a 1°C rise in temperature. The increase is % of this value for a 1 deg F rise.

**Critical pressure** The pressure of a saturated vapour at its critical temperature.

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**Critical temperature** The temperature above which a gas cannot be liquefied by pressure alone (see Appendix 3).

**Dew point** The temperature at which the water vapour present in a gas saturates the gas and begins to condense.

**Endothermic** A process which is accompanied by absorption of heat. **Exothermic** A process which is accompanied by evolution of heat.

**Explosion proof/flame proof equipment** Equipment or apparatus which will withstand, without damage and in accordance with its prescribed rating (including recognised overloads), any explosion of a prescribed flammable gas to which it may be subjected under practical operating conditions and which will prevent the transmission of flame to the surrounding atmosphere (see Appendix 7).

**'Explosimeter'** (See Combustible Gas Detector)

**Filling limit (or ratio)** That volume of a tank, expressed as a percentage of the total volume, which can be safely filled, having regard to the possible expansion (and change in density) of the liquid.

**Flame arrester** A device used in gas vent lines to arrest the passage of flame into enclosed spaces.

**Flame proof equipment** (See Explosion Proof Equipment)

**Flame screen (gauze screen)** A portable or fitted device incorporating one or more corrosion resistant wire woven fabrics of very small mesh used for preventing sparks from entering a tank or vent opening, or for A SHORT PERIOD OF TIME preventing the passage of flame, yet permitting the passage of gas (not to be confused with Flame Arrester).

**Flammable** Capable of being ignited and burning in air. **Flammable gas** A vapour/air mixture within the flammable range.

**Flammable limits** The minimum and maximum concentrations of vapour in air which form

flammable (explosive) mixtures are known as the lower flammable limit (LFL) and upper flammable limit (UFL) respectively. (These terms are synonymous with lower explosive limit (LEL) and upper explosive limit (UEL) respectively.)

**Flammable range** The range of flammable vapour concentrations in air between the lower and upper flammable limits. Mixtures within this range are capable of being ignited and of burning.

**Flash point** The lowest temperature at which a liquid gives off sufficient vapour to form a flammable mixture with air near the surface of the liquid or within the apparatus used. This temperature is determined by laboratory testing in a prescribed apparatus.

**Gas absorption detector** (See Chemical Absorption Detector)

**Gas-dangerous space or zone** A space or zone within the cargo area which is designated as likely to contain flammable vapours and which is not equipped with approved arrangements to ensure that its atmosphere is maintained in a safe condition at all times.

**Gas detector** An instrument which alerts someone to the presence of gas, especially in spaces where gas is not normally expected.

**Gas-free** Gas-free means that a tank, compartment or container has been tested using approved gas detection equipment and found to be sufficiently free, at the time of the test, from toxic, flammable or inert gases for a specific purpose.

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**Gas-freeing** The process of displacing toxic or flammable vapours, or inert gas from a tank, compartment or container, followed by the introduction of fresh air into the tank, compartment or container (for correct procedures, see Chapter 4).

**Gas-safe space** A space not designated as a gas-dangerous space.

**'Gascope'** A trade name for an instrument used to detect and indicate the presence of cargo vapour. (See Appendix 6, section 7)

**Gauze screen** (See Flame Screen)

**Hold space** The space enclosed by the ship's structure in which a cargo containment system is situated (see Cargo Containment System).

**Hot work** Work involving flames, incandescence sparks or temperatures likely to be sufficiently high to cause ignition of flammable gas. The term includes any work involving the use of welding, burning or soldering equipment, blow torches, some power-driven tools, portable electrical equipment which is not intrinsically safe or contained in an explosion-proof housing, and equipment with internal combustion engines.

**Hot work permit** A document issued by an authorised person permitting specific work to be done for a specified time in a defined area employing tools and equipment which could cause ignition of flammable gas (see 'Hot work').

**Hydrates** The compounds formed at certain pressures and temperatures by the interaction between water and hydrocarbons.

**IMO** The International Maritime Organization; this is the United Nations specialised agency dealing with maritime affairs.

**IMO codes** The IMO Codes for the Design, Construction and Equipment of Ships carrying Liquefied Gases in Bulk. They are described in Appendix 2, section 5.

**Incandescence spark** A spark of sufficient temperature and energy to ignite flammable gas.

**Inert gas** A gas (e.g. nitrogen) or mixture of gases, containing insufficient oxygen to support combustion.

**Inerting** The introduction of inert gas into a space to reduce and maintain the oxygen content at a level at which combustion cannot be supported.

**Inflammable** (See Flammable) **Inhibited cargo** A cargo which contains an inhibitor.

**Inhibitor** A substance used to prevent or retard cargo deterioration or a potentially hazardous chemical self-reaction, e.g. polymerisation.

**Insulating flange** An insulating device placed between metallic flanges, bolts and washers, to prevent electrical continuity between pipelines, sections of pipelines, hose strings and loading arms, or equipment/apparatus.

**Interbarrier space** The space between a primary and a secondary barrier, whether or not completely or partially occupied by insulation or other material.

**Intrinsically safe** Intrinsically safe equipment, instruments, or wiring are incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration (see Appendix 7, section 2).

**Liquefied gas** A liquid which has an absolute vapour pressure exceeding 2.8 bar at 37.8°C, and certain other substances of similar characteristics specified in the IMO Codes.

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**Lower flammable limit** (See Flammable limits) (LFL)

LNG Liquefied Natural Gas; the principal constituent of LNG is methane.

LPG Liquefied Petroleum Gases - these are mainly propane and butane, shipped either separately or in mixtures. They may be refinery by-product gases or may be produced in conjunction with crude oil or natural gas.

**MARVS** The Maximum Allowable Relief Valve Setting of a cargo tank.

**MARPOL** The International Convention for the Prevention of Pollution from Ships, 1973, as modified by its Protocol of 1978.

**Mole** The amount of a substance, in any convenient system of weight measurement, which corresponds to the numerical value of the molecular weight of the substance (e.g. for propane, molecular weight of 44.1, a gram-mole

weighs 44.1 grams; a pound-mole weighs 44.1 pounds).

**Mole fraction** The number of moles of any component in a mixture divided by the total number of moles of each component.

**Mole percentage** The mole fraction multiplied by 100.

**Oxygen analyser** An instrument used to measure oxygen concentrations, expressed as a percentage by volume.

**Peroxide** A compound formed by the chemical combination of cargo liquid or vapour with atmospheric oxygen, or oxygen from another source. These compounds may in some cases be highly reactive or unstable and constitute a potential hazard.

**Polymerisation** The phenomenon by which the molecules of a particular compound link together into a larger unit containing anything from two to thousands of molecules, the new unit being called a polymer.

A compound may thereby change from a free-flowing liquid into a viscous one or even a solid. A great deal of heat may be evolved when this occurs.

Polymerisation may occur spontaneously with no outside influence, or it may occur if the compound is heated, or if a catalyst or impurity is added. Polymerisation may, under some circumstances, be dangerous, but may be delayed or controlled by the addition of inhibitors.

**Pressure** Force per unit area.

**Primary barrier** The inner element designed to contain the cargo when the cargo containment system includes two boundaries.

**Purging** The introduction of a suitable cargo vapour to displace an existing tank atmosphere.

**Relative vapour density** The mass of the vapour compared with the mass of an equal volume of air, both at standard conditions of temperature and pressure.

Thus vapour density of 2.9 means that the vapour is 2.9 times heavier than an equal volume of air under the same physical conditions-

**Reliquefaction** Converting cargo boil-off vapour back into a liquid by refrigeration (see Appendix 3).

**Responsible officer** The Master or any officer to whom the Master may delegate responsibility for any operation or duty.

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**Responsible terminal** The shore supervisor in charge of all operators and operations at the terminal

**representative** associated with the handling of products, or his responsible delegate.

**Restricted gauging system** A system employing a device which penetrates the tank and which, when in (also known as restricted use, permits a small quantity of cargo vapour or liquid to be released to the ullage system) atmosphere. When not in use the device is completely closed (see Appendix 6).

**Secondary barrier** The liquid-resisting outer element of a cargo containment system designed to afford temporary containment of any envisaged leakage of liquid cargo through the primary barrier and to prevent the lowering of the temperature of the ship's structure to an unsafe level. Types of secondary barriers are more fully defined in the IMO Codes.

**Self-reaction** The tendency of a chemical to react with itself, usually resulting in polymerisation or decomposition.

**Sloshing** Wave formations which may arise at the liquid surface in a cargo tank from the effects of ship motions.

**SOLAS** The International Convention for the Safety of Life at Sea.

**Span gas** A vapour sample of known composition and concentration used to calibrate (or span) a ship's gas detection equipment.

**Specific gravity** The ratio of the weight of a volume of a substance at a given temperature to the weight of an equal volume of fresh water at the same temperature or at a different given temperature.

(Since temperature affects volume, the temperature at which a specific gravity comparison is made needs to be known and is stated after the ratio.)

**Static electricity** The electrical charge produced on dissimilar materials through physical contact and separation.

**Tank access hatch** The access hatch for tank entry, fitted to the tank dome.

**Tank cover** The structure intended to protect the cargo containment system against damage where it protrudes through the weather deck, or to ensure the continuity and integrity of the deck structure, or both.

**Tank dome** The upward extension of a portion of the cargo tank. For below-deck cargo containment systems the tank dome protrudes through the weather deck, or through a tank skirt.

**Tank skirt** The vertical cylindrical structure attached to the ship's foundation deck, supporting a spherical cargo tank at its equator.

**Thermal conductivity meter** A fixed or portable instrument used to detect the presence of gas concentrations from 0 to 100%. It must be calibrated for a particular gas. (See Appendix 6)

**Threshold limit value** The 'time-weighted average' (TWA) concentration of a substance to which it is (TLV) believed workers may be repeatedly exposed, for a normal 8-hour working day and 40-hour working week, day after day, without adverse effect. It may be supplemented by a 'short-term exposure limit' (STEL) TLV.

**Upper flammable limit** (See Flammable Limits)

**Vapour Density** See Absolute Vapour Density and Relative Vapour Density

**Vapour pressure** The pressure exerted by the vapour above the liquid at a given temperature (see Appendix 3).

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**Ventilation** The process of maintaining in a space an atmosphere suitable for human access, by natural or mechanical means using a fixed or portable system. (Reference should be made to the relevant IMO Code chapters for specific requirements.)

**Venting** The release of cargo vapour or inert gas from cargo tanks and associated systems.

**Void space** The enclosed space in the cargo area external to a cargo containment system, not being a hold space, ballast space, fuel oil tank, cargo pump or compressor room, or any space in normal use by personnel.

**Water fog** Very fine droplets of water generally delivered at a high pressure through a fog nozzle.

**Water-spray system** A system of sufficient capacity to provide a blanket of water droplets to cover the cargo manifolds, tank domes, deck storage tanks, and boundaries of superstructure and deckhouses.

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Normally there should be no need to add any inhibitor to the cargo during the voyage. If it should become necessary, however, any such additions should be made in accordance with the shipper's instructions.

The inhibitor may not boil off with the cargo and it is possible for reliquefaction systems to contain uninhibited cargo. The system should therefore be drained or purged with inhibited cargo when shut down.

Many inhibitors are much more soluble in water than in the cargo, so to avoid a reduction in inhibitor concentration, care should be taken to exclude water from the system. Similarly the inhibitor may be very soluble in anti-freeze additives if these form a separate phase and the shipper's instructions on the use of anti-freeze should be observed. If the ship is anchored in still conditions the cargo should be circulated daily to ensure a uniform concentration of inhibitor.

Certain cargoes which can self-react (e.g ethylene oxide, propylene oxide), but which cannot be inhibited, have to be carried under inert gas. Care should be taken to ensure that a positive pressure is maintained in the inerted atmosphere at all times and that the oxygen concentration never exceeds 0.2% by volume.

(Note: For provisions concerning the avoidance of uninhibited stagnant liquid pockets refer to the IMO IGC Code, paragraph 17.4.2.)

#### 1.4.3 *Reaction with Air*

Some cargoes can react with air to form unstable oxygen compounds which could cause an explosion. The IMO Codes require these cargoes to be either inhibited or carried under nitrogen or other inert gas. The general precautions in paragraph 1.4.2 apply and care should be taken to observe the shipper's instructions.

#### 1.4.4 *Reaction with Other Cargoes*

Certain cargoes can react dangerously with one another. They should be prevented from mixing by using separate piping and vent systems and separate refrigeration equipment for each cargo. Care should be taken to ensure that this positive segregation is maintained.

To establish whether or not two cargoes will react dangerously, the data sheet for each cargo should be consulted. This issue is also covered in various national regulations, which should be observed.

#### 1.4.5 *Reaction with Other Materials*

The data sheets list materials which should not be allowed to come into contact with the cargo. The materials used in the cargo systems must be compatible with the cargoes to be carried and care should be taken to ensure that no incompatible materials are used or introduced during maintenance (e.g. gaskets).

Reaction can occur between cargo and purge vapours of poor quality: for instance, inert gas with high CO<sub>2</sub> content can cause carbamate formation with ammonia (see paragraph 4.6.1). Reaction can also occur between compressor lubricating oils and some cargoes, resulting in blockage and damage.

### 1.5 CORROSIVITY

Some cargoes and inhibitors may be corrosive. The IMO Codes require materials used in the cargo system to be resistant to corrosion by the cargo. Care should therefore be taken to ensure that unsuitable materials are not introduced into the cargo system. AH precautions specific to the cargo should be strictly observed (refer to data sheets at Appendix 1).

Corrosive liquids can also attack human tissue and care should be taken to avoid contact: reference should be made to the appropriate data sheets. Instructions about the use of protective clothing should be observed (see Section 9.2).

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### 1.6 VAPOUR CHARACTERISTICS

One characteristic of liquefied gases is the large quantity of vapour readily produced by a small volume of liquid (1m<sup>3</sup> of LNG will produce 600m<sup>3</sup> of vapour at ambient temperature). The venting of cargo vapour should therefore be avoided. However, if the venting of cargo vapour is unavoidable, it should be done with care and in full knowledge of the potential hazards. In most port areas the venting of flammable or toxic vapours is forbidden, and applicable local regulations should be observed (See Sections 2.9 and 4.16).

### 1.7 LOW TEMPERATURE EFFECTS

As liquefied gas cargoes are often shipped at low temperatures it is important that temperature sensing equipment is well maintained and accurately calibrated (see paragraph 5.3.6 and Appendix 6, section 5).

Hazards associated with low temperatures include:

#### 1.7.1 *Brittle Fracture*

Most metals and alloys become stronger but less ductile at low temperatures (i.e. the tensile and yield strengths increase but the material becomes brittle and the impact resistance decreases) because the reduction in temperature changes the material's crystal structure.

Normal shipbuilding steels rapidly lose their ductility and impact-strength below 0°C. For this reason, care should be taken to prevent cold cargo from coming into contact with such steels, as the resultant rapid cooling would make the metal brittle and would cause stress due to contraction. In this condition the metal would be liable to crack. The phenomenon occurs suddenly and is called 'brittle fracture'.

However, the ductility and impact resistance of materials such as aluminium, austenitic and special alloy steels and nickel improve at low temperatures and these metals are used where direct contact with cargoes at temperatures below -55 °C is involved.

#### 1.7.2 Spillage

Care should be taken to prevent spillage of low temperature cargo because of the hazard to personnel (see Section 1.3) and the danger of brittle fracture (see paragraph 1.7.1). If spillage does occur, the source should first be isolated and the spilt liquid then dispersed (see paragraph 7.3.3). (The presence of vapour may necessitate the use of breathing apparatus.) If there is a danger of brittle fracture, a water hose may be used both to vaporise the liquid and to keep the steel warm. If the spillage is contained in a drip tray the contents should be covered or protected to prevent accidental contact and allowed to evaporate. Liquefied gases quickly reach equilibrium and visible boiling ceases; this quiescent liquid could be mistaken for water and carelessness could be dangerous.

Suitable drip trays are arranged beneath manifold connections to control any spillage when transferring cargo or draining lines and connections. Care should be taken to ensure that unused manifold connections are isolated and that if blanks are to be fitted the flange surface is clean and free from frost. Accidents have occurred because cargo escaped past incorrectly fitted blanks.

Liquefied gas spilt onto the sea will generate large quantities of vapour by the heating effect of the water. This vapour may create a fire or health hazard, or both. Great care should be taken to avoid such spillage, especially when disconnecting cargo hoses.

#### 1.7.3 Cooldown

Cargo systems are designed to withstand a certain service temperature; if this is below ambient temperature the system has to be cooled down to the temperature of the cargo before cargo transfer. For LNG and ethylene the stress and thermal shock caused by an over-rapid cooldown of the system could cause brittle fracture. Cooldown operations should be carried out carefully in accordance with instructions (see paragraph 4.7.2).

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#### 1.7.4 Ice Formation

Low cargo temperatures can freeze water in the system leading to blockage of, and damage to, pumps, valves, sensor lines, spray lines etc. Ice can be formed from moisture in the system, purge vapour with incorrect dewpoint, or water in the cargo. The general precautions given in paragraph 1.4.1 apply. The effects of ice formation are similar to those of hydrates, and anti-freeze can be used to prevent them.

#### 1.7.5 Rollover

Rollover is a spontaneous rapid mixing process which occurs in large tanks as a result of a density inversion. Stratification develops when the liquid layer adjacent to a liquid surface becomes more dense than the layers beneath, due to boil-off of lighter fractions from the cargo. This obviously unstable situation relieves itself with a sudden mixing, which the name 'rollover' aptly describes.

Liquid hydrocarbons are most prone to rollover, especially cryogenic liquids. LNG is the most likely by virtue of the impurities it contains, and the extreme conditions of temperature under which it is stored, close to the saturation temperatures at storage pressures.

If the cargo is stored for any length of time and the boil-off is removed, evaporation can cause a slight increase in density and a reduction of temperature near the surface. The liquid at the top of the tank is therefore marginally heavier than the liquid in the lower levels. Once stratification has developed rollover can occur.

No external intervention such as vibration, stirring or introducing new liquid is required to initiate rollover. The response to a small temperature difference within the liquid (which will inevitably occur in the shipboard environment) is sufficient to provide the kinetic energy to start rollover, and release the gravitational driving forces which will invert the tank contents. The inversion will be accompanied by violent evolution of large quantities of vapour and a very real risk of tank over-pressure.

Rollover has been experienced ashore, and may happen on a ship that has been anchored for some time. If such circumstances are foreseen the tank contents should be circulated daily by the cargo pumps to prevent rollover occurring.

Rollover can occur if similar or compatible cargoes of different densities are put in the same tank. For example, if tank pressure is maintained by boil-off reliquefaction, the condensate return may be of slightly different temperature (and hence density) from the bulk liquid, and likewise if condensate from two or more cargoes is returned to one tank. In such circumstances, rollover may be prevented by returning condensate that is less dense than the bulk liquid to the top of the tank, and condensate that is denser to the bottom of the tank.

Rollover may also occur when two part cargoes are loaded into the same tank (e.g. propane and butane). In this case there will be a large boil-off (up to 3% of the total liquid volume) due to the temperature difference between the two. For this reason, the practice is considered unsafe unless a thorough thermodynamic analysis of the process is undertaken, and the loading takes place under strictly controlled conditions.

Rollover in a ship on passage is most unlikely. Essentially, stratification and the subsequent rollover process is confined to shore LNG storage. However, if the use of LNG carriers for floating storage were to be introduced, personnel manning such vessels would need to be as aware of the problem and as vigilant to avoid rollover as their counterparts managing shore based storage.

## 1.8 PRESSURE

Liquefied gases are normally carried as boiling liquids at either:

- ambient temperature (fully pressurised ships), or
- atmospheric pressure (fully refrigerated ships), or
- intermediate temperatures and pressures (semi-pressurised ships, often referred to as semi-refrigerated).

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Particularly hazardous cargoes such as ethylene oxide and propylene oxide may be carried below their boiling points to reduce boil-off and increase safety. In such cases the tank pressure is maintained above atmospheric with nitrogen padding.

Any heat input to the cargo will vaporise some of the liquid and gradually increase the tank pressure. Pressure vessels are designed to accommodate this increase, but on fully or semi-refrigerated ships the boil-off is condensed by the reliquefaction system and returned to the cargo tanks as a boiling liquid. On LNG vessels cargo tank pressure is almost always controlled by burning the boil-off in the main propulsion system or in rare cases (e.g. emergency) by venting it to atmosphere.

If the pressure above a boiling liquid is increased, vaporisation from the surface is reduced, and vice versa.

### 1.8.1 *High and Low Pressure Effects*

Pressures above or below the design range can damage a system, and operating personnel should be fully aware of any pressure limitation for each part of the cargo system; pressures should always be kept between the specified maximum and minimum.

### 1.8.2 *Pressure Surge*

High surge pressures (shock pressures or 'liquid hammers') can be created if valves are opened or shut too quickly, and the pressure may be sufficient to cause hose or pipeline failure (see paragraph 4.5.2 and Appendix 8).

### 1.8.3 *Pressurised Systems*

In pressurised systems, with the cargo at ambient temperature, there is normally no external frosting to indicate the presence of liquid or vapour anywhere in the system. Checks should be made for the presence of high pressure vapour or liquid by gauges and test cocks before opening valves etc.

It is possible for vapour trapped in a system to condense in cold weather, causing a slight reduction in pressure. If the cargo is inhibited, this condensed liquid will be uninhibited and the precautions given in paragraphs 1.4.2, 1.4.3 and 1.8.4 should be observed.

### 1.8.4 *Reciprocating Compressors*

If vapour trapped in a reciprocating compressor condenses, it can dilute the lubricating oil in the crankcase which could cause bearing failure, overheating or possibly an explosion. The crankcase heating equipment, if fitted, should be used to reduce the possibility of cargo condensing and should be operated before the compressor is started. Liquid condensed in the compressor may also cause mechanical damage.

### 1.8.5 *Cargo Tank Pressures*

Cargo tank pressure should normally be maintained above atmospheric pressure to prevent the ingress of air and the possible formation of flammable mixtures. Positive pressures should be maintained if the tank contains any cargo vapour or inert gas. However, many pressure vessels are designed to withstand vacuum and it is possible to reduce tank pressure below atmospheric without drawing in air, for example during inerting and gas freeing (but see paragraph 4.6.4).

Cargo operations such as cooldown, warm-up, loading and discharge may affect pressures in hold or interbarrier spaces. Pressures can also be affected by climatic changes and the variation in temperature between day and night. Pressure in cargo tanks and hold or interbarrier spaces should be closely monitored, especially during cargo operations, and the equipment provided should be used to make the necessary adjustments. Particular care is necessary with membrane or semi-membrane systems which are vulnerable to damage from vacuum or incorrect differential pressures because of the thin barrier material.

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Pressures in cargo tanks may be maintained above atmospheric by:

- equalising pressures between tanks which contain the same cargo, or
- circulating cargo liquid or vapour, or both, between tanks containing the same cargo, or
- circulating cargo within a tank by use of the cargo pumps, or
- allowing the cargo to warm up.

### 1.8.6 *Liquid Gas Samples*

Liquid gas samples should not be placed in containers which cannot withstand the pressure created by the sample at the highest ambient temperature expected. Sufficient ullage should be left in the container to ensure that it does not become liquid full at the highest temperature anticipated (see paragraph 4.18.1). Liquid gas samples should be stored within the cargo area.

### 1.8.7 *Sloshing*

Within a range of tank filling levels, the pitching and rolling of the ship and the liquid free-surface can create high impact pressure on the tank surface. This effect is called 'sloshing' and can cause structural damage. Filling levels within this range must therefore be avoided.

However, some cargoes may be carried safely within the range specified for a particular system if the sloshing forces are permissible; guidance should be sought from the shipowner, the designer and the Classification Society.

### 1.8.8 *Pressure Relief Valves*

Pressure relief valves depend on accurate setting of opening and closing pressures for effective operation (see paragraph 5.3.8 and Appendix 5, Section 9).

### 1.8.9 *Cargo Heat Exchangers*

Heat exchangers should be pressure tested prior to use. This is especially important after a long period of idleness and before a ship is delivered on time charter. In addition to testing the tubes for tightness, the seawater low temperature cut-out must be tested to ensure that the cargo inlet valve to the heater closes, thereby avoiding damage to the tubes from freezing should the outlet temperature of the seawater fall below 5°C. In use, seawater flow through the heater must be established before product flow commences.

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## GENERAL PRECAUTIONS



### 2.1 INTRODUCTION

This chapter covers general precautions which should be observed irrespective of the cargo carried. Additional precautions for specific cargoes are dealt with in other chapters. The existence of local regulations is mentioned in this chapter; it is the master's responsibility to see that any applicable local regulations are understood and observed.

### 2.2 CARGO INFORMATION

The IMO Codes require the following information to be available to every ship and for each cargo:

- a full description of the physical and chemical properties necessary for the safe containment of the cargo
- action to be taken in the event of spills or leaks
- counter-measures against accidental personal contact
- fire-fighting procedures and fire-extinguishing agents
- procedures for cargo transfer, gas freeing, ballasting, tank cleaning and changing cargoes
- special equipment needed for the safe handling of the particular cargo
- minimum inner hull steel temperatures
- emergency procedures
- compatibility
- details of the maximum filling limits allowed for each cargo that may be carried at each loading temperature, the maximum reference temperature and the set pressure for each relief valve.

The master should request the correct technical name of the cargo as soon as possible and before loading. The master must only load a cargo which is listed on his certificate of fitness. Data sheets for these cargoes should be on board.

The master and all those concerned should use the data sheet and any other relevant information to acquaint themselves with the characteristics of each cargo to be loaded. If the cargo to be loaded is a mixture (e.g. LPG), information on the composition of the mixture should be sought; the temperature and pressure readings in the shore tank can be used to verify this information.

Special notes should be made of any contaminants that may be present in the cargo, e.g. water.

### 2.3 MOORINGS

The consequences of a gas carrier ranging along or breaking out of a berth could be disastrous, particularly during cargo transfer when damage could be caused to loading arms or hoses. Correct mooring is therefore of the utmost importance.

Mooring requirements are usually determined by the terminal, supplemented by advice from, the pilot. For general guidance on moorings, see the OCIMF publication 'Effective Mooring'.

Once the vessel has been secured, moorings should be regularly checked and tended to ensure that they remain effective.

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### 2.4 EMERGENCY TOWING-OFF WIRES (FIRE WIRES)

The ship should provide towing-off wires, ready for immediate use without adjustment, in case the ship needs to be moved in the event of fire or other emergency.

Wires should be positioned fore and aft on the offshore side of the ship, be in good condition, of adequate strength, and properly secured to the bits such that full towing loads can be applied. The eyes should be maintained at or about the waterline in a position that tugs can reach without difficulty. Sufficient slack to enable the tugs to tow effectively should be retained between the bits and the fairlead, but prevented from running out by a rope yarn or other easily broken means.

There are various methods currently in use for rigging emergency towing wires, and the arrangement may vary from port to port. A terminal which requires a particular method to be used should advise the ship accordingly.

### 2.5 ACCESS TO SHIP

#### 2.5.1 Means of Access (Gangways or Accommodation Ladders)

Personnel should only use the designated means of access between ship and shore.

When a ship is berthed or at anchor, the means of access should be so placed as to be convenient for supervision and if possible away from the manifold area. Where practicable two means of access should be provided.

Gangways or other means of access should be properly secured and provided with an effective safety net. In addition, suitable life-saving equipment should be available near the access point to shore.

#### 2.5.2 *Lighting*

During darkness the means of access and all working areas should be adequately illuminated.

#### 2.5.3 *Unauthorised Persons*

Persons who have no legitimate business on board, or who do not possess the master's permission to be there, should be refused access. The terminal, in agreement with the master, should restrict access to the jetty or berth. A crew list should be given to the terminal security personnel.

#### 2.5.4 *Persons Smoking or Intoxicated*

Personnel on watch on a gas carrier must ensure that no one who is smoking approaches or boards the ship. The company policy on drugs and alcohol should be strictly enforced.

## 2.6 NOTICES

### 2.6.1 *Permanent*

Permanent notices or internationally accepted signs should be displayed in conspicuous places on board, indicating where smoking and naked lights are prohibited, and where ventilation is necessary before entry.

### 2.6.2 *Temporary*

On arrival at a terminal, a gas carrier should display temporary notices at points of access, in appropriate languages, to indicate the following:

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#### **WARNING**

**NO NAKED LIGHTS**

**NO SMOKING NO UNAUTHORISED PERSON**

In addition, when the liquefied gases being handled present a health hazard, further notices in appropriate languages should be prominently displayed stating:

#### **WARNING**

**HAZARDOUS LIQUEFIED GAS**

Local regulations may require additional notices and such requirements should be observed.

## 2.7 CRAFT ALONGSIDE

Unauthorised craft should be prohibited from securing alongside or approaching close to the ship.

No tugs or other self-propelled vessels should be allowed alongside during operations which involve the venting of cargo vapours.

Regulations against smoking and naked lights should be strictly enforced on any craft permitted alongside and on shore if applicable. Operations should be stopped if these rules are violated and should not be restarted until the situation has been made safe.

## 2.8 WEATHER PRECAUTIONS

### 2.8.1 *Wind Conditions*

In conditions of little or no wind, vapour resulting from an accidental release or from purging or gas-freeing operations may persist on deck. A strong wind may create low pressure on the lee side of a deckhouse or structure and thereby cause vapour to be carried towards it.

In any such conditions it should be assumed that local high concentrations of vapour may exist, and all cargo operations should cease.

### 2.8.2 *Electrical Storms*

Cargo operations or the venting of flammable cargo vapours should be stopped during electrical storms in the immediate vicinity of the ship. See Section 8.3 for action if a vent mast is struck by lightning.

### 2.8.3 *Cold Weather*

Particular attention should be paid to pneumatic valves and control systems which can freeze in cold weather if the control air supply is damp, and to relief valves and cooling water systems. If fitted, heating systems should be used. Any water collected on the discharge side of relief valves should be drained off. Cooling water systems should either be dosed with anti-freeze or drained. If a system is drained, the fact should be logged and the system refilled before subsequent use. Water in fire main or spray systems should be circulated continuously or drained where there is a risk of freezing- Attention should be paid to emergency showers or eye-wash stations to ensure availability of facilities.

Cold weather can also cause cargo vapour trapped in rotating equipment (e.g. in a cargo compressor) to condense, enter the crankcase and dilute the lubricating oil, and cause damage. Crankcase heaters should be used if fitted, and started in ample time before running up cargo compressors (see paragraph 1.8.4).

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## 2.9 DISPERSAL OF VENTED CARGO VAPOURS

Cargo vapour, whether toxic or flammable, should be vented to atmosphere with extreme caution, taking account of regulations and weather conditions (see Section 2.8).

If the temperature of the vented vapour is below atmospheric dewpoint, clouds of condensed water vapour will form. Condensed water vapour (fog) is heavier than air whereas the cargo vapour may or may not be heavier than air, depending on temperature. The cargo vapour cloud is likely to be oxygen deficient, and should only be entered by personnel wearing breathing apparatus. Furthermore, it should never be assumed that the cargo vapour is contained entirely within the boundaries of the visible water vapour cloud.



If the cargo vapour is heavier than air it may accumulate on deck and enter accommodation spaces. The precautions in Section 2.10 should therefore be observed. In some cases it may be possible to heat vapour before venting to reduce its density and assist dispersion. If such facilities are provided they should be used.

## **2.10 OPENINGS IN DECKHOUSES AND SUPERSTRUCTURES**

Regulations require that superstructures are designed with certain portholes fixed shut and openings positioned to minimise the possibility of vapour entry. These design features should not be modified in any way.

All doors, portholes and other openings to gas-safe spaces should be kept closed during cargo operations. Doors should be clearly marked if they have to be kept permanently closed in port, but in no circumstances should they be locked.

Mechanical ventilation should be stopped and air conditioning units operated on closed cycle or stopped if there is any possibility of vapour being drawn into the accommodation.

## **2.11 ENGINE AND BOILER ROOM PRECAUTIONS**

### **2.11.1 Combustion Equipment**

Boiler tubes, uptakes, exhaust manifolds and combustion equipment should be in good condition as a precaution against funnel fires and sparks. In the event of a funnel fire, the engine should be stopped and the engine room should be maintained in a safe condition.

In the event of a funnel fire, or if sparks are emitted from the funnel, cargo operations should be stopped and, at sea, the course should be altered as soon as possible to prevent sparks falling onto the tank deck.

### **2.11.2 Blowing Boiler Tubes**

Funnel uptakes and boiler tubes should not be blown in port.

At sea they should only be blown in conditions where soot will be blown clear of the tank deck.

### **2.11.3 Cargo Vapour**

Care should be taken to ensure that cargo vapour does not enter the engine or boiler room from any source. Special attention should be paid to engine room equipment connected to the cargo plant e.g. the inert gas plant, with its cooling water system. Particular care is necessary if LNG cargo vapour is used as fuel (see paragraph 4.9.3).

If malfunction of equipment, explosion, collision or grounding damage should give rise to a situation where cargo vapour is likely to enter the machinery space, immediate consideration should be given to its possible effect on the operation of equipment. Any necessary action should be taken; e.g. isolating the source, closing access doors, hatches and skylights, shutting down mechanical ventilation system, auxiliary and main machinery, or evacuation. Apart from the obvious hazards, diesel engines are liable to overspeed and destroy themselves if flammable vapour is present in the air supply, even at concentrations well below the lower

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flammable limit (LFL). It is recommended that diesel engines are fitted with a valve on the *i* intake to stop the engine in these circumstances.

## **2.12 CARGO MACHINERY ROOM PRECAUTIONS**

Cargo vapour may be present in cargo pump or compressor rooms, and gas detection systems are installed to warn of its presence. In ships carrying cargoes whose vapours are lighter than air (e.g. ammonia) and heavier than air (e.g. LPG) gas detector points are fitted at high and low levels and the relevant detector points should be used for the cargo carried.

Ventilation systems are provided to disperse any vapour that may collect in the pump or compressor room. The space should be ventilated for at least ten minutes before cargo operations begin and throughout their duration, and also if liquid or vapour leakage is suspected. Ventilation systems should be maintained carefully; if the fans fitted are of non-sparking design their design features should not be modified in any way.

The precautions given in Section 6.3 should be observed before personnel enter cargo machinery rooms.

Lighting systems in cargo machinery rooms must be certified flame proof. It is essential to ensure that such systems are properly maintained. Additional lighting, if required, should be of a suitably safe type (see paragraph 3.5.2).

Gas-tight bulkhead gland seals and air lock doors to cargo machinery electric motor rooms should be carefully checked and maintained to ensure that cargo vapour does not enter.

## **2.13 SHIP'S READINESS TO MOVE**

At all times during discharge, loading and ballasting operations the ship should have adequate stability and suitable trim to allow for departure at short notice in the event of an emergency. While berthed at a terminal the ship's boilers, main engines, steering machinery, mooring equipment and other essential equipment should be kept ready to permit the ship to move from the berth at short notice, and in accordance with the terminal regulations.

Repairs and other work which may immobilise the ship should not be undertaken at a berth without the prior written agreement of the terminal. It may also be necessary to obtain permission from the local Port Authority before carrying out such work.

## **2.14 NAVIGATION**

The normal high standards of navigation should be maintained and any navigational restrictions (routeing, reporting requirements etc) should be observed. If the ship is permitted to burn LNG vapour in the main machinery at sea, it may be necessary to change over to oil fuel when manoeuvring or when entering restricted or territorial waters.

## **2.15 POLLUTION PREVENTION**

It is the responsibility of the master or those in charge of transfer operations involving cargo or bunkers to know

the applicable pollution prevention regulations and to ensure that they are not violated. Exercises should be held to train personnel in accordance with the Shipboard Oil Pollution Emergency Response Plan, and recorded.

There is a danger of violating pollution prevention regulations if ballast taken on in polluted waters is discharged in another port. If ballast has to be taken on in polluted areas, it may be necessary to exchange it for clean ballast when in deep water on passage. Some terminals have specific requirements in this respect, and the master should ensure that they are observed.

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## 2.16 FIRE -FIGHTING AND FIRE PROTECTION EQUIPMENT

Fire-fighting appliances should always be kept in good order, tested regularly, and available for immediate use at all times (see Section 3.8).

## 2.17 HELICOPTERS

Gas carriers are recommended not to undertake routine helicopter operations unless a purpose-built helicopter platform is provided. Whenever helicopter services are used the safety measures recommended in the ICS 'Guide to Helicopter/Ship Operations' should be taken into account.

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# FIRE HAZARDS AND PRECAUTIONS

## 3.1 INTRODUCTION

This chapter addresses the hazards presented by flammable liquefied gases and vapour emissions, and recommends practices to prevent the risk of fire. Information is also provided on precautions against the dangers of inhaling vapour and of fire hazards from sources other than the cargo.

The avoidance of cargo fires depends upon preventing flammable cargo vapour, oxygen and sources of ignition coming together.

Cargo vapours in flammable concentrations are likely to be present in areas such as cargo tanks, cargo machinery spaces and at times on deck. It is essential that all possible sources of ignition are eliminated from these areas, both by design and operation.

Sources of ignition are inevitably present in spaces such as the accommodation, galleys and engine rooms, and it is essential to prevent cargo vapour entering these spaces.

Personnel should be continuously on their guard, not only against the more obvious dangers, but also against unforeseen circumstances which could lead to flammable vapours and sources of ignition coming together.

## 3.2 FLAMMABILITY OF LIQUEFIED GASES

It is the vapour given off by a liquid and not the liquid itself which burns. A mixture of vapour and air cannot be ignited unless the proportions of vapour and air lie between two concentrations known as the Lower Flammable Limit (LFL) and the Upper Flammable Limit (UFL). The limits vary according to the cargo (see data sheets).

Concentrations below the lower limit (too lean) or above the upper limit (too rich) cannot burn. However, it is important to remember that concentrations above the upper limit can be made to burn by diluting them with air until the mixture is within the flammable range, and that pockets of air may exist in any system, leading to the creation of a flammable mixture.

A liquid has to be at a temperature above its flash point before it evolves sufficient vapour to form a flammable mixture. Many liquefied gas cargoes are flammable, and since they are shipped at temperatures above their flash points flammable mixtures can be formed.

The source of flammable material may be vapour from the cargo, or from anything else that will burn. Oxygen normally derives from the atmosphere, which contains approximately 21 % oxygen by volume. Ignition can be caused by anything capable of providing the necessary energy, such as a naked flame, an electrical or electrostatic spark, or a hot metal surface.

Fire is prevented by ensuring that at least one of these three elements is excluded.

In the presence of a flammable substance, sources of ignition or oxygen should be excluded. Oxygen can be restricted to a safe level within the cargo system by keeping the pressure above atmospheric pressure with cargo vapour or inert gas. Many sources of ignition are eliminated during the design stage and care should be taken to ensure that design features are not impaired in any way. Other sources of ignition need to be excluded by correct operational practices.

Where sources of ignition and oxygen are likely to be present, such as in accommodation, engine and boiler rooms, galley, motor rooms etc., it is vital to exclude flammable vapour. Particular care is necessary if there is a direct connection between the engine room and the cargo system (e.g. when cargo vapour is burnt as fuel, see paragraph 4.9.3), or if the inert gas plant is located in the engine room.

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### 3.3 CARGO VAPOUR GENERATION AND DISPOSAL

Liquefied gas cargoes are usually carried either fully refrigerated or pressurised in order to avoid loss of cargo. Cargo vapour is evolved and is normally treated in the following ways:

- During loading, vapour is displaced by cargo liquid; this vapour is either reliquefied and returned to the tanks as a boiling liquid or returned to shore through a vapour return line.
- During carriage, the cargo will boil off because of heat transfer through the insulation. In this case the vapour is either reliquefied or (in the case of LNG only) burnt in the main engines. If the cargo system is fully pressurised any vapour will be retained within the cargo tank.
- During gas-freeing at sea, the vapour is normally a mixture of cargo vapour and inert gas or inert gas and air. It cannot be used as fuel or reliquefied, and is vented to atmosphere. During gas-freeing in port, the vapour is returned through a shoreline.

Whatever methods are provided for handling vapour, it is essential to ensure that they function properly and are operated correctly. Failure to do so may create a hazard to the ship, the ship's crew or the environment.

### 3.4 ATMOSPHERE CONTROL

#### 3.4.1 *General*

When carrying a flammable cargo the cargo system contains liquid and vapour. The atmosphere around the cargo tanks is normally inerted to prevent the formation of flammable mixtures. The IMO Codes use the term 'environmental control' to describe this process. The precautions necessary to ensure safety are dealt with in the following paragraphs.

#### 3.4.2 *Hold and Interbarrier Spaces*

These spaces may have to be filled with inert gas if the cargo is flammable. Different cargo containment systems require different procedures, as follows:

Containment System	Hold or Interbarrier Space Atmosphere
Full secondary barrier	Dry inert gas or nitrogen; maintained with make-up gas provided by the shipboard inert gas generation system, or by shipboard storage which should be sufficient for at least 30 days at normal rates of consumption

Partial secondary barrier	Dry inert gas or nitrogen; maintained with make-up gas provided by the shipboard inert gas generation system, or by shipboard storage which should be sufficient for at least 30 days at normal rates of consumption. Alternatively, subject to certain conditions, the space may be filled with dry air (see Regulation 9.2.2.2 of the IGC Code).
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No secondary barrier

Dry air or dry inert gas depending on the cargo; maintained either with dry air provided by suitable air drying equipment, or with make-up inert gas provided by the shipboard inert gas generation system or shipboard storage.

#### 3.4.3 *Cargo Tanks and Piping Systems*

The formation of a flammable vapour mixture in the cargo system should be prevented by replacing the air in the system with inert gas before loading, and by removing cargo vapour by inert gas after discharge, prior to changing cargoes or gas-freeing. Suitable pipe connections should be provided for this purpose. Inerting should be continued until the concentration of oxygen or cargo vapour in the space is reduced to the required level. The tank atmosphere

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should be monitored at different levels to ensure there are no pockets of excessive concentrations of oxygen or cargo vapour, particularly in tanks with complex internal structures or bulkheads.

Some cargoes require the oxygen content in the vapour space to be kept extremely low (in some cases less than 0.2%) to prevent a chemical reaction occurring. For instance, ethylene oxide /propylene oxide mixtures can decompose spontaneously unless special precautions are taken to control the atmosphere; and butadiene can react with oxygen to form unstable peroxide compounds. The oxygen content in the tanks must be reduced as necessary before loading begins. While such cargoes remain on board, oxygen is excluded either by keeping the ullage space full of inert gas at a positive pressure or, in the case of butadiene, by keeping the cargo vapour above atmospheric pressure. In every case, shippers' requirements should be strictly observed.

#### 3.4.4 *Inert Gas Quality*

Inert gas used for atmosphere control should be suitable for the intended purpose, regardless of source. In particular it should:

- be chemically compatible with the cargo and the materials of construction throughout the full range of operating temperatures and pressures;
- have a sufficiently low dewpoint to prevent condensation, freezing, corrosion, damage to insulation etc. at the minimum operating temperature;
- have an oxygen concentration not exceeding 5%, but as low as 0.2% if the cargo can react to form peroxides;
- have a low concentration of CO<sub>2</sub> to prevent it freezing out at the anticipated service temperature (see paragraph 4.6.1);
- have minimal capacity for accumulating a static electrical charge.

#### 3.4.5 *Inert Gas Hazards and Precautions*

The main hazard associated with inert gas is asphyxiation of personnel due to lack of oxygen. Asphyxiation can

occur in those parts of the cargo system which have been inerted, or in other enclosed spaces into which inert gas has leaked. Nobody should enter spaces which are not in common use until it has been established that the atmosphere will support life (see Chapter 6).

As the inert gas plant is often situated in the engine room, great care should be taken to ensure that cargo vapour does not flow back along inert gas supply lines; non-return valves should be tested for effectiveness, at regular intervals. Any temporary connection between the inert gas plant and the cargo systems should be disconnected and tightly blanked after use.

If a liquid nitrogen system is used, care should be taken to avoid contact with skin and eyes, or severe cold burns will be caused. Any metal structure or component likely to come into contact with liquid nitrogen could suffer brittle fracture unless it has been designed for a service temperature of  $-196\text{ }^{\circ}\text{C}$ . Great care should be taken to ensure that vaporisers are used correctly.

## **3.5 PRECAUTIONS AGAINST SOURCES OF IGNITION**

### *3.5.1 Smoking*

Company policy and local regulations should be strictly observed.

Smoking can only be permitted under controlled conditions. The designated smoking places on a gas carrier must be known to the crew, and when in port should be agreed in writing between the master and the terminal representative before cargo operations start. The master is responsible for ensuring that all persons on board the tanker are informed of the places in which smoking is permitted, and for posting suitable notices.

The agreed smoking places should be confined to locations abaft all cargo tanks, and should not have doors or portholes which open directly to open decks.

The use of matches and cigarette lighters outside designated smoking spaces should be  
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prohibited. The risks involved in carrying matches and, more particularly, cigarette lighters should be impressed on all personnel. The use of lighters should be discouraged. Matches used on board should be of the safety type.

### *3.5.2 Portable Electrical Equipment*

Portable electrical equipment (self-contained or on extension cables) should not be used inside cargo tanks, cargo pumprooms, compressor rooms, or adjacent spaces unless:

- the equipment circuit is intrinsically safe;
- the equipment is contained within an approved explosion-proof housing;
- flexible cables are of a type approved for extra hard use, have an earth conductor, and are permanently attached to the explosion-proof housing in an approved manner;
- the compartments around and within which the equipment and/or cable are to be used are free from flammable vapour throughout the period during which the equipment is in use; and
- adjacent compartments are free from flammable vapour or have been made safe by inerting or completely filling with water, and all connections with other compartments that are not free from flammable vapour are firmly closed and will remain so.

If the equipment is only to be used on the tank deck, explosion-proof and other types of certified-safe equipment can be used (see Appendix 7).

Air-driven lamps of an approved type may be used in non gas-free atmospheres, although to avoid the accumulation of static electricity on the lamp it should either be earthed or the hose should have a resistance low enough to allow static dissipation.

Only approved safety torches or hand lamps should be used.

Small battery powered personal items such as watches and hearing aids are not significant ignition sources when correctly used. However portable domestic radios, electronic calculators, tape recorders, cameras and other non-approved battery powered equipment should not be used on the tank deck or wherever flammable vapour may be encountered.

When in port, reference should be made to local regulations which may totally prohibit the use of any electrical equipment. All portable electrical equipment should be carefully examined for possible defects before use. Special care should be taken to ensure that insulation is undamaged, that cables are securely attached and remain so while the equipment is in use, and that mechanical damage to cables is prevented.

### *3.5.3 Communication Equipment in Port*

Main radio transmitters should not be used and the main aerials should be earthed during cargo operations because energy may be induced into conducting objects in the radio wave field. This energy can be sufficient to create a spark if discontinuity occurs. Heavy sparking can also occur at the insulators, particularly in humid weather. Permanently and correctly installed VHF equipment is not affected.

If it is necessary to operate the ship's radio in port for maintenance etc., the agreement of the terminal and port authorities should be sought. The issue of a work permit may be necessary, and to ensure safety the terminal may require operation at low power, use of a dummy aerial load, or transmission only when no cargo operations are in progress.

It is advisable to consult the terminal before radar scanners or satellite communication equipment are used, because they may include non-approved equipment such as drive motors. The radiation itself is considered not to present an ignition hazard.

Loud hailers, searchlights, signal lamps, etc. should not be used in port.

### *3.5.4 Use of Tools*

Although grit blasting and the use of mechanically powered tools are not normally considered to fall within the definition of hot work, both these operations should only be permitted under controlled conditions. Section 1 of the

Hot Work Permit is suitable (see Appendix 12).

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The work area should not be subject to vapour release or a concentration of combustible vapours, and should be free from combustible material. The area should be gas-free, and tests with a combustible gas indicator should give a reading of not more than 1% LFL. The ship must not be alongside at a terminal- There must be no cargo, bunkering, ballasting, tank cleaning or gas-freeing operations in progress.

The hopper and hose nozzle of a gritblasting machine should be electrically earthed to the deck or fitting being blasted.

There is a risk of perforation of pipelines when grit blasting or chipping, and great care must be taken over planning such work.

Cargo and inert gas pipelines should not be blasted or mechanically chipped unless the entire ship is gas-free.

Adequate fire fighting equipment must be laid out and ready for immediate use.

The use of hand tools such as chipping hammers and scrapers for steel preparation and maintenance may be permitted without a hot work permit. Their use must be restricted to deck areas and fittings not connected to the cargo system. The work area should not be subject to vapour release or a concentration of combustible vapours. The area should be gas-free and clear of combustible materials. There must be no cargo, bunkering, ballasting, tank cleaning or gas-freeing operations in progress. Work on cargo pipelines and inert gas pipelines should be subject to the same precautions as applies to powered tools.

#### 3.5.5 Aluminium Equipment and Paint

Aluminium equipment should not be dragged or rubbed across steel since it may leave a smear. If a heavy smear of aluminium on rusty steel is struck it is possible to cause an incendive spark.

Extensive experience indicates that the normal use of aluminium paint creates no special hazard.

#### 3.5.6 Ship/Shore Insulating, Earthing and Bonding

In order to provide protection against static electrical discharge at the manifold when connecting and disconnecting cargo hose strings and metal arms, the terminal operator should ensure that they are fitted with an insulating flange or a single length of non-conducting hose, to create electrical discontinuity between the ship and shore. All metal on the seaward side of the insulating section should be electrically continuous to the ship, and that on the landward side should be electrically continuous to the jetty earthing system.

The insulating flange or single length of non-conducting hose must not be short-circuited by contact with external metal; for example, an exposed metallic flange on the seaward side of the insulating flange or hose length should not make contact with the jetty structure either directly or through hose handling equipment.

Simply switching off a cathodic protection system is not a substitute for the installation of an insulating flange or a length of non-conducting hose.

Cargo hoses with internal bonding between the end flanges should be checked for electrical continuity before they are taken into service and periodically thereafter.

A ship/shore bonding cable is not effective as a safety device and may even be dangerous. A ship/shore bonding cable should therefore not be used.

**Note: Although the potential dangers of using a ship/shore bonding cable are widely recognised, attention is drawn to the fact that some national and local regulations may still require a bonding cable to be connected. If a bonding cable is demanded, it should first be visually inspected to see that it is mechanically sound. The connection point for the cable should be well clear of the manifold area. There should always be a switch on the jetty in series with the bonding cable and of a type suitable for use in a hazardous area. It is important to ensure that the switch is always in the 'off position before connecting or disconnecting the cable. Only when the cable is properly fixed and in good contact with the ship should the switch be closed. The cable should be attached before the cargo hoses are connected and removed only after the hoses have been disconnected.**

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#### 3.5.7 Auto-Ignition

The vapours from flammable liquids (including fuel and lubricating oil) may ignite, even in the absence of external flame or sparks, if the liquid comes into contact with a surface heated above its auto-ignition temperature (e.g. steam lines, overheated equipment). This is called 'auto-ignition'. In any case, evaporation of the liquid will create an additional fire hazard.

Immediate steps should be taken to remedy any leakage. Care should also be taken to avoid rags or other materials soaked in oil or chemicals from coming in contact with hot surfaces. Lagging should not be allowed to become saturated with oil.

#### 3.5.8 Spontaneous Combustion

Wet, oily or chemically impregnated fibrous materials are liable to ignite as a result of a gradual build-up of heat due to oxidation. The hazard is increased if the material is kept warm, for example by proximity to a hot pipe. Furthermore, contact with other liquids, such as strong acids, may cause such materials to ignite or to be destroyed by chemical attack.

Cotton waste, canvas, or similar absorbent materials should therefore not be left lying on decks, on equipment, or on or around pipelines, and should not be stowed near oil, paint etc. If such materials become damp or contaminated they should either be cleaned and dried before storing, or destroyed.

## 3.6 HOT WORK

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**It is anticipated that owners and operators of liquefied gas tankers will issue clear guidance to masters and crews on the control of hot work outside repair yards. The following is intended to assist safety by indicating principal areas that should receive attention.**

#### 3.6.1 General

Hot work means any work requiring the use of electric arc or gas welding equipment, cutting burner equipment or other forms of naked flame, as well as spark generating tools. It covers all such work, regardless of where it is carried out aboard a ship, including open decks, machinery rooms and the engine room.

Repair work outside the engine room which necessitates hot work should only be undertaken when it is essential for the safety or immediate operation of the ship, and no alternative repair procedure is possible.

Hot work outside the engine room (and in the engine room when associated with fuel, lubrication or cargo systems) must be prohibited until the requirements of national legislation and other applicable regulations have been met, safety considerations taken into account, and a hot work permit has been issued. This may involve the master, owners' superintendent, shore contractor, terminal representative and port authority as appropriate.

Hot work in port at a gas terminal is normally prohibited. If such work becomes essential for safety or urgent operational needs, then port regulations must be complied with. Full liaison must be arranged with port and terminal authorities before any work is started.

#### 3.6.2 *Assessment of Hot Work*

The master shall decide whether the hot work is justifiable, and whether it can be conducted safely. Hot work in areas outside the engine room should not be proceeded with until the master has informed the ship's operators of details of the work proposed, and a procedure has been discussed and agreed.

Before hot work is started a safety meeting under the chairmanship of the master must be held, at which the planned work and the safety precautions are carefully reviewed. The meeting should be attended at least by all those who will have responsibilities in connection with the work. An agreed written plan for the work and the related safety precautions should be made. The plan must clearly and unambiguously designate one officer who is responsible for the supervision of the work, and another officer who is responsible for safety precautions and communications between all parties involved.

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A flow chart to assist is shown overleaf.

All personnel involved in the preparations and in the hot work operation, must be briefed and instructed on their own role. They must clearly understand which officer is responsible for work supervision and which for safety precautions. A written hot work permit should be issued for each intended task. The permit should specify the duration of validity, which should not exceed a working day. An example of a hot work permit is given in Appendix 12.

#### 3.6.3 *Preparations for Hot Work*

No hot work must be undertaken inside a compartment until it has been cleaned and ventilated, and tests of the atmosphere in the compartment indicate 21% oxygen content by volume, not more than 1% LFL and it is free from toxic gases. It is important to continue ventilation during hot work (see Chapter 6).

No hot work should be undertaken on the open deck unless the area is free from flammable vapour and all compartments, including deck tanks, within a radius of at least 30 metres around the working area have been washed and freed of flammable vapour and/or inerted.

All sludge, cargo-impregnated scale, sediment or other material likely to give off flammable or toxic vapour, especially when heated, should be removed from an area of at least 10 metres around all hot work. All combustible material such as insulation should either be removed or protected from heat.

Adjacent compartments should either be cleaned and gas freed to hot work standard, freed of cargo vapour to not more than 1% by volume and kept inerted, or completely filled with water. No hot work should be undertaken in a compartment beneath a deck tank in use.

Care should be taken to ensure that no release of flammable vapour or liquid can occur from non-adjacent compartments that are not gas-free.

No hot work should be carried out on bulkheads of bunker tanks in use. An adjacent fuel oil bunker tank may be considered safe if tests using a combustible gas indicator give a reading of not more than 1% LFL in the ullage space of the bunker tank, and no heat transfer through the bulkhead of the bunker tank will be caused by the hot work.

All pipelines interconnecting with cargo spaces should be flushed, drained, vented and isolated from the compartment or deck area where hot work will take place.

Hot work on pipelines and valves should only be permitted when the item needing repair has been detached from the system by cold work, and the remaining system blanked off. The item to be worked on should be cleaned and gas freed to a safe-for-hot work standard, regardless of whether or not it is removed from the hazardous cargo area. All other operations utilising the cargo or ballast system should be stopped before hot work is undertaken, and throughout the duration of the hot work. If hot work is interrupted to permit pumping of ballast or other operations using the cargo system, hot work should not be resumed until all precautions have been re-checked, and a new hot work permit has been issued.

#### 3.6.4 *Checks by Officer Responsible for Safety During Hot Work*

Immediately before hot work is started the officer responsible for safety precautions should examine the area where it is to be undertaken, and ensure that tests with a combustible gas indicator show not more than 1% LFL, and that the oxygen content is 21% by volume.

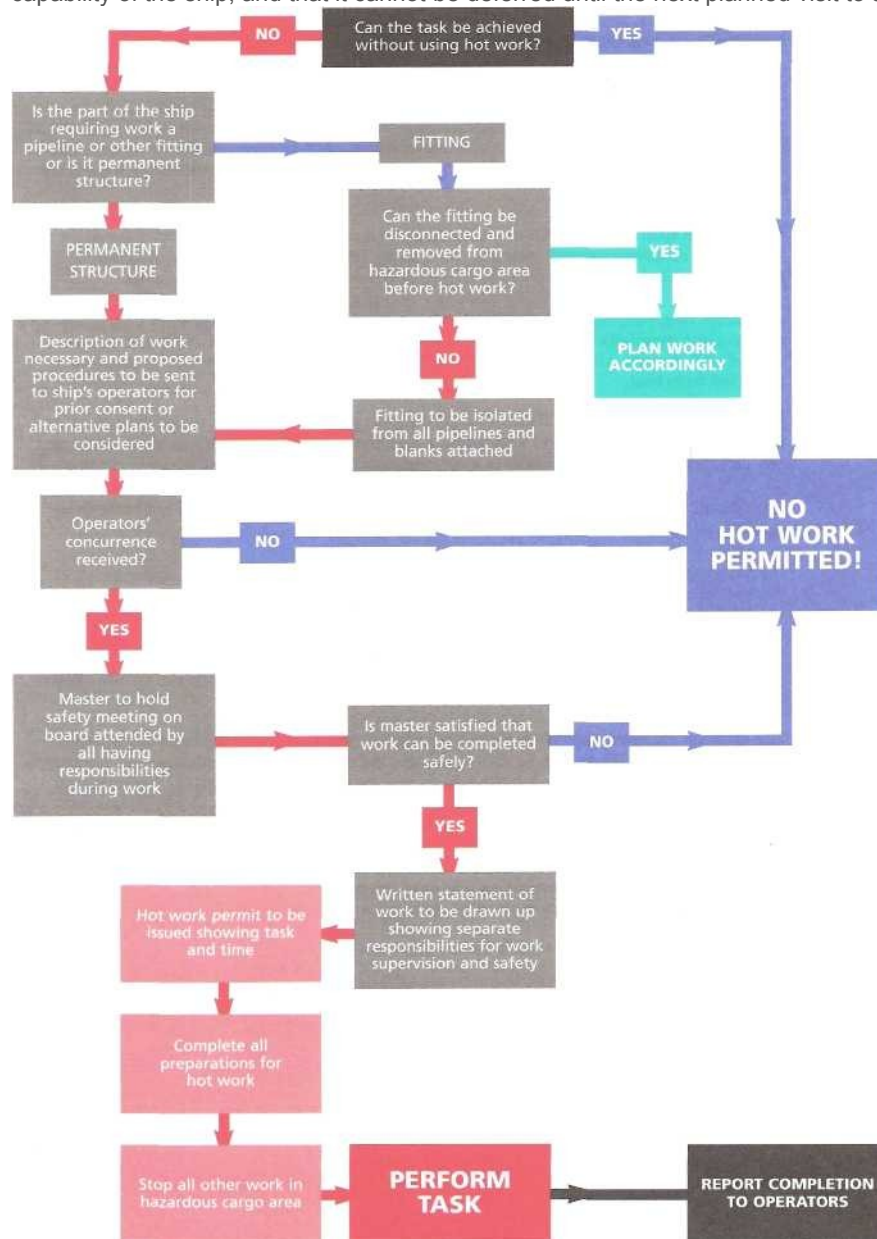
Adequate fire-fighting equipment must be laid out and ready for immediate use. Fire watch procedures must be established for the area of hot work and in adjacent, non-inerted spaces where the transfer of heat may create a hazard. Effective means of containing and extinguishing welding sparks and molten slag must be established. The work area must be adequately and continuously ventilated. Flammable solvents must not be present, even for cleaning tools.

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## 3.6.2 HOT WORK

This flowchart assumes the work is considered essential for safety or the immediate operational capability of the ship, and that it cannot be deferred until the next planned visit to a repair yard.



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The frequency of atmosphere monitoring must be established. Atmospheres should be re-tested at regular intervals and after each break in work periods. Checks should be made for flammable vapours or liquids, toxic gases or inert gas from non-gas free spaces.

Welding and other equipment to be used should be carefully inspected before each occasion of use to ensure that it is in good condition. Where required it must be correctly earthed. Special attention must be paid to electric-arc equipment to ensure that:

- electrical supply connections are made in a gas-free space;
- existing supply wiring is adequate to carry the electrical current demanded without overloading and consequent heating;
- flexible electric cables laid across the deck have sound insulation; and
- the cable route to the worksite is the safest possible, only passing over gas-free or inerted spaces.

### 3.7 STATIC ELECTRICITY

Static electricity can cause sparks capable of igniting a flammable gas. Some routine operations can cause electrostatic charging, and precautions to minimise the hazard are given below.

#### 3.7.1 Electrostatic Generation

The extent to which materials, whether solid, liquid or vapour, can generate and retain a static charge depends on their electrical resistance. If the resistance is high, a charge can be built up. It is also possible for a charge to build up on materials in a system with low resistance (e.g. metals) that are electrically insulated from each other. The

cargo system of a gas carrier is electrically bonded to the ship's hull to prevent charge build-up. It is important that such bonding connections are maintained in an efficient condition.

Hoses are normally bonded to their flanges by the metal reinforcement, and thus provide a continuous path to earth through the ship's manifold and the hull. If an insulating flange is inserted at the shore manifold, the intermediate flanges and metal reinforcement will still provide that continuous path.

A significant static electrical charge can be caused by high fluid velocities, change from liquid to vapour/liquid droplet flow, small particles carried in a vapour stream and by impingement.

In an unbonded system static electricity could be generated by:

- flow of liquid through pipes
- flow of liquid/vapour mixtures through spray nozzles
- flow of a vapour containing particles (e.g. rust) through piping.

The risk of causing ignition by static electricity is reduced if the system is correctly bonded or if flammable mixtures are avoided.

### 3.7.2 *Steam*

High velocity water droplets in a jet of steam may become charged in passing through a nozzle and could produce a charged mist. For this reason steam should not be injected into a tank, compartment or piping system which contains a flammable mixture. Steam may sometimes be used to provide external heat to defrost or dry a bonded system containing flammable liquid or vapour, but only if the surrounding atmosphere is non-flammable.

### 3.7.3 *Carbon Dioxide*

When liquid carbon dioxide under pressure is released at high velocity, rapid evaporation causes cooling and particles of solid carbon dioxide may form. The solid particles in the cloud of CO<sub>2</sub> may become electrostatically charged. For this reason carbon dioxide should not be released into spaces containing a flammable mixture.

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### 3.8 FIRE-FIGHTING AND FIRE PROTECTION EQUIPMENT

#### 3.8.1 *Fire-fighting Equipment*

Fire-fighting appliances should always be kept in good order, tested regularly, and available for immediate use at all times.

When the ship is berthed, the responsible officer should familiarise himself with the availability of the shore fire-fighting services and with the means of communicating with the appropriate authorities. This information should be obtained while completing the ship/shore safety checklist prior to cargo operations.

Immediately prior to commencing cargo transfer, the ship's fire-fighting system should be made ready. If practicable, a pump should maintain pressure on the fire water main, but in any case it should be on standby. Fire hoses should be uncoiled and connected to the main; at least two should be placed near **the manifold**, one forward and one aft of it.

The water spray system to protect the manifold area should be tested. Fixed monitors should be made ready and, if remotely activated, adjusted to protect the manifold before operations begin. A portable dry powder extinguisher should be placed conveniently for use near the manifold or a hose from a fixed dry powder monitor uncoiled and placed upwind of the manifold (see also Chapter 8).

#### 3.8.2 *Flame Arresters and Gauze (Flame) Screens*

Flame arresters and screens, when required to be fitted, should be maintained in good condition and replaced if they become defective. Passage of gas may be dangerously restricted if these devices become blocked; the passage of cold vapour through a damp screen can cause freezing and blockage. Flame screens should never be painted.

#### 3.8.3 *Inert Gas*

If inert gas is used in the cargo system (e.g. tanks, hold or interbarrier space) the gases in each space should be checked regularly to ensure that the oxygen concentration is below the required level and that the pressure is above atmospheric. All instruments and equipment used in the system should be maintained in good condition.

It should be remembered that an inert gas/cargo vapour mixture may become flammable if it should escape to the atmosphere.

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## CARGO OPERATIONS

### 4.1 INTRODUCTION

This chapter outlines the range of cargo operations normally encountered on liquefied gas carriers and the general safety precautions to be observed in connection with these operations. The procedures outlined should be considered as general guidance only; there is considerable variation in the design of cargo containment and cargo handling systems, and specific instructions should be prepared for inclusion in the cargo operations manual for individual ships. These instructions should be carefully studied by all personnel involved in cargo handling operations.

Although the cargo containment and handling systems have been carefully designed, and have been constructed under strict supervision, the required levels of safety in cargo operations can only be achieved if all parts of systems and equipment are maintained in good working order. Similarly, the personnel involved in cargo operations must be fully aware of their duties and thoroughly trained in the correct procedures and handling of the equipment.

Training in emergency procedures is particularly important (see Chapter 7).



## 4.2 RESPONSIBILITY

It is the responsibility of the master to ensure that the officers and crew are properly and correctly informed of their duties, and understand how to fulfil them.

The master or an officer appointed by him is responsible for the safety of the ship and all cargo operations. The responsible officer should be present at all times and be satisfied that all equipment under his care is in good working condition.

The master should ensure that there is proper liaison between the responsible officer on the ship and his counterpart at the shore installation (see Ship/Shore Safety Checklist in Appendix 9). These personnel should establish the programme for all cargo operations and the procedures to be adopted in the event of an emergency. Details of emergency contact names, positions, telephone numbers etc. should be distributed before cargo operations begin. Any special safety requirements of the shore installation should be brought to the attention of those concerned.

## 4.3 COMMISSIONING THE CARGO SYSTEM

Before a new ship is commissioned to carry liquefied gas it is essential that all parts of the cargo system are clean and dry to prevent faults or damage and that safety equipment has been checked and tested.

After drydocking or repairs, cargo tanks should be cleaned and inspected at all levels to ensure that accumulations of rust, water and possible loose objects have been removed. Internal fittings should be checked for tightness and security of nuts, bolts etc., which preferably should have been spot welded. Manholes should be checked for the correct type of gaskets and possible damage; covers should be properly tightened down.

It is essential that pipelines, valves and pumps are carefully dried out. Piping systems should be thoroughly blown through with adequate quantities of compressed air followed by nitrogen, making full use of the drains in the system in proper sequence. Special attention should be paid to the body cavities of valves and to convolutions of expansion bellows.

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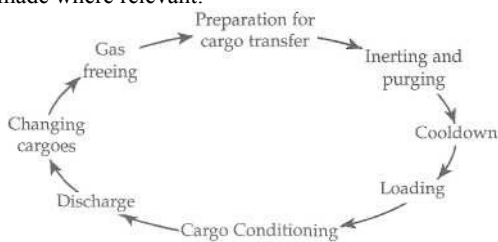


The emergency shutdown system and the operation of all actuator valves, compressor and pump cut-outs etc. should be checked.

Final adjustment and testing of some cargo plant control equipment can only be carried out with cargo on board. Arrangements should be made in advance with the shore installation to allow this work to be carried out by competent personnel during early stages of first loading. Pipe supports should be checked, especially where expansion bellows are fitted.

## 4.4 GENERAL CYCLE OF CARGO OPERATIONS

Every liquefied gas carrier must have a Procedures and Arrangements Manual which gives specific operating instructions. The following sequence outlines a general cycle of operations, and supplementary comments are made where relevant:



## 4.5 PREPARATION FOR CARGO TRANSFER

### 4.5.1 General

Before cargo transfer starts, the responsible officer should be satisfied that the precautions set out in Chapters 2 and 3 are being observed. The use of safety check lists, appropriately adapted for the specific ship, is strongly recommended.

The following pre-arrival checks should be made by the ship:

- deck lighting is working to provide for safe working conditions;
- ventilation systems are in operation as necessary (see section 6.4);
- fixed gas detection systems are calibrated for the cargo concerned and are in operation;
- fire protection equipment has been tested and is ready for immediate use, including water spray (see Section 3.8);
- personnel protection equipment has been checked and breathing apparatus air bottles are fully charged;
- protective clothing and breathing apparatus are being worn or are immediately available as necessary;
- no unauthorised work is being done in the cargo area and non-essential personnel are being kept away from the cargo area;
- restricted liquid level gauges are secured in the closed position if their use is not permitted with the cargo

concerned;

- adjustable relief valves are correctly set: if multi set point relief valves are fitted the correct setting device should be used;
- flame screens or similar devices in the vent system are clear, will not restrict gas flow and are suitable for the product;
- the oxygen content is below the specified maximum level in spaces required to be kept inerted, and a supply of inert gas is available to maintain a slight positive pressure in these spaces during all cargo transfer operations;
- spill pans or trays are in place beneath manifold connections or portable extension pipes, the relevant drain valves are closed and a hose for draining spillage is connected if required;

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- all cargo pipelines, filters, plant, instrumentation and controls have been checked and are in good working order;
- those involved in operations know who is responsible for instructions to open or close valves and to stop or start equipment;
- the ship's pipeline system is set for the relevant operation, and the valves have been checked; the stern cargo line, if fitted, is isolated if it is not to be used; any removable pipe sections or hoses connecting the cargo system to the ship's inert gas plant have been removed and blind flanges properly fitted.

The following ship-shore checks should be made:

- local regulations have been ascertained and are being observed;
- agreement has been reached with the responsible terminal representative about:
  - the signals to indicate 'Stand by', 'Start operations', 'Slow down', 'Stop operations';
  - pumping rates;
  - pumping or loading sequence;
  - action to be taken in the event of fire or other emergency;
  - emergency shutdown procedures; the ship's system should have been tested and the shore warned of the shutdown period of the ship's isolating valves; if the ship and shore systems have been linked, their functioning should have been tested;
  - access to the ship, and smoking restrictions;
- a ship-shore bonding connection, if used, is made before hoses are connected; if an insulating flange is used its insulation has not been impaired;
- cargo hoses, loading arms and gaskets are suitable for the cargo and are in good condition; flexible hoses are suspended from suitable equipment, are not subjected to excessive bending and are not putting excessive strain on the manifold (especially when the manifold is extended by unsupported reducing pieces); care is being taken not to damage mechanical loading arms; and the ship-shore flange connection is specially checked by the responsible cargo officer.

Full specimen Ship/Shore Safety Checklists are given in Appendix 9. 4.5.2 *Pressure Surge*

The potential hazards of pressure surges (shock pressures or liquid hammers) resulting from rapid operation of valves should be emphasised to all personnel engaged in cargo transfer. Pressure surges can be created when the flow in a liquid line is stopped too quickly. The hazard is greatest when cargo is being transferred over long distances and at high velocity. If a valve is shut too quickly under these conditions the deceleration of the large column of liquid in the line sets up shock waves which can travel up and down the line causing extremely high surge pressures. The cargo hose is most vulnerable to failure in these circumstances.

Pressure surges may be caused by automatic shut-off valves operated by level sensors. It is important that emergency shutdown valve systems are well maintained and accurately adjusted. Such valves often have different torque characteristics at service and ambient temperatures. If possible, they should be connected to the terminal system so that the shore and ship systems operate together. The operation should be adjusted so that upstream valves close first to safeguard the cargo hose or loading arm. Where such co-ordinated systems do not exist, those responsible for cargo operations should be aware of the potential hazard of the ship shutting down against the shore pumps, or vice versa.

The following precautions should be taken to avoid pressure surge during cargo transfer:

- During loading, when flow is diverted from one tank to another, the valves on the tank about to receive cargo should be fully opened before the valves on the tank being isolated are shut.

On Completion of ludding the flow should be stopped by the terminal using the shore valves to prevent overstressing of the cargo hose.

- During discharge, cargo flow should be controlled by the pump discharge valves or the valve on the tank dome, if possible, to minimise pressure effects and restrict them to a short length of pipe mostly within the cargo tank.

Likewise pump discharge valves should be shut before ship and shore manifold valves are closed.

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- While cargo is being transferred, valves in the liquid system should not be opened or shut suddenly. Valves should be set in the position required before transfer begins, and only those needed for throttling or control duty should be used during operations. Manual valves not required for normal operations may be lashed, but should never be locked in case they have to be used in an emergency.

A pressure surge can be generated when a valve maintaining a pressure difference in the liquid line is opened. If the pressure difference is high and the valve is opened too quickly a high flow velocity will result, giving rise to a high surge pressure when the flow is stopped. This could occur, for example, when liquid is trapped between valves in a deck line and becomes warm: in such cases the valve should be opened very carefully to equalise the pressures slowly. Liquid lines should be drained after use to prevent this problem.

A more detailed description of the pressure surge phenomenon is given in Appendix 8.

## 4.6 INERTING AND PURGING

### 4.6.1 General

The term 'inerting' generally refers to the replacement of air or cargo vapour by inert gas before loading or gas-freeing respectively, to prevent the formation of flammable mixtures.

The term 'purging' generally refers to the introduction of a suitable cargo vapour to displace an existing tank atmosphere. The extent of purging and the vapours used will normally be laid down by the IMO Codes or shippers' requirements. Shippers should always be consulted about the atmosphere required on arrival at the loading port. Inerting or purging operations may take place at sea if the ship is suitably equipped, or in harbour. In either case, due consideration should be given to the safety of venting cargo vapour to atmosphere, and any local regulations should be observed. Venting is not normally permitted in port. If venting is unavoidable, operations should be carefully controlled to prevent dangerous vapour concentrations in the vicinity of the ship. Facilities may however be available for venting vapour to shore flare facilities.

During inerting or purging the relevant gas concentrations should be monitored regularly at different tank levels to ensure safe concentrations. This is particularly important in tanks with internal structures, wash bulkheads etc.

Tanks can be inerted or purged separately, in parallel or in series according to the arrangement of the system. If tanks are inerted or purged in parallel, back pressure effects in the line may cause an uneven vapour supply to each tank unless the vapour supply to each tank can be accurately measured and controlled.

Ship generated inert gas produced by combustion will contain up to 15% carbon dioxide and is unsuitable for use in certain circumstances. Such inert gas should not be used before loading a cargo with a temperature below  $-55^{\circ}\text{C}$  because at such temperatures the  $\text{CO}_2$  will freeze out and may contaminate the cargo. The  $\text{CO}_2$  can also react with ammonia to produce carbamates which will be deposited on the tank walls and may block pipelines etc. To prevent reaction, for instance when preparing to load ammonia after carrying LPG, the inerted tank should be ventilated with air before the ammonia is loaded; and when preparing to load LPG after carrying ammonia, the ammonia concentration should be reduced to 100ppm by gas-freeing with air before inerting.

### 4.6.2 Inerting

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The purpose of inerting is to prevent the formation of explosive vapour/air mixtures. The production of inert gas is outlined in paragraphs 5.3.12 and 5.3.13 and the gas used for inerting should be suitable for the purpose (see paragraph 3.4.4).

When inerting a tank which has been ventilated with air, the oxygen content should be checked regularly. The oxygen content after inerting should never exceed 5% by volume, and should normally be in the order of 2% to allow for uneven distribution. Much lower levels may be required for oxygen reactive cargoes (e.g. butadiene).

The dew point temperature for the particular cargo to be loaded must be achieved during this operation.

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When inerting a tank which has contained cargo vapour, the process should be continued until the cargo vapour concentration is sufficiently low to prevent formation of flammable mixtures during subsequent ventilation with air. For further information on the oxygen and cargo vapour concentration for each cargo see data sheets in Appendix 1.

To avoid possible back-flow of cargo vapour, the cargo lines should be opened to the vent system before the inert gas system is connected. It is advisable to use hot gas or some other suitable method to warm up tanks that have contained low temperature cargoes before inerting, so that the steel temperature is above the dew point temperature. Failure to do so means that much larger quantities of inert gas will be required and moisture or  $\text{CO}_2$  will freeze out. Similarly, if cold nitrogen vapour is used for inerting, atmospheric moisture is likely to be deposited in tanks.

### 4.6.3 Purging

The purpose of purging is to prepare tanks for receiving cargo. Normal shipboard inert gas may have to be displaced with pure nitrogen for cargo requirements (e.g. to remove  $\text{CO}_2$  or to obtain a low dew point). Neither inert gas nor nitrogen can be condensed by the ship's reliquefaction plant. Purging with cargo vapour is therefore necessary before loading so that the ship's reliquefaction plant can operate continuously (see paragraph 4.9.2). Cargo vapour for purging can be taken from a shipboard storage vessel via a vaporiser and the cargo vapour/inert gas mixture vented to atmosphere. When purging with cargo vapour in port, the cargo vapour/inert gas or nitrogen mixture should be led to a proper vent or flare stack ashore for safe disposal. Purging is completed when analyses of vapour samples from the tank are satisfactory, or when the inert gas concentration is sufficiently low for the reliquefaction plant to operate continuously, or both.

### 4.6.4 Methods of Inerting and Purging

One of three methods may be adopted:

- Stratification (Displacement)

This method makes use of the difference in vapour densities between the gas in the tank and the inerting or purging gas.

A fairly distinct layer (or stratum) is formed between the two gases because of the density difference. Most hydrocarbons are heavier than inert gas, whereas ammonia is lighter than air. Nitrogen and inert gas have almost equal densities though nitrogen is denser at low temperatures. It is advisable and economical to use warm nitrogen. The lighter gas is passed into or vented from the top of the tank and the heavier gas is passed into or vented from the bottom. Considerably less inerting or purging vapour is used than with other methods, but the vapour has to be introduced at a controlled rate, otherwise the turbulence will cause mixing and prevent distinct layers from forming. This method can be used for all types of tanks but is most efficient for those with a simple internal

structure.

- Turbulence (Dilution or Mixing)

Large volumes of inerting or purging gas are blown into the tanks and mixed with the existing vapour. The inerting or purging gas should be blown in vigorously to reduce the possibility of isolated pockets of vapour remaining undisturbed.

- Vacuum/Pressure

**Warning: This is now an uncommon procedure which can result in a total low-pressure shutdown, making renewed start-up a very complex process. It should only be employed with the utmost care.**

The method is used with pressure or semi-pressure type cargo tanks. A vacuum is created in the tanks (within design limitations) using the ship's compressors. Inerting or purging gas is then admitted until a positive pressure is achieved. The process is repeated until the required inert or purge gas concentration is reached. In order to assist the process, the original gas in the tank should be reduced to a minimum and the inerting or purging gas should be introduced rapidly at several points to give maximum mixing.

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## 4.7 PREPARATION FOR LOADING, INCLUDING COOLDOWN

### 4.7.1 General

After a tank has been inerted or purged as necessary, it has to be correctly prepared for loading in order to prevent uncontrolled pressure rises and unsafe temperature gradients developing during the initial stages of loading.

Most cargoes have sub-zero boiling points at atmospheric pressure (butane -5°C, ammonia -33 °C, propane -42°C, ethylene -104°C, methane -163 °C). These boiling points are correspondingly higher at higher pressures (see data sheets). Cargo liquid entering cargo tanks and piping which are at ambient temperature and pressure will therefore immediately begin to boil, and its temperature will correspond to the boiling point at atmospheric pressure. Boiling and evaporation will continue to result from heat transfer into the liquid until the structure reaches the liquid temperature.

This initial boiling will cause a rapid pressure rise in the cargo system. The pressure attained will depend on the quantity of liquid, the heat available for evaporation and the capacity of the vapour return line or vent stack. The ship's reliquefaction plant cannot condense vapour until very nearly all the incondensable inert gas has been removed. If the rate of vapour generation exceeds the vapour return capacity, the pressure will increase quickly and may exceed the relief valve setting, causing venting through the vent mast. Care should therefore be taken to introduce cargo liquid into warm cargo tanks sufficiently slowly to avoid an alarming pressure rise and uncontrolled venting.

The initial boiling will also cause local cooling of the tank structure, resulting in thermal stresses. Great care should therefore be taken during cargo operations to avoid undue thermal stress or shock, particularly in the case of low boiling point cargoes.

### 4.7.2 Cooldown

Cooldown of tanks and pipelines is undertaken to control thermal stresses, and loading rates should be restricted during cooldown. If tanks are fitted with spray equipment it should be used, and the liquid distributed around the inside of the tank as evenly as possible to avoid thermal stresses. Spray cooling is essential for very cold cargoes such as ethylene or LNG. Certain restrictions on the rate of cooldown may also apply to LPG carriers. Pressure build-up in the tanks will restrict the rate at which liquid is introduced. The use of a vapour return line is recommended to avoid cooldown and loading rates being dictated by the capacity of the reliquefaction plant. Cargo pipework and equipment should be cooled down by circulating liquid at a controlled rate. The system should reach liquid temperature sufficiently slowly to prevent undue thermal stresses in materials or expansion/contraction fittings. The liquid used can come from the shore, shipboard storage vessels or cargo tanks. The temperature sensors will indicate when liquid is present on the tank bottom, but the liquid should be introduced slowly until the bottom is completely covered.

The cooldown of tanks may cause a pressure reduction in sealed hold or interbarrier spaces, and dry air, inert gas or dry nitrogen should be introduced in order to maintain a positive pressure. This is usually done by automatic equipment. Pressure gauges should be observed regularly during cooldown to ensure that acceptable pressures are maintained.

### 4.7.3 Ice or Hydrate Formation

Ice or hydrates may form during cooldown if moisture is present in the tank atmosphere.

During cooldown, valves should be operated frequently to ensure that they are free; where practicable, pump shafts should be turned manually at intervals.

LPG from pressure storage at above 0°C may contain water. If used for cooldown before loading LPG, ice or hydrates can form where expansion occurs. Water can be prevented from freezing by dosing with anti-freeze (see paragraph 1.4.1). Anti-freeze should only be used with the approval of the shipper.

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### 4.7.4 Minimum Cargo Tank Temperature

Some cargo tanks, such as fully pressurised tanks and some semi-pressurised tanks, have a minimum allowed cargo tank temperature, which is higher than the boiling point for one or more of the products which the ship is certified to carry.

In order to avoid cooling such tanks below their limit during loading, they must be pressurised until the corresponding liquid temperature is above the minimum permissible tank temperature.

On completion of discharge any remaining liquid must be thoroughly stripped before the tank vapours are

evacuated, in order to prevent the temperature of any remaining liquid from dropping below the minimum permissible tank temperature.

## 4.8 CARGO LOADING

Before cargo is loaded, a Pre-arrival and Ship/Shore Checklist should be completed (see paragraph 4.5.1), and the responsible officer must be satisfied that the cargo system is in all respects ready. Loading must not commence until information on the cargo has been obtained (see Section 2.2).

During loading, cargo is transferred from shore through the appropriate midships or stern manifolds, and led into the cargo tanks via the filling lines, which usually terminate close to the tank bottoms. If the tank has not been cooled down it is normal to by-pass some of the incoming liquid through the tank sprays, if fitted, to reduce the temperature gradient from tank top to bottom, and to even out the rate of boil-off. The loading rate is determined by the rate of change of the tank pressure.

As the liquid level in the tank rises, the tank pressure is increased by:

- vapour pressure of the 'warm' cargo;
- vapour displaced by the incoming liquid;
- vapour generated by heat transfer through the tank walls to the liquid; and
- vapour generated by heat transfer from the ship and shore pipelines and the shore pumps.

On fully or semi-pressurised ships the vapour pressure increase during loading can be reduced by spray loading, provided the cargo temperature will give a saturation pressure safely below the relief valve set pressure. With fully or semi-pressurised tanks, the boil-off and displaced vapour is either returned to shore or condensed by the ship's reliquefaction plant. Venting during loading must be avoided. In the case of LNG the boil-off cannot normally be condensed and the ship will be dependent on full vapour return to shore.

The responsible officer should ensure that the following precautions are observed, in addition to those set out in Section 4.5:

- In the event of an emergency, the emergency shutdown procedures should be implemented.
- AH fixed gas detection equipment should be operated throughout all loading operations.
- During the early stages of loading, the incoming liquid may be relatively warm and generate quantities of vapour in excess of capacity of the reliquefaction plant or vapour return line. The tank pressure should be regularly observed during loading and the loading rate reduced in good time before approaching safety valve set pressures. If reducing the loading rate does not reduce the pressure rise, loading should cease immediately, and the terminal should be notified to enable proper steps to be taken in the event of hazard to the adjacent shore areas. If venting occurs it will cause self-refrigeration, thus reducing the cargo temperature and pressure.

% Filling of the cargo tanks may cause a significant loss of pressure in the hold or interbarrier spaces, depending upon the cargo system design. This should be continuously monitored and pressure maintained by the addition of supplementary inert gas, dry air or dry nitrogen.

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- Filling limit regulations should be observed. The maximum liquid level in each tank should be calculated before or during the early stages of loading.
- If large quantities of vapour are being generated (i.e. the cargo liquid is boiling rapidly) the bubbles created will increase the liquid volume. To measure tank contents accurately under such circumstances it is recommended that vapour removal should be reduced temporarily to allow the liquid level to stabilise.
- In all tanks, whether or not being loaded, the liquid level and pressure readings should be monitored throughout loading. A reading which does not change as expected may indicate a fault which should be investigated.
- When liquid flow is diverted from one tank to another the valves on the tank about to receive cargo should be fully opened before those on the tank being isolated are shut.
- On completion of loading all ship's lines should be drained into the cargo tanks using the facilities provided.

Liquid in hoses or loading arms should also be drained to the cargo tanks, if possible, or blown to shore and pressed past shore valves by vapour pressure. If possible the ship-shore connection should be purged before being disconnected. Ship-shore connections should not be broken until it has been ascertained that all liquid has been removed and the lines are depressurised. Adjacent isolating valves on ship and shore and any other relevant valves should then be closed before connections are broken.

- Bonding wires, if fitted, should not be disconnected until after the hoses have been disconnected.
- The relief valves of some ships have dual or multiple settings, either for operational purposes or to meet differences in national regulations. Changes to the relief valve setting should be carried out in accordance with the procedures specified and under the supervision of the master. Changes should be recorded in the ship's log and a sign posted at the relief valve and in the cargo control room, if provided, stating the set pressure.
- It is normally necessary to deballast during loading and the precautions set out in Section 4.12 should be observed.

## 4.9 CARGO CONDITIONING

### 4.9.1 General

The term 'cargo conditioning' refers to the care and attention given to the cargo on passage to ensure that:

- there are no undue losses in cargo quantity;
- cargo tank pressures are kept within design limits; and
- cargo temperature is maintained or adjusted as required.

These aims are achieved either by reliquefaction or, on most LNG ships, by using boil-off as propulsion fuel. Cargo conditioning may not be necessary on ships with pressure vessel tanks.

If reliquefaction plant is fitted the responsible personnel should have a thorough understanding of its operational principles. When running, the plant should be monitored so that anything which might adversely affect its safety or efficiency is quickly recognised and corrective action taken. Plant is normally fitted with shutdown devices to sense high liquid level, temperature or pressure.

#### 4.9.2 Reliquefaction and Boil-off Control

General guidance on safe procedures for reliquefaction and boil-off control is given below. The detailed instructions for any ship depend upon the system fitted, and manufacturers' operating instructions should be closely followed. Procedures and precautions for individual components in the system are given in Appendices 5 and 6.

There are several different types of reliquefaction system and these are discussed in Appendix 3. The most common involves compressing the cargo vapour and condensing it in a seawater-cooled condenser. Alternatively the condenser may be cooled by a refrigerant from a secondary refrigerating unit (cascade-type refrigeration). Another type of reliquefaction is achieved by circulation of the refrigerant through coils inside the tank or through a separate heat exchanger outside the tank (indirect cooling). Cargo-incompatible refrigerants should not be used, nor refrigerants which are known to have a high ozone depleting potential.

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The vapour of certain cargoes (e.g. ethylene oxide, propylene oxide) cannot be compressed. Such cargoes can only be refrigerated by indirect cooling and cargo compressors usually have to be isolated or blanked off.

LPG is normally reliquefied by direct compression and condensation in one or two stages, with condensation against water, in what is called a direct reliquefaction system (see Appendix 3 Section 6.2 and 6.3). Colder cargoes such as ethylene, although still requiring direct compression, require a cascade system with the cargo condensing against a secondary refrigerant, which is condensed using water as the coolant (see Appendix 3 Section 6.4).

A reliquefaction plant is not normally fitted to LNG carriers. Instead the boil-off is used as fuel for main propulsion machinery. During ballast passages the tanks are kept cold using cargo deliberately retained on board: this cargo is known as a 'heel'. Boil-off from the heel is also used for propulsion during the ballast voyage. The retention of a heel requires consideration of sloshing loads (see paragraph 1.8.7): care has to be taken to ensure that the retained liquid is properly distributed. A heel is often also retained on board fully refrigerated or semi-refrigerated LPG carriers to enable the tanks to be kept cold on the ballast voyage. As LPG boil-off is heavier than air, regulations do not permit it to be used as propulsion fuel and it is therefore reliquefied and returned to the tanks. Return should be by the spray line, if fitted, for best cooling efficiency.

The specific operating instructions for the system fitted should be observed in addition to the following precautions:

- The purpose of the reliquefaction system is to prevent loss of cargo and ensure that the cargo liquid is either kept at the loading temperature or is at the temperature required for discharge on arrival. In the latter case it may be necessary either to cool or to warm up the bulk liquid on passage. If the system is used only to keep cargo tank pressure just below the relief valve set point, the cargo will warm up to a new temperature and it may be too hot for discharge at the terminal. If it is necessary to cool down the liquid on passage, the loading temperature and system capacity should be assessed to ensure that the necessary operations can be completed during the voyage.
- If two or more cargoes are carried simultaneously, they should be segregated throughout all cargo operations. Particular care is required with incompatible cargoes (see Section 4.13).
- Gas detection equipment in spaces containing reliquefaction plant, instrumentation and controls should always be activated. Upper and lower sample points (if fitted) should be selected according to the relative vapour density of the cargo (see data sheets).
- Ventilation equipment for the reliquefaction plant space should be started well in advance of activating the plant.
- Filters on the suction side of compressors should be checked and carefully cleaned if necessary. If they are blocked the efficiency of the plant may be reduced drastically.
- The lubricants used for all machines should be compatible with the cargo and suitable for the temperatures and pressures experienced both in operation and when stopped. Oil levels should be checked and crankcase heaters started if necessary before the plant is activated.
- All plant, instrumentation, control and shutdown equipment should be tested on a regular basis.
- The precautions on ice or hydrate formation, reactivity and cargo contamination should be observed (see Sections 1.4 and 4.13).
- All pipelines and valves should be double-checked to ensure that they are correctly set before starting the plant.
- To prevent overheating, the cooling water supply to condensers should be established and the refrigerant system (where fitted) started before cargo compressors are run.
- Cargo compressors should never be operated with discharge valves shut.
- Sub-atmospheric pressures should normally be avoided in any part of the system to prevent the ingress of air. Flammable vapour/air mixtures should never be passed through cargo compressors.
- Refrigerant or cargo vapour compressors should be started and suction valves opened very slowly to prevent damage from liquid carry-over.
- If the capacity of cargo or refrigerant compressors is controlled manually, plant should be started on the minimum setting and the capacity increased gradually as necessary.

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- Operation of the reliquefaction plant will be affected by any incondensable gases in the vapour drawn from the

cargo tanks. These incondensibles may originate from the cargo itself (e.g. ethane, methane) or may be inert gas remaining from previous purging. Incondensibles will cause abnormally high condenser pressure and will reduce condensation of the cargo vapour. To re-establish full condensation the incondensibles have to be vented regularly. Problems with incondensibles mainly arise during the early stages of reliquefaction. Reliquefaction plant liquid levels should be checked regularly during operation to prevent overfilling of receivers or condensers, which may be caused by sticking control valves or expansion valves. It is desirable to keep comprehensive records so that any unexpected changes can be quickly noticed and remedial action taken.

- Care should be taken to prevent liquid cargo from entering compressors, particularly if liquid separation equipment is not fitted. In heavy weather this could be a significant problem which may require shutdown of compressors. Under certain conditions liquid entrainment may also occur during spray cooling of the tanks. Liquid entrainment in the vapour may cause severe mechanical damage to compressors.
- If condensate is returned to more than one tank simultaneously, or if vapour is taken from several tanks and is returned to a single tank, the liquid levels should be checked regularly and remedial action taken to avoid possible overfilling.

#### 4.9.3 Use of Cargo as Fuel

Boil-off from LNG cargo may be burnt as fuel in the main propulsion system. Two factors influence the sanctioning of this practice:

- LNG vapour, being mainly methane, is lighter than air at ambient temperatures. It is therefore safe to be used because if it were to leak into the machinery space it would escape through exhaust vents and not accumulate within the machinery space. Consequently LNG is the only cargo vapour allowed to be used as fuel.
- Reliquefaction of LNG would require a complex refrigeration cycle requiring considerable power, and such equipment is rarely fitted.

It is possible to burn LNG vapour in boilers, diesel engines or gas turbines. In each case cargo vapour is introduced into a space from which it is normally excluded, and the design of the cargo vapour-to-fuel system is therefore subject to strict requirements. It is vital to ensure that the integrity of the system is not impaired in any way. LNG boil-off may be either vented or burnt (or both) to keep tank pressures at the required level. The decision whether to vent or burn the boil-off depends on many factors, some economic, some the result of regulations. Regulations may, for instance, either prohibit venting or the use of cargo *as* fuel in certain places. Such regulations should always be observed.

[Note: Attention should also be paid to Chapter 16 of the IGC Code, Regulation 11-2/15.1 of the SOLAS Convention, IMO recommendations concerning the use of low flashpoint cargoes as fuel e.g. IMO Resolution A565(14), and to classification requirements.]

On the high seas, cargo vapour may provide the main fuel, though oil pilot burners are also required. In the case of steam plants, cargo vapour may also be burnt when propulsion machinery is not in operation provided that means for steam-dumping are installed.

Boil-off is normally heated and pressurised before delivery to the machinery space; it is sometimes odourised as well. The pressure of the vapour is boosted to promote stable and efficient combustion. It is heated so that conventional steel can be used in the system, fuel economy is increased and any vapour which may leak from the system will more readily rise and escape.

The following precautions should be observed:

- Personnel should fully understand the system, its limitations, maintenance requirements and the danger of cargo leakage. The system should be kept clean and efficient and machinery performance logged so that changes can be identified.
- Ventilation fans for the machinery space and the fuel supply line trunking should be operated before and during gas burning operations. Attention should be paid to the ventilation of any areas near untrunked gas piping.

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- Gas detection equipment for the system should be working throughout burning operations.
- Supply lines should be purged with inert gas immediately before and after burning operations.
- All operating instructions for the system should be observed. Safety equipment (such as interlocks) should not be overridden.
- If the gas flame goes out, the reason should be established before it is relit. If both oil and gas flames are lost all combustion spaces should be ventilated of flammable vapour before the flame is relit, otherwise an explosion could occur. Attention should be paid to flame failure sensors; low sensitivity will result in failure to shut down and high sensitivity will cause unnecessary shutdowns.
- Cargo tank pressures should be monitored during all burning operations: if boil-off is removed too fast, the pressure could be reduced below atmospheric and air drawn into the tank, creating a flammable mixture. Cargo tank pressures should be maintained above atmospheric at all times.
- Care should be taken to prevent liquid cargo from entering compressors, especially if liquid separators are not fitted. Rapid changes in supply pressures should be avoided, otherwise the flame will not be stable.
- The gas supply lines should be checked regularly for leaks. If a leak does occur, the fuel supply should be isolated immediately and not reconnected until the leak has been repaired.
- No modification whatsoever should be made to the system without the permission of a responsible authority.
- Reference should be made to Appendices 5 and 6 for safety precautions specific to instrumentation or items of plant.
- All joints in the supply line should be pressure tested after maintenance before the system is recommissioned.
- Water should be drained from carbon steel fuel lines to prevent corrosion.

- Flame screens may be fitted in the supply line or within each burner: they have very small holes which are easily blocked, and should be cleaned regularly.
- The gas heaters should be regularly checked to ensure that no leakage occurs between the gas and steam systems. Steam condensate has to be returned to the feed water system via a ventilated drain tank: the water level in these tanks should be maintained and vents checked periodically for blockage which could cause gas to enter the feed system.
- Gas booster compressors should be carefully maintained and attention paid to the condition of shaft seals.
- All incidents, however trivial they may seem, should be recorded and brought to the attention of the responsible officer.

#### **4.10 CARGO DISCHARGE**

The general precautions in Section 4.5 should be observed during cargo discharge, and particular attention should be paid to cargo equipment (e.g. pumps, compressors, vaporisers). If the cargo is to be discharged by pumping and the shore cannot accept the full pump capacity, flow should be reduced by shutting down pumps or recirculating rather than by throttling, as throttling will tend to heat the cargo.

Pressure-vessel ships may discharge cargo by displacement (i.e. by increasing the pressure above the liquid with the compressors) instead of or in addition to the use of pumps.

The following precautions should be observed in addition to those in Section 4.5:

- Fixed gas detection equipment should be working throughout cargo discharge.
- If a submerged electrical pump is fitted, the insulation reading should be checked before starting up.
- Cargo pumps are normally started with the discharge valve shut or fractionally open to reduce both the starting load and pressure surge. It may also be necessary to recirculate to adjust pressures and cool deck lines. Pump manufacturers' instructions and ship's operating manuals should be consulted. Booster pumps should be circulated with cargo from the main cargo pumps and should not be started until there is sufficient liquid supply to prevent cavitation.
- Pressures in the liquid lines will be considerably higher during discharge than during loading. Joints and glands are therefore more likely to leak during this operation and should be inspected frequently.

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- The tank pressure will tend to fall as cargo is removed. If the discharge rate is high there may be insufficient boil-off to maintain positive pressure in the tank, and vapour should be added to prevent a vacuum. The vapour may come from the shore, or can be generated aboard by diverting some cargo liquid to a vaporiser. Tank pressures should be monitored throughout the discharge.
- Discharge can cause pressure changes in the hold or interbarrier spaces, the rate of change depending upon the cargo system design. Pressures in such spaces should be watched during discharge and any necessary action taken.
- All cargo tank level readings should be watched, whether or not their cargo is being discharged. Any reading that does not change as expected may indicate a fault that needs to be investigated. Care should be taken to ensure that cargo pumps do not cavitate: it is normal to close the discharge valve gradually when a tank is nearly empty both to prevent cavitation and to assist in pumping out the maximum quantity of cargo. It is dangerous to run pumps dry as the cargo liquid provides the required lubrication and cooling for bearings, seals, glands, etc.
- In the event of any emergency, the emergency shutdown procedures should be implemented.
- On completion of discharge, liquid lines and cargo hoses or loading arms should be drained, purged and depressurised using the facilities provided. The isolating valves should then be closed and the ship-shore connections can then be broken. Bonding wires, if fitted, should not be disconnected until after the hoses have been disconnected.
- See Section 4.13 for precautions when two or more cargoes are transferred simultaneously and Section 4.18 for sampling procedures.
- The ship's stability should be carefully checked at all stages during the discharge and necessary precautions taken (see Section 4.12).

#### **CARGO TRANSFER BETWEEN VESSELS**

If cargo is to be transferred from one ship to another, or to a barge, the precautions above should be observed (see Sections 4.5, 4.8 and 4.10). In addition, the relevant precautions in the ICS/OCIMF publication 'Ship to Ship Transfer Guide (Liquefied Gases)' should be closely observed.

Before starting transfer operations the two masters involved should agree on every aspect of the transfer procedure and appoint a person in overall charge. Transfer operations between gas carriers should be carried out in accordance with the requirements of the receiving vessel.

In all cases, however, each master remains fully responsible for the safety of his own ship, its crew and cargo, and must not permit safety to be prejudiced by the actions of the other master concerned.

Transfer operations should only be carried out in favourable weather conditions and should not begin until the master or responsible officer of each vessel is satisfied that the situation is safe. A safety checklist should be used prior to commencing operations and, in the event of subsequent stoppages, a further check should be made before resuming operations.

During operations the maximum transfer rate must be consistent with the receiving vessel's reliquefaction capacity. Alternatively, a vapour return hose connection should be made to the discharging vessel.

In the case of ship to barge transfers the following additional precautions should be taken:

- before transfer begins the person in overall charge should be satisfied that the barge personnel are fully conversant with the nature of the hazards presented by the cargo being transferred and with the necessary safety



precautions;

- moorings should be of such a nature that the barge can be quickly released in an emergency;
- the rate of transfer should be controlled according to the nature and size of the barge;
- operations should be stopped immediately if the barge fails to comply with the safety requirements in any respect;
- the barge should be requested to move from alongside as soon as possible after completion of loading or discharge.

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## 4.12 BALLASTING/DE-BALLASTING

Depending upon ship design, it may be necessary to undertake loading/de-ballasting or discharging/ballasting operations simultaneously. If this is the case, consideration should be given to the stability of the ship, especially to free surface effect in tanks, correct use of cargo tank centreline bulkhead valves, and cargo and ballast distribution to ensure adequate stability. Care should also be taken to ensure that the weight distribution does not lead to excessive trim, list or stress in transverse and longitudinal directions.

Concern about the introduction of alien organisms into environmentally sensitive waters and adjacent areas has prompted some national administrations to establish controls on the discharge of ballast water from ships. If it is necessary to change ballast at sea, the same care and attention must be paid to trim, stress and stability.

## 4.13 SEGREGATION OF CARGOES

When common pipeline systems are provided for various cargo-related operations, contamination will occur when different grades of cargo are carried simultaneously. If segregation is needed to avoid cargo contamination, shippers' instructions and regulatory requirements must be observed. If a common piping system has to be used for different cargoes, great care should be taken to ensure complete drainage and drying of the piping system before purging with new cargo.

Wherever possible separate reliquefaction systems should be used for each cargo. However, if there is a danger of chemical reaction, it is necessary to use completely segregated systems, known as positive segregation, at all times, utilising removable spool pieces or pipe sections. This restriction should apply equally to liquid, vapour and vent lines as appropriate. Whilst positive segregation may be acceptable for most cargoes, some substances may require totally independent piping systems. Special treatment of certain cargoes is specified in the relevant IMO Gas Carrier Code.

If there is any doubt about the reactivity or compatibility of two cargoes, the data sheets for each cargo and a cargo compatibility chart should be checked and advice sought from shippers or other authority. If this advice seems inconclusive, the cargoes should be treated as incompatible and positive segregation provided.

The following precautions should be observed:

- Where codes and regulations call for segregation, the position of the valves, blanks, portable bends and spool pieces associated with such segregation should be carefully arranged and clearly identified. These arrangements for segregation must be followed as part of the approved system.
- If the cargoes to be carried are not compatible, the responsible officer should ensure that the pipeline systems for each cargo are completely isolated from each other. This entails checking that all necessary blanks are fitted or that pipe spool pieces have been removed. A cargo log book entry should be made of the action taken.
- In cases where two cargoes are compatible and an apparent negligible mix is permitted, the adjacent systems carrying the different cargoes should be isolated by at least two valves at each connection, or by one positive visible blank.
- Common pipelines and associated equipment should be drained, dried, ventilated and monitored before being used for another cargo.
- All temporary pipework should be gas-freed, monitored, disconnected and properly stored when not in use.

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## 4.14 CHANGING CARGOES

### 4.14.1 *Cargo Stripping*

Before changing cargoes or gas-freeing it is most important to remove all cargo liquid from tanks, piping, reliquefaction plant and any other part of the cargo system. Any remaining cargo liquid will continue to give off vapour and will frustrate subsequent purging or gas-freeing.

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If previous and subsequent cargoes are similar in chemical properties - e.g. propane and butane - purging may not be required (subject to shippers' considerations), but even in such cases it is normally required that no previous cargo liquid remains. Shippers' instructions regarding purging requirements should always be sought.

To achieve maximum drainage of liquid during discharge, the following advice should be followed:

- Careful trimming or listing of the ship can, depending on the design of a tank, assist drainage of liquid.
- If pumps are used for discharge, the pump discharge valve should be throttled towards completion of discharge to maintain suction to minimum liquid level. Manufacturers' instructions should be consulted as to the liquid level at which throttling should be started and the pump pressure that has to be maintained during later stages of pumping to obtain maximum, stripping. Each pump should be kept under continuous control during stripping to obtain the best results without pumps running dry.
- Even with good operation of cargo pumps, some liquid will remain in the tanks at termination of pumping. In the case of ships whose cargo tanks can accept overpressure, further stripping of liquid may be achieved by increasing tank pressure sufficiently to press out the liquid through the piping system ashore. Alternatively, all

stoppings may be collected in one of the tanks for subsequent discharge ashore. The use of cargo compressors, taking suction from other tanks, will ensure that all tanks and associated piping systems are left liquid-free. Proper stripping of tanks should be checked by the bottom sampling line or temperature sensors.

- In the case of ships with cargo tanks designed for pressures only slightly above atmospheric (fully refrigerated ships), stripping by pressure alone is not possible. On such ships (and on ships with pressure tanks, if pressure stripping is not successful) the remaining liquid should be boiled off by introducing hot vapour from the cargo compressors to the bottom of the tanks, through puddle heat coils (if fitted). During such operations the tank pressure must be closely observed, to avoid exceeding the relief valve set pressure. When pressure has increased to a safe level below the relief valve pressure, the cycle is reversed by starting compressor suction from the tank, relieving the vapour in the condenser, and discharging the condensate to shore or retaining on board in a deck pressure vessel. Alternatively, if the ship is at sea the vapour may be vented instead of being relieved.

- Provided the temperature of the liquid remaining in the tanks is above the saturation temperature corresponding to atmospheric pressure, the liquid may also be boiled off by using the compressor to draw off gases from the tank (maintaining the tank pressure at atmospheric pressure), instead of using hot gas. This is known as the vacuum method. The quantity of liquid that can be removed by this method is limited, however, as the boiling will soon sub-cool the liquid and no further evaporation will take place. The presence of sub-cooled liquid still remaining may be difficult to establish, as there will be insufficient tank pressure to detect it using the bottom sampling line. It will take some time before the liquid picks up sufficient heat from the surrounding tank structure to start boiling again and raise the pressure in the tank. Evaporation of the remaining liquid by means of hot gas is therefore recommended rather than the vacuum method.

(Note: the sub-cooled temperature should not fall below the temperature assigned to the tank (see paragraph 4.7.4). To ensure that this does not occur tank bottom temperatures should be closely observed.)

- Some ships are fitted with heating coils in the tank bottom to evaporate liquid residues. The heating medium is hot cargo vapour for internal coils or may be thermal heating oil for coils fitted externally to the tank. Vapour circulating coils should be purged either with inert gas, or with vapour from the subsequent cargo if it is compatible with the previous cargo. Similar precautions should be taken with cargo compressors.

- Liquid is removed from the piping system and equipment by blowing through with vapour (see above). Hot gas from the compressors passed through the liquid lines will provide heat to evaporate liquid not removed by pressure displacement. In cold weather and in insulated pipelines, liquid butane, butadiene etc. may evaporate very slowly even at atmospheric pressure.

- It may be necessary to change compressor lubricating oils when changing cargoes (the compressor manufacturer's instructions should be observed).

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#### 4.14.2 *Change of Cargo*

When all remaining liquid from the previous cargo has been removed from the system, a slight overpressure should be maintained to prevent the entry of air until the preparation necessary for the next cargo is established. When preparing for the next cargo the possibility of a chemical reaction with the previous cargo should be checked by referring to the data sheets. In addition care must be taken to avoid contaminating the new cargo. Many products are subject to very strict specifications for commercial reasons, and vapour from the previous cargo, even if compatible with the new product, may be sufficient to cause unacceptable contamination. Shippers' instructions should be obtained as far in advance of loading as possible.

In some rare cases the tanks have to be inspected internally before loading, requiring gas-freeing and ventilation with air before arrival. The precautions in Section 6.3 should be observed before tank entry. Before loading, tanks should be inerted and purged again as necessary (see Section 4.6).

#### 4.14.3 *Displacing Atmosphere with Inert Gas (Inerting)*

Vapours from the last cargo in the system are displaced by inert gas from the ship's inert gas generator, or by pure nitrogen from shore. If the ship's inert gas is used, the cargo piping system from the tank should be opened to the vent before the inert gas supply is connected as an additional precaution against the possible backflow of flammable vapour to the generator.

Regulations regarding venting of cargo vapour in port should be observed. Such regulations may require that vented cargo vapours should be led to a flare or vent stack ashore.

Inerting is continued until the required dew point or concentration of cargo vapour or oxygen level has been reached.

#### 4.14.4 *Displacing with Vapour of the Next Cargo (Purging)*

If the two cargoes are compatible, in terms of both chemical reaction and shippers' requirements, vapour from the previous cargo may be replaced (purged) directly by vapour from the next cargo, from shipboard storage vessels or from shore (see paragraph 4.6.3).

If purging is carried out in port, local regulations may require the expelled vapours to be led ashore for safe disposal, either to a vent or flare stack or for use in the shore plant.

In all cases advance notification should be given to the port authorities and permission obtained before starting the operation. Purging should be carried out in the most suitable way (see paragraph 4.6.4) until acceptable conditions for the next cargo are reached.

#### 4.14.5 *Water Washing after Ammonia Cargoes*

Ammonia vapour is normally removed from the tanks at sea by introducing large amounts of air and ventilating to atmosphere. However, the removal of all traces of ammonia by ventilation alone is a lengthy process.

If desirable, remaining traces of ammonia may be removed by water washing or water sweeping. Ammonia is extremely soluble (one volume of water dissolves up to 1000 volumes of ammonia vapour), and the introduction of

water into tanks containing high concentrations of ammonia may immediately cause dangerous vacuum conditions unless unrestricted access of air is provided. Ship's inert gas containing  $CO_2$  should never be used for purging after ammonia cargoes as carbamates will be formed which may block the cargo pipe lines (see paragraph 4.6.1).

If water washing, the following precautions should be taken:

# Personnel should wear breathing apparatus and protective clothing as necessary.

# Low ammonia concentrations must be achieved before water washing. All tank manhole covers should be opened up to provide unrestricted access of air and prevent dangerous vacuum conditions which may cause the tank to collapse.

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- Fresh water should be used, because sea water will leave deposits which are difficult to remove and will considerably increase rust formation on steel surfaces.
- Tanks should not be washed if they contain submersible pumps unsuitable for water immersion. Even if water is not harmful to the cargo pumps, separate portable pumps should preferably be used for removal of washing water from the tanks. If the use of cargo pumps is proposed, the possibility of over-loading pump motors when pumping water (SG = 1) should be considered; pump manufacturers' instructions should be consulted.
- After pumping out as much water as possible, any remaining water on the tank bottom should be wiped up and the tanks dried out by ventilation before being closed. For water washing to be successful it is essential to dry the tank and cargo lines with dry air from the inert gas system. In conditions of high relative humidity ventilation with warm air may be necessary. If cargo pumps have been used for pumping washing water, they should be carefully dried out by ventilation and treated with anti-freeze. Excess anti-freeze collecting at the tank bottom should be wiped up, as it may not be acceptable for the next cargo.
- The discharge overboard of ammonia washings may be prohibited in certain areas, and care should therefore be taken. The requirements for the control of pollution in Annex II of the MARPOL 73/78 Convention should be observed. If discharged overboard, ammonia-contaminated washings should not be allowed to enter the ship's seawater intakes because ammonia is corrosive to copper-based alloys in the seawater system.

## 4.15 GAS-FREEING

To gas free a cargo tank the following procedures should be followed:

- Remove any remaining cargo liquid (see paragraph 4.14.1). Pressure should be released with caution.
- If the tank temperature is near cargo saturation temperature at atmospheric pressure, the tank atmosphere should be warmed up by circulating hot gas. This is a very time-consuming operation and it is essential that all the steel in the tank has reached a temperature above dew point. It will assist in evaporating any remaining liquid (including condensation on tank structures) and will reduce the quantity of inert gas required (see paragraph 4.6.2).
- Remove the cargo vapour in the system with inert gas (see Section 4.6). This stage may be omitted when gas-freeing after the carriage of ammonia (see paragraph 4.14.5).
- After inerting the system to a safe cargo vapour concentration (see data sheets), it may be necessary to ventilate the system with air to provide safe access for inspection or repairs. Venting with air should be continued until an oxygen content of 21% by volume is obtained. Samples should be taken at various levels, and sampling repeated some time after the first acceptable readings are obtained, to allow possible pockets of inert gas to mix with the air, and the consequent reduction in oxygen content to be detected before tanks are entered.

When a tank and associated pipelines have been certified gas-free maintenance work may take place. The precautions set out in Sections 3.5 and 6.3 and in Appendices 5 and 6 should be observed.

## 4.16 VENTING AT SEA

In favourable ambient temperature and wind conditions venting may take place at sea. Rapid dispersion and dilution of toxic or flammable cargo vapour vented to the atmosphere is essential to safety. The critical factor is the ability to disperse potentially high concentrations of vented vapour. Such vapour needs to be diluted many times to bring its concentration below the Lower Flammable Limit, and even greater dilution may be necessary if inhalation of vapour could cause danger to personnel. Furthermore, the density of the escaping vapour mixture may be much greater than that of air and consequently the vapour mixture will tend to sink and form a layer across the deck. Wind speed plays an important part in the dispersion of vapour. It may be necessary to suspend operations in still air conditions (see paragraph 2.8.1). Wind direction relative to the ship's course is also important. Eddy currents may cause pockets of high gas concentrations to form in the lee of superstructures. Alterations to the ship's course and speed should be made to assist dispersal of cargo vapour.

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Cold cargo vapour will freeze out moisture in the air in the venting system and in the vicinity of the vent outlets. On ships designed for carrying soluble toxic gases such as ammonia a scrubber is sometimes fitted to reduce the quantity of vapour emitted. If such a system is fitted it should be used.

## 4.17 DECK STORAGE TANKS

Some ships have dedicated storage tanks on deck for cargo liquid which can be used to purge cargo tanks at sea. Normally these tanks are pressure tanks designed for containment of the liquid gas at ambient temperature.

The following precautions should be observed for pressure storage tanks on deck:

- Filling limits should be heeded, particularly when handling cold liquid which will expand as its temperature increases towards ambient.
- If storage tanks contain gas different from that carried in the cargo tanks, the storage tanks should be completely segregated from the cargo system by the removal of relevant spool pieces to prevent cargo contamination.
- For gas-freeing and access, the precautions set out in Sections 4.15 and 6.3 should be observed. When not in

use, storage tanks should be gas-freed and preferably filled with clean, dry inert gas to prevent corrosion. They should be completely segregated from the cargo system by removal of relevant spool pieces and fitting of blank flanges.

## 4.18 SAMPLING

Cargo is normally sampled by shippers' or receivers' personnel, or by authorised petroleum inspectors. The responsible officer should make proper records of the samples taken as they may subsequently be of considerable value. A good rule is to request that samples be taken from the liquid shore connections at the start of loading to safeguard against possible contamination from shore transfer lines.

The following precautions should be taken when sampling cargo liquid or vapour. 4.18.1 *Liquid Samples*

- The responsible officer should be present when any cargo sampling is carried out. He should be fully conversant with all aspects of the ship's sampling system including the operational characteristics of all valves. He should clearly recognise that the responsibility rests entirely with him for ensuring that sampling operations are conducted in a safe and efficient manner which will preclude any escape of cargo liquid or vapours to the atmosphere beyond that required by the sampling process, whoever is performing the actual sampling operation.
- The responsible officer should satisfy himself that the sampling equipment is compatible with the ship's sampling points before starting any sampling operation. If the two are incompatible for any reason he should ensure that any action taken to rectify the situation does not impair the gas tight integrity of any part of the ship's system or endanger life or property.

- Sample containers should be completely clean and compatible with the cargo to be sampled. They should be of a recognised standard and able to withstand the extremes of temperature and pressure anticipated.

- Sample containers should be purged with nitrogen before use.

- If the sample is to be representative its container has to be purged thoroughly with cargo from the sampling connection. Sufficient cargo should be passed through the container to

COOL it uOWn tO liquid LCIIipidIUie. If cargo is a mixture (which is often the case) the most volatile components will evaporate more rapidly than the heavier fractions as the container is cooled down. This will leave the sample with a higher concentration of the heavier fractions than is present in the cargo, and it will therefore be unrepresentative. To counteract this effect, sample containers should be turned with the vent valve downwards during cooldown, to drain off any liquid which collects. For the same reason, samples taken from the bottom of

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cargo tanks at or just after the beginning of loading may not be representative. If possible the cargo should be circulated, using the cargo pump, before taking bottom samples.

- It is imperative that sufficient ullage or vapour space is left in the sample container to allow the liquid to expand when the temperature increases to ambient. To this end a container should be used which is suitably designed for the product being sampled, with a built-in ullage tube and bursting disc. The safe ullage space is created by holding the sample container vertically, with the ullage tube end at the top. The container is then filled from the bottom connection and thus cannot be overfilled above the level set by the ullage tube.

- Unless the sample container is free from cargo vapour, it should not be stored in an unventilated space.

- Gloves, goggles and necessary protective clothing should be worn when sampling cold cargoes.

0 If the cargo is toxic, self-contained breathing apparatus must be worn. If sampling in an enclosed space, a respirator is insufficient because lack of oxygen may lead to asphyxiation.

- Any electrical equipment used when taking samples should be of the certified-safe type.

### 4.18.2 *Vapour Samples*

The precautions in paragraph 4.18.1 above should be observed when sampling cargo vapour or inert gas. Plastic sample bags are sometimes used for collecting vapour samples. They should be handled carefully, never used for liquid samples and always purged after use.

## 4.19 DRYDOCKING AND REFIT PERIODS

Appendix 4 outlines specific precautions to be observed during drydocking and refit periods.

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# CARGO EQUIPMENT



## 5.1 INTRODUCTION

Much of the equipment in the cargo system of a gas carrier is precision made. It depends upon correct assembly and maintenance of design tolerances for safe operation. Equipment should always be operated in accordance with manufacturers' and owner's instructions, and with due regard for the properties of the cargo. Equipment should never be operated outside its specified limits. General operational and maintenance precautions are outlined in this chapter; precautions for individual types of equipment and instrumentation are given in Appendices 5, 6 and 7.

## 2 OPERATIONAL PRECAUTIONS

### 5.2.1 *Maintenance*

Any defect can impair operation and present a hazard to personnel, equipment, the ship or the environment. Equipment should be carefully maintained and the following precautions should be observed:

- All maintenance should be undertaken carefully by personnel who are familiar with the equipment. The manufacturer's instructions should be complied with.
- If equipment has been exposed internally to cargo liquid or vapour, all toxic or flammable vapours should be drained and purged thoroughly before the equipment is dismantled. If the internal volume is significant, any inert gas should be removed by ventilation with air to prevent a hazard to personnel from asphyxia.
- No dismantling should begin until the relevant equipment has been depressurised and isolated, and a full working knowledge obtained of the internal construction and assembly details. Associated controls should be rendered inoperative, and the situation adequately logged and reported to subsequent watches.
- All sensing and control piping should be leakproof, especially if the system operates under a vacuum.
- All spares used should be at least equivalent to the manufacturer's specification and compatible with the cargoes to which they may be exposed, and should be suitable for the design temperatures and pressures of the system.
- During reassembly of an internal component of a system all nuts, bolts and other fastenings should be checked and suitably locked in position.
- All instruments used to calibrate equipment should be accurate; the composition and concentration of any gas samples used for calibration should be accurately known. Calibration should be recorded on or near the equipment.
- All maintenance work should be recorded.
- If maintenance involves hot work, the possible necessity for subsequent stress relief should be considered before the work is undertaken, especially for cargo equipment. The precautions for hot work given in Section 3.6 should be observed.
- Suspected leaks from piping and equipment should be investigated using safe means such as portable gas detectors or soapy water. A naked light should never be used.

(N.B. Soapy water can freeze, thereby sealing the leakage.)

#### 5.2.2 *Action in the Event of a Defect*

The following action should be taken if a defect is discovered:

- The responsible officer and all personnel concerned should be informed of the nature of the defect.

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- A suitable entry should be made in the cargo log.
- The defect should be rectified as soon as possible.
- An alternative back-up or duplicated system should be activated; this may entail a manual operation. If equipment is temporarily decommissioned it is essential that it is isolated from the cargo systems. All associated controls should be rendered inoperative. The facts of the situation should be adequately logged and conveyed to subsequent watches.
- All sensing and control piping to the defective equipment should be isolated to prevent leakage or malfunction of other equipment.

If any alarm is activated, immediate investigation is necessary and the appropriate action should be taken.

## 5.3 PLANT AND EQUIPMENT PRECAUTIONS

Equipment should be operated in accordance with the instructions for the particular ship, manufacturers' instructions and the cargo properties outlined in Chapter 1. Logs of equipment readings should be kept. General precautions are given below and further precautions for individual types of equipment are given in Appendices 5, 6 and 7.

### 5.3.1 *Pumps*

Ships' pumps should be used and maintained with care. The following precautions should be observed:

- Before starting, check deepwell pumps manually to establish that the pump is free to turn, dosing with anti-freeze if necessary (but see paragraph 1.4.1). If the pump is submersible check the electrical resistance.
- Start up in accordance with instructions. Pay special attention to pump priming, discharge valve setting and what to do if the pump does not gain suction immediately.
- When pumps are started, valves should be opened slowly, allowing flash gas to dissipate, and avoiding cavitation. Discharge pressure must be maintained above manifold pressure. If the manifold pressure exceeds the pump capacity, then a booster pump will have to be used. The pump capacity curve will give the design pressure at which the pump should be operated.
- During normal discharge the flow should be controlled using a by-pass (recirculation) rather than by throttling. Prolonged throttling will heat the cargo and the pumps, and where ball valves are installed the seal will be damaged.
- Towards the end of pumping, discharge valves should be throttled to maintain suction and improve drainage. Manufacturers' instructions should be observed.
- During maintenance particular attention should be paid to keeping filters clean and to the condition of seals, bearings and pressurising circuits.

### 5.3.2 *Compressors*

Compressors are used in cargo systems to compress vapour for pressurisation, reliquefaction or, in the case of LNG, delivery to the engine room. Compressors are easily damaged by liquid that has condensed in the cylinders, crankcases or separators. The following precautions should be observed:

- Before starting, check that no liquid has condensed in the machine, that heating systems, if fitted, are operating as required, that filters are clean and that cut-outs are correctly set.
- When running, open suction valves slowly to prevent liquid carry-over. Keep lubricating oil clean and

separators working efficiently. Check for signs of leakage, especially on the discharge side, and watch pressures. Pressures higher than expected could be due to incondensable gases or blockage downstream, e.g. a level gauge stuck, or an expansion valve iced up.

- After shutting down and when changing cargoes it may be necessary to change lubricating oil (e.g. after ammonia/ butadiene or vinyl chloride cargoes). Oil coolers, filters/ separators, crankcases and any traps where remaining lubricating oil can accumulate should be checked for cleanliness after carriage of butadiene.
- During maintenance particular attention should be paid to cut-outs, bulkhead glands and crankcase seals, suction filters (both to prevent damage and because blockage reduces efficiency), and all pipe flange joints.

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##### 5.3.3 Heat Exchangers

Heat exchangers may be used for a number of purposes, including condensing and reliquefying cargo vapour, vaporising cargo liquid, puddle heating, inter-cooling and drying. The specific instructions for the operation concerned should be observed, especially with regard to the sequence for introducing the 'hot' and 'cold' phases, and the relative pressures of each. The equipment should be kept free from fouling (see also paragraph 1.8.9). Sea water cargo heaters should be operated with care, especially if the cargo is at low temperature. The sea water supply should be established first and the cargo liquid supply carefully regulated to prevent the water freezing, which could block the equipment and cause damage. When the sea water temperature is below 5°C such equipment cannot be used.

##### 5.3.4 Electrical Equipment

The design and installation of fixed electrical equipment in the cargo area is subject to strict regulations to prevent fire or explosion. It is essential that this design safety is maintained. Portable electrical equipment which is not certified safe should not be taken anywhere where cargo vapour might be present (see paragraph 3.5.2).

The following maintenance precautions should be observed:

- Equipment should be de-energised and isolated before maintenance is undertaken.
- High voltage test equipment should only be used on circuits which can withstand it, and never on intrinsically safe circuits. Low voltage circuits may be permanently damaged and sparks may be created.
- If there is internal condensation in any equipment, that equipment should be isolated, opened up and dried out before being resealed.
- On reassembly, cable penetrations should be fitted with proper seals (not stuffing tubes or putty) and all bolts etc. should be replaced.

##### 5.3.5 Control and Alarm Systems

Gas carrier cargo systems are often complex, with many remote control and automatic cut-out systems. It is important that these control systems are kept in good working order.

All control systems should be checked regularly, especially shut-down systems, and adjustments made if necessary; equipment should be at service temperature when this is done. Checks or tests should not be carried out during cargo operations or cargo transfer as they may create unforeseen situations for shore installations or other vessels alongside.

Control fluids and control air should be kept clean, dry and uncontaminated, and should be replenished as necessary. Filters in the system should be kept clean.

Control fluids should only be drained when strictly necessary. If a different fluid is to be used, it must be compatible with the gasket and sleeve materials.

##### 5.3.6 Instrumentation

Instruments should be treated with great care. The lives of personnel and the safety of the ship often depend on decisions based on readings from delicate and sensitive instruments. In particular the following precautions should be observed:

- Manufacturers' instructions should be studied carefully before use or calibration and recommendations on factory reconditioning should be observed as closely as possible.
- Instruments should only be used for their intended purpose and records of readings should be kept.
- With chemical absorption or reaction equipment, the tubes or fluids have a limited life, which should not be exceeded.

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Equipment should be calibrated as often as necessary (N.B. gas detection equipment readings may 'drift', even during cargo operations). Calibration equipment should be accurate and of good quality. Supplies of calibration gas samples (span gas) should be available at all times and should be replenished frequently. Zero points should be checked and adjusted if necessary, and the equipment should then be calibrated throughout its operating range. Calibration or overhaul should be logged on or near the instrument.

##### 5.3.7 Valves

The valves used on gas carriers differ in detail from those used on other tankers because of the temperatures and pressure ranges they are subjected to. It is important to keep valves leak-tight and functioning properly.

The following precautions should be observed:

- Valves should be set correctly before cargo operations begin. They should be operated during cooldown to check that they are free.
- During operations, spindles should be kept free from ice. Manual valves should be operated slowly to prevent pressure surge. Protective gloves should be worn when handling cold spindles, wheels etc.
- When changing tanks during loading, the valve to the tank about to be filled should be opened before closing the valve to the tank which is almost full.
- During maintenance, valve packings should be checked carefully.

- Care should be taken when draining lines to avoid trapping liquid between adjacent valves. In such circumstances excessive pressure may build up if the trapped liquid heats up.

#### 5.3.8 *Cargo Vent Systems*

Vent systems are provided for the disposal of cargo vapour from tanks and liquid retained in pipelines. It is essential that cargo vent systems are kept clear otherwise they will become over-pressurised and may be damaged.

The following precautions should be observed:

- If relief valves have multiple settings, then any changes in the settings should be made in accordance with instructions, and should be logged.
- Vent systems should be kept clear; water should be drained off regularly from stacks. Drains should be kept closed when not in use, otherwise liquid on the discharge side of relief valves could be ejected onto the deck when a valve operates.
- Flame screens, if fitted, should be clean and in good condition but not painted. Snuffer flaps, if fitted, should be kept free to move.

#### 5.3.9 *Expansion/Contraction Fittings*

The cargo systems of all gas carriers are subject to considerable temperature variation and some means of accommodating expansion and contraction has to be provided. It is important that the procedures work properly, otherwise parts could be over-stressed and damaged.

The following precautions should be observed:

- Sliding feet should be kept free to move.
- Fittings should be protected from freezing.
- A check should be made that constraints which should be in place have been fitted and that all others have been removed.
- The condition and alignment of bellows should be checked. Bellows should be protected against mechanical damage.

#### 5.3.10 *Cargo Pipelines*

Liquid and vapour lines can be complicated and difficult to trace, so it is important that the settings of valves etc. are carefully checked before any line is used. Pipelines are particularly vulnerable to pressure surges and to the risk of freezing of trapped water.

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The following precautions should be taken:

- Manifold flanges should be cleaned before blanks or hoses are connected, paying particular attention to the removal of ice.
- Protective gloves should be worn by personnel handling cold lines or blanks etc.
- Filters should be cleaned and baskets replaced carefully.
- All missing supports, chocks etc. should be replaced.

#### 5.3.11 *Ships' Cargo Hoses*

The liquid and vapour hoses are the most vulnerable part of the cargo transfer system and should be treated with great care, both when in use and during storage. During cargo loading or discharging all non-essential personnel should keep away from the manifold area.

If cargo hoses are carried on the ship the following precautions should be observed:

- Hoses should be checked to ensure that they are suitable, in terms of chemical compatibility, temperature and pressure ratings etc. for the cargo to be carried. The hose details should be checked (see Appendix 13) and the condition of the hose inspected. Hoses should be tested at least every six months and the test results recorded: the tests should be at ambient temperature and up to the working pressure. The IGC Code, Section 5.7 should be referred to.
- Gaskets should be checked for suitability.
- The hose should be supported correctly at all times, especially during use, when tidal and draught variations should be taken into account.
- Pipeline flanges should be cleaned before connecting.
- Nuts and bolts should be of the correct size and material, and damaged bolts should not be used. A bolt should be fitted in every hole and tightened correctly.
- Hose bonding or insulation should be checked (see paragraph 3.5.6).
- Hoses should be drained, purged and depressurised before disconnection. Hoses not purged of cargo vapour should not be stored in enclosed spaces.
- Hose ends should be blanked before storage.

#### 5.3.12 *Inert Gas Systems*

Inert gas has an important role in maintaining safety aboard a gas carrier and the inert gas system should be kept in good working order. Regardless of frequency of use it should be tested regularly to prevent deterioration and enable any faults to be detected and rectified.

The following precautions should be observed:

- The whole system should be visually checked before starting up, in particular the deck nonreturn valves.
- The piping system to the vent outlet should be opened to release any pressure and prevent back-flow, and the temporary connections to the cargo system fitted.
- The scrubber water supply should be started before beginning combustion.
- The gas produced should be vented to atmosphere until it is of sufficiently good quality for use.
- The air supply should be adjusted to produce the best quality inert gas possible: oxygen, carbon dioxide, carbon monoxide and soot levels should be controlled (see paragraph 4.6.2). If the air supply is reduced in order to lower the oxygen concentration the gas produced may often have a high soot content which can clog driers, non-return valves etc.
- The gas quality should be continually monitored while the plant is in use,
- After use, the temporary connections to the cargo system must be disconnected and the flanges blanked securely.

#### 5.3.13 *Nitrogen System*

If liquid nitrogen is used as an inert gas, it should not be allowed to come into contact with any metal (other than the dedicated nitrogen storage and piping system) with a service temperature above -196°C. If it does, brittle fracture will occur. If the storage bottles and transfer line are vacuum insulated, the vacuum should be carefully maintained to prevent excessive boil-off. It is rarely possible to replace lost nitrogen except in port. (See also Appendix 5, section 13.)

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Ships may have the means to produce nitrogen gas on board by physical separation from the atmosphere, using the pressure swing absorption method or the membrane method. It is important to appreciate that the exhaust from the plant will be oxygen-rich compared to normal atmosphere.

##### 5.3.14 Ventilation Equipment

All ventilation motors and fans should be well maintained. Poor electrical contacts, blocked air intakes and interference between moving parts should be avoided. In some installations the fan impellers are made from special materials that cannot create sparks. When maintenance of such equipment is undertaken, care should be taken to ensure that the design safety features are not impaired in any way.

All components in ventilation systems, such as non-return flaps, flame arresters and dampers should be kept in good working order.

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## ENCLOSED SPACES



### 6.1 INTRODUCTION

When it is intended that personnel should enter or work in an enclosed space, great care should be taken to create and maintain safe working conditions, even if the duration of the work is to be short. The hazards and precautions associated with entering or working in enclosed spaces are outlined in this chapter.

### 6.2 ATMOSPHERE IN ENCLOSED SPACES

When an enclosed space is left closed and unventilated for any length of time, the internal atmosphere may become unsafe either because it contains less than 21% oxygen, or because it contains contaminants, or both. The oxygen content may be reduced by the presence of inert gas or by the process of rusting, which absorbs oxygen from the air. Cargo vapour is the most common contaminant, although fumes from other sources (e.g. stores) may present a hazard.

Cargo vapour or inert gas should always be anticipated in cargo tanks and hold or interbarrier spaces. Leakage should be suspected in the case of enclosed spaces separated by a single gas-tight bulkhead from cargo tanks and hold or interbarrier spaces. Similarly, leakage should be suspected in the case of any space containing cargo or inert gas equipment (e.g. compressor rooms and control rooms with direct connections to the cargo systems). The concentration of oxygen in fresh air is approximately 21%. An atmosphere with a lower oxygen concentration can be breathed for some minutes before the effects become apparent. If the oxygen supply to the brain is depleted the victim will feel dizzy and have a headache before losing consciousness. This is particularly dangerous because he may not recognise that he is in danger or be capable of finding his way out of the space. He therefore becomes a risk to himself and others. There is a danger of permanent brain damage after only four minutes in a very oxygen-deficient space. A successful rescue depends upon the victim being resuscitated in the shortest possible time. If the space contains hydrocarbon vapour the victim may act as though drunk, and behave aggressively. His judgement may be impaired and he may not recognise the danger before losing consciousness.

It is therefore vital that nobody ever enters an enclosed space without breathing apparatus until it has been confirmed that the atmosphere is safe and will remain so. As a general rule, enclosed spaces should not be entered unless it is absolutely necessary. If entry is essential the precautions set out below should be followed. Suitable notices should be prominently displayed to inform personnel. Instructions should be given detailing the precautions to be taken when entering tanks or other enclosed spaces, and listing any restrictions placed upon the permitted work.

### 6.3 ENTRY INTO ENCLOSED SPACES

#### 6.3.1 General

No one should enter an enclosed space which is known or suspected to contain cargo vapour, or in which the atmosphere may be deficient in oxygen, unless it is essential. The master or responsible officer should ensure that the space is sufficiently ventilated and that company procedures covering entry permit requirements or check lists are correctly observed. In particular it is critical to ensure that;

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- the levels of oxygen and contaminants are continuously checked, and are within safe limits; or
- suitable breathing apparatus and life-saving equipment is worn, including a life-line if practicable.

In either case it should be confirmed that:



- the space is ventilated while personnel remain inside;
- a rescue plan has been drawn up;
- an experienced crew member is standing by at the entrance;
- a reliable system of communication has been established and is understood both by those entering and by the crew member standing by at the entrance;
- a rescue team is readily available with escape equipment, breathing apparatus and resuscitation equipment placed near the entrance.

The emergency plan should clearly set out how to raise the alarm and summon assistance. Access to the space concerned, deployment of reserve equipment and communication between the emergency party and command centre should also be arranged (see Chapter 7).

#### 6.3.2 *Testing Before Entry*

Before the space is entered it should be thoroughly ventilated. The time necessary to ensure thorough ventilation depends upon the size of the space, the capacity of the system used, the level of contamination and the efficiency of the ventilation system.

Once the space has been ventilated, the atmosphere should be checked as follows:

- the oxygen content should be sampled with a suitable and reliable detector: 21% oxygen is required for entry;
- if a flammable cargo vapour may be present, a combustible gas indicator should also be used: a content of not more than 1% LFL is required for entry;
- if a toxic gas may be present, the appropriate toxic gas detector should be used.

It is vital that the correct instruments are used: a combustible gas indicator will not measure an oxygen deficiency, the presence of toxic gas or the presence of flammable vapour in inert gas. It is also essential to ensure that readings are taken at several levels, bearing in mind that vapours which are heavier than air will be found at the bottom of any space; the air at this point should be sampled if the suspected vapour has a relative vapour density greater than that of air (see data sheets). Similarly, the top of a space will have to be sampled if the suspected vapour has a relative density less than that of air. Vapour will also tend to remain where the ventilating airflow is least effective. Ventilation should be stopped about 10 minutes before tests are made and not restarted until the tests are completed. Sampling the atmosphere may require the use of breathing apparatus. A number of samples may have to be taken before the air in the whole space can be judged safe.

It is essential that all gas testing equipment used is of an approved type. It must be correctly maintained and, where appropriate, frequently check-tested against standard samples. Gas testing should be done by personnel familiar with the use of the equipment and sufficiently knowledgeable to understand the results obtained.

Chemical absorption indicators with the appropriate detector tube can be used for measuring oxygen content but the reading may be less accurate if other chemical vapours are present. An indicator which may be reliable for measuring oxygen content in a space after thorough ventilation may not be suitable for checking the oxygen content in a cargo vapour/air/inert gas mixture.

If the atmosphere in the space has been found safe for entry, the precautions in paragraph 6.3.1 should also be rigorously observed.

Even after a space has been made gas-free and found to contain a respirable atmosphere, local pockets of gas should always be suspected. Hence a person moving around to different areas of a tank or compartment, or descending to the lower part after work in the upper part, should remain alert to the possible need for further tests to be made. Generation of vapour should always be considered possible even after loose scale has been removed.

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Ventilation should be continued and the atmosphere monitored at regular intervals while personnel are inside the space. If they begin to feel dizzy or unwell they should leave the space at once. Care should be taken when pipes or equipment in the space are opened up; if liquid or vapour escapes, the space should be evacuated and not re-entered until the atmosphere in the entire space has again been found to be safe. Frequent gas tests should be made, appropriate to the work in hand or to any change in conditions. In particular, tests should be made before each daily resumption of work or after any interruption or break in the work. Tests should be so arranged that readings representative of the condition of the entire space are obtained.

#### 6.3.3 *Breathing Apparatus*

Unless all the above precautions can be followed, spaces should only be entered by personnel wearing breathing apparatus, and, if practicable, a life-line.

Personnel using breathing apparatus, as well as their support teams, should be thoroughly familiar with the equipment and with action to be taken in the event of an accident whilst using it.

#### 6.3.4 *Rescue from Enclosed Spaces*

It is imperative that regular drills and exercises in rescue from enclosed spaces are carried out and that every member of a rescue team knows what is expected of him.

When personnel are in need of rescue from an enclosed space, the first action must be to raise the alarm. Rescue and resuscitation equipment should already be positioned at the entrance. Although speed is often vital in the interest of saving life, rescue operations should not be attempted until the necessary assistance has been obtained. There are many examples of lives having been lost through hasty, ill-prepared rescue attempts.

Whenever it is suspected that an unsafe atmosphere has been a contributory factor to an accident, breathing apparatus and, where practicable, life-lines must be used by persons entering the space. A code of signals should be agreed in advance.

The officer in charge of the rescue should remain outside the space, where he can exercise the most effective control.

## 6.4 VENTILATION OF SPACES

Ventilation equipment should be carefully maintained (see paragraph 5.3.14). The ventilation precautions for various parts of the ship, which are additional to those in Section 6.3, are discussed in the following paragraphs.

### 6.4.1 *Cargo System*

Cargo tanks, cargo piping and cargo equipment will contain cargo vapour unless they have been gas-freed, or inert gas unless they have been ventilated.

Other parts of the cargo system may contain inert gas. Care should be taken to ensure that oxygen levels in the space are safe before personnel enter without breathing apparatus. The other precautions listed in Section 6.3 should also be observed.

Cargo equipment may contain cargo vapour or inert gas. It is important to ensure that such equipment has been adequately ventilated before it is opened up for maintenance.

When ventilating membrane cargo systems, care should be taken to ensure that manufacturers' instructions on differential pressures are observed, otherwise damage may occur.

### 6.4.2 *Enclosed Spaces Separate from the Cargo System*

No cofferdam, ballast tank, peak tank, fuel or lubricating oil tank, fresh water tank, duct keel, void space, access trunk, or any other enclosed space should be entered unless the precautions listed in Section 6.3 are strictly observed.

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The principal danger in such spaces is that rusting has depleted the oxygen content of the atmosphere to the point where it cannot support life. However, it is also possible for cargo vapour or inert gas to leak into them, and the atmosphere should therefore be checked for both oxygen content and cargo vapour before entry.

### 6.4.3 *Cargo Control Rooms*

Any cargo control or instrument room which is not classified as gas-free should be ventilated thoroughly before entry (see paragraph 6.3.1), but access doors or hatches should never be left open. Ventilation and gas detection equipment should be operated and checked throughout the period that the room is in use. If fixed equipment is not fitted or is not working, portable equipment should be used.

In ships designed to carry cargoes whose vapours are either lighter or heavier than air, alternative upper and lower ventilation points and gas sampling heads are normally provided. The changeover devices should be set according to the relative vapour density of the cargo (see data sheets).

### 6.4.4 *Cargo Pump or Compressor Rooms, Motor Rooms and Air Locks*

The following precautions are additional to those in paragraph 6.4.3.

Ventilation fans should be run continuously for at least 10 minutes before cargo operations begin, and throughout their duration. Fans should also be run continuously when leakage of vapour or liquid into the space is suspected. Safety interlocks are provided to ensure that no machinery can be started until the ventilation system has been operating for at least 10 minutes, long enough to have dispersed any toxic or flammable vapour that may have collected in cargo pumprooms or compressor rooms, and to build up sufficient pressure in motor rooms and air locks. Loss of ventilation pressure can cause shutdown of equipment.

Regular inspections should be undertaken of inlet and outlet grilles to ensure that they have not become obstructed.

### 6.4.5 *Engine or Boiler Rooms*

On LNG ships using cargo boil-off as fuel, the ventilation equipment in the gas supply system should be running before gas is allowed to pass to the machinery space. All detection equipment in the supply system and machinery space should be working before gas supply begins.

If a gas leak is detected, the gas supply should be stopped until the leak has been repaired.

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# EMERGENCY PROCEDURES



## 7.1 INTRODUCTION

It is impossible to predict the nature of every potential emergency, but standard emergency procedures should be developed for each ship and it is essential that personnel are properly trained for these procedures. The overriding consideration of those responsible for operations should be the continued safety of all personnel on board and anyone in the immediate vicinity. General guidance on procedures for the most readily foreseeable emergencies is given in this chapter.

In addition the extensive advice given in the ICS/OCIMF/SIGTTO Contingency Planning Guides should be consulted.

### PRE-PLANNING

Emergency procedures have to be pre-planned and ready for immediate implementation in the event of an emergency. The procedures must anticipate and cover such foreseeable types of emergencies which might be encountered at sea or in port as grounding, fire, collision and cargo spill. In each situation, the first stages of a plan should be:

- raising the alarm,
- locating and assessing the incident, the possible dangers, and action to be taken,
- organising manpower and equipment.

The detailed circumstances of an actual emergency will differ in many cases from those envisaged during pre-planning; however, the standard procedures should ensure that basic action can be taken quickly and that decisions on how to tackle any additional problems can be made in an orderly and adequate manner.

Company regulations will be tailored to individual ships, and will cover organisation, preliminary action and procedures to be followed. This guide gives general advice on aspects relevant to the carriage of liquefied gas.

#### 7.3.1 *Water Leakage into Hold or Interbarrier Space*

If water leaks into a hold or interbarrier space, it may damage the insulation and, in the case of a membrane tank system, result in tank wall corrosion. These spaces are normally equipped with a water detection alarm system which will indicate if leakages occur; the water should be pumped out and the leakage remedied if possible.

#### 7.3.2 *Hose Burst, Pipezvork Fracture or Cargo Spillage*

This is likely to result from the effects of pressure surge, excessive ship movement, defective hoses, leaking flange packing or overfilling of tanks.

The following actions should be taken immediately:

• the alarm should be raised and the terminal informed immediately;

- all cargo operations should be stopped and all valves in the liquid line closed both on the ship and ashore as necessary;

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- all accommodation access doors should be shut and all ventilation (except closed-circuit systems) shut down;
- smoking and naked lights should be prohibited everywhere on the ship, and electrical switches used as little as possible;
- if liquid spillage occurs, fire hoses and water sprays (which should always be ready for immediate action) should be used to disperse the liquid overboard and to maintain steel temperatures so that brittle fracture is avoided: water sprays from hoses can also be used to deflect a gas cloud: for this reason water spray equipment should be available in way of the manifold during cargo operations and transfer (see paragraph 7.3.3); and
- appropriate fire-fighting equipment and breathing apparatus should be assembled for immediate use: the emergency parties should wear breathing apparatus and protective clothing.

#### 7.3.3 *Dispersion of Liquid Spill and Vapour Emissions by Water Spray*

The best design and operational technique is to prevent liquid spillage and vapour emission incidents altogether. However, if such incidents occur existing fire-fighting water monitors and hand-held water spray nozzles can often provide a rapid and flexible means of effecting dispersion:

- by controlling the direction of the dispersion;
- by diluting the gas with air entrained in the water spray;
- by heating the relatively cold gas cloud to increase its buoyancy;
- by absorbing some toxic gases which are soluble in water e.g. ammonia and chlorine.

The size of a spillage or vapour emission which can be controlled or dispersed by water spray will depend upon available fire main water pressure and the number of jet/spray nozzles which can be employed. Leakages which can generally be dealt with will be those from loading arm swivel joints, pipeline flange connections and cargo pump shaft seals. Vapour vented from a ship's mast riser due to the operation of a cargo tank pressure relief valve may also be dispersed in this way.

However, large flammable gas leakages require extreme caution in the use of water sprays as the spray may not dilute the gas to below the LFL but simply increase the volume of the premixed cloud, increasing its buoyancy and thus enhancing the likelihood of access to an ignition source. Similarly the use of water sprays may not prevent ignition: indeed, the turbulence and mixing caused by water spray may increase the flame speed on ignition. On the other hand, water spray will assist the protection of people, structures and equipment from radiation heat damage should ignition occur.

If a flammable gas cloud is to be controlled by water spray, for example to prevent it reaching a potential source of ignition, the maximum quantity of water spray available should be brought to bear as quickly as possible to redirect the gas cloud away from the ignition source. Small pipeline liquid leakages may be vapourised with water from one hose and dispersed to below LFL with water spray from another hose. It is normal practice to protect the steel deck structure of a ship by sluicing liquid spills over the side, and additional water jets can assist spill dispersal down and away from the ship's side.

#### 7.3.4 *Tank Leakage*

Cargo tank leakage to the hold space or interbarrier spaces is detected by the gas detection equipment, and constant monitoring will give continuous information on the change of vapour concentration. The stability or rate of change of equipment readings will indicate the magnitude of the leakage and, together with constant monitoring of the hold or interbarrier space pressure and temperature, will enable the operator to establish the leak rate. All leakages from cargo tanks should be regarded as serious and reported immediately.

Any specific instructions for the ship should be observed, and the following courses of action should be considered:

- pumping liquid in the hold or interbarrier spaces into an undamaged tank with compatible cargo and sufficient ullage available,
- using the reliquefaction plant or other means in order to reduce the tank pressure, and therefore the static head on the leak. Care should be taken to avoid drawing air into the tank, thereby creating a flammable mixture.

### 7.3.5 *Emergency Discharge of Cargo at Sea*

If any tank develops a serious defect at sea, cargo should be transferred to any other tank containing compatible cargo and with sufficient ullage available. Remaining cargo which cannot be transferred will need to be discharged overboard, taking into account trim, stability and stress considerations, local circumstances and the amount of cargo to be discharged.

If cargo is to be discharged, the stern line should be used. If no stern line is fitted, an extension pipe for the midship crossover should be provided, sufficiently long to extend over the side and properly supported to prevent overstressing the manifold. The extension piece should be of material suitable for the cargo, angled downwards and fitted at the end with a suitable reducer to increase the discharge velocity and to prevent liquid from coming into direct contact with the hull and causing brittle fractures.

If emergency cargo discharge has to be undertaken, the precautions listed in paragraph 7.3.2 should be observed. In addition, the following points should be considered:

- informing or consulting the operator;
- advising local authorities such as the Coast Guard;
- broadcasting a radio warning to all other ships in the vicinity;
- heading the ship so that the direction of discharge is down the relative wind, if possible, while ensuring that the vessel is free from gas clouds;
- controlling the pumping rate in such a way as to get the cargo as far as possible from the ship, and
- taking any other precautions specified for the particular ship.

### 7.3.6 *Accidents Involving Personnel*

If personnel come into contact with the cargo, the emergency action specified in the data sheet for that cargo should be taken (see Chapter 9 and Appendix 1).

If personnel are overcome or affected by the cargo, the alarm should be raised and the rescue team mobilised. The agreed rescue plan should be implemented and the responsible officer informed.

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## FIRE-FIGHTING



# The first few moments are vital"!

## 8.1 INTRODUCTION

If a fire occurs, the action taken in the first few moments is vital. The man on the spot should raise the alarm and assess the situation. The emergency plan should be implemented (see Chapter 7).

With liquefied gas fires it is essential to isolate the fuel source before extinguishing the flames to minimise the danger of a potentially flammable gas cloud forming.

## 8.2 FIRE-FIGHTING ORGANISATION

The requirements for fire-fighting equipment are laid down by national and international regulations and are not covered in this guide. General fire-fighting theory is included in the International Safety Guide for Oil Tankers and Terminals (ISGOTT).

Company regulations will be tailored to individual ships, and will cover organisation and training of personnel and maintenance of fire-fighting equipment. Fire-fighting cannot be successful unless all equipment is operational and all personnel are well trained in the use of the equipment and in emergency procedures.

## 8.3 SPECIAL CONSIDERATIONS FOR FIGHTING LIQUEFIED GAS FIRES

### 8.3.1 *Isolating the Source*

The main considerations in fighting a liquefied gas fire are the large quantity of vapour given off by the liquid and the considerable heat generated by the flames. In the event of fire every effort should be made to isolate the fuel source: dry powder or water sprays should be used on local fires which prevent access to valves. The flames should not be extinguished before the source of fuel has been shut off, to prevent a potentially flammable gas cloud forming and being re-ignited downwind or by surfaces heated in the original fire. If the fuel source cannot be isolated it is safer to let the fire burn while continuing to cool the area.

### 8.3.2 *Use of Dry Powder*

It is not beneficial to use low expansion foam or water for liquefied gas fires because their application increases the rate of vapourisation. Dry powder is used instead (see Section 8.4), although it provides a negligible cooling effect. Cooling is required to prevent re-ignition until all liquid has dispersed and the area is free from flammable

vapour. It is best achieved by water from fitted spray systems or hand hoses. Sprays from hand hoses are excellent in protecting firefighters from the radiant heat of a liquefied gas fire.

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Care should be taken to ensure that the limited capacity of dry powder extinguishing systems is used effectively, especially when being used with other fire-fighting media. It is possible to waste a large proportion unless there has been careful planning of large scale fire-fighting operations.

A fire in stores or machinery spaces may affect the cargo and increase boil-off. This can be reduced by cooling the area with water sprays, use of reliquefaction plant (provided the power supply is still available) or both. However, a water jet should never be used on a liquid fire.

If a fire occurs in a cargo equipment space, such as a compressor room, the source of fuel should be cut off and the fire attacked in the first instance with dry powder. If necessary all personnel should be evacuated, the compartment closed down and the fixed fire-fighting system activated. The area should be cooled with water sprays. As soon as the fire has been extinguished, the space should be ventilated carefully to disperse any vapour.

### 8.3.3 Vent Mast Fires

Ignition can be caused at the vent mast by a lightning strike or other source of ignition when venting a flammable vapour.

The following actions should be considered:

- stopping venting;
- injecting inert gas into the vent if possible;
- spraying the mast head with water.

Venting may be resumed when the mast head and its surroundings are cool and the electrical storm is over.

### 8.3.4 Fires Near to the Ship

In the event of a fire in the immediate vicinity of the ship, whether ashore or aboard another vessel, the following actions should be considered:

- making ready the ship's fire-fighting organisation and equipment;
- stopping all cargo and bunkering operations;
- isolating and disconnecting hoses;
- closing all compartment openings;
- bringing the main engines to immediate readiness.

## 8.4 DRY CHEMICAL POWDER AS AN EXTINGUISHING AGENT

Dry chemical powder (also known as 'dry powder') is a flame inhibitor. Discharged from an extinguisher as a free-flowing cloud it can be effective in dealing initially with a fire resulting from a liquid spill on deck or in a confined space. It is especially effective on burning liquids such as liquefied gas, or oil escaping from leaking lines and joints, and on vertical surfaces e.g. diesel equipment fires. It is a non-conductor and thus suitable for use in dealing with electrical fires, although there is a possibility of some damage to the electrical machinery from its abrasive nature.

Dry powder has a negligible cooling effect and so may not give protection against possible re-ignition from a hot surface.

Certain types of dry powder can cause a breakdown of a foam blanket and only those known to be 'foam compatible' should be used in conjunction with foam.

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# PERSONNEL PROTECTION AND LIFESAVING

## CHAPTER

### 9.1 INTRODUCTION

The minimum requirements for lifesaving equipment on board all ships are laid down by national and international regulations and are not repeated in this guide. All equipment should be inspected regularly and kept ready for immediate use in a clearly marked and accessible place. Practical demonstrations, training and drills should be regularly undertaken so that personnel become experienced in the use of all safety equipment and know the location of each item.

### 9.2 PROTECTIVE CLOTHING

Appropriate protective clothing should be worn as necessary to protect those involved in cargo operations from the hazards associated with the cargo. The suits, gloves, boots, goggles, face shields and other items used should be suitable for the cargo. Many plastics become brittle and crack when subjected to low temperatures, or can be dissolved by the cargo, although clothing of PVC or similar material is less susceptible to absorption, and should be worn when exposure to vapour or liquid emissions is involved.

In particular, gloves should be worn when handling cold equipment, valves or slip tubes, face protection should be worn when there is a danger of liquid emission (e.g. dismantling cargo equipment, using slip tubes, or sampling) and respiratory protection should be worn during cargo operations involving toxic or asphyxiating gases (see Sections 9.4 and 9.5).

Cargo vapour may be absorbed into working clothing in sufficient quantities to create a hazard when taken into accommodation, galley, smoke room etc.

### 9.3 DECONTAMINATION WATER SPRAYS AND SHOWERS

Full use should be made of changing rooms between deck areas and accommodation, and of showers which may

be provided. Personal hygiene is very important if the cargo is toxic.

#### 9.4 CANISTER OR FILTER TYPE RESPIRATORS

» Canister or filter type respirators should never be used in enclosed spaces where the oxygen content of the atmosphere may be insufficient to sustain life. Such equipment filters out toxic or poisonous elements but does not replace oxygen.

Canisters are available for absorption of a variety of different vapours, but the following precautions should be observed:

- The correct type of canister should be fitted for the vapour concerned: it may be necessary to change canisters when changing cargoes;
- Canisters should not be opened to the atmosphere until needed for use because they may become gradually saturated and ineffective;
- Canisters have a limited life: they should be discarded and destroyed after use unless it is known with certainty how much of their life remains.

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#### 9.5 BREATHING APPARATUS

Breathing apparatus should be used as necessary by personnel engaged in cargo operations involving toxic cargoes, by fire-fighters, and when entering an unsafe space. Tanks or compartments which are not gas-free, which are deficient in oxygen or which contain smoke should not be entered unless absolutely necessary.

Breathing apparatus should always be used in accordance with manufacturers' instructions. Practical demonstrations and training in the use of breathing apparatus should be carried out to give personnel experience in its use.

Ships carrying toxic cargoes are provided with small breathing apparatus sets supplying air for approximately 15 minutes. This equipment is for emergency escape only and should not be used for other purposes.

#### 9.6 CITADEL AREAS

When certain toxic cargoes such as chlorine are carried in gas tankers, the IMO IGC Code requires that a space within the accommodation area be arranged to provide a safe haven for personnel against the effects of a major cargo release. This is commonly referred to as the 'citadel'. The protected area, usually the bridge and the cargo control room, is required to house the whole of the ship's company and provide uncontaminated air for a period of not less than four hours. Access is to be easily and quickly available from the open deck and the accommodation area via an airlock which has a decontamination shower adjacent to it.

#### 9.7 FIRST AID

The first aid procedures for accidents involving cargo are given in the data sheets in Appendix 1.

If cargo liquid should enter the eye, the correct treatment for most cargoes is to flood the eye with clean water and to continue washing for at least 15 minutes. If cargo liquid comes into contact with the skin, the affected area should be washed and any contaminated clothing removed. If frostbite has occurred it should be treated by immersing the affected part in warm water (see Section 9.9).

If any personnel experience the symptoms of vapour exposure they should leave the area and advise other personnel in the vicinity. The possibility of similar symptoms in others should be constantly borne in mind. Emergency treatment, correct for most cargoes, is to remove the victim to fresh air and, if breathing is weak or irregular or has stopped, provide resuscitation.

#### 9.8 RESUSCITATION

Personnel should be instructed in the technique of mouth-to-mouth and mouth-to-nose resuscitation as the most important and effective means of resuscitating a victim. However, if the victim has inhaled toxic vapour or inert gas the person providing resuscitation may be overcome by the gas pressed out from the victim's lungs. In this case a resuscitator should be used, or the person giving resuscitation should wear breathing apparatus and remove the mask only when blowing air into the victim's lungs.

Responsible personnel should be instructed in the use of resuscitation apparatus. Specially marked cylinders should be used for training purposes so that, in an emergency, only fully charged cylinders can be selected for use. This apparatus should NOT normally be kept locked up. The operating instructions for the apparatus should be clearly displayed.

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Resuscitation equipment should not be taken into an enclosed space containing flammable cargo vapour unless the equipment is approved as safe for use. As a general rule it is better to concentrate on removing the victim to a safe place first than to attempt resuscitation in a hazardous area.

#### 9.9 FROSTBITE

This term applies to cold injury where there is destruction of tissue by freezing, usually localised but possibly covering an extensive area. The parts most commonly affected are fingers, toes, cheeks, ears and nose.

Ice crystals form in skin and other tissues of the affected part. The patient may not be aware of it until told. Frostbitten tissue appears white or greyish-yellow. There may be early pain which subsides, or a stinging aching sensation. In severe cases the area feels numb, hard and solid. As the affected area thaws it becomes red and swollen: gangrene and tissue death can be the end result.

Treatment should be started as soon as possible. Wet, rapid warming, as explained below, is the preferred method. Once treatment is started it must be maintained until thawing is complete.

To rewarm the victim, remove cold wet clothing and constricting items such as shoes and socks, and completely

immerse the affected area in warm water at around 42 °C (but not more than 44°C). Never use dry heat. Thawing may take from 15 to 60 minutes, and should be continued until the pale blue colour of the skin turns to pink or red. Avoid bending of joints or massaging the flesh. Pain killers (Paracetamol or morphine) and tranquillisers may be required to control pain during thawing.

After rewarming, gently cleanse the affected area with water and soap, and apply a soft sterile dressing. Ointment or creams should not be used. Keep the patient warm in bed, with the affected part elevated if possible. Avoid contact with bedclothes by using an improvised bed cradle.

Guidance from Radio Medical Advice should always be sought. Bending of joints or massaging of flesh should be avoided.

Alcohol and cigarettes decrease the blood flow to the damaged tissue, and neither should be given to the patient.  
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## CARGO INFORMATION (DATA SHEETS)



### All GENERAL

The safe handling and carriage of liquefied gases demands a knowledge of the physical and chemical properties of the cargo, of the hazards it presents, and of the action to be taken in the event of an emergency. The data sheets provide essential information about the liquefied gases and other products listed in Chapter 19 of the IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (the IGC Code). Some data sheets refer to chemicals which may be carried and used for operational reasons, e.g. to prevent ice formation or as a refrigerant for the reliquefaction plant.

The data generally are for individual liquefied gases, but some commercial cargoes are mixtures: for example, LPG cargoes may be mixtures of propane, butane and other gases in varying amounts, for which it is not possible to give complete data. Information on any mixture should be obtained from the shipper and/or the terminal management before loading is started. A specimen cargo information form is given in Appendix 10.

#### A1.1.1 Guidelines on the Use of Cargo Data Sheets

The cargo data sheets and these accompanying guidelines have been compiled to provide background information on the safe handling of liquefied gases. While every effort has been made to ensure that they are both comprehensive and accurate, the International Chamber of Shipping cannot accept any liability for their use howsoever arising.

#### A1.1.2 Cargo Data Sheets

The data sheets have been laid out to convey health and safety information in a convenient and consistent manner, and every effort has been made to use clear and understandable language. However, certain basic assumptions have been made, and the purpose of these guidelines is to explain the data sheets so that the maximum benefit can be derived from their use.

A second copy of each cargo data sheet is included, printed on sturdy material, and it is recommended that the appropriate sheet(s) for the cargo(es) being carried are made available to all personnel by display on a notice board.

The content of the data sheets is in eight sections. The layout ensures that the information most likely to be needed in an emergency is near the head of the sheet.

An explanation on what each section covers is given below.

### A1.2 GENERAL INFORMATION

This section contains:

- The name of the product and its synonyms.
- The United Nations (UN) number.
- Appearance of the product: colourless, green gas, amber liquid, etc..
- 0 Odour of the product: pungent, suffocating, mild aromatic, fishlike, odourless, etc.
- The Main Hazard: flammability, toxicity, corrosivity, reactivity or any combination of the above, or if it is non-hazardous.
- The IMO Medical First Aid Guide (MFAG) Table Number.

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### A1.3 EMERGENCY PROCEDURES

This table is set out in such a way that the action to be taken in an emergency is clearly indicated, in the form: "If this happens....Do this".

First aid information is given for the forms of exposure expected. It is emphasised that this is only first aid; qualified medical advice should be obtained where so instructed, or if there are any doubts about the effectiveness of treatment.

First aid treatment must be applied quickly and efficiently. Swift action can minimise harmful effects while delay can lead to unnecessary injury or complications. The correct table in the IMO Medical First Aid Guide should be consulted.

**Fire:** Fire-fighting procedures will depend greatly on the circumstances and should be under the control of the responsible senior officer. To assist such personnel, this section gives general guidance on fire-fighting and extinguishing agents. In all cases where hazardous substances are likely to be released by the fire, or by fire fighting methods, the precautions to be observed by fire fighters are given. As a general rule fire fighters should wear protective clothing and respiratory protection equipment. Refer to Chapter 8 on fire-fighting for more detailed guidelines.

**Liquid in Eye:** This normally gives rise to local eye effects such as irritation or burns, but there are a few materials which can be absorbed into the body through the eye and which may cause systemic toxic effects.

**Liquid on Skin:** Two effects may occur:

- Local reactions such as skin irritation arising from direct action by the material at the site of first contact. Direct contact with low temperature liquefied gases or uninsulated equipment and pipes can cause cold burns (frostbite).
- Systemic effects - toxicity caused in tissues remote from the site of first contact due to the material penetrating the skin and passing into the body.

**Vapour Inhalation:** Three effects may occur:

- Lack of oxygen can cause asphyxiation, whether or not the vapour is toxic.
- Toxic effects can cause poisoning which may or may not be reversible once the victim is in fresh air.
- Inhalation of cold vapours may permanently damage the respiratory system.

**Spillage:** If spillage occurs prompt consideration must be given to stopping the outflow of liquid. Personnel engaged in spill control should be safeguarded against contact with cargo liquid or vapour. Potential sources of ignition should be extinguished-

#### A1.4 HEALTH DATA

**Threshold Limit Values (TLVs):** The values shown on the data sheets are normally drawn from the lists of recommended values published by the American Conference of Governmental Industrial Hygienists, the United Kingdom Health and Safety Executive and other authorities. Where a product is not included in these lists, the TLV is determined on the basis of experience, knowledge and chemical industry research. Some differences in published values exist, and the figure quoted is the lowest. All cargoes where the TLV is very low should be treated with respect.

TLVs take account of factors which include discomfort, irritation and acute toxic effects, as well as chronic toxicity, and the exposure levels at which these occur. The data are obtained from animal toxicity studies and from previous human experience. A safety factor allowing for variations in individual susceptibility is added.

TLVs for gases and vapours are expressed as parts per million parts of air.

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**Odour Threshold:** Odour threshold is generally expressed in parts per million parts of air. Odour is a very unreliable check on the presence of material as the nose can readily become accustomed to the vapour.

**Nature of Hazard (Effects of Liquid and Vapour):** Descriptions of the effects of liquid and vapour by each route of exposure are arranged in the same order as the first aid information. Where appropriate a statement such as "No hazard by this route in normal industrial use" will appear indicating that the amount of a substance to which an individual would be exposed by this route, under conditions of normal industrial use, would be insufficient to lead to toxic effects.

**Personal Protection:** Wherever possible engineering control procedures, such as proper ventilation, should be adopted to control hazardous substances at source. Personal protection and emergency response equipment should be considered as secondary lines of defence against exposures which are unavoidable.

Where personal protective equipment and clothing is used it must be carefully chosen to ensure correct fit and suitability for its purpose. It must be kept clean and in good repair. Cleaning procedures should be specified to ensure safe removal of harmful substances.

#### A1.5 HRL AND EXPLOSION DATA

**Flash Point:** Flash point can be determined by a number of test methods which are of either the open cup or closed cup types; the method may be stated with the value given.

**Auto-Ignition Temperatures:** In the course of obtaining these values from reference sources, several instances of conflicting values were found. In such cases the value quoted is the lowest value obtained. These values must not be regarded as absolute but as indications only since auto-ignition temperature is particularly sensitive to changes in pressure and humidity.

**Flammable Limits:** When known, lower and upper explosive limits are quoted in per cent by volume.

**Explosion Hazard:** To supplement information provided under flash point and auto-ignition temperatures, the explosion hazards associated with the product are given in general terms.

#### A1.6 CHEMICAL DATA

Data shown are for 100% concentrations, unless otherwise stated.

**Formula:** The chemical formula is the representation of the nature and number of the atoms present in a molecule of a compound by means of letters and numbers (e.g. C<sub>2</sub>H<sub>6</sub> for ethane).

**Chemical Family:** Alkali, aliphatic, halogen, etc. are compounds all exhibiting similar chemical properties and reactivities. Chemical and physical properties show a gradual variation from one compound to the next within the family.



## A1.7 REACTIVITY DATA

In this section substances **are** listed which are known to react in a hazardous manner with the substance covered by the data sheet. It should be emphasised that the type of mixture referred to here is an uncontrolled or accidental mixing.

If hazardous decomposition occurs, this is indicated in the Notes.

It is strongly emphasised that this list is not exhaustive and other references, e.g. the IMDG Code, should be consulted.

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## A1.8 PHYSICAL DATA

Typical physical properties are given in this section. They should not be construed as exact specifications for the product being handled.

**Boiling Point:** Unless otherwise stated, all boiling points are quoted at a pressure of 760 mmHg, equal to 101.3 kPa or 1 atmosphere.

**Vapour Pressure:** Wherever possible vapour pressure has been indicated at several temperatures over the normal operating range. It is normally quoted in S.I. units i.e. kiloPascals. To allow conversion the relationships between different systems of units are as follow:

1 mm Hg - 0.133 kPa 1 psi = 6.89 kPa

1 atm = 101.3 kPa

N.B. These are all **absolute**, not gauge pressures.

**Specific Gravity:** For the majority of materials specific gravity is quoted at 15.5/15.5°C (i.e. relative to water at 15.5 °C), unless otherwise stated.

**Coefficient of Cubic Expansion:** The volumetric coefficient of thermal expansion per °C rise in temperature. This is used to determine the maximum volume of cargo with which a tank can be filled, and for cargo quantity calculation purposes.

**Vapour Density:** Vapour density is expressed relative to the density of air under given physical conditions. It is used in the calculation of cargo in the vapour phase and will be a governing factor in the dispersal or accumulation of accidental releases of vapour.

**Molecular Weight:** The weight of one kmole of the substance. One kmole consists of  $6.02309 \times 10^{23}$  molecules and occupies a volume of 22.4 m<sup>3</sup> at 0°C and 1.01325 bar (standard conditions). The molecular weight is useful in converting from molecular units to weight units and in calculating the pressure, volume and temperature relationships for gaseous substances. The molecular weight is expressed in kg/kmole.

**Enthalpy:** Enthalpy is the sum of the internal energy of a substance plus the product of the substance's volume multiplied by the pressure exerted on the substance by its surroundings. It is also known as heat content, sensible heat or total heat. Enthalpy is expressed in kJ/kg. For additional guidance refer to Appendix 3.

**Latent Heat of Vaporisation:** The value is the heat that must be added to a specified weight of a liquid before it can change to vapour. It varies with temperature. The value given is that of the boiling point at 1 bar: the unit used is kJ/kg.

**Freezing Point:** The freezing point (or melting point) of a pure substance is the temperature at which its crystals are in equilibrium with the liquid phase at atmospheric pressure.

**Electrostatic Generation:** This section refers to the risk exhibited by low conductivity products which are liable to create electrostatic charges during transfer or handling.

## A1.9 CONDITIONS OF CARRIAGE

This section gives an indication of the conditions under which the product is normally carried, with particular reference to the mode of transportation (pressurised, fully refrigerated), ship type as defined by the IMO Codes, type of gauging and vapour detection system requirements etc.

The following conditions are indicated:

- normal carriage condition
- ship type
- whether independent tank required

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- control of vapour within cargo tanks
- vapour detection
- gauging

## A1.10 MATERIALS OF CONSTRUCTION

General guidance is given here on materials which are unsuitable and suitable for containment or transfer operations. Written primarily from a hazard prevention standpoint, account has been taken of known effects of different product quality.

## A1.11 NOTES AND SPECIAL REQUIREMENTS

Any notes expanding upon the information in the other sections are given here. Attention is also drawn to special requirements which must be complied with when handling and carrying the substance.

*Flammability Diagram*

When this information is available, the relationship between composition and flammability of mixtures of cargo vapour, air and inert gas is given in the form of a flammability diagram. The purpose of these diagrams is to enable procedures to be developed for avoiding flammable mixtures in the cargo system at all times.

When inert gas or nitrogen is added to a mixture of air and flammable vapour the result is to raise the lower flammable limit concentration and to decrease the upper flammable limit concentration. These effects are illustrated in Figure A1.1, which should be regarded only as a guide to the principles involved.

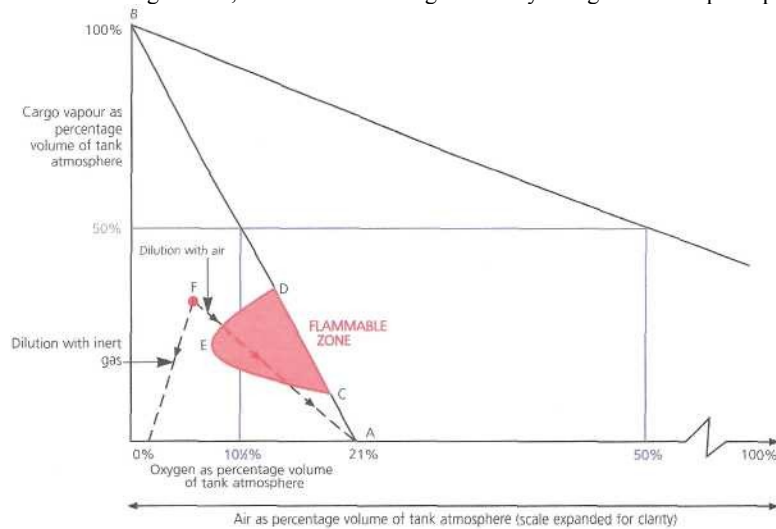


Figure A1.1a

Every point on the diagram represents a mixture of air, flammable vapour and inert gas, specified in terms of its flammable vapour and oxygen content. Air and flammable vapour mixtures without inert gas lie on the line AB, the slope of which reflects the reduction in oxygen content as

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the flammable vapour content increases (i.e. at 50% air and 50% cargo vapour, oxygen is 10M% of tank atmosphere). Points to the left of the line AB represent mixtures in which the oxygen content is further reduced by the addition of inert gas.

The lower and upper flammability limits for mixtures of flammable vapour and air are represented by the points C and D. As the inert gas content increases so the flammable limits change, as indicated by the lines CE and DE, which finally converge at the point E. Only those mixtures represented by points in the shaded area within the loop CED are capable of burning.

It is evident from Figure A1.1a that as inert gas is added to flammable vapour and air mixtures the flammable range decreases until the oxygen content reaches a level at which no mixture can burn.

On such a diagram, changes in the composition of the tank atmosphere are represented by movements along straight lines. When adding air the line is directed towards point A, at which only pure air is left in the tank. When adding inert gas the line is directed towards a point on the x-axis corresponding to the oxygen content of the inert gas, at which only inert gas is left in the tank (and in the case of nitrogen will be 0%). These lines are shown on Figure A1.1a for an inerted mixture with concentrations corresponding to point F. When such an inerted mixture is diluted by air its composition moves along the line FA and therefore enters the shaded area of flammable mixtures.

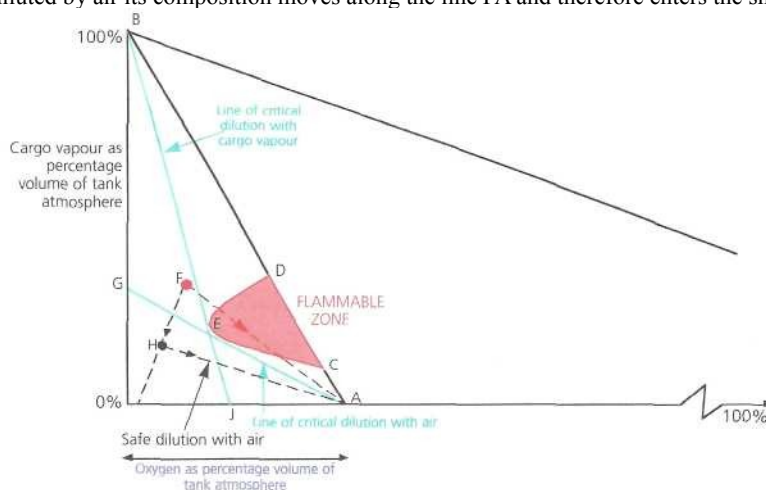


Figure A1.1b

Figure A1.1b shows that a point G can be established from which a line GA will separate all mixtures (above and to the right, including point F) which **will** pass through a flammable condition as they are mixed with air during a gas-freeing operation, from those mixtures which **will** not become flammable on dilution with air (those below and to the left of line GA, including point H). The line GA is called a line of critical dilution. Note that it is possible to move from mixtures such as at point F to one such as at point H by dilution with additional inert gas. Likewise

there is a line of critical dilution when inerting a cargo vapour atmosphere or purging a tank with cargo vapour, and this line is JB; mixtures above and to the right of the line JB go through a flammable condition, mixtures below and to the left of the line JB do not.

It can be seen that an initial oxygen content of less than J% will ensure that no flammable mixtures are formed when purging with cargo vapour, and an initial cargo vapour content of less than G% will prevent the formation of flammable mixtures when gas-freeing with air. In practice a safety factor of 2 is adopted to account for less than perfect mixing, equipment error etc. Therefore, the cargo vapour concentration in the cargo system after inerting should not exceed

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(G/2)% before gas-freeing begins and the oxygen concentration should be below (J/2)% after inerting before purging with cargo vapour. Although a safety factor of 2 is adopted, every effort should be made to ensure that the inerting and purging operations are carried out properly using correct equipment and procedures, and accurately calibrated gas detection equipment.

The diagrams attached to relevant data sheets indicate the limits of flammability of the product in mixtures of air and nitrogen. They also show the lines of critical dilution.

*Properties of Liquefied Gases*

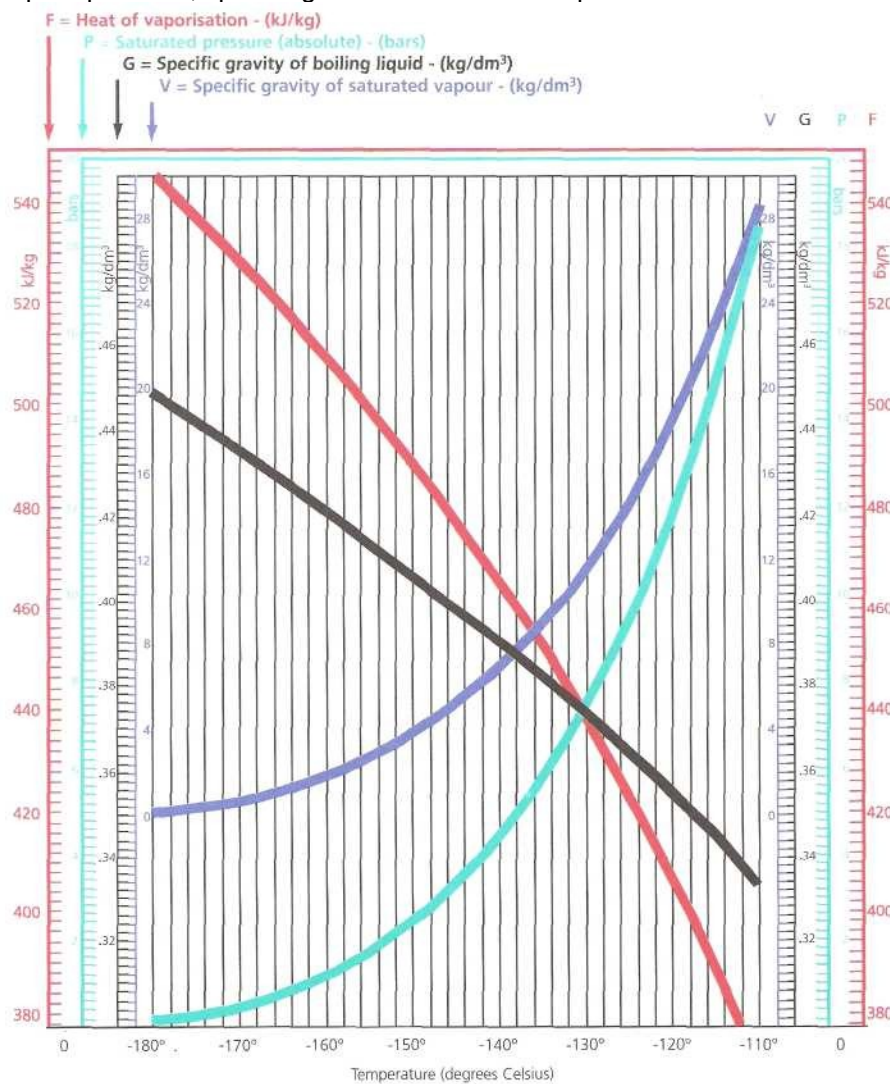
The properties of liquefied gases that influence their carriage by sea are saturation pressure, temperature, enthalpy of the boiling liquid and the saturated vapour, heat of vapourisation, and the specific gravity of the boiling liquid and the saturated vapour.

The required figures for each product can today be obtained from published tables and computer programmes, with more accuracy than graphs provide. Nevertheless, to indicate how the different properties vary as a function of temperature, and their inter-relationship in a typical cargo, the graph for methane is shown in figure A1.2 overleaf.

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**Vapour pressure, specific gravities and heat of vaporisation of Methane**



■ Use a ruler between appropriate graduations on each side

Figure A1.2

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## CHEMICAL INDEX REFERENCES

Data sheet number    Cargo Name

- 1 Acetaldehyde
- 2 Ammonia  
(anhydrous)
- 3 Butadiene  
(inhibited)
- 4 Butanes
- 5 Butenes
- 6 C3/C4
- 7 Crude steam  
cracked  
C4 product
- 8 Spent steam  
cracked  
C4 Product
- 9 Chlorine
- 1 Diethyl ether
- 0
- 11 Dimethylamine
- 1 Ethane
- 2
- 1 Ethyl alcohol
- 3
- 1 Ethylamine
- 4
- 1 Ethyl chloride
- 5
- 1 Ethylene
- 6
- 1 Ethylene oxide
- 7
- 1 Ethylene oxide/  
8  
Propylene oxide  
mixtui
- 1 Isoprene (inhibited)
- 9
- 2 Isopropylamine
- 0
- 2 LPG
- 1
- 2 Methane/LNG
- 2
- 2 Methyl alcohol
- 3
- 2 Methylacetylene/  
4  
Propadiene  
mixtures
- 2 Methyl bromide
- 5

2 Methyl chloride  
6  
2 Nitrogen  
7  
2 Pentanes (all  
8 isomers)  
2 Pentene (all  
9 isomers)  
3 Propane  
0  
3 Propylene  
1  
3 Propylene oxide  
2  
3 Refrigerant gases  
3  
8 Spent steam  
cracked  
C4 product  
3 Sulphur dioxide  
4  
3 Vinyl chloride  
5  
3 Vinyl ethyl ether  
6  
3 Vinylidene chloride  
7

See See data  
data  
sheet sheet

numb er	Synonym number	Synonym	Synonym
1	AAD	13	Cologne spirits
2	AMA	23	Colonial spirit
1	Acetic aldehyde	23	Columbian spirit
16	Acetene	11	DMA
23	Acetone alcohol	13	Denatured alcohol
1	Acetyl hydride	33	Dichloro-difluoro- methane
IS	Aethylis	37	1,1- Dichloroethylene
15	Aethylis chloridum	3	Diethylene
13	Alcohol	10	Diethyl oxide
1	Aldehyde	17	Dihydro oxirene
24	Ailene methylacetylene mixture	12	Dimethyl
		11	Dimethyammine anhydrous
5	Alpha-butylene	17	Dimethylene oxide
3	Alpha-gamma butadiene	5	Dimethylethylene
		30	Dimethylmethane
29	Alpha n-amylene	3	Di vinyl
14	Aminoethane	3	Divinyl biethylene
20	2-Aminopropane	3	Divinyl butadiene
2	Ammonia gas	34	Dioxide of sulphur (anhydrous)
28	Amyl hydride		
10	Anaesthesia ether	14	EAM
2	Anhydrous ammonia	15	ECL
IS	Anodynon	17	EO

33	Arcton 12	18	EO/PO Mixtures
33	Arcton 22	17	EOX
26	Artie	12	ETH
<b>es</b>	BDI	16	ETL
3			
5	BTN	17	ETO
4	BUT	36	EVE
5	Beta-butylene	16	Elayl
19	Beta-methyl bivinyll	25	Embafume
29	Beta n-amylene	17	Epoxyethane
16	Bicarburetted hydrogen	17	1,2-Epoxyethane
12	Bimethyl	32	Epoxypropane
3	Bivinyll	32	1,2 Epoxypropane
3	Bivinyll butadiene	3	Erythrene
25	Bromomethane	1	Ethanal
3	1, 3 butadiene	14	Ethanamine
3	Buta 1,3-diene	12	Ethane compressed
21	Butane/propane mixture	12	Ethane liquid
4	n-Butane	12	Ethane refrigerated liquid
4	i-Butane	13	Ethanol
5	Butene-1	16	Ethene
5	Butene-2	17	Ethene oxide
5	i-Butene	10	Ether
9	CLX	15	Ether chloratis
23	Carbinol	16	Etherin
22	Carburetted hydrogen	10	Ethoxyethane
15	Chelen	1	Ethyl aldehyde
9	Chlorgas	10	Ethyl ether
26	Chloride of methyl	5	Ethyl ethylene
15	Chloridum	12	Ethyl hydride
33	Chloro-difluoro- methane	13	Ethyl hydroxide
15	Chloroethane	10	Ethyl oxide
35	Chloroethene	36	Ethyl vinyl ether
15	Chloroethyl	13	Fermentation alcohol
35	Chloroethylene	22	Fire damp
26	Chloromethane	33	Freon 12
15	Chloryl	33	Freon 22
15	Chloryl anaesthetic	5	Gamma-butylene
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Data

sheet

numb	Cargo Name
er	
1	Acetaldehyde
2	Ammonia (anhydrous)
3	Butadiene (inhibited)
4	Butanes
5	Butenes
6	C3/C4
7	Crude steam cracked C4 product
8	Spent steam cracked C4 Product

- 9 Chlorine
- 10 Diethyl ether
- 11 Dimethylamine
- 12 Ethane
- 13 Ethyl alcohol
- 14 Ethylamine
- 15 Ethyl chloride
- 16 Ethylene
- 17 Ethylene oxide
- 18 Ethylene oxide/  
Propylene oxide  
mixtures
- 19 Isoprene (inhibited)
- 20 Isopropylamine
- 21 LPG
- 22 Methane/LNG
- 23 Methyl alcohol
- 24 Methylacetylene/  
Propadiene mixtures
- 25 Methyl bromide
- 26 Methyl chloride
- 27 Nitrogen
- 28 Pentanes (all  
isomers)
- 29 Pentene (all isomers)
- 30 Propane
- 31 Propylene
- 32 Propylene oxide
- 33 Refrigerant gases
- 8 Spent steam cracked  
C4 product
- 34 Sulphur dioxide
- 35 Vinyl chloride
- 36 Vinyl ethyl ether
- 37 Vinylidene chloride

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See See data  
data  
sheet sheet

numbe r	Synonym number	Synonym
13	Grain alcohol	16 Olifant gas
33	Halocarbon 12	17 Oxacydopropane
33	Halocarbon 22	17 Oxane
16	Heavy carburetted hydrogen	17 Oxide of ethylene
15	Hydrochloric ether	17 Oxidoethane
22	Hydrogen bicarbide	17 Oxirane
4	Isobutane	32 FO
S	Isobutene	32 POX
5	Isobutylene	31 PPL
28	Tso-pentane	30 PRP
15	Kelcnc	28 Pentane-plus
27	LN2	28 n-Pentane
		29 1-Pentene

22	LNG	29	2-Pentene
2	Liquified ammonia	29	Pent-1-ene
22	Liquified natural gas	30	Petroleum gas
		36	Phenetole
21	Liquified petroleum gas	21	Propane/butane mixtures
		24	Propadiene-methylacetylene mixture
2	Liquid ammonia	—^	
16	Liquid ethylene	31	Propene
27	Liquid nitrogen	32	Propene oxide
24	MAP	29	Propylethylene
25	MBC fumigant	30	Propyl hydride
25	MTB	32	1,2-Propylene oxide
26	MTC	5	Pscudo butylene
22	MTH	23	Pyroxylic spirit
24	Maggas	3	Pyrrylene
24	Mapp gas	33	R12
22	Marsh gas	33	R22
23	Methanol	26	R40
24	Methylacetylene-allene mixture	7	Raffinate C4
		34	SFD
19	2-Methyl 1,3 butadiene	10	Solvent ether BP
		13	Spirits of wine
19	3-Methyl 1,3 butadiene	34	Sulfurous oxide
		10	Sulphuric ether
19	2-Methylbutadiene 1,3	34	Sulphur oxide
28	2-Methylbutanc	34	Sulphurous acid (anhydride & anhydrous)
29	Methylbutenc		
13	Methyl carbinol	29	Sym-methylethylethylene ~>
31	Methylethene	37	Unsym-dichloroethylene
31	Methylethylene	37	VC
4	Methyl ethyl methane	35	VCL
		35	VCM
32	Methylethylene oxide	36	Vinamar
		35	Vinyl chloride monomer
22	Methyl hydride	3	Vinyl ethylene
23	Methyl hydroxide	23	Wood alcohol
12	Methylmethane	23	Wood spirit
32	Methyl oxirane		
5	2-Methyl propane		
25	Monobromomethane		
15	Monochloroethane		
26	Monochloromethane		
14	Monoethylamine		
20	Monoisopropylamine		
15	Muriatic ether		
2	NH3		
27	NXX		



- 15 Narcotic
- 4 n-butane
- 28 n-pentane

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# THE SEA TRANSPORT OF BULK LIQUEFIED GAS



## A2.1 GENERAL

The carriage of liquefied gases in bulk began in the late 1920s and the earliest ships carried butane and propane in pressure vessels at ambient temperature. The subsequent development of refrigeration techniques and, more particularly, materials suitable for containment at low temperatures permitted the carriage of cargoes at temperatures below ambient. In the late 1950s these gases began to be carried commercially in a partially refrigerated state in ships equipped with pressure vessels made with material tolerant of low temperatures. By the mid-1960s fully refrigerated LPG ships were in service carrying cargo at atmospheric pressure; ethylene and LNG ships had also entered service. In the meantime ammonia had become a common cargo, and 'chemical' gases such as butadiene also became commercially important.

This appendix is a general review of the sea transport of liquefied gas in bulk, its development, the types of gas ships, the fleet, and the trades.

## A2.2 BASIC CARGO SYSTEM DESIGN CONSIDERATIONS

### A2.2.1 General

For economical marine transportation, gas is carried in a liquefied state. As a liquid, the volume to weight ratio at atmospheric pressure is in the range of 650 times less than in the gaseous state. Even so, the relative densities are low and vary between 0.42 (methane) and 0.97 (VCM).

The temperature at which a gas condenses is a function of its pressure. The combination of pressurising and cooling is fundamental to gas carrier design, and the scientific aspects of these processes are explained in Appendix 3.

Most of the commercially important gases have a density about half that of water. The cargo carrying capability is therefore more related to volume capacity than deadweight capacity, and the cargo capacity is usually quoted in cubic metres cargo tank volume.

The design of gas carriers, together with their low specific gravity cargoes, results in high freeboard and relatively shallow draught. This design, combined with the free surface effect of the cargo, requires particular attention to be paid to the stability of the ship.

### A2.2.2 Pressurised Carriage

Cargo tanks have to be able to withstand the relevant pressures if liquefied gas cargoes are to be carried at ambient temperatures. A maximum temperature of 45 °C is normally assumed, which corresponds to a pressure of about 15 bar g for propane, and 17 bar g for ammonia. 17 bar g is the common design pressure for this type of cargo tank although a lesser design pressure can be used for ships with restricted ambient requirements.

Pressure vessel type tanks are used to contain the cargo because normal integral, membrane or rectangular independent tanks are not permitted for pressures above about 0.7 bar g. Pressure vessels are constructed from shaped sections, and are normally spherical or cylindrical with torispherical or elliptical heads.

Pressure vessels do not generally require internal or external stiffening members except at supports. However, perforated wash plates may be fitted athwart long horizontal cylinders to reduce sloshing.

Cylindrical, bi-lobe and spherical pressure vessels have a high degree of proven reliability  
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### A2.2.3 Refrigerated Carriage

If the cargo is refrigerated to temperatures below 0°C, the tank has to be made from special materials. Normal steels have reduced ductility at temperatures below (TC, becoming brittle and less able to withstand the stresses at lower temperatures.

For marine purposes, normal steels are suitable for cargo temperatures down to 0°C. Steel with fine grain structures and improved tensile properties can be used at lower temperatures. The IMO Codes have specific requirements for steels which are permitted to be used for cargo tanks, depending on thickness and design service temperature.

For temperatures down to -55 °C low temperature steel is necessary for cargo tanks. The most common material is

fully-killed, fine-grain-treated, carbon-manganese steel. For temperatures as low as -105 °C (ethylene) or -165 °C (LNG) aluminium alloys or special alloys such as nickel-steel or stainless (austenitic) steels are necessary for cargo tank construction.

The design pressure of the tank depends on the carriage temperature of the intended cargoes. If the cargo is refrigerated so that its pressure is equal to atmospheric, the cargo tank need not be of pressure vessel configuration; the cargo is said to be 'fully-refrigerated', and the carriage temperature is the atmospheric pressure boiling point of the cargo. If the cargo is refrigerated to below ambient temperature, but is not fully refrigerated, it can still exert a significant vapour pressure. In this case, the cargo is said to be 'semi-pressurised' and the tank construction must be suitable for the design pressure and cargo temperature.

#### A2.2.4 The Cargoes

The most significant cargoes in terms of tonnages moved are methane/LNG, LPG (butane, propane and mixtures of these), and ammonia. Other cargoes of commercial significance are butadiene, butylene, ethylene, propylene, and vinyl chloride.

Apart from ethylene and methane/LNG, all these gases can exist as liquids at normal ambient temperatures. They may therefore be transported in pressurised cargo containment systems at any temperature up to the highest expected ambient temperature.

The critical temperatures for ethylene and methane/LNG are below normal ambient temperatures. Above the critical temperature the gas cannot be transformed into a liquid at any pressure and must therefore be refrigerated for shipboard carriage.

Carriage of ethylene, ethane and methane/LNG requires semi-pressurised or fully refrigerated cargo containment. These considerations lead to the following options for carriage conditions.

Cargo	Boiling point in °C at atmospheric pressure	Vapour pressure at 45°C in bars absolute	Practical carriage conditions
n-butane	-0.5	4.3 bar a	Fully pressurised, semi-pressurised or fully refrigerated
i-butane	-12	5.2 bar a	
Butadiene	-5	5.1 bar a	
Butene	-6	5.2 bar a	
Vinyl chloride	-14	6.8 bar a	
Ammonia	-33	17.8 bar a	
Propane	-43	15.5 bar a	
Propylene	-48	18.4 bar a	
Ethane	-89	Above critical temperature	Semi-pressurised or fully refrigerated
Ethylene	-104	Above critical temperature	
Methane/LNG	-161	Above critical temperature	Fully refrigerated

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Materials exposed to liquefied gas cargoes should be resistant to any corrosive action of the gases. For this reason copper alloys (e.g. brass) have to be excluded from the cargo systems of ships intended for the carriage of ammonia. Details of materials of construction which should not be used for certain products are given in Chapter 17 of the IGC Code.

## A2.3 CARGO CONTAINMENT SYSTEMS

### A2.3.1 General

The main division within the wide range of cargo containment systems in service is the design pressure. According to the IMO Codes, pressure vessel configurations are necessary for systems designed for gauge pressures above 0.7 bar g. Below that pressure, containment systems can be made in a prismatic configuration. In each case the considerations outlined in Section A2.2 have to be taken into account. The choice of system depends to a large extent on the cargoes to be carried and the intended trading pattern of the ship.

### A2.3.2 Pressure Vessel Systems

The design pressure of a pressure vessel type cargo tank depends primarily on the transport temperature of the intended cargo. For fully pressurised carriage of LPG and ammonia at ambient temperature, a design pressure of about 17 bar g is required.

If a refrigerated cargo is carried, it is necessary to use materials suitable for the lowest intended service temperature.

Fully refrigerated cargo systems, especially for vessels below 10-15,000 m<sup>3</sup> capacity, are often built with pressure vessel type cargo tanks having a moderate (4-6 bar) design pressure. This gives an extra degree of operational flexibility in loading and carrying cargoes, and allows the carriage of higher boiling point cargoes in the fully pressurised mode.

The proportion of the hull volume used to contain cargo can be increased to some extent by the use of 'lobed' tanks; these are made from the elements of two cylinders, and are generally tapered to follow the hull contours, especially towards the bow.

Another way to make better use of the hull volume is to extend the tanks above the main deck or to install extra pressure vessel tanks above deck which, if insulated, are protected by a watertight cover. This capitalises on the low specific gravity of the cargo. A limitation on this arrangement is the stability of the ship.

Pressure vessel systems are independent of the ship's hull, but rest on supports or stools, built into the hull structure. The pressure vessel tank system is known as the 'Independent Tank, Type C.

#### A2.3.3 *Low Pressure Systems*

For a fully refrigerated cargo it is possible to use tank types other than pressure vessels. The tank types commonly adopted are independent self-supporting tanks (spherical or prismatic) or tanks integrated with the hull using load bearing insulation with metal membranes in contact with the cargo.

#### A2.3.4 *Hull and Insulation Arrangements*

The cargo containment system largely dictates the hull arrangement in the cargo area of the ship. Independent tanks are supported on seats which transfer the weight of the cargo and tank to the ship's hull whereas membranes transfer loads to the hull structure directly via the insulation.

Except for pressure vessels qualified as Independent Tank, Type C and for cargo tanks with design temperatures above -10 °C, a system of secondary containment is required to hold in the cargo if the main cargo tank fails. The extent of the secondary barrier required depends on the design of the cargo system.

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Independent prismatic tanks and membrane systems normally require a full secondary barrier. Independent tanks based on pressure vessel design are allowed a partial secondary barrier because stress analysis, coupled with advanced fracture mechanics, crack propagation analysis and model tests, permits the assumption that if a crack occurs it will not propagate rapidly. Tanks of this type are known as Independent Tank, Type B.

For temperatures down to -55 °C the secondary barrier may be part of the hull. This provides useful flexibility for fully refrigerated LPG ships, as the grades of steel required are the same as the cargo tanks and are easily worked. The cargo tank will normally require insulation for refrigerated cargo. The insulation serves two purposes, to reduce evaporation of the cargo and to prevent excessive temperature reduction and brittleness in the hull structure. The effectiveness of the insulation, and the nature of the cargoes intended to be carried, have to be taken into account at the design stage; a greater thickness of insulation will reduce cargo boil-off and reduce the reliquefaction plant capacity required, but will reduce the freight earning volume of the hull.

Insulation for self-supporting tanks on modern ships is fitted to the cargo tank external surface. On earlier ships, it was sometimes fitted on the inner hull, but while this method may have had some advantages, the practical aspects have caused it to be abandoned.

Some shipbuilders fit the insulation in granular form (perlite) in the space between the hull and the freestanding prismatic type cargo tank. This gives very high insulating properties but is, on the other hand, very vulnerable if water penetrates into the hold space.

#### A2.3.5 *Reliquefaction Systems*

Liquid gas cargoes are carried at their boiling point corresponding to the actual tank pressure, irrespective of the types of cargo containment system.

For the fully pressurised cargo carrying condition, the design pressure of the tank will exceed the cargo vapour pressure at the highest expected ambient temperature and no refrigeration is required to prevent cargo from being released from the tank.

Semi-pressurised and fully refrigerated carrying conditions rely on refrigeration to keep the cargo below the ambient temperature in order to prevent the cargo vapour pressure exceeding the design pressure of the cargo tank. The required refrigeration may be achieved by 'indirect' systems e.g. external/internal coils circulating refrigerant, or by the 'direct' method of removing the boil-off vapours from the tank.

The direct method is by far the most common on gas carriers, and for all gases except methane/LNG, a reliquefaction plant is fitted to condense the boil-off and return it to the tanks. On methane/LNG carriers it has been found expedient and economical to use the boil-off as a fuel for the main propulsion.

Further information on reliquefaction systems is given in Appendix 3.

## **A2.4 SHIP TYPES**

### A2.4.1 *General*

A description of the five general types of gas carriers follows, taking into account the consideration outlined in A2.2 and A2.3.

### A2.4.2 *Fully Pressurised Ships*

The cargo is carried in mild steel pressure vessels designed to withstand about 17 bar g, and no means of cargo temperature or pressure control is needed. The ships tend to be small, with a cargo capacity of up to about 3,000m<sup>3</sup>. The tanks are normally Type C horizontal cylinders or

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spheres, and no secondary barrier is required. Double bottom tanks are normally arranged for fuel oil and segregated ballast.

The hold space, in which the cargo tanks are located, is not required to be inerted. See Figure A2.1.

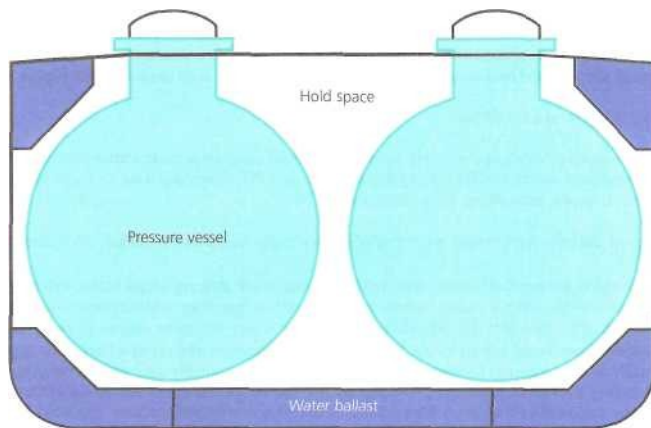


Figure A2.1 Fully pressurised ship

#### A2.4.3 Semi-Pressurised Ships

For most of the wide range of ships of this type a more appropriate term would be semi-pressurised/fully-refrigerated, as they are fitted with refrigeration plants providing a fully refrigerated capability whilst still having a design pressure, albeit below that required for fully pressurised carriage.

While early ships were designed for temperatures between -1°C and -33 °C, newer semi-pressurised ships are almost without exception designed for -48°C to allow fully refrigerated carriage of LPG, ammonia and the commercial chemical gases such as butadiene, vinyl chloride and propylene.

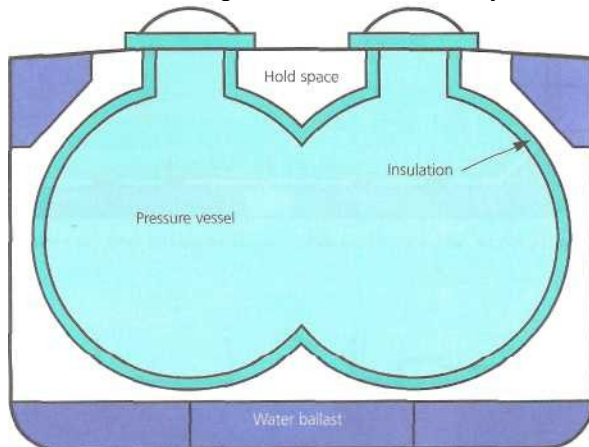


Figure A2.2 Semi-pressurised ship

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These ships are larger than the fully pressurised ships, mostly between 2-15,000m<sup>3</sup>, although some ships are up to 30,000m<sup>3</sup>. They trade on both coastal and deep sea routes and tend to use the hull volume more efficiently (e.g. tapered cylinders, bi-lobed tanks, transverse tanks). The number of tanks varies from two for the smallest, up to six. While earlier designs had tanks penetrating the deck to utilise the hull volume, IMO requirements for damage stability have virtually ruled out that arrangements on newer ships.

The ships normally have a full double bottom, and some have topside ballast tanks. No secondary barrier is required. The hold space is normally ventilated with fresh or dry air. This type of ship often has a reliquefaction system with a very high capacity. See Figure A2.2.

#### A2.4.4 Fully refrigerated LPG Ships

These ships are designed to carry fully refrigerated cargoes at near atmospheric pressure at temperatures down to -50 °C. The cargoes include LPG, ammonia and, in most cases, some of the chemical gases, butadiene, propylene and VCM.

Ships of the fully refrigerated type generally have capacities above 15,000m<sup>3</sup>, up to about 85-100,000m<sup>3</sup>.

These ships are normally equipped with between three and six cargo tanks, extending almost the full beam of the ship. Double bottom tanks are fitted, together with topside or complete side ballast tanks. Prismatic free-standing tanks (Type A) are the most common, being supported on wooden chocks and keyed to the hull to permit expansion and contraction. This type of tank usually has an internal centreline bulkhead to improve stability and reduce sloshing. The secondary barrier is normally provided by the use of special steels for all hull structure which may be exposed to the cargo if a rupture of the primary barrier occurs. The hold is inerted when flammable cargoes are carried or filled with dry air for non-flammable cargoes. See Figures A2.3a and b.

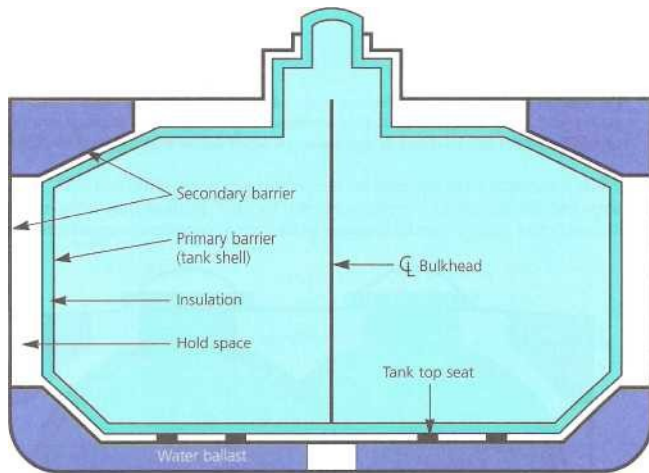


Figure A2.3a Self-supporting independent prismatic tank for LPG/Ammonia  
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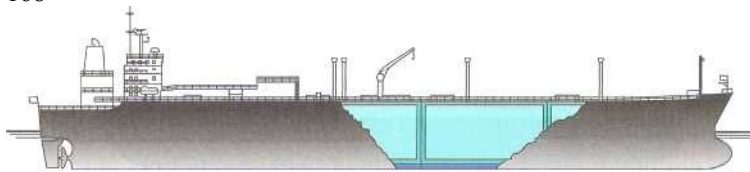


Figure A2.3b Fully refrigerated 75,000m<sup>3</sup> LPG-carrier with independent prismatic tanks

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#### A2.4.5 Ethylene Carriers

In appearance this type of ship is very similar to the semi-pressurised ship, and competes for the same cargoes when the ethylene market is less profitable. The main difference is the design temperature of -104°C for the cargo containment system.

The sizes are typically between 2-12,000m<sup>3</sup>, and the cargo tanks are independent pressure vessel Type C tanks made from nickel-steel or stainless steel. For the Type C tanks, no secondary barrier is required. The ships are normally fitted with a double bottom.

A cascade type refrigeration plant is fitted, of sufficient capacity for reliquefaction of ethylene carried fully refrigerated at -104 °C, and the cargo tanks normally have a thicker insulation than on fully refrigerated LPG ships.

A few ethylene carriers of small size have been built with semi-membrane tanks and secondary barrier. A2.4.6

#### Methane/LNG Carriers

Methane/LNG is carried at atmospheric pressure at -163 °C in cargo tanks made from aluminium, nickel-steel or stainless (austenitic) steel. Insulation is fitted and most LNG ships are more correctly described as fully insulated since they usually have no reliquefaction plant; boil-off gas is normally burnt in the main propulsion machinery. The ships are large, mainly from 40,000 to 135,000m<sup>3</sup>, with four to six cargo tanks of Type A, B or membrane. The space between the primary and secondary barriers is inerted. However, for Type B systems with only a partial secondary barrier, the hold space is usually filled with dry air. A full double bottom and side ballast tanks are fitted. The arrangement of primary and secondary barriers varies widely from system to system. The common proprietary designs are described below.

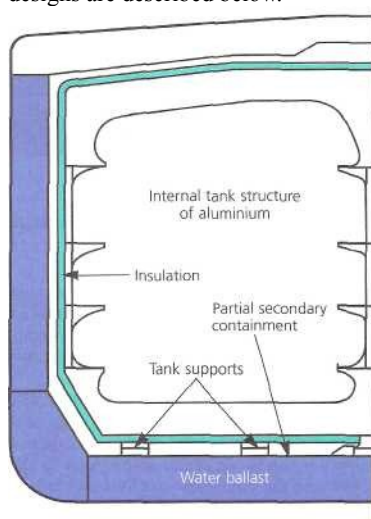


Figure A2.4a Independent prismatic tank

- Prismatic Free-standing Tanks

Ships built to the 'Conch' system have aluminium Type A tanks, with a treated plywood secondary barrier and a balsawood/polyurethane foam insulation system fitted to the inner hull. The tanks have centreline bulkheads, with a common vapour space.

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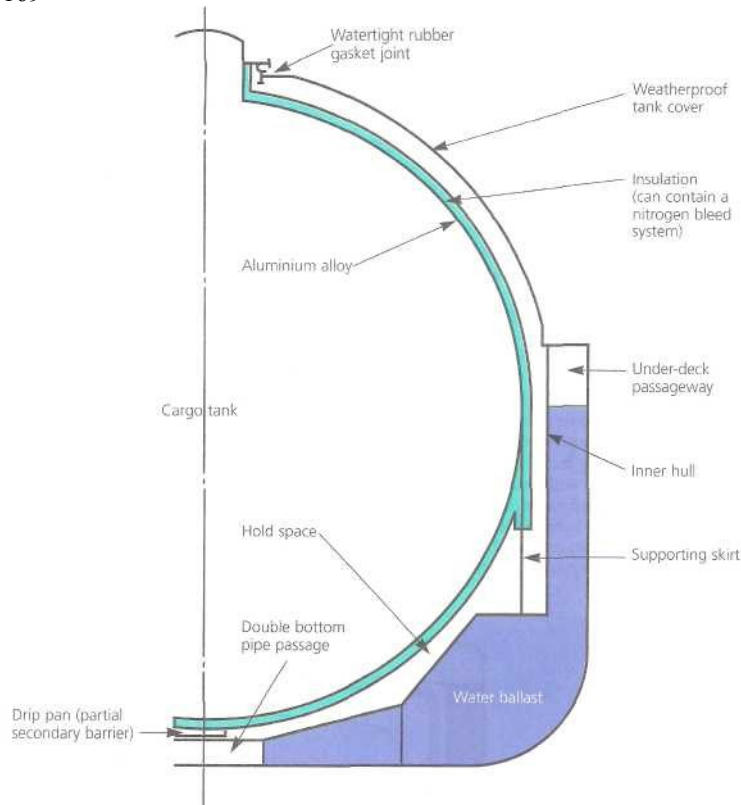


Figure A2.4b Spherical free-standing tank

- Prismatic Type B Tanks

The IHI Type B (known as SPB) system has self-supporting prismatic tanks. The tanks have a stiffened plate structure of aluminium and require a partial secondary barrier. They rest on reinforced plywood supports which allows them to expand or contract freely. Sloshing is controlled by a centreline bulkhead in conjunction with a transverse swash bulkhead. See Figure A2.4(a)

- Spherical Type B free-standing Tanks

These are low pressure tanks, requiring only a partial secondary barrier. The Moss-Rosenberg system comprises spherical tanks of aluminium alloy or 9% nickel-steel with external insulation, supported by cylinders (or skirts) attached to the equatorial circumference of the sphere and supported on the ship's structure. A spray shield of low temperature material may be fitted between the cargo tank and the inner hull, to deflect any leakage to an insulated drip pan beneath the tank. The tanks protrude well above main deck level. See Figure A2.4(b).

- Membrane Systems

A containment system comprising primary and secondary barriers made of thin material which are supported by the inner hull via insulation. The two principal systems use different construction techniques.

The Gaz-Transport membranes have identical primary and secondary barriers of 36% nickel-steel (or Invar). The tanks are made from long strakes with turned-up edges acting as flanges for welding to the adjacent strake flange. The 36% nickel has an extremely low expansion coefficient (Invar is short for invariable) and contraction caused by cooling to cargo temperature leads to only moderate stresses. The insulation is perlite in plywood boxes.

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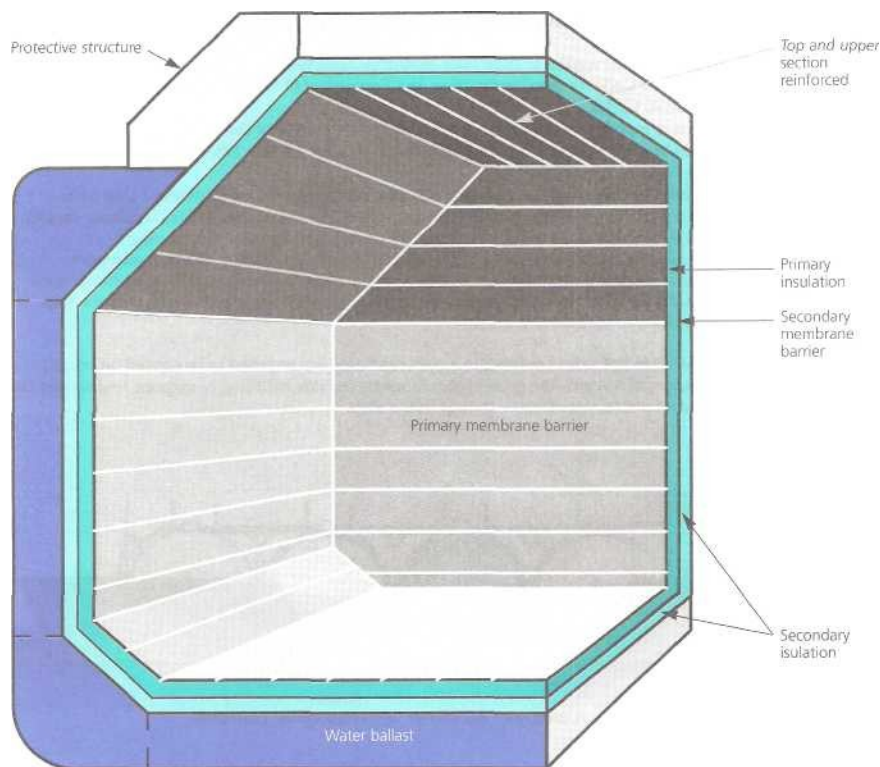


Figure A2.4c Membrane system

Technigaz' membrane systems have a primary barrier of austenitic stainless steel in small plates welded together and having specially shaped orthogonal pressed swedges (or waffles) to allow for expansion and contraction. Early systems had a plywood secondary barrier and balsa insulation while the later design has a glass fibre aluminium foil (Triplex) membrane and polyurethane foam insulation. It is not practical to fit a centre-line division for either system, and the upper regions of the cargo tanks have a pronounced chamfer to reduce free surface and sloshing loads. The tanks extend above main deck level and have reinforced insulation in the upper part to resist sloshing forces. See Figure A2.4(c).

#### A2.4.7 Other Types of Ship and Containment Systems

Some gas carriers are constructed to carry other liquid cargoes in addition to liquefied gases. The most common arrangement is found in the larger fully refrigerated ships which carry volatile white oils (i.e. naphtha), and ethylene carriers with stainless steel pressure vessel tanks to comply fully with the requirements for carriage of chemicals. Some of the volatile chemicals are included in the IMO Gas Carrier Codes.

### A2.5 CONSTRUCTION AND EQUIPMENT REQUIREMENTS

There are three IMO Codes applicable to gas carriers:

- 'Code for Existing Ships Carrying Liquefied Gases in Bulk' (The Existing Ships Code). This code generally applies to ships delivered before 31st December 1976.

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- 'Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk' (the GC Code).

This code generally applies to ships built on or after 31st December 1976 but prior to 1st July 1986.

- 'International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk' (IGC Code).

This code is mandatory under the provisions of Chapter VII of the 1974 SOLAS Convention. It applies to ships the keels of which are laid on or after 1st July 1986.

The IMO Codes are intended to produce a common set of regulations, allowing a ship to be issued with a Certificate of Fitness indicating compliance with the Code. This Certificate should be accepted by the nations to which the ship may trade as an assurance of the ship's constructional safety, in a similar way to the international acceptance of Safety Equipment, Construction, Loadline and Radio Certificates which are also issued to signify compliance with IMO standards. As with other certificates, the Codes require periodic re-inspection of the ship during its lifetime to maintain validity.

The relevant Code or Codes applying to a particular ship are required to be carried on board. The IGC Code also contains the present requirements for safe handling of cargoes, and should be available for reference regardless of the age of the ship.

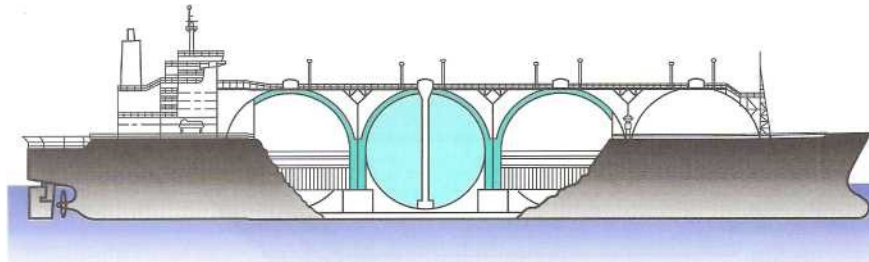


Figure A2.5 A modern LNG carrier with helicopter platform

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## RELIQUEFACTION AND BOIL-OFF CONTROL

### APPENDIX

#### A3.1 GENERAL

There are two types of gas carriers which employ reliquefaction systems, the so-called 'semi-pressurised ships' and the 'fully refrigerated ships'. Whatever the choice of cargo tank design pressure, the capacity of the reliquefaction plant must be such that the cargo can be maintained at a temperature giving a saturated vapour pressure below the corresponding cargo tank safety valve set pressure. The general arrangements and fundamental thermodynamic principles of reliquefaction systems are explained in this Appendix.

#### A3.2 TYPES OF REFRIGERATED GAS CARRIERS

Semi-pressurised gas carriers evolved from the earliest designs of LPG carriers, where the technology of refrigeration otherwise limited their capability, but are today designed to meet the carriage requirements of particular cargoes. Modern semi-pressurised gas carriers are described in Appendix 2, paragraph A2.4.3. Fully refrigerated gas carriers transport the cargo at its boiling temperature corresponding to atmospheric pressure. The most common type of fully refrigerated carrier is the LPG/ammonia carrier which has a design temperature of about  $-50\text{ }^{\circ}\text{C}$ . LNG carriers are designed to carry liquid natural gas at  $-163\text{ }^{\circ}\text{C}$  at atmospheric pressure. Cargo boil-off is usually used as fuel in the main propulsion machinery, so reliquefaction plant is rarely fitted because of the high power requirement. A few LNG ships are fitted with reliquefaction plant to enable them to carry ethylene or LPG cargoes.

#### A3.3 RELIQUEFACTION SYSTEMS

##### A3.3.1 Plant Requirements

The number and capacity of the reliquefaction units fitted depends on the service for which a ship is intended and the number of segregated cargoes it is designed to carry. These considerations lead to the fitting of a wide range of reliquefaction systems.

The plant capacity is designed to maintain the cargo temperature at a level such that the pressure does not exceed the relief valve setting under the most extreme service conditions, usually taken as  $45\text{ }^{\circ}\text{C}$  air and  $32\text{ }^{\circ}\text{C}$  sea temperatures. Spare capacity at least equal to the largest single unit has to be provided. In most cases the stand-by capacity is a complete unit including compressors with their driving motors, heat exchangers, control systems and piping, though this is in excess of the minimum requirement of the IMO Codes. If additional capacity is provided in the form of an independent unit, this can be used to increase the rate of cool down, or to reliquefy boil-off during loading.

Where two or more refrigerated cargoes which may react chemically in a dangerous manner are carried simultaneously, the refrigeration systems should be completely isolated from each other by removable pipe sections or other means so as to prevent mixing of the cargoes. In such cases a reliquefaction plant, complete with its own stand-by unit, should be provided for each cargo.

##### A3.3.2 Plant Duties

Reliquefaction plant is provided to perform the following essential functions:

- to cool down cargo tanks, and associated piping before loading;
- to reliquefy cargo vapour generated during loading and return it to the cargo tanks;
- to keep the cargo at a temperature and pressure within the design limits of the cargo system during transport.

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##### A3.3.3 Plant Auxiliary Functions

Parts of the reliquefaction plant can often be used for the following auxiliary functions:

- On semi-pressurised ships, the cargo compressors can raise the tank pressure enough to prime deck-mounted discharge pumps prior to discharge. Cargo vapour is drawn off and compressed, and the hot gas discharged is returned to the cargo tank. When the cargo tank pressure is sufficient (about 2 bars) the liquid valve is opened and the tank vapour pressure will deliver the liquid to the pump suction.
- Similarly the cargo compressor can be used to boil off cargo residues left in pump sumps at the end of discharge. As before, the cargo compressors draw vapour from the cargo tanks and compress it, the hot vapour discharged being returned to the cargo tank sump through an open ended pipe immersed in the remaining liquid, or a perforated heating coil which is sometimes provided. Alternatively the hot vapour can be circulated through closed heating coils to evaporate the remaining liquid. Care is needed to ensure that the set pressure of the cargo tank safety valve is not exceeded during this operation.



### A3.3.4 R22 System Auxiliary Functions

On ships which have cascade systems with R22 as a secondary refrigerant, parts of the R22 system are often used for the following auxiliary functions:-

- Hot R22 vapour, generated in a steam heated vaporiser, is compressed in the R22 compressor, and the superheated R22 vapour is passed to a cargo vaporiser to generate cargo vapour from cold liquid cargo. This cargo vapour can be used either to purge the cargo tanks in preparation for loading, or to prevent a vacuum forming in the cargo tanks during discharge. There are also a number of other types of cargo vaporising systems which do not use R22.
- Superheated R22 vapour from the R22 compressor can be passed through a heating coil in the cargo tank sumps to vaporise cargo remaining at the end of discharge. Care has to be taken with this system to avoid the R22 vapour condensing in the heating coil because it is very difficult to clear the coil of R22 condensate.
- Cold R22 vapour from the R22 system can be used in coolers to produce dry ventilation air or inert gas. Water vapour in the saturated air or inert gas condenses on the tubes through which the cold R22 vapour flows. Care has to be taken to prevent the temperature of the R22 vapour from falling below 0°C, otherwise ice will form inside the cooler and render it ineffective. Such coolers normally provide a dew point of about 5°C.

## A3.4 BASIC THERMODYNAMIC THEORY

### A3.4.1 General

Cargo officers should be familiar with the elementary thermodynamic principles of heat transfer insofar as they relate to the operation of reliquefaction plant. The most important points are dealt with briefly in this section. Cargo officers are recommended to refer to text books on the subject for a more complete description of the theory.

### A3.4.2 Principles and Definition

Thermodynamics concerns the behaviour of materials when they are heated or cooled. In general, when a solid is heated it melts and becomes a liquid; if it is heated further the liquid boils and becomes a gas. The sequence is reversible and if heat is removed from a gas it returns to liquid form (or is reliquefied). The temperatures at which the melting and boiling processes occur depend on the material involved: e.g. steel melts at a higher temperature than ice, propane boils at a lower temperature than water.

The behaviour of water when heated and cooled is familiar; it can be used to illustrate the behaviour of a liquefied gas cargo and to introduce the thermodynamic definitions. See Figure A3.1.

*Heat* is a form of energy; when applied to a substance it increases the speed of motion of the molecules which make up the substance: The *temperature* of a substance is a measure of the quantity of heat in a substance or the rate of molecular vibrations; it is also a measure of the ability of one body to pass heat to another which is at a lower temperature.

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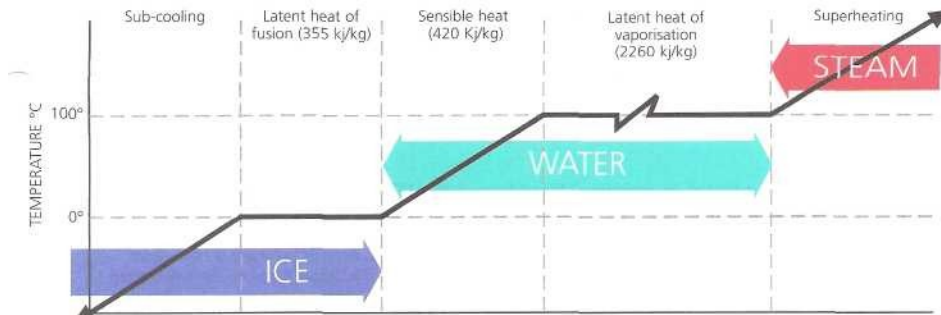


Figure A3.1 Behaviour of water when heated

Below 0°C water is a solid (ice). As heat is applied to the ice its temperature increases until it reaches 0°C. The total quantity of heat required in this or any similar process is called the *sensible heat*. The quantity of heat required to raise the temperature of a unit quantity of ice by 1 °C is called its *specific heat*.

On reaching 0°C, the temperature of the ice does not continue to increase as before. The heat is used to alter the internal structure of the ice. When a certain quantity of heat has been absorbed, the ice melts and becomes water but still at 0°C; the quantity of heat to achieve this is defined as the *latent heat of fusion* of ice. 0°C is defined as the *freezing point* of water.

Water can be heated in an open container until its temperature increases to 100°C; the heat absorbed in the process is again the sensible heat. During heating, molecules at the surface of the water acquire energy and escape into the atmosphere, and the force of this process exerts a pressure called the *vapour pressure*. Molecules at the liquid surface are in equilibrium between the liquid and vapour phases (i.e. both phases are at the same temperature and pressure); the vapour at the liquid surface is said to be *saturated*. At any given liquid surface temperature, the vapour exerts a pressure known as the *saturation pressure*. More molecules escape as the temperature increases and this increases the vapour pressure: a graph of temperature to saturated vapour is called the *vapour pressure diagram*.

When the water temperature reaches 100 °C, its temperature again remains constant until sufficient heat has been absorbed to change it to steam; the quantity of heat absorbed is the *latent heat of vaporisation*. At 100 °C the saturation pressure of the water equals atmospheric pressure and it boils; this temperature is defined as the *boiling point* of water.

However if water being heated is not in an open container subject to atmospheric pressure, but in a partial vacuum

or under a higher pressure, the saturated vapour pressure will equal the pressure on the liquid surface at a different temperature; that temperature will be the new 'boiling point' of water at that pressure. The term 'boiling point' is therefore rather inappropriate, and it is preferable to use *saturation temperature* for the temperature at which the saturated vapour pressure equals the pressure on the liquid surface. The latent heat of vaporisation of a substance varies with its saturation pressure.

If saturated steam is heated further it is said to be *superheated*. It is no longer in equilibrium with the boiling water and is at a higher temperature and pressure. The specific heat of a superheated vapour depends on whether it is heated at constant volume or constant pressure.

In general, if the pressure on a superheated vapour is increased and the temperature is kept constant, the vapour will eventually reach saturation conditions and will liquefy. However, above a certain temperature no pressure, however high, will liquefy the vapour; this temperature is defined as the *critical temperature*. The pressure required to liquefy a gas which is at its critical temperature is called the *critical pressure*.

The total heat content of a substance depends on its temperature (or internal energy), its volume and its pressure: this quantity is known as the *enthalpy* of the substance.

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When heat is applied to or removed from a substance during a reversible process, the heat involved divided by the temperature of the substance is called its *entropy*, if the temperature changes during the process (e.g. addition or removal of sensible heat) the entropy is evaluated by dividing the process into small steps such that the temperature can be considered constant, and summing the result. Only changes in entropy occur during reliquefaction.

#### Summary

# When ice is heated, its enthalpy (H) and temperature (T) increase until it melts. The initial temperature rise involves the absorption of sensible heat and melting absorbs the latent heat of fusion.

# When water is heated, absorbing sensible heat, its saturated vapour pressure (P) increases until, at saturation temperature, it reaches the pressure on the liquid surface. The water then absorbs the latent heat of vaporisation and boils.

# The saturated vapour absorbs more heat and becomes superheated.

Liquefied gas cargoes behave in a very similar manner to water when they are carried at their saturation temperature (i.e. as boiling liquids), corresponding to the cargo tank pressure. The cargo absorbs heat from the surroundings and it begins to evaporate. When saturation temperature is reached any further heat absorbed superheats the boil-off. It is necessary to remove this superheat and the latent heat of vaporisation to reliquefy the boil-off. The reliquefaction plant is designed to do this.

#### A3.4.3 Thermodynamic Units

It is important to consider the units used in thermodynamics before discussing its laws and formulae further.

Every scale of units (such as temperature or pressure) has a starting point (or zero point); this can be chosen arbitrarily or fixed according to the absolute limit below which it is impossible to go.

In many cases the difference between initial and final conditions of, for instance, temperature and pressure is important, and given the same units, this difference is the same irrespective of the zero point used.

In many instances the units used in thermodynamic formulae are *absolute* units, based on a scale with a zero fixed according to the absolute physical lower limit of the scale. However, some charts of enthalpy etc., use arbitrarily chosen zeros and this fact should be considered carefully when using charts for calculations.

The three most important scales of units to consider are temperature, pressure and enthalpy. As will be seen, a number of scales can be used in each case, and it is essential to use consistent units throughout any calculations.

##### (a) Temperature

The two most important temperature scales are the Centigrade scale and the Fahrenheit scale. On the Centigrade scale the freezing point of water is denoted by (TC, and its boiling point by 1(XTC, i.e. there are 100 Centigrade degrees between these two temperature levels. On the Fahrenheit scale the freezing point of water is 32 °F and the boiling point is 212 T, i.e. there are 180 Fahrenheit degrees between these two temperature levels.

0°C = 32°F, and "100°C = 212T. To convert between Fahrenheit and Centigrade the following

equations are used:

$$^{\circ}\text{F} = (^{\circ}\text{C} \times \frac{9}{5}) + 32 \quad ^{\circ}\text{C} = \frac{(^{\circ}\text{F} - 32) \times 5}{9}$$

These rules apply over the complete scale of temperatures but a minus sign must be used for values below 0°.

There is a temperature at which the internal energy of all substances is zero and this is the absolute lowest temperature that can be obtained. Temperature based on scales using this as zero are called *absolute temperatures*.

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Absolute zero is 273.1 Centigrade units below the freezing point of water (i.e. -273.1 °C); on the Fahrenheit scale absolute zero is -459.6 T. The scale based on absolute zero using Centigrade units is called the Kelvin scale (°K), and the absolute scale using Fahrenheit units is called the Rankine scale (°R).

$$0^{\circ}\text{K} - 0^{\circ}\text{R} = -273.1^{\circ}\text{C} - -459.6 \text{ T}$$

To convert from °C to °K add 273.1 (e.g. 5°C = 278.1 °K) To convert from T to °R add 459.6 (e.g. 5°F = 464.6 °R)

Absolute temperatures are used in most thermodynamic tables, charts and calculations. In the SI system of measurement, Centigrade temperature units (i.e. °C or °K) are used.

A Fahrenheit-Centigrade temperature conversion chart is given in Appendix 14.

##### (b) Pressure

Pressure is defined as force per unit area. There are many units in common use; the preferred SI unit is newtons per square metre, though this is rarely used on ships.

Pressure measuring devices normally read pressures above or below atmospheric (i.e. atmospheric pressure is the chosen zero for that system of units). This pressure is called a gauge pressure.

The *absolute* pressure is the sum of gauge pressure and atmospheric. Absolute pressures are used in most thermodynamic tables, charts and calculations.

A table of conversions for various pressure units is given in Appendix 14.

(c) *Heat*

There are three commonly used units of heat, namely the kilojoule (kJ), kilocalorie (kcal) and the British Thermal Unit (BTU).

The preferred SI unit is the kilojoule, and is used throughout this appendix. It is the amount of heat, measured in Joules, required to raise the temperature of 1 kilogram of water by 1 °C.

The kilocalorie is the amount of heat, measured in calories, required to raise the temperature of 1 kilogram of water by 1 °C.

$$1 \text{ kJ} = 0.2389 \text{ kcal}$$

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The British Thermal Unit is the amount of heat required to raise the temperature of 1 pound of water by 1T.

$$1 \text{ kJ} = 0.9479 \text{ BTU}$$

The scale of heat measurement (i.e. enthalpy) can be regarded as an absolute scale because by definition the internal energy of a substance is zero at absolute zero temperature.

#### A3.4.4 *Thermodynamic Laws and Processes*

Thermodynamics is an exact science, with its own laws and formulae. For practical purposes it is not necessary to go into the detailed mathematics, but it is necessary to understand the general principles of the rules and their significance.

(a) *The First Law of Thermodynamics*

This states that the heat lost from a source is equal to the total of heat gained and work done on

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the bodies receiving that heat. This law introduces the equivalence of heat and work as forms of energy. Heat has been defined in A3.4.2; work is said to have been performed if a force moves through a distance and the SI unit of work is a Joule.

The importance of the First Law to reliquefaction systems is that the sum of the heat and work put into the boil-off must be equal to the heat dissipated into the sea to maintain cargo temperatures and pressures. The work done by the compressor in compressing the gas can be taken as the addition of an equivalent amount of heat.

(b) *The Second Law of Thermodynamics*

This states that heat always flows from a hot body to a cooler one and it is of fundamental significance to liquefied gas carriage. If the temperature of the sea or air is above cargo temperature, heat will flow into the cargo until the temperatures are equal. One purpose of the cargo tank insulation is to reduce the rate of heat leakage into the cargo; the purpose of the reliquefaction plant is to reject heat that leaks into the cargo and put it into the sea. If heat is to flow into the sea, the cargo vapour boil-off, or an intermediate heat transfer medium such as R22, has to be at a temperature above sea water temperature somewhere in the reliquefaction system.

(c) *The Gas Laws*

There are many laws which describe the behaviour of gases and the most important ones are given here. A gas which obeys them exactly is called a perfect gas. Typical cargo gases obey these laws quite closely:

(i) *Boyle's Law* states that at constant temperature, the volume of a given mass of gas varies inversely to its absolute pressure. If, in a process, a perfect gas at constant temperature changes from initial pressure and volume  $P_1$  and  $V_1$  to final pressure and volume  $P_2$  and  $V_2$ , then by Boyle's law:

$$P_1 \cdot V_1 = P_2 \cdot V_2$$

(ii) *Charles' Law* states that the volume of a given mass of gas at constant pressure varies in proportion to its absolute temperature. If the initial and final volumes of the gas are  $V_1$  and  $V_2$  and the initial and final temperatures are  $T_1$  and  $T_2$ , then by Charles' law:

$$V_1 = V_2 \frac{T_1}{T_2}$$

(iii) *The General Gas Equation* is derived by combining the above Laws and is stated as:

$$P_1 \cdot V_1 = P_2 \cdot V_2 \frac{T_1}{T_2}$$

or  $PV = mRT$  where  $m$  is the mass of gas and  $R$  is called the gas constant which can be obtained from tables.

(iv) *Dalton's Law* states that the total pressure of a mixture of different gases in a space is the sum of the pressure which each gas would exert if it occupied the space alone at the temperature of the mixture. Each constituent of the mixture behaves as if it occupied the space alone. For example, the addition of a small quantity of ethane will increase the saturated vapour pressure of propane quite considerably (see A3.4.6).

(v) *Joule's Law* states that the internal energy of a perfect gas depends only on its temperature and is independent of changes in pressure and volume.

Therefore if the pressure and volume of a gas change in a process, the energy of the gas remains constant unless its temperature changes.

(vi) *The Joule-Thompson effect* describes the deviation from Joule's Law for non-perfect gases. In theory if a gas was allowed to expand freely without doing work, there should be no change in temperature. However, in practice the gas temperature falls by an amount inversely proportional to the initial absolute temperature. This effect is used in reliquefaction plant to produce low temperatures after the expansion valve.

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(d) Thermodynamic Processes

There are a number of thermodynamic processes which are relevant.

(i) An isentropic process is one in which no change of entropy occurs,

(ii) An adiabatic process is one in which no heat is transferred into or out of the system; it is also isentropic. If a gas expands or is compressed so that there is no time for heat exchange with the surroundings the process is virtually adiabatic; this is the case when cargo vapour is passed through a compressor, unless the machine has a cooling jacket.

{Hi} An isothermal process is one that takes place at constant temperature. If a gas expands isothermally, the work it does must be at the expense of heat from an external source, and if a gas is compressed isothermally, it must dissipate the heat created by the work done on it.

A3.4.5 The Mollier (Pressure - Enthalpy) Diagram

Enthalpies are normally tabulated for saturation conditions; however, for other conditions the tables would be large and impractical. For this reason diagrams are used in which enthalpy is plotted on the x-axis and absolute pressures on the y-axis. These diagrams are called Mollier diagrams or pressure-enthalpy diagrams. The absolute pressure is normally plotted on a logarithmic scale.

Figure A3.2 shows part of a Mollier diagram for propane. The curved blue line running from the bottom left up to the right is called the saturated liquid line. The line then turns downwards and the red part is called the saturated vapour line. The area enclosed by the saturated liquid line and the saturated vapour line indicates mixtures of liquid and gas. The area to the left of the saturated liquid line indicates sub-cooled liquid and the area to the right of the saturated vapour line indicates superheated vapour where the General Gas Equation  $PV = mRT$  applies. The horizontal distance between the saturated liquid line and saturated vapour line denotes latent heat, i.e. the difference in enthalpy between the saturated liquid and saturated vapour. As can be seen, the latent heat decreases when the pressure increases until it is zero at the critical point. The green lines indicating  $m^3/kg$  denote specific volume, which is the volume of a substance per unit weight.

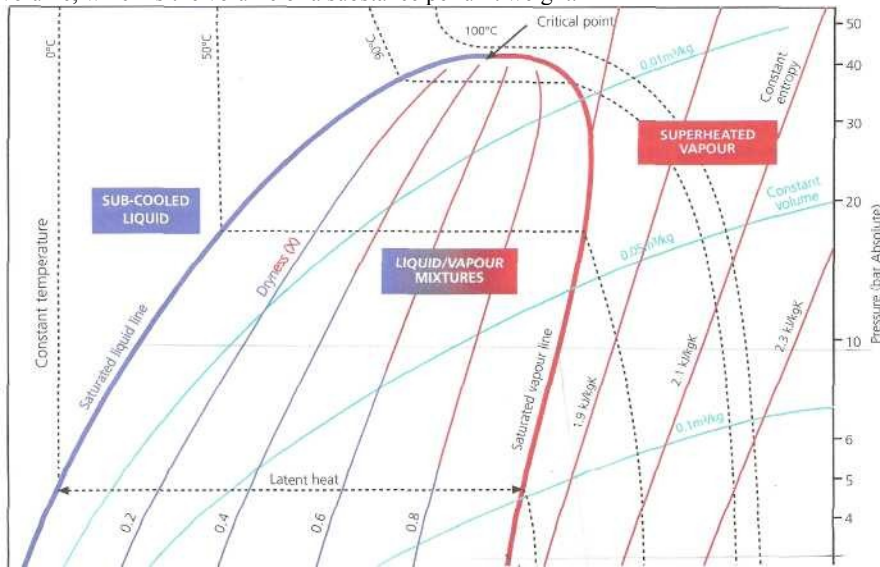


Figure A3.2 Schematic Mollier diagram

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The broken lines running through one temperature are lines of constant temperature in °C.

The thin red lines run through points of constant entropy and are given in kilojoules/kilogram/ °C (kJ/kg/ °C).

Lines of constant entropy indicate the increase in heat content when the gas is compressed, and such lines show adiabatic compression. Actual compression differs from this curve due to various losses.

The red-and-blue lines in the area between the saturated liquid line and the saturated vapour line run through points having the same dryness fraction (X). The dryness fraction denotes the ratio between gas and liquid, i.e. X = 0.4 means that 40% of the substance is gaseous and 60% is liquid.

A3.4.6 Vapour Pressure of a Mixture

The saturated vapour pressure of a mixture of individual liquefied gases (e.g. LPG) differs from the vapour pressure of its components. However, the total vapour pressure can be calculated (see A3.4.4).

From Dalton's Law and the General Gas Equation, it can be shown that, for ideal gases, the partial pressure of any component of a mixture is equal to the pressure that would have been created by that component alone multiplied by the mole fraction of that component in the liquid phase. The mole fraction is the mole percentage divided by 100; the mole fraction factor accounts for the different weights of the individual gases. For example, for an LPG of the following composition at -40 °C:

Component	Mole %	Pressure of pure component at -40°C (kg/cm <sup>2</sup> )	Partial Pressure of component at -40°C (kg/cm <sup>2</sup> )*
Ethane	3.7	7.78	0.288
Propane	86.1	1.13	0.973
n-Butane	2.1	0.17	0.0036
i-Butane	8.1	0.29	0.0234
Total vapour pressure of mixture at -40°C = sum of partial pressures =			1.288 kg/cm <sup>2</sup> .
*Pressure of pure component × $\frac{\text{mole \%}}{100}$			

The components of the mixture are in solution with each other, and this is why the low boiling fractions (e.g. ethane in the above example) remain in the liquid phase even at temperatures above the saturation temperature of the pure material. However, the example shows how the addition of a small quantity of a volatile fraction can increase the vapour pressure considerably. The vapour phase will contain a larger concentration of volatiles than the liquid phase, and figure A3.3 shows that for propane with 4 mole % ethane in the liquid phase, the vapour phase contains 22% ethane.

### A3.5 THERMODYNAMIC THEORY APPLIED TO A SIMPLE GAS RELIQUEFACTION CYCLE

#### A3.5.1 Simple Gas Reliquefaction Cycle

Figure A3.4 shows a simple reliquefaction cycle. The cycle comprises:

- The cargo tanks (1). In the direct reliquefaction systems these act as evaporators in which the liquid cargo is vaporised. Evaporation removes a certain quantity of heat Q1 from the tank, the liquid in the tank, and its surroundings.
- A mechanical compressor (2). The vapour formed in the cargo tanks is at a pressure P1; the compressor draws and compresses it, and delivers it to the condenser at a pressure P2. In the process of compression an amount of heat energy Q2 is added to the gas; the compressor uses an equal amount of work energy W1.

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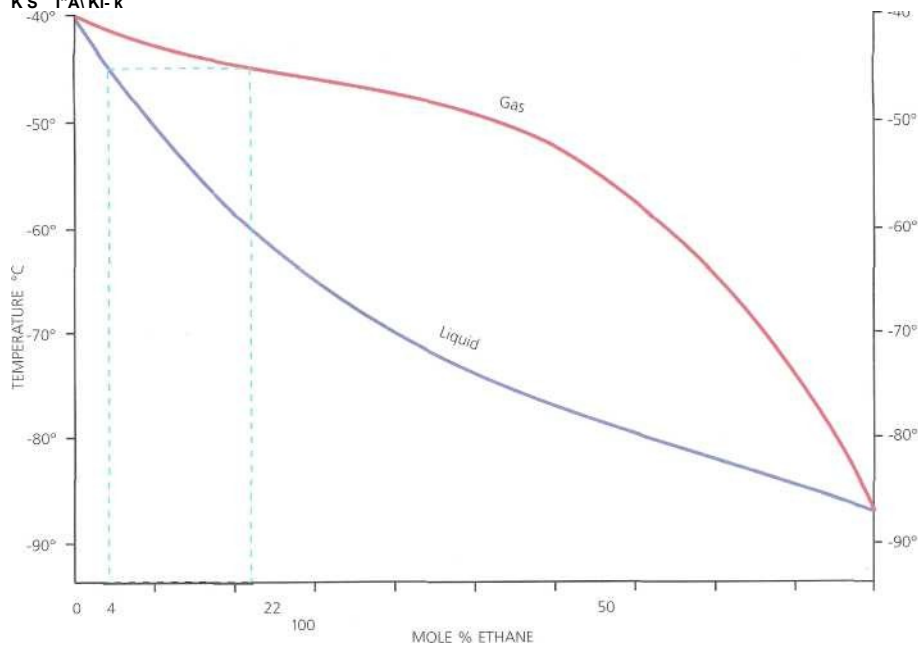


Figure A3.3 Propane - Ethane equilibrium diagram Pressure = 1.1 bar (A); Mole % propane = 100-Mole % ethane

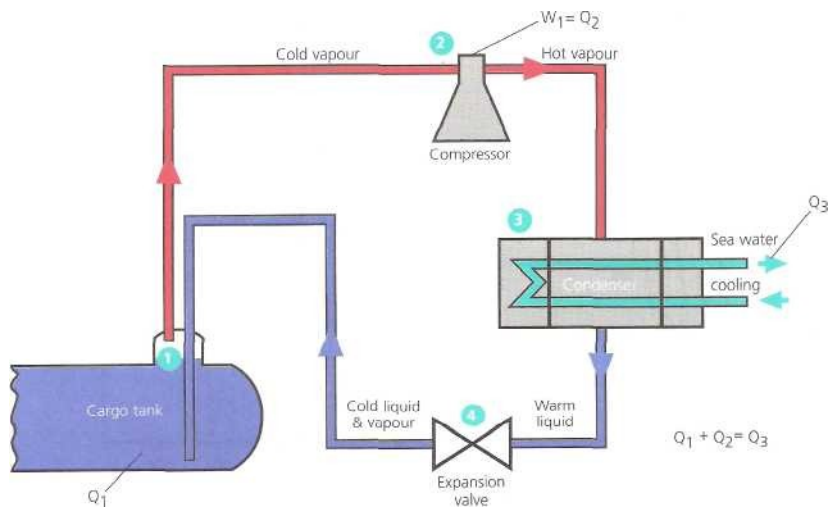
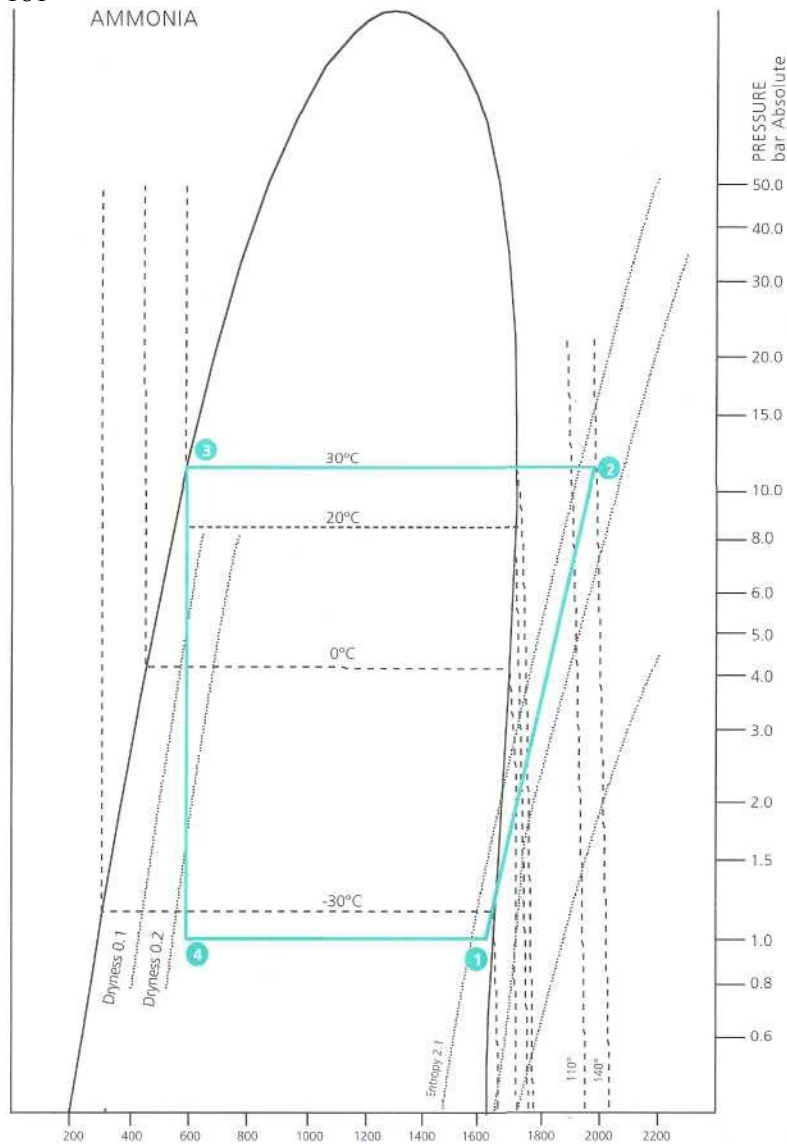


Figure A3.4 Simple gas reliquefaction cycle

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ENTHALPY kj/kg Figure A3.5 Simple reliquefaction cycle shown on Mollier Chart

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- A condenser (3). The vapour supplied by the compressor is liquefied in the condenser, giving up a certain amount of heat  $Q_3$  to the cooling water.

- An expansion valve (4). This reduces the pressure of the condensate from P2 to P1 while passing from the condenser to the cargo tank.

According to the First Law of Thermodynamics

$$Q1 + Q2 = Q3 \quad \text{A3.5.2} \quad \textit{The Mollier Diagram applied to the Simple Cycle}$$

Figure A3.5 shows the Mollier Diagram for ammonia which is the cargo to be reliquefied. For example, suppose the cargo is refrigerated with a consequent temperature of -33 °C and assume the compressor draws the vapour at -33 °C (disregarding pressure losses in the suction piping and presuming that the gas is neither heated nor cooled). The starting point (1) of the cycle (saturated vapour) is therefore characterised by:

Temperature (T1)	-33 °C
Pressure (P1)	1.031 bar
Enthalpy (H1)	1636 kJ/kg
Vapour Density	0.905 kg/m <sup>3</sup>

Suppose that the gas is compressed adiabatically and condensed at 30 °C: i.e. following a line of constant entropy this gives a condensation pressure of about 11.7 bars.

At the end of compression the gas has the following characteristics at point (2):

Temperature (T2)	140 °C
Pressure (P2)	11.7 bars
Enthalpy (H2)	1999 kJ/kg

The condensate in the condenser has the following characteristics at point (3)

Temperature (T3)	30 °C
Pressure (P3)	11.7 bars
Enthalpy (H3)	560 kJ/kg

The difference in enthalpies between that of the condensate (H3) and that of the gas delivered by the compressor (H2) equals Q3 (the heat removed by the cooling water in the condenser):

$$\text{i.e. } H3 - H2 = Q3$$

$$560 - 1999 = -1439 \text{ kJ/kg}$$

(Note that Q3 is a negative figure as it represents heat given up to the surroundings).

The condensate liquid is then expanded through the expansion valve without giving up or receiving heat: i.e. the transformation is carried out at constant enthalpy and therefore follows a vertical straight line. After expansion the liquid has the following characteristics at point (4):

Temperature (T4)	-33 °C
Pressure (P4)	1.031 bar
Enthalpy (H4)	560 kJ/kg
Dryness fraction (X)	22%

It can be seen, therefore, that to bring the temperature of the liquid down from 30°C to -33 °C, a fraction of the liquid, 22% by volume, has evaporated to absorb the heat necessary to achieve this cooling effect.

Finally, on entering the cargo tank the remaining condensate is evaporated by heat absorbed from the tank, the liquid in it and its surroundings, so the cycle is completed and initial point (1) is reached.

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The cold produced, or the refrigerating effect Q1, is therefore the difference in enthalpy between starting point (1) (saturated vapour) and that of the liquid entering the tank at point (4):

$$\text{i.e. Refrigerating effect } Q1 = H1 - H4 = 1636 - 560 = 1076 \text{ kJ/kg}$$

Since the vapour has a density of 0.905 kg/m<sup>3</sup> the quantity of heat per unit volume of the gas drawn by the compressor will be:

$$1076 \times 0.905 = 974 \text{ kJ/m}^3 \quad \text{The energy absorbed in the compressor is equivalent to:}$$

$$Q2 = H2 - H1 = 1999 - 1636 = 363 \text{ kJ/kg}$$

To summarise this cycle:

- At point (1) the saturated ammonia vapour in the cargo tanks at a pressure of 1.031 bar (P1) with a corresponding temperature of -33 °C (T1) is drawn by the compressor. During compression the pressure is increased to 11.7 Bars (P2) at a temperature of +140 °C (T2). The energy absorbed in the compressor is equivalent to 363 kJ/kg (Q2) and at point (2) the ammonia vapour is in the superheated region.
- In the condenser condensation takes place at a constant pressure of 11.7 Bars, and during the condensation process the vapour is first desuperheated, and the latent heat is then extracted which brings it to point (3). The heat extracted by the sea cooling water in the condenser is 1439 kJ/kg (Q3). The condensate in the condenser is at +30 °C.
- Expansion from point (3) to point (4) takes place across the expansion valve between the condenser and the cargo tank. During this process the pressure drops from 11.7 Bars (P3) to 1.031 Bar (P4). It is assumed that the liquid does not give up or receive heat during this process and the enthalpy remains constant. The temperature also drops from 30 °C (T3) to -33 °C (T4) which is the cargo temperature. To produce this cooling effect 22% by volume of the condensate is vaporised.
- To complete the cycle the balance of the condensate returned to the tank is vaporised from point (4) to point (1), producing 1076 kJ/kg of cooling which removes heat from the cargo tank, its contents and its surroundings.

Finally according to the First Law of Thermodynamics

$$Q1 + Q2 = Q3$$

$$1076 + 363 - 1439 \text{ kJ/kg}$$

Note: The amount of heat removed in the condenser (in this case 1439 kJ/kg) is always greater than the

refrigeration effect in the cargo tanks (in this case 1076 kJ/kg), the difference being the heat absorbed in the compressor (in this case 363 kJ/kg).

### A3.5.3 Difference Between Real Cycles and the Simple Cycle

In practice, real reliquefaction cycles differ from the simple cycle described above because of heat losses that arise in the processes involved. The calculation of these losses is described below; the results are sufficiently accurate for practical purposes.

#### (a) Loss by Heating in the Compressor Suction Piping

These losses arise from the heating of the vapour in the suction line between cargo tank and compressor. Heat is absorbed if the line is uninsulated; if the line is insulated the heat absorption is greatly reduced, but is never totally eliminated. Some plants are arranged with a heat exchanger in the suction line; the compressor discharge gas is slightly desuperheated and this heats up the suction vapour.

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The extent of these losses can easily be evaluated from the Mollier diagram (Fig. A3.5).

Assume, for example, that the ammonia is at 3.98 bars in the tank, the temperature of the vapour on leaving the tank is -2°C and its specific volume is 0.315 m<sup>3</sup>/kg

(i.e. a specific weight of  $\rho = 3.17 \text{ kg/m}^3$ ).

If this vapour enters a compressor at a temperature of 20°C, its specific volume at the same pressure will be about 0.350 m<sup>3</sup>/kg (i.e. specific weight of  $\rho = 2.90 \text{ kg/m}^3$ ).

Therefore there is a loss of weight per m<sup>3</sup> drawn in by the compressor of:

$$3.17 - 2.90 = 0.27 \text{ kg/m}^3$$

0.27 or expressed as a percentage,  $\frac{0.27}{3.17} \times 100 = 8.5\%$

that is, as a percentage per °C of heating  $\frac{8.5}{22} = 0.4\%$

Whatever the cargo, it is found that the loss in weight per cubic metre is always in the order of 0.4% per °C of heating.

Therefore, if a curve of refrigerating power is established for a compressor, assuming that the vapour enters the compressor at the pressure of evaporation in the tank, the actual refrigerating power will be reduced by about 0.4% per degree of difference between the temperature of the tank and that at suction intake.

#### (b) Loss by Pipe Friction

Loss of pressure in the suction piping also causes a reduction in the weight of the gas per m<sup>3</sup>; this loss can also be established from Figure A3.5 and is approximately equal to:

Loss of pressure Suction pressure

If the tank is at 4 bars and the loss of pressure is 0.4 bar (that is, 3.6 bars at suction intake), the

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loss expressed as a percentage will be  $\frac{0.4}{4} \times 100 = 10\%$

#### (c) Volumetric Efficiency of Reciprocating Compressors

Cargo compressors may be single or multi-stage, depending upon the refrigerant and its condensing pressure, and they may also be of variable capacity.

The efficiency of the compressor has to be maintained at maximum to achieve the design efficiency. Several factors reduce the compressor's efficiency:

- If the refrigerant condensing pressure is higher than necessary for a given condition, then the amount of gas pumped per stroke will decrease.

- # If the suction pressure decreases because of low pressure, shortage of refrigerant or excessively low temperature, the amount of gas pumped per stroke will decrease.

- Any increase in the clearance pocket will reduce the amount of gas pumped. The clearance pocket is usually defined as the volume of gas left in the compressor cylinder at the top of the piston stroke.

- An escape of gas past the piston, and leaking compressor suction or discharge valves, will decrease the volume of gas pumped.

- ◆ Leakage of discharge gas across by-pass lines to the suction side of the compressor will reduce efficiency.

- # Overheating of the compressor due to friction will reduce the efficiency of the system by imparting superfluous superheat to the discharge gas.

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Compressors have a theoretical output per hour, which is the volume swept by the pistons. Taking into account piston head clearance and the resistance to vapour flow in the suction and discharge valves, the actual output is calculated from the theoretical volume by multiplying it by a volumetric efficiency coefficient of less than 1. This coefficient is given by:

actual volume of gas pumped theoretical output

The coefficient varies mainly according to compression ratio, which is the ratio between absolute suction and discharge pressures; it also varies according to suction and discharge pressures, but these are usually disregarded.

#### (d) Condensers, Heat Exchangers, Evaporators

These items of plant are all designed to effect a heat exchange from one substance to another across a barrier. They may be described as evaporators when used to convert liquid to vapour; as condensers when used to convert vapour to liquid; and as heat exchangers when the main purpose is to effect a heat exchange without evaporation or condensation necessarily occurring. In cargo systems the same heat exchangers may act as condensers for one operation, and as evaporators in another. Shell and tube condensers are used extensively and are either water cooled, or refrigerant cooled as in cascade systems.



Condenser efficiency is directly proportional to the total surface area of the tubes, their conductivity, and the rate of flow and temperature differential between the substances passing through.

Refrigerant efficiency will be lost in the condenser when:

- the temperature of the cooling medium is comparatively high;
- the rate of flow of the cooling medium is low;
- the conductivity of the tubes is insulated by scale or deposit formation;
- when there is a decrease in the tube surface area due to leaking tubes which have been plugged;
- when a 'back-up' of condensate covers the cooling tubes or shell and restricts the heat exchange area.

### A3.6. REFRIGERATION CYCLES

#### A3.6.1 General

The four common reliquefaction cycles used aboard gas carriers are described below. Each works on the principle of removing the excess heat from the boil-off vapour, condensing it and returning the liquid to the cargo tank. The heat removed is the latent heat of vaporisation of the cargo plus any extra heat (or superheat) the boil-off has absorbed. This heat leaks into the cargo through the insulation from the air, sea and sun; the reliquefaction plant removes the heat and returns it to the sea.

#### A3.6.2 Direct System: Single-Stage

The single-stage direct compression reliquefaction system is described and illustrated in Figure A3.6; the stages in the cycle are also shown on a schematic Mollier Diagram (see Figure A3.7).

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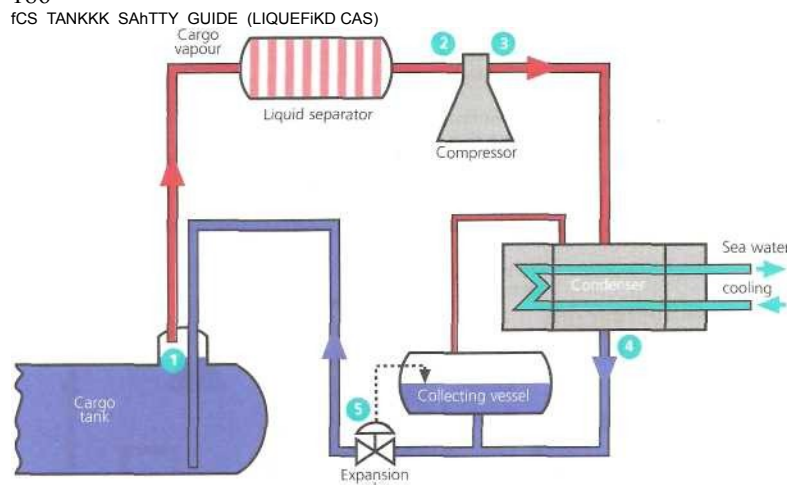


Figure A3.6 Single stage direct compression cycle

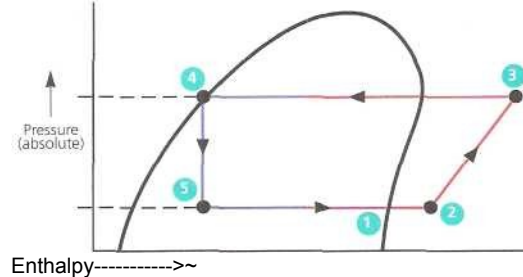


Figure A3.7 Schematic mollier chart Single stage direct compression cycle

Boil-off vapour (1) is taken from the cargo tank to the compressor (2) via a liquid separator; any liquid in the vapour would damage the compressor. The compressor is used to increase the temperature of the vapour so that a sea-water condenser can be used. The superheated vapour from the compressor (3) is condensed to an ambient temperature liquid in a sea-water cooled condenser (4), and is collected in a collecting vessel, known as a condensate receiver, before being passed through an expansion valve (5) to cool it. The flow through the expansion valve is controlled by a level switch in the collecting vessel to prevent back-pressure from the cargo tank reaching the condenser and compressor. The throttling (expansion) valve is designed to ensure that there is sufficient pressure to press the liquid into the cargo tank.

This simple system can be used aboard semi-pressurised ships for high boiling point cargoes. A3.6.3 Direct System: Two-Stage

If the compressor discharge-to-suction pressure ratio in a single stage system exceeds about 6:1 the efficiency of the machine is reduced and two stage compression is necessary. This can take place in two separate machines or in one two-stage compressor.

The first part of the two-stage cycle is the same as the single-stage cycle. Boil-off (1) is taken from the tank via a liquid separator to the first-stage compressor (2) where it is superheated (3). The

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vapour can then be cooled in an interstage cooler (or "intercooler") (4) before passing to the second stage compressor. The purpose of the intercooler is to reduce the suction pressure of the second stage and increase

efficiency; it is essential for a cargo such as fully refrigerated ammonia.

The second compression further superheats the vapour (5) which is then cooled and condensed in a sea-water cooled condenser (6). The ambient temperature liquid is then collected and passed through the expansion valve (8) as in the single stage cycle. Before the expansion valve, the condensed liquid can be used as the intercooler coolant (7).

This system can be used for semi-pressurised and fully refrigerated LPG ships.

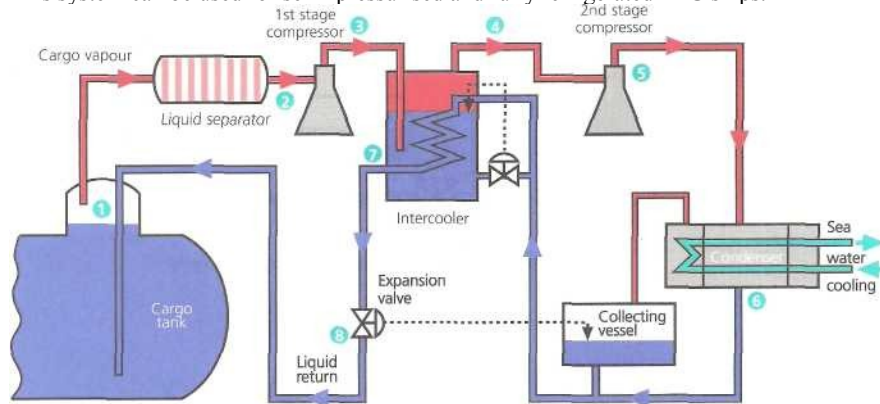
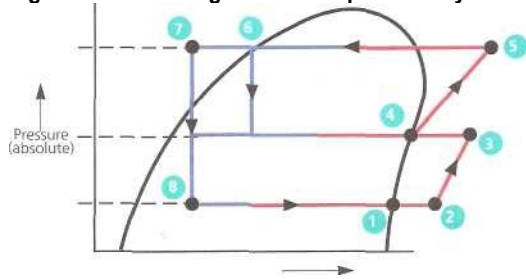


Figure A3.8 Two stage direct compression cycle



Enthalpy

Figure A3.9 Schematic mollier chart Two stage direct compression cycle

#### A3.6.4 Direct System: Cascade

This system is virtually identical to the single-stage direct system, except that the cargo condenser is cooled by liquid refrigerant gas such as R22. The heat from the cargo evaporates the R22 which is compressed, condensed in a sea-water cooled condenser, and cooled by passage through an expansion valve. The R22 cycle is also a direct cycle, working in a cascade with the cargo reliquefaction cycle. See Figures A3.10 and A3.11.

The system can be used for fully refrigerated cargoes. Its major advantage is that the capacity of the system is not affected by sea-water temperatures as much as other systems. The cycle is also more efficient, as the R22 temperature in the LPG condenser can be below 0°C.

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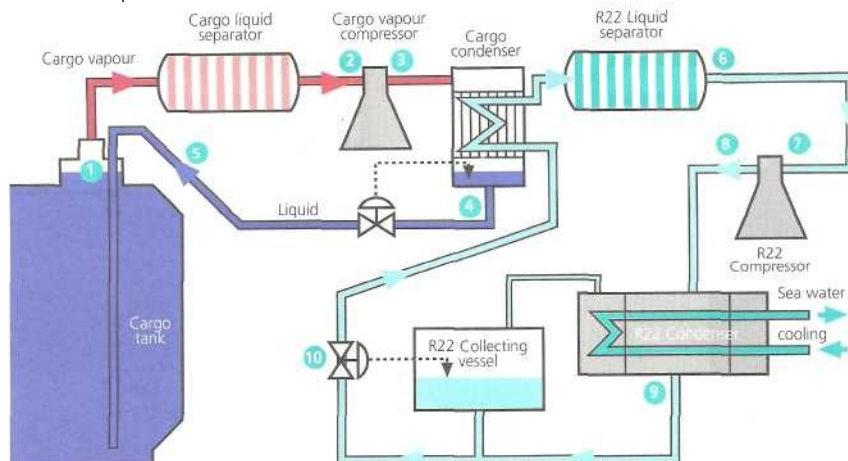
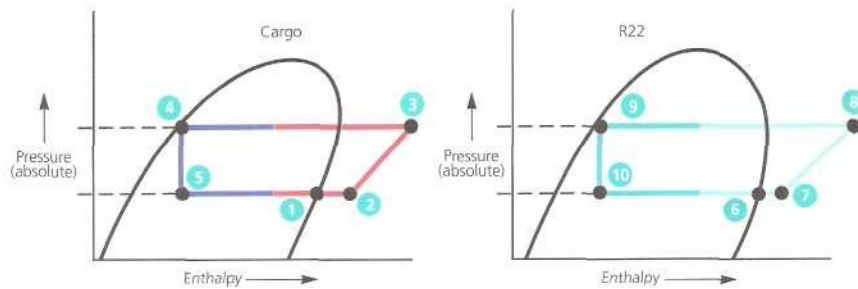


Figure A3.10 Cascade cycle



### A3.6.5 Indirect System

Figure A3.11 Schematic mollier chart Cascade cycle

Indirect cooling is used for cargoes which cannot be compressed for chemical reasons. In Figure A3.12(a) the boil-off passes from the tank (1) under its own pressure to a condenser which cools and liquefies it (2). The condensate then returns to the tank under its own pressure or by pump. It is also possible (Figure A3.12(b)) to arrange condensation by cooling coils in the vapour dome, below the liquid surface or welded to the tank exterior.

The cycle has to use a very cold refrigerant in the condenser for efficiency; the common refrigerants are hydrogen, helium and propane. The refrigerant works in a cycle, in cascade with the cargo cycle.

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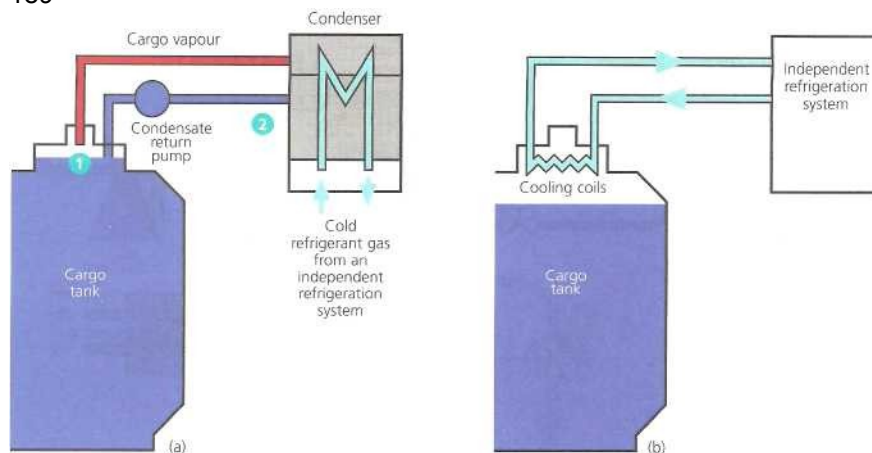


Figure A3.12 Indirect cycle

## A3.7 RELIQUEFACTION PLANT OPERATIONS

### A3.7.1 General

During loaded passages, the duration of reliquefaction operation will be dictated by a number of factors, especially:

- cargo temperature on loading;
- required cargo temperature on discharge;
- cargo composition; and
- weather conditions.

Reliquefaction operations should be scheduled to suit the ship's normal routine, as far as possible.

On completion of loading, cargo tank pressure may need to be reduced to meet the ship's needs; for fully-refrigerated ships it is usually preferable to operate the plant at maximum capacity until tank pressures approach atmospheric.

During a loaded passage, cargo temperature should be maintained (or reduced) by operating the reliquefaction plant as necessary. The stand-by capacity should not normally be required, but it may be needed, for instance to reduce the cargo temperature when severe weather conditions are anticipated.

During a ballast passage, cargo tanks may be kept cold by a "heel" of cargo retained after discharge. The heel is distributed around the cargo tanks in the most efficient manner possible, and the vapour evolved is reliquefied.

Occasionally, severe weather and violent ship movement may make it impossible to operate reliquefaction plant for fear of liquid entering the compressors. Rough weather will also cause tank pressures to rise due to sloshing of liquid cargo against warmer surfaces in the vapour space. For this reason, cargo tank pressures should be kept near atmospheric at all times.

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### A3.7.2 Preliminary Precautions

Before reliquefaction operations begin, the responsible officer should ensure that:

- compressor lubricating oil is suitable for the cargo concerned and that the oil levels are correct; if the oil level is high it should be suspected that cargo or refrigerant has entered the crankcase; in most cases small quantities of cargo leakage will boil off without damage. However if the cargo is butadiene, even small quantities will polymerise and affect the lubricating oil; similar problems can arise with propylene;
- lines and valves are correctly set; compressor discharge valves should always be open before starting but it is

normal to open compressor suction, lubricating oil separator and compressor hot gas bypass valves after starting;

- full seawater supply to appropriate condensers has been established;
- the glycol plant is running (see A3.7.6); and
- variable capacity compressors are set to manual operation at minimum capacity.

#### A3.7.3 *Cargo Reliquefaction Plant Operations*

Before starting and whilst reliquefaction plant is running, the responsible officer should ensure that the following precautions are observed:

- cargo compressor discharge valves are open, and crankcase heaters activated;
- the suction valve is opened slowly after the compressor is started. If 'compressor hammer' is heard this means that liquid is entering the machine, and the suction valve should be shut immediately to prevent damage. Small quantities of liquid can be evaporated by careful regulation of the suction valve with the plant running, but if hammering persists the machine should be stopped and drained. If necessary the lubricating oil should be changed. In cold weather, butane and similar cargoes may condense in the compressor and in such cases the by-pass should be used to superheat the suction gas;
- crankcase oil levels and pressures are within manufacturer's limits. When the machine is operating normally and the oil separator has warmed up, the crankcase oil return valve should be opened. However if delivery is opened too early, cargo can return to the crankcase, especially in cold weather;
- suction and discharge pressures are correct. There will be a pressure drop along the suction line, but the gas may become superheated. The discharge pressure will depend on cargo composition, suction pressure, sea water or R22 temperature. It is advisable to keep careful logs of readings for future reference;
- cargo condenser liquid level controls are operating correctly. If the liquid level in the condenser is above the set point, the manual by-pass should be operated. If the level continues to rise, it is probable that ice has formed in the line; the plant should be stopped and the ice thawed, for example by injection of anti-freeze;
- condensing pressure and gas discharge temperatures are correct. If the pressure is higher than expected, it is likely that incondensable gases are present (see A3.7.9) and these should be vented until the correct condensing pressure is restored;
- when correct pressures, levels and balances have been established in the system, any manual controls can be returned to automatic operation;
- when running, the plant operating conditions should be checked frequently to ensure that the designed efficiency levels are met; and
- if condensate is being returned to more than one tank simultaneously, it should be ensured that none of the tanks is overfilled. For example trim can lead to preferential filling of the aftermost cargo tank.

#### A3.7.4 *R22 System Operations*

If the ship's system is of the R22 cascade type, the R22 cycle should be started first. If there is a protracted delay in starting the cargo plant, the R22 suction pressure may fall sufficiently to stop the plant, and it may be necessary to open the discharge to suction by-pass.

The responsible officer should ensure that the following precautions are observed:

- the R22 liquid separator is not flooded;
- the R22 compressor discharge valve is open;
- the compressor is started and the suction valve opened slowly to prevent cut-out due to the starting load. If compressor hammer is heard the machine should be stopped;

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- the R22 compressor oil level and crankcase pressures are within the manufacturer's limits.
- Depending on the type of equipment, the R22 system is not put on automatic control until normal conditions have been established; and
- R22 liquid level devices are checked regularly for correct operation during reliquefaction.

#### A3.7.5 *Completion of Reliquefaction Operations*

When the desired cargo temperature is reached, the reliquefaction plant can be shut down. The responsible officer should ensure that the following precautions are observed:

- the cargo compressor is stopped and the suction valve closed;
- the expansion valve by-pass is opened to permit the condenser pressure to clear the condensate line to the cargo tank;
- the R22 compressor is stopped and the oil separator return to the crankcase is closed;
- all cargo valves are shut when the cargo condenser is at tank pressure;
- the compressor discharge and suction valves are closed to prevent condensate collecting in the cylinders or crankcase;
- the sea-water supply to the condensers and glycol circulation in the system should either be stopped or left running, in accordance with instructions; and
- it should be ensured that no cargo liquid remains in the system; any residue will heat up and cause the relief valves to lift. If necessary the lines may be cleared with the vapour from the cargo compressor.

It should be noted that butadiene condensate is not inhibited and may polymerise, causing blockage; uninhibited condensate can be removed by purging with inhibited cargo liquid.

#### A3.7.6 *Glycol Systems*

The use of water alone as a cooling or heating medium in low temperature cargo systems is impracticable because it can freeze and cause blocked or burst pipes. Where cooling or heating coils are essential to plant operations for certain cargoes a mixture of ethylene glycol and water is normally used.

For ships carrying cargo down to -55 °C, a 60% volume mixture of glycol in fresh water should be adequate for all

purposes. If the glycol content is less than 60% the mixture may freeze, but excess glycol will provide no practical advantage.

The ethylene glycol mixture is usually circulated through a tank fitted with electric heating coils and sea-water cooling coils by means of a pump to maintain it at the required temperature. It may be used in the following applications:

- as a cooling system for cargo compressor bearings;
  - in a cargo compressor suction gas superheating unit to prevent pre-compression condensation;
  - for heating jackets on differential pressure transmitters fitted to condensers and receivers to prevent freezing;
  - as a means of heating compressor lubricating oil, to vaporise refrigerant which may contaminate the oil;
  - for cargo compressor cylinder head cooling; or
- 9 for cooling at two-stage compression intercoolers.

#### A3.7.7 Anti-freeze Injection

If it is known or suspected that water is present in the cargo there is a danger of valves and pumps in the cargo system freezing, with subsequent damage. In such cases an anti-freeze may be added, but it should be noted that in modern trading practices the use of an anti-freeze is an unusual occurrence, and the shipper must always be consulted (see paragraph 1.4.1).

If water vapour is mixed with cargo vapour in a reliquefaction cycle, the water will condense with the cargo in the condenser. In most cases the water will remain in suspension as a free liquid provided the condensate temperature is above 0°C. However in most reliquefaction systems, the condensate temperature is below 0°C at the expansion valve and free water will freeze in that vicinity.

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The amount of ice formed at the expansion valve will depend upon the quantity of free water present, the condensate temperature and, to some extent, the pressure differential across the expansion valve. Blockage of the condensate return may occur suddenly and without warning, or ice may build up on the pipe wall over a period and become evident by a gradually diminishing condensate flow and a condensate build-up in the receiver. Automatic expansion valves are usually provided with a manual by-pass to avoid the necessity of shutting down the plant in the event of a blockage.

To prevent or reduce ice formation, some reliquefaction plants are equipped with an anti-freeze injection system up-stream of the expansion valve. The anti-freeze, which is usually an alcohol, is stored in a tank fitted with a pump capable of developing comparatively high pressures. When ice forms in the expansion valve, the injection line is opened and anti-freeze pumped in until the ice clears. If the ice does not clear rapidly, it can be assumed that the build up is extensive. The plant must be shut down or operated on the by-pass, and the anti-freeze pressure against the ice maintained until the blockage clears.

Where ice blockage is extensive, the pressure at which the anti-freeze is applied to the ice will be a decisive factor in the time taken to clear the line. As the ice clears, the anti-freeze will mix with the water and lower its freezing point.

#### A3.7.8 Hydrate Formation

Methane, ethane, ethylene, propane and butane may combine with water, under conditions of increasing pressure or reducing temperature, to form white crystalline solids which are known as hydrates. These hydrocarbons are unusual in their ability to carry more water in solution as a vapour than as a liquid (for propane, eight times more at 6°C). Thus, propane vapour which is saturated with water vapour will release free water upon being condensed in a reliquefaction plant, and hydrate may form if this condensate-water mixture is cooled in a heat exchanger or by pressure reduction at a regulation valve or cooling spray. For a propane condensate (83.4% propane, 12.4% ethane and 4.2% methane), hydrates form at the following temperatures and pressures:

Pressure bars	Temperature °C
0	-2
0.7	0
2.7	3
<b>4.1</b>	<b>5</b>
<b>5.2</b>	<b>6</b>

#### A3.7.9 Incondensible Gases

Incondensible gases found in compressor systems will be above their critical temperature and cannot be condensed by pressure alone. The most commonly encountered incondensibles are oxygen and nitrogen, remaining after purging operations, and low boiling point cargo components (e.g. ethane).

The effect of incondensibles in a reliquefaction cycle is to increase the condensing pressure and reduce the efficiency of the plant. When the condensing pressure during a reliquefaction operation rises to an appreciable extent above the saturation pressure for a particular grade of cargo, the presence of incondensibles should be suspected and they should be vented to the atmosphere, if local regulations permit, by way of the manual blow-off valve on the condenser vent line. Some systems also provide an alternative incondensibles return line to the cargo tank.

Incondensibles are most likely to occur after the cargo system has been inerted or gas-freed and particularly when the subsequent purging operation has not been efficiently performed. Venting of incondensibles should be continued during the initial reliquefaction operation until the condensing pressure stabilises at or near the correct theoretical value. Incondensibles air or inert gas will only exist in the cargo tank vapour phase, and with a fully loaded ship this venting operation is unlikely to be prolonged.

If venting of incondensibles over a fairly long period (e.g. several hours) does not succeed in reducing the condensing pressure to the anticipated value, the high pressure can usually be attributed to components of the cargo and be accepted, provided that the pressure is within the design limits of the plant.

To ensure that essential minor components (e.g. ethane) of some cargoes are not treated as incondensibles and blown to the atmosphere, the saturated vapour pressure in relation to the anticipated condensing temperature of the cargo should be noted from the appropriate Mollier or vapour pressure diagram before reliquefaction operations commence. Comparatively small volumes of ethane in the liquid phase of propane will produce considerably larger volumes of ethane in the vapour phase, and this vapour mixture will require a higher condensing pressure than is normal for pure propane.

## DRYDOCKING AND REPAIR PERIODS



### A4.1 GENERAL

All systems which contain flammable or toxic vapours or inert gas should be gas-freed, and a gas-free certificate must be obtained from a competent person, before or immediately upon entry into a port for drydocking or repair. Such certification will be for personnel entry only. It will not imply, and it must not be assumed, that any spaces in the ship are necessarily safe for hot work.

Before commencing any hot work, the repair yard would normally be expected to take its own precautions and arrange for the issue of certificates allowing hotwork to be carried out. The master should satisfy himself that the system employed is satisfactory, and that the procedure for renewal of certificates is adequate.

### A4.2 SPECIAL CONSIDERATIONS

#### A4.2.1 *Cargo Tanks and Hold or Interbarrier Spaces*

The provisions of Chapter 6 should be fully considered before permission is given for entry into or work in an enclosed space.

Pockets of cargo vapour may have collected in interbarrier spaces or insulation and a competent person should be present to check for the presence of gas before work in such places begins. Cargo vapour trapped in insulation and interbarrier spaces may leak out over a period of time and it is therefore essential to ensure that adequate ventilation is provided and that the atmosphere is monitored regularly. Insulation spaces should be kept as dry and moisture-free as possible to prevent deterioration of the insulation.

Special attention should be paid to membrane systems when work is undertaken. Differential pressures should be maintained when ventilating interbarrier spaces. If work inside the tank is necessary, the membrane should be protected by liners of plywood or similar material, especially on the tank bottom. When the work has been completed and the liners have been removed, a careful inspection should be made to ensure that the membrane has not been ruptured or damaged.

Before cargo tanks and other enclosed spaces are closed up, careful checks should be made to ensure that all tools, equipment and debris have been removed, all fixtures are secure, and that contaminants such as rust or water have been removed. It should also be confirmed that valves, pumps, depth gauge floats etc. are free to operate.

#### A4.2.2 *Instruments*

Instruments and their controls, and sensing and sampling lines should be protected from mechanical damage. If necessary pressure gauges, thermometers and other delicate equipment should be removed and stored in a safe place during repair work.

Before recommissioning all the cargo system instruments and safety devices should be checked for integrity, operation, and calibration.

The ship's plans and specifications should be clearly amended to indicate any modification made to systems and circuitry, and any added wording should be understandable to those on board.

#### A4.2.3 *Hot Work During Repair Periods*

The implications of hot work and safety measures necessary will be governed by local regulations when such work is to be undertaken in port.

Hot work should not be permitted unless the immediate vicinity and adjacent compartments are certified gas-free. Hot work includes welding, burning, brazing, chipping, caulking and the use of gas torches to heat impellers, rotors etc. as an aid to other work.

Adequate ventilation should always be provided, and special care taken when hot work is to be undertaken near combustible materials, which should either be protected against heat or removed. Materials such as polyurethane used for tank insulation produce toxic and asphyxiating vapour if they catch fire. Hot work should not be carried out near such materials unless a qualified fireman is in attendance and suitable fire-fighting and escape apparatus is immediately available.

All equipment which is to be opened up for repair or maintenance should be checked internally for the presence of flammable or toxic vapours or inert gas, and should be purged if necessary before work proceeds.

Before hot work is undertaken, it should be recognised that stress relief may be necessary on completion of work before some materials can be used for their intended duty.

#### A4.2.4 Deck Storage Tanks

It is usually necessary to gas-free deck storage tanks before hot work can be commenced in the vicinity. However, if permission is granted for cargo liquid to be kept stored, the following precautions should be observed:

- all pipe connections to the cargo system should be disconnected and securely blanked;
- access to the immediate area of the tank should be restricted, barriers erected and warning notices clearly displayed;
- smoking and hot work should not be allowed in the restricted area;
- no work should be permitted on the tanks or their fittings;
- tank pipework and fittings should be protected from mechanical damage: particular care is necessary if cranes are being used nearby;
- fire-fighting equipment should be ready for immediate use: water sprays should be connected to a pressurised fire main;
- tank contents and tank pressures should be checked daily and any leaks rectified immediately.

### A4.3 RECOMMISSIONING

In addition to the provisions of Chapter 4 Section 3, all equipment and systems should be thoroughly checked for integrity, cleanliness, correct operation and accurate calibration, as appropriate, before recommissioning.

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# CARGO HANDLING PLANT AND EQUIPMENT

APPENDIX

### A5.1 GENERAL

The range of equipment that may be found in the cargo system of a gas carrier is outlined in this Appendix and the considerations necessary for safe and efficient operations are highlighted. For many years now, the cargo handling plant of a liquefied gas carrier has been conceived and set up as a complete system, in which all parts are necessarily compatible and complementary to each other. For specification details of any particular element, such as a pump, compressor or valve, reference must always be made to the system designer's manual or the component supplier's handbook. The general precautions to be observed during cargo operations are given in Chapters 4 and 5.

### A5.2 CARGO PUMPS

Reference should always be made to manufacturers' instruction manuals for the particular equipment fitted.

#### A5.2.1 Deepwell Pumps

These are single or multi-stage centrifugal pumps with deck mounted electric or hydraulic motors driving impellers near the tank bottom. The impeller casing is supported by the discharge tube which is flange-connected to the tank dome. The drive shaft runs inside the discharge tube and is lubricated by the cargo.

Particular attention is drawn to the following points:

- a) Before starting pumps, care should be taken to ensure that they are free to rotate, if possible by turning manually.
- b) Pumps should be started with discharge valves shut (or slightly open according to manufacturers' instructions) to reduce current demand by electric motors and pressure surge.
- c) If protection equipment is not operational or not fitted, care should be taken to ensure that pumps are not allowed to cavitate as lubrication would be lost and damage could occur.
- d) Flame-proof electric motors may only be drip-proof and it may be necessary to fit waterproof covers when not in use.
- e) If fitted, heaters should be used to maintain insulation resistance when a pump is not in service.
- f) Thrust bearings are susceptible to indentation (or 'brinelling') when pumps which are not operating are subjected to shipboard vibration, because of the heavy weight they have to support: when not in use the pump shaft should be rotated at frequent intervals to vary the surface area bearing the load.
- g) If necessary (and permissible, see paragraph 1.4.1), before pumping LPG an antifreeze should be injected to prevent freezing of any water collected in bearings, shaft sleeves, impellers etc; freezing could cause pumps to seize and electric motors to burn out. Ice-free operation is best achieved by use of dry inert gas to avoid moisture inside the tanks: antifreeze should be avoided if possible as excessive use will entail cargo claims.

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- h) When pumps have been overhauled, care should be taken to ensure that they are re-installed correctly: steadying devices must be correctly positioned to prevent movement from torsional reaction, and all fittings in the tank must be locked in position (e.g. with split pins, wires or lock washers).
- i) Shaft intermediate bearings are lubricated by the cargo, and passages in the bearing housing must be kept clear.
- j) Liquid seals at the upper end of the pump discharge tube must be kept in good condition to prevent cargo leakage, as well as leakage of the pressurising liquid into the cargo.
- k) Great care must be taken to ensure that local stop/start switches are properly maintained (see Appendix 7).

#### A5.2.2 Fixed Submerged Pumps

These are fixed combined pump and electric motor assemblies vertically mounted on a seating in the bottom of the tank. Power is supplied through copper or stainless steel sheathed cables which terminate in a junction box at the tank dome. Motors are normally fitted with low liquid level shutdown devices to prevent them running dry. For ammonia duty the cable and the motor are sheathed or 'canned' in stainless steel to prevent ammonia attacking copper components. This sheath is very thin, and great care has to be taken to avoid damage (e.g. never kink cables).

Particular attention is drawn to the following points:

- the precautions listed in points a), b), g) and k) of paragraph A5.2.1 should be observed;
- cables must be checked for insulation resistance before the pump is started;
- heaters should be used to prevent condensation when tanks are gas-freed: in some cases heat is provided by applying low voltage to two of the three supply phases and care is necessary to prevent all three being connected, especially if interlocks are not fitted, otherwise the pump will rotate at high speed with no lubrication;
- when reassembling pumps the discharge piping must be prevented from imposing stresses on the pump casing: fixing devices and cables must be locked in position;
- bearings are lubricated by the cargo so lubricating passages must be kept clear: filters (whether integral or separate) must be cleaned at every pump overhaul;
- in order to prevent ammonia attacking copper conductors, cable connections at the pump should be assembled using new compression washers and should be pressure or vacuum tested if possible;
- stainless steel sheathed cables should be checked for external defects (e.g. cracks, chafing): they must not be kinked and sharp bends must be avoided (see manufacturers' instructions);
- before the tank is closed down, the pump should be turned by hand to ensure freedom of rotation.

#### A5.2.3 Removable Submerged Pumps

These are similar to fixed submerged pumps but are located within a tube which acts as a support and discharge pipe and which has a foot valve so the pump can be removed while the tank still contains cargo. If the liquid and vapour contents of the tube are purged with inert gas the pump can be raised slightly to close the foot valve. The pump can then be removed in stages.

The precautions given in paragraph A5.2.2 should be observed. In addition manufacturers' instructions on installation and removal should be closely followed, especially if the tank contains cargo.

#### A5.2.4 Deck Mounted Pumps

These are normally horizontally mounted motor driven centrifugal pumps. They may be used as main pumps, booster pumps, heater supply pumps, or deck storage tank supply pumps.

Particular attention is drawn to the following points:

- the precautions listed in points a), b), c), d), g) and k) of paragraph A5.2.1 should be observed;
- the pump must be primed and, if necessary, cooled down before starting, and the cargo tank should be sufficiently pressurised to provide an adequate liquid suction head;

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- mechanical seals must be maintained in an efficient condition and, where a pressurising circuit is used, consumption of the pressurising medium should be noted to ensure that levels are maintained and that adequate sealing of the cargo liquid is achieved;
- motor-pump alignment must be correct to prevent coupling damage: all clearances and tolerances specified by the manufacturer should be observed;
- after pumps have been replaced, pipework alignment should be adjusted to avoid stressing the assembly: adjacent sliding feet should be free and lubricated;
- where fitted, gas-tight bulkhead seals must be maintained.

#### A5.2.5 Hold or Interbarrier Space Pumps

These pumps are installed for the removal of cargo liquid or ballast water that has leaked into a hold or interbarrier space. They may be submerged pumps (in which case the precautions given in A5.2.2 should be observed) or they may be ejectors working on the venturi principle; as the latter have no moving parts they require less maintenance. Motor driven pumps should be checked frequently for freedom of rotation; condensation may collect in bearings unless the atmosphere in the space is kept dry.

### A5.3 VAPOUR PUMPS AND COMPRESSORS

Reference should always be made to manufacturers' instruction manuals for the particular equipment fitted.



#### A5.3.1 *General*

A variety of types of vapour pumps and compressors may be encountered; the main ones are described in outline. They are used for cargo reliquefaction, vapour supply to and from shore, gas freeing, and (on LNG ships only) for vapour supply to the engine room. Such equipment is powered by hydraulic or electric motors, or steam turbines. The following general precautions should be taken:

- equipment should be operated within design limits and in compliance with any special conditions for individual cargoes;
- the electrical resistance of motors should be checked at regular intervals;
- motors in exposed positions should be protected when not in use: if fitted, heaters should be used;
- prescribed lubricants and coolants should be used according to the equipment and the cargo: it may be necessary to change lubricants after use with certain cargoes (e.g. ammonia, butadiene, or vinyl chloride);
- all materials of components, jointings, packings, diaphragms etc. should be compatible with the cargo;
- all associated fittings, alignments, provision for expansion or contraction, tolerances, piping and pipe supports, bulkhead seals, electrical equipment, monitoring and alarm equipment should be properly maintained, so as to be reliable and operational;
- when pressure testing pipeline systems, compressor crankcases should be isolated unless they can withstand the test pressure.

#### A5.3.2 *Reciprocating Compressors*

Two types may be found, conventional compressors and oil-free compressors. They are used mainly in reliquefaction plant for compression of refrigerant gases or cargo vapour. If used with refrigerants, the considerations applicable to normal refrigeration plant should be observed. If used with cargo vapour, special precautions may be necessary, depending on the cargo.

The following precautions apply in addition to those given in paragraph A5.3.1:

- if the compressor is fitted with capacity control, automatic unloading devices require careful routine maintenance;
- pressure-temperature switches should be checked and calibrated as a routine: the set points should be adjusted for certain cargoes (e.g. butadiene, vinyl chloride, or methylacetylene-propadiene gas) and reset to the normal maxima and minima for other cargoes;

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- suction valves should be opened slowly when starting as this will vaporise any liquid present by pressure reduction;
- pressure in cargo tanks and piping systems should not normally be reduced below atmospheric, in order to prevent the entry of air through leaks and the creation of flammable mixtures: if a vacuum is to be created for gas-freeing (see paragraph 4.6.4 and warning), the system in general and the shaft seal in particular should be checked for proper functioning before the operation begins;
- damage can be caused if liquids or solids enter the compressor, and therefore the performance of level switches in liquid separation equipment and suction filters should be carefully monitored.

Conventional compressors have a conventional pressurised crankcase and the cargo vapour comes into contact with the lubricating oil. Two additional precautions to be observed, therefore, are to ensure that oil separation equipment is working properly and kept clean, with oil levels being monitored; and to be aware that cargo vapour may condense in the crankcase and dilute the oil, requiring heaters, if fitted, to be used.

In oil-free compressors vapour and oil do not come into contact with each other and therefore cargo contamination is avoided. Two additional precautions to be observed are that cooling systems should be inhibited to prevent corrosion or freezing, and that crankcase cylinder assembly seals should be kept in good condition to prevent contamination between cargo and lubricating oil (usually mechanical seals which require careful maintenance).

#### A5.3.3 *Centrifugal Compressors*

These are normally single or multi-stage impellers driven at high speed by a steam turbine through a gearbox. They are often used on LNG ships for vapour supplies to the engine room or shore.

The following precautions should be observed in addition to those in paragraph A5.3.1:

- although compressors can be run against a closed discharge valve the practice, if prolonged, will lead to overheating and damage to insulation material.
- speed control equipment should be well maintained to prevent overspeeding in case of load reductions (speed controls work by sensing suction pressure (tank pressure) and adjusting speed by turbine throttles). Damage may be caused by compressor surge. When the rate of flow is reduced a momentary reversal of flow may occur which lowers the pressure in the discharge line. Normal compression then resumes and the cycle is repeated. This cycle can cause low period shock or high period vibration and lead to the complete destruction of the compressor.

Compressors are most vulnerable to surge when operating in parallel, when the need to balance flow rates is critical.

Automatic surge controls are normally fitted to keep the flow rate above the set point line, giving a factor of safety over the maximum operating limits. The differential pressure across the compressor is sensed, and when the set point is approached the discharge vapour is returned to the suction to prevent reversal. It is most important that surge controls function reliably. They should be recalibrated after maintenance according to manufacturers' instructions.

#### A5.3.4 *Rootes-ty-pe Compressors*

These are positive displacement machines with two mating lobe-shaped rotors. Compression ratios are

comparatively small giving a pressure increase of about 0.5 bar. The following precautions should be observed in addition to those in paragraph A5.3.1:

- clearances between moving parts and casings are very small and the passage of solids (e.g. rust or weld slag) or liquid will cause damage: filters and liquid separation equipment must be well maintained;
- if subjected to a pressure differential when stopped the rotors will turn: a non-return valve is usually fitted to prevent reverse rotation which could occur without lubrication: when compressors are stopped the suction and delivery valves should be closed;

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- compressors should never be run with the discharge valve shut, otherwise over-heating and mechanical failure could occur.

#### A5.3.5 Screw Compressors

These are positive displacement high speed compressors with mated screw rotors. The following precautions should be observed in addition to those in paragraph A5.3.1:

- filters must be kept in good condition because internal clearances are very fine and the passage of solids (e.g. rust or weld slag) will cause damage;
- liquids should not be allowed to pass through compressors designed to handle vapours only;
- compressors should not be operated with the discharge valve closed.

### A5.4 HEAT EXCHANGERS

Heat exchangers may be fitted for any of the following purposes:

- as vaporisers (for cargo or nitrogen liquid);
- as heaters (for liquid or vapour);
- as condensers (for cargo vapour or refrigerant gas);
- as driers (for inert gas, cargo vapour or compressed air);
- as intercoolers (in refrigeration plants);
- as coolers (for water or lubricating oil).

Reference should always be made to the manufacturers' instruction manuals for the particular equipment fitted.

Particular attention should be paid to the following points:

- hot or cold phase flow should be established in the correct sequence: many heat exchangers have special internal coating or bi-metal tubing which is easily damaged by temperatures only slightly different from normal operating temperatures: seawater heated cargo vaporisers can be blocked and damaged if excess cargo flow freezes the water;
- heat exchangers should be pressure tested or otherwise checked for leaks at regular intervals;
- instrumentation and associated equipment such as pressure and temperature switches, float controllers or relief valves should be functioning correctly;
- the sea water side should be kept clear: fouling will lead to loss of efficiency, leading to sub-cooling and freezing when used as a cargo heater, or overheating when used as a cooler.

### A5.5 RELIEF DEVICES

#### A5.5.1 General

The following devices may be fitted to allow the release of liquid or vapour when pressure rises above a pre-set level:

- spring loaded relief valves
- pilot operated relief valves
- # deadweight relief devices
- # bursting discs.

#### A5.5.2 Cargo Relief Devices

The following general precautions should be observed:

- both sides of any relief device should be kept free from obstructions. Water, oil or polymers should not be allowed to collect against them: the set point of low pressure valves such as are fitted to atmospheric pressure cargo tanks can be affected by even a small head of water, or a discharge of cold vapour from the valve can freeze the water and cause a blockage: a means of drainage is usually provided which should be kept clear and used frequently;

# if valves have more than one setting, changes should be made under the supervision of the master and in accordance with specified procedures: changes should be recorded in the ship's log and a notice posted at the valve and in the cargo control room stating the set pressure;

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- relief valves should never be used as control valves by temporarily altering the set point;
- if it is possible to open or close valves manually, personnel should be familiar with the action to be taken if a valve is seized in either the open or closed setting: manual operating mechanism should be kept clean, lubricated and free from paint or rust;
- discharge piping should never be left disconnected, and no piping should impose stress on the body of a valve;
- jointing, gland packing and diaphragm materials should be compatible with the cargo, and any spares used should be checked for compatibility;
- relief valve set pressure may be affected by the use of incorrect thickness jointing material;
- routine checks should be made of set points, blow-down characteristics and tightness of sealing: only good quality, accurate gauges should be used.

Spring-loaded and pilot operated relief valves are precision made devices often having small delicate components

(e.g. needle valve or thin spindles) and care should be taken to prevent damage at all times. The following precautions should be observed:

- if dismantling is necessary, there should be no interference between moving parts on reassembly; 9 small bore pipes, passages and sensing connections should be clear and unobstructed;
- 9 all joints, external sensing pipework etc. should be leak-tight to ensure operation at the correct pressure and to prevent cargo leakage;
- all setting devices should be securely locked in position and sealed to prevent alteration by vibration, shock or tampering.

#### A5.5.3 Void Space Relief Devices

Deadweight relief devices do not normally form part of the cargo system but may be used to protect the hold space and cargo tanks.

Bursting discs require the following precautions to be observed:

- discs should be inspected frequently for deterioration or corrosion which may affect the bursting pressure: the disc material should be compatible with anything with which it will be in contact;
- 9 if the disc is domed the concavity should be on the pressure side;
- 9 gaskets should be fitted on both sides of the disc but should not reduce its effective diameter.

If a disc fractures:

- 9 the cause should be investigated;
- 9 the system should be inspected for debris particles, and any that are found should be removed;
- 9 a replacement disc, checked for correct set pressure and compatibility specification, should be fitted carefully.

### A5.6 VALVES

All valves in the cargo system should be treated as precision equipment. They should be regularly inspected and maintained to ensure safe and efficient operation, observing the following precautions:

9 valves should only be operated by the responsible officer or under his direct supervision: every effort should be made to avoid pressure surges (see paragraph 4.5.2);

9 during cargo transfer no valve which affects the flow of cargo liquid or vapour to or from shore should be operated except under the direction of the responsible officer, and then only after shore personnel have been informed;

9 portable handles should be readily available near all valves which can be manually operated

in an emergency;

9 control valves should be checked frequently for correct operation over their entire range, and only good quality, calibrated equipment should be used to simulate pressure or temperature signals: valves should be locked at correct settings to resist tampering or the effects of vibration;

9 actuating systems, whether remote or local, should be kept free to operate;

9 leaks from joints or glands should be repaired as soon as possible: leakages can be suppressed temporarily using a wet bandage;

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# pneumatic signal lines to actuators should be leak-tight, and air supplies should be dry and oil-free;

# ball and gate valve body cavities are normally provided with some means of pressure relief if used with cargoes below -50 °C because the PTFE seats then become rigid and cannot flex to relieve pressure: either a hole is drilled between the cavity and one side of the valve, or a pressure relief valve is fitted: such arrangements should be kept clear and in good working order;

# when valves are removed for maintenance, the flanges should be blanked or joined with a spool piece, using a suitable material: the removal of a valve should be noted in the cargo handling log and all operators informed: a notice should be posted at the control position, and the activating controls should be isolated or taped over: if hydraulic or pneumatic signal lines are disconnected, they should also be blanked to prevent false alarms or shutdowns and loss of hydraulic fluid;

# materials used in maintenance should be compatible with the cargo;

# before a valve is replaced, it should be thoroughly dried to prevent ice or hydrate formation, and if necessary (and permissible, see paragraph 1.4.1), a small quantity of anti-freeze should be left in the valve body: particular attention must be paid to valves in the cargo tank (centreline bulkhead valves, foot valves etc.), which are only accessible after the tank has been warmed up and gas-freed;

# after signal lines are replaced, they should be carefully checked for cross or reverse connection before cargo service;

# non-return valves may be fitted to prevent reverse flow into compressors, pumps etc. and to prevent the back-flow of cargo vapours along inert gas lines to machinery spaces: it is particularly important to ensure that the seals of these valves are kept clean and undamaged: if there is a risk of cross-contamination it is normal to have two valves in series: a non return valve, even if duplicated, should never be considered to be gas-tight.

### A5.7 FILTERS AND STRAINERS

Many types of filters may be fitted (gauze, mesh, felt, sintered metal or ceramic) but the correct operation of any filter depends on good maintenance. Filters should be kept working correctly to protect plant and equipment from contaminants; gradual blocking will affect performance and operating conditions, and may lead to damage to other equipment.

Some filters can be fitted the wrong way round. For instance, if this is done with conical filters in ship-shore connections, the filter can collapse and block the line.

Gauges for differential pressure across a filter and alarms or switches should be properly maintained, and monitored during operations.

Where the risk of corrosion exists, filter baskets should be inspected frequently. Systems should never be operated with filter elements removed.

#### **A5.8 EXPANSION BELLOWS**

Bellows may be used to accommodate thermal contraction and expansion in a number of applications including:

- in pipework systems to accommodate lateral and axial movement;
- 9 in heat exchangers a bellows may be put in the shell to accommodate tube expansion and contraction, or there may be bellows in both the shell and tube sides;
- in bulkhead seals for sealing pipes or drive shafts;
- in valve spindle seats instead of the traditional gland seal to provide a more leak-proof assembly;
- in automatic controls to accommodate movement without loss of pressure, for example in pneumatic control equipment.

If used properly, bellows pieces are very durable, but they are vulnerable to misuse and for this reason expansion loops and offsets may be used instead. If bellows are intended to be fitted, the design will take careful account of pressure, temperature, diameters, pipe layout and movements. All associated parts such as anchor-points, supports etc., are vital to safe operation within design limits.

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The following precautions should be observed:

- bellows should never be subjected to unnecessary shocks such as pressure surge;
- every effort should be made to protect bellows from internal and external damage: personnel should not stand on or mishandle bellows units;
- for low temperature service, a flexible sleeve may be fitted to protect the unit from excessive ice build-up: such sleeves should not be permanently removed;
- the design efficiency of anchor-points, supports, guides or constraints should be maintained: their operation should never be impaired, for example by incomplete re-assembly, change of position, misalignment of pipework, or any other action which would place stress on the unit for which it was not designed;
- bellows should be inspected regularly for cracks, corrosion, cleanliness etc.;
- before replacement units are installed, it should be determined whether pre-compression or extension is necessary;
- when bellows are stored they should be properly protected against over-extension, compression, misalignment and mechanical damage;
- when pressure tests are carried out, bellows should be prevented from extending beyond design limits in order to avoid damage or possible bellows failure;
- temporary tie-bars or constraints should be removed before cargo service and replaced with normal constraints.

#### **A 5.9 VENT AND PURGE MASTS**

Discharges from relief valves and purging systems are carried to the atmosphere through vent masts, the outlets of which are designed to promote vapour dispersal and reduce the risk of flammable mixtures being produced.

Vents are likely to collect water and should be drained frequently to guard against freezing due to the discharge of cold vapour. Drains should never be left open, otherwise vapour could be discharged at low level. Some vent masts have provision to extinguish (snuff out) flames resulting from a lightning strike, normally a remotely operated flap and a connection for the injection of CO<sub>2</sub> or inert gas.

Cargo liquid should never be vented through vent masts as this could over-pressurise the system. A spillage of liquid could also endanger personnel or cause brittle fracture of the ship's structure. Particular care is required when operating reliquefaction plant; seized expansion valves or level controllers can cause a condenser to flood, forcing open the purge valves and spilling liquid. Plant operating conditions should be carefully monitored at all times.

#### **A5.10 PIPELINE SUPPORTS**

Pipeline supports may be of a number of designs. They provide secure mountings which support pipework and prevent transverse movement, but will ensure correct alignment and, at the same time, permit expansion and contraction of pipes without imposing stress.

All supports or anchor points should be correctly assembled, and securing devices locked. Some designs require bolts to be fully tightened but in others clearance is provided: the arrangement should be checked before reassembly. If relative movement is to be provided, all moving surfaces should be clean and, if necessary, lubricated.

In some designs, pipework may be supported by load-bearing insulating chocks; the correct type of material should be used and pieces found to be missing should be replaced to prevent transverse movement and damage.

If the system or part of it is being pressure tested, special care is necessary to ensure that adequate support is given, and that any side forces or couples which may be created are controlled. Sudden pressurisation or depressurisation of the system should be avoided.

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#### **A5.11 HOSES**

The cargo hose is the weakest link in the cargo transfer system and should be treated with great care. If the appearance of shore hoses gives cause for concern, the master should ask to see the relevant certificates.

The precautions to be observed for the handling, storing and inspection of ships' hoses are given in paragraph 5.3.11.

#### **A5.12 INSULATION**

Insulation materials intended for use with cold cargoes are easily damaged by high temperatures. All insulation should be protected against deterioration or mechanical damage in order to preserve the integrity of the ship's structure and, at the same time, prevent a level of cargo boil-off which could exceed plant capacity. Insulation boundaries should be adequately vapour/water sealed to prevent corrosion of the adjoining material. The sealing should be inspected periodically. During maintenance, care should be taken to exclude moisture which may be absorbed by the insulation and reduce its effectiveness. Occasionally repairs to insulation may be required. Insulation materials should be regarded as flammable, and protected from flames or sparks, with proper fire fighting precautions taken. The material may also be toxic and personnel working with it may therefore require protection. Adequate ventilation during work should be provided.

#### **A5.13 INERT GAS SYSTEMS**

Atmospheric air contains about 21% oxygen and 78% nitrogen. To produce inert gas the oxygen content has to be removed or reduced considerably. Inert gas may be generated on board by controlled combustion of fuel oil, but will contain some free oxygen, carbon monoxide, carbon dioxide, nitrogen oxides and nitrogen. It may not be sufficiently pure for use with certain cargoes. The inert gas has to be water-scrubbed to remove soot and other products of combustion, and then dried before use. The fuel used in the plant must be of a high quality to reduce impurities (e.g. sulphur) in the inert gas produced. See paragraph 5.3.12 for operation of an inert gas plant. Alternatively, inert gas from shore (usually liquid nitrogen) may be stored on board in vacuum insulated vessels (see paragraph 5.3.13).

A recent trend is for ships to be provided with the means to produce nitrogen gas on board by physical separation from the atmosphere, using the pressure-swing absorption method or the membrane method. Nitrogen produced this way remains gaseous throughout. Ship's personnel should be aware that the exhaust from the plant is oxygen-rich, and be fully alert to the increased flammability hazard which this presents.

#### **A5.14 SCRUBBERS**

Scrubbers are used to remove contaminants from a gaseous mixture. The most common application is the removal of sulphur dioxide and solid combustion products from inert gas. The scrubbing medium is seawater, and the scrubber may contain coke beds or ceramic pall rings to increase the reaction surface. When using scrubbers the following precautions should be observed:

- # water should be flowing before the gas flow is started to prevent over-heating or damage to internal anti-corrosion coatings;
  - internal packing beds should be kept clean and should be checked for dislodged rings which could block drains;
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- packings should be removed and reinstalled or replaced periodically to prevent compaction and pulverisation;
- internal components should be inspected regularly for corrosion and security of fixing;
- fouling of components in the flow path will cause a large pressure drop across the unit;
- if used to dissolve ammonia, the gas flow should be opened slowly to prevent violent mixing and the formation of a vacuum (see paragraph 4.14.5);
- water flow rate should be controlled within design limits: excessive flow will cause flooding, and carry-over may cause ice or hydrate formation in a low temperature part of the system;
- associated refrigeration coolers should be adjusted to produce vapour with the required dew point: coolers will be overloaded by excessive water carry-over.

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## **INSTRUMENTATION**



#### **A6.1 GENERAL**

A wide range of instrumentation may be fitted on a modern liquefied gas carrier. Only an outline is given in this Appendix, providing guidance on the safe and efficient operation of the equipment.

#### **A6.2 LIQUID LEVEL GAUGES**

##### *A6.2.1 General*

Level gauges are important because cargo systems on gas carriers are closed, and levels cannot be sounded. Gauges are fitted to cargo tanks, deck storage tanks and reliquefaction systems. High level alarms are fitted to give warning before a tank becomes full, and shutdown systems are fitted to prevent cargo over-filling a tank. If the cargo pump is submerged there is usually a low level shutdown system to prevent the pump running dry. The accuracy required of gas carrier level gauges is high because of the nature and value of the cargo; hence the gauges are generally sophisticated and require careful maintenance.

The type of level gauge required by the IMO Codes for a particular cargo is indicated on the data sheets in

Appendix<sup>1</sup>. The gauges described below are all of the closed or indirect types, except for fixed or slip tubes which are of the restricted type.

#### A6.2.2 *Float Gauges*

These consist of a float which rises vertically on the liquid. It is attached by a tape to an indicating device for local reading, with provision for a drive mechanism for remote read-out.

Particular attention is drawn to the following:

- floats should be secured when at sea except briefly during measurement of tank contents: if the float remains unsecured at sea it will almost certainly be damaged due to sloshing of the cargo;
- remote and local readings should be compared frequently to determine discrepancies: correction tables are normally provided to allow for tape and tank expansion or contraction, and ship trim and heel: the corrections should be applied to readings;
- tapes should be checked regularly for free vertical movement of the float, and if damaged, should be replaced: particular care is necessary with the rewind mechanisms which are carefully balanced: if obstructed the gauge readings will be inaccurate;
- when tapes are renewed, or a gauge reassembled after maintenance, allowance should be made for the level at which the float begins to lift: this will depend upon the cargo density which determines the depth to which the float is immersed: manufacturers' instructions should be consulted;
- parts should be securely locked in position; special care is necessary with tape-to-float and tape-to-reel attachments.

#### A6.2.3 *Slip-Tube and Fixed Tube Gauges*

These gauges can be used for pressure vessels. The tube penetrates the tank and has a valve at the top: when the valve is opened, a restricted amount of cargo is emitted. If the open end of the tube is in the cargo vapour phase, vapour comes from the valve: if it is in the cargo liquid phase a fine spray is emitted.

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Three types of tube gauge may be fitted:

- a fixed tube which indicates that the liquid has reached a certain level;
- a calibrated pipe which can be raised or lowered vertically through a gland to determine the liquid level: this pipe is called a 'slip-tube';
- a curved pipe at one end of a cylindrical tank mounted on the tank's axis: the pipe can be rotated and the liquid level is indicated on a circular scale on the tank.

These simple instruments are easy to use and require the minimum of maintenance. The following precautions should be observed:

- sources of ignition should be excluded from the area;
- spray from the valve should be directed away from personnel and protective clothing should be worn;
- pressure in the tank may cause a slip-tube to be pressed up with great force: personnel should not stand directly in the path of the tube: there should be a stopper to prevent the tube from being pressed out completely;
- expansion of gas through the valve can cause freezing: it may therefore be necessary to use an anti-freeze to prevent this or to free the valve;
- screw threads and gland packings should be inspected, and repaired or replaced if there are signs of deterioration;
- valves should be protected from damage, and care taken to avoid the orifice becoming blocked by paint, salt, rust etc.

#### A6.2.4 *Nitrogen Bubbler Gauge*

This type of gauge measures the pressure necessary to displace the cargo liquid from a small-bore sensing pipe mounted in the tank. Initially, the level of the liquid in the pipe will match the level of liquid in the cargo tank. Nitrogen is introduced into the pipe at an increasing pressure until just sufficient to displace the liquid, which is indicated by bubbles of nitrogen escaping (hence the name). Since the pressure required is related to the cargo density and the liquid level, if the cargo density is known, the liquid level can be calculated directly. If the cargo density is not known, then it is possible first to determine this from pressure difference if two gauges are fitted, one at the bottom of the tank and one at a known height above it.

The gas flow rate in the system should be kept low to avoid back pressure which would give inaccurate readings. Any leak in the sensing pipes will cause inaccuracy and therefore all joints and glands should be checked frequently.

#### A6.2.5 *Capacitance Probe*

This type of gauge employs a fixed electronic sensor, electrically insulated from the tank, which detects the change in capacitance (or dielectric constant) between vapour and liquid. The readout is normally by means of a digital or lamp display. It is possible to use a probe extending the whole depth of the tank or a number of probes at different levels.

Capacitance probes have no moving parts and are very simple; however care should be taken to ensure that probes are kept clean, as dirt, rust or ice will cause inaccurate readings. Water must be kept out of the probe and the electrical circuits, as water has a very high dielectric constant compared with most cargoes and the slightest trace will cause inaccuracy.

#### A6.2.6 *Ultrasonic Gauges*

These work on the same principle as an echo sounder; sound waves are transmitted from the top of the tank and the time taken for them to be reflected back is measured.

An accurate determination of density is essential at the time the gauge is to be used, as changes in density of the

cargo liquid or of the vapour space can seriously affect the accuracy of this type of gauge. Particular care is necessary to protect the delicate transmitters and receivers, and in the calibration of this type of gauge.

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### **A6.3 LEVEL ALARMS AND AUTOMATIC SHUTDOWN SYSTEMS**

High and low level alarms and automatic shutdown systems may be required depending on the cargo system. These systems may be activated by floats operating a switch device, capacitance probes, ultrasonic or radioactive sources, pump motor current or temperature sensitive devices.

Whatever system is used the set point may be affected by the properties of the cargo (e.g. density or dielectric constant), and adjustments should be made in accordance with the manufacturers' instructions.

Automatic shutdown systems require particular care. They are normally designed to shut the main cargo tank filling valve if the liquid level rises above the maximum level permitted by the IMO Codes. Great care should be taken to ensure that the activation point is set accurately, and that the operation of the device is checked by simulation whenever the system is recommissioned. If the ship and shore shutdown circuits can be linked their operation should be checked before cargo transfer begins; if not, the terminal should be informed of the closing rate of the ship's valves. See Appendix 8 (pressure surge).

### **A6.4 PRESSURE INDICATING DEVICES**

#### *A.6.4.1 General*

Pressure gauges are fitted at various points in the cargo system, in accordance with the requirements of the IMO Codes. They may be used to indicate tank pressures, hold or interbarrier space pressures, or compressor discharge pressures. Pressure gauges can be linked to shutdown or alarm systems.

It is important that gauges are calibrated regularly. *A6.4.2 Bourdon Tubes*

These instruments measure pressure by movement of a coiled or helical tube, the amount being directly proportional to the applied pressure. The movement is used to drive a pointer for local readings, or to control a gas pressure valve or alter a variable resistance to serve indirect readings. Indirect readings may be necessary to avoid direct connection between safe and dangerous areas.

The following precautions should be observed:

- the indicator should be periodically checked for zero calibration;
- the gauge should not be used beyond 75% of its maximum reading if the pressure is steady, or 60% if it is fluctuating;
- Bourdon tubes may be damaged by vibration or by excessive pressure pulsations; the latter can be eliminated by the use of a flow restrictor.

#### *A6.4.3 General Precautions*

The following precautions should be observed with all pressure sensing equipment:

- materials of construction should be compatible with the cargo (e.g. copper or brass cannot be used with ammonia);
- before measurements are taken all valves in the direct line should be opened and all cross-connections shut;
- no pressure gauge should be subjected to violent pressure change;
- calibration should be regularly checked with accurate test equipment;
- in ships carrying cargoes which can form polymers (e.g. butadiene) it may be necessary to flush gauge lines and sensor chambers;
- if sensor lines are temporarily disconnected during maintenance they should be blanked.

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### **A6.5 TEMPERATURE MONITORING EQUIPMENT**

#### *A6.5.1 General*

Temperature sensors are fitted so that the temperatures of both the cargo and the structure around the cargo system can be monitored, and also to meet the requirements of the IMO gas carrier codes. It is important to know the cargo temperature in order to be able to calculate the amount of cargo on board, and because tanks have a minimum temperature below which they should not be cooled. For all LNG carriers and for other ships intended for the carriage of cargoes at temperatures below -55 °C the temperature of the steel around the cargo tanks has to be monitored to detect any lowering of hull steel temperature resulting from insulation failure.

It is also very important to be able to monitor temperatures in the cargo system during cool-down and warm-up operations to ensure that unsafe thermal stresses are avoided.

#### *A6.5.2 Liquid-vapour Thermometers*

These instruments rely on the expansion or contraction of liquid in a very fine-bore calibrated tube or capillary. The liquids most commonly used are mercury, ethanol or xylene; mercury thermometers should not be used with ammonia cargoes.

It is important to ensure that the liquid column in the instrument is continuous, otherwise the reading will be inaccurate.

#### *A6.5.3 Liquid-filled Thermometers*

These instruments have a metal bulb containing a fluid which changes volume with temperature change. The changes are transmitted via capillary tubing to an indicator or recorder. The system is sealed under considerable pressure to overcome the effects of vapour pressure from the liquid.

Mercury filled thermometers should not be used with aluminium and certain other materials. *A6.5.4 Bi-metallic*

### *Thermometers*

Two metals with different co-efficients of expansion are welded together to form a bi-metallic strip which, when heated, will bend because of the unequal expansion. The flexing movement can be used to drive a pointer in a similar manner to the Bourdon tube.

Bi-metallic thermometers may be affected by vibration and should be installed in positions which will avoid this effect.

#### *A6.5.5 Thermocouples*

Heat applied to the junction of two dissimilar metals will generate a very small voltage which can be measured and thereby indicate an increase in temperature. Normally the voltage is sensed electronically and the read-out is remote.

#### *A6.5.6 Resistance Thermometers*

The electrical resistance of certain materials changes with temperature, and can be measured to indicate temperature. The material normally used in resistance thermometers is fine platinum wire. Its resistance is measured by means of an electrical resistance bridge which can be connected to an indicator or recorder, normally by electronic means; the read-out is remote.

#### *A6.5.7 General Precautions*

The following precautions should be observed with all temperature indicating devices:

- the thermometers used should be suitable for the complete range of temperatures expected (e.g. metals may become brittle or liquids freeze at low temperatures);
- the sensor should make good thermal contact with the material whose temperature is to be measured;

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- if readings do not change when expected, the instrument should be checked;
- thermometers, especially those with capillary tubes, are easily damaged: they should be handled with care and protected from mechanical damage and extremes of temperature beyond their scales, otherwise they may become inaccurate;
- when a thermometer is removed from its working location, care should be taken to avoid loosening or removing its pocket, especially if the system is pressurised;
- when a thermometer is fitted in a working location, care should be taken that it does not bottom in the pocket when screwed in as this could cause damage: if the bulb is slack in the pocket a material with high thermal conductivity (e.g. a suitable lubricating oil) can be used to ensure accurate readings;
- electrical connections should be clean, tight and correct: care should be taken to see that intrinsically safe leads are not cross-connected with ordinary power sources.

## **A6.6 PRESSURE AND TEMPERATURE SWITCHES**

These devices are fitted to protect personnel and equipment by triggering an audible alarm or operating shutdown equipment. Manufacturers' operating and maintenance procedures should be followed, together with the following general precautions:

- the device should be correctly calibrated over its full range using accurate test instruments;
- if the set point of the device is fixed, it should be locked to prevent disturbance from vibration or tampering;
- if the set point is adjustable, no changes should be made unless the full implications are understood and other operators are advised: adjustments should be made under the direction of a responsible officer and in accordance with the cargo carried;
- if shut-off cocks are fitted, they should be open during normal operations: no additional shut-off cocks should be fitted.

## **A6.7 VAPOUR DETECTION EQUIPMENT**

### *A6.7.1 General*

The provision and use of vapour detection equipment is required by the IMO Codes for a number of functions, including:

- detecting cargo vapour in air, inert gas or the vapour of another cargo;
- measuring concentrations of gas in or near the flammable range;
- measuring concentrations of oxygen in inert gas or cargo vapour, or in enclosed spaces.

Personnel should fully understand the purpose and limitations of vapour detection equipment, whether fixed or portable.

### *A6.7.2 Infra-red Detectors*

Gases absorb infra-red radiation, and this property is used in fixed equipment to detect gas in concentrations over the full range 0-100%.

Infra-red radiation is passed through two tubes, one containing a known concentration of gas, the other containing the sample to be measured. The extent of absorption is in proportion to the gas concentration, and the output from the two tubes is compared electronically. The electronic signal can be used to drive an indicating meter, a pen recorder or other equipment. Calibration of the instrument is set for each gas to be measured.

### *A6.7.3 Thermal Conductivity Meters*

Some gas detectors work by measuring thermal conductivity of samples. They are called thermal conductivity meters or 'catharometers', and can be used to detect concentrations of gas from 0-100%.

When power is applied to a heater filament used as the sensing element its temperature stabilises at a value depending on the thermal conductivity of the gas around it. Any variation in the

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concentration of the gas affects the filament temperature, resulting in a change in electrical resistance which is indicated by a meter.

The filament may be mounted so that the sampled gas flows directly over it or diffuses into it. The direct-flow type responds more quickly to concentration changes but is dependent on flow rates; the diffusion type gives a slower response but is not flow sensitive. It is important to note that almost any change in operating conditions (e.g. filament voltage or gas flow rate) will alter the filament temperature.

A thermal conductivity meter can be set to detect cargo vapour mixed with inert gas. The meter must be calibrated to suit the gas being tested for, and therefore separate instruments are usually held on board for use with different gases.

Reference must be made to manufacturers instructions before every occasion of use.

**Note: The roles of thermal conductivity meter and combustible gas detector (see below) can be combined into one instrument, although the two functions - measuring concentration of vapour and percentage of LFL respectively - remain distinct.**

#### A6.7.4 Combustible Gas Detectors

This type of equipment can be used to detect certain combustible hydrocarbon gases. The principle is similar to that of the thermal conductivity meter with a head filament of a special metal to oxidise the gas catalytically, but the filament temperatures are higher and the concentration range lower (usually 0-100% LFL). The equipment works by resistance measurement and can be fixed or portable.

The filament can easily be de-activated by materials such as silicones, halogenated gases, acids, water, oil and lead. Filters may be required in the sample lines.

Calibration may be affected by the vapour sampled, and if different from that used for calibration, an appropriate conversion factor should be used. The equipment needs oxygen to operate, and can only detect combustible gas in air atmospheres, not inerted atmospheres. (If an inert gas/cargo vapour mixture has to be tested, either an infra-red or thermal conductivity meter must be used, or a sample must be mixed with air before a combustible gas detector can be used.)

Portable combustible gas detectors are frequently used to check atmospheres. When used for this purpose, the following precautions should be observed:

- readings should be taken by or under the supervision of a responsible officer who should be satisfied that the instrument readings are correct, and are accurately interpreted, before allowing the safety of personnel to depend upon them;
- the responsible officer should ensure that the calibration is correct;
- # readings will be inaccurate if inert gas is present in the sample;
- # readings will not be sufficiently accurate to indicate a safe atmosphere if the vapour concerned is toxic: in such cases a different type of instrument should be used;
- readings should be taken from the top or bottom of a space depending on the vapour density of the cargo;
- # in using the instrument every reaction of the meter is important, and not just the final resting position: the **first** movement indicates the presence of combustible vapour, the **final** rest position gives a calibrated reading of the vapour concentration expressed as percentage LFL:

a **final** rest position within the scale indicates a gas concentration below LFL, expressed as a percentage of LFL; a **final** rest position beyond 100% LFL indicates a concentration within the flammable range; a needle movement first above 100% LFL and then to a final rest position of zero indicates a concentration above UFL.

It is therefore strongly recommended that when a space is being checked the responsible officer should not be satisfied that an atmosphere is safe until consistent zero readings are obtained.

Fixed gas detectors working on this principle have the same limitations as portable ones.

In some ships the fixed gas detection equipment may use combustible gas indicators for reading from 0-100% LFL and thermal conductivity or infra-red detectors for LFL-100% gas concentration.

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#### A6.7.5 Chemical Absorption Indicators

These instruments normally function by drawing a sample of vapour through a chemical reagent in a glass tube. The detecting reagent becomes progressively discoloured if vapour is present and the length of discoloration - which can be read from the tube or from a graduated scale - gives a measure of vapour concentration.

Chemical absorption indicators give an accurate indication of vapour concentration whatever the oxygen content of the mixture.

It is important that the correct volume of sample, according to the manufacturer's instructions, is passed through the indicator, otherwise the measurement will not be accurate. Too small a sample volume will give a low value.

With some instruments the length of hose is a critical factor in obtaining a correct reading.

The presence of a 'second' gas may affect readings and cause inaccuracies. Chemical detector tubes are specific for particular gases or vapours, which need not have flammable or combustible properties. The tubes are designed to measure low vapour concentrations accurately. They should always be used when the cargo vapour presents a serious inhalation hazard, e.g. ammonia or vinyl chloride.

#### A6.7.6 Oxygen Analysers

There are several types of oxygen analysers; some are chemical absorption indicators using special tubes, others use chemicals to dissolve oxygen from a sample and yet others rely on the paramagnetic property of oxygen.

If detector tubes are used the readings may be affected by the presence of chemical vapours. An indicator which may be reliable for measuring the oxygen content of a space after thorough ventilation may not be suitable for

checking the oxygen content of an air/inert gas/cargo vapour mixture. Manufacturers' instructions should be observed.

Paramagnetic instruments measure the deflection of a magnet pivoted in a symmetrical non-uniform magnetic field; the magnet is in a sealed chamber into which the gas sample is introduced. The deflection is directly proportional to oxygen concentration. Some other gases, notably oxides of nitrogen, have comparable paramagnetic properties; therefore this technique cannot be used if such gases may be present in other than trace amounts. These instruments can be used for detecting oxygen in mixtures of other vapours.

In liquid absorption instruments a sample of known volume is passed through the absorbing liquid and the final volume is measured on a scale which indicates the oxygen content of the original sample.

The use of oxygen detectors for checking the atmosphere in enclosed spaces is discussed in Chapter 6.

#### *A6.7.7 General Precautions*

Vapour detection is a means of measuring vapour concentrations, and great care is necessary to ensure that the readings are accurate, especially when the lives of personnel depend upon them. The following precautions should be observed:

- the maker's handbook should be studied before use or for calibration purposes;
- zero points should be checked regularly and reset if necessary before the instrument is calibrated: great care should be taken to ensure that the sample is free from any gas that will give a reading when the zero is set: pure nitrogen should be used if possible.
- the instrument should be calibrated frequently throughout its operating range: the concentration and composition of the gas used for calibration (span gas) should be accurately known: calibration may 'drift' in as little as one hour in some cases: re-calibration should be recorded on or near the instrument;
- when oxygen detectors are calibrated it is essential to use clean and uncontaminated air;
- the same precautions must be observed when handling span gas which is toxic or flammable as would apply if the gas were carried as cargo;

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- tubes or liquids for equipment using the chemical absorption or reaction principles have a limited life with an expiry date: they should be replaced before expiry, otherwise readings will be inaccurate;
- all sample lines should be clean, unobstructed, leak-tight and connected to the correct point;
- if upper or lower sample points are provided (for lighter- or heavier-than-air cargoes respectively) the correct position should be used for the cargo carried and care should be taken to change sample points when changing cargoes if this is necessary;
- care should be taken when using portable equipment: even on an open deck personnel have been overcome because of oxygen deficiency caused by inert gas from a sampling point;
- portable sensing equipment should not be used in a flammable atmosphere, other than in a certified safe enclosure;
- pumps, filters, flame screens and other components of the system should be well maintained to ensure accurate readings;
- catalytic filament elements may be de-activated if exposed to water or oil vapour (see paragraph A6.7.4);
- remote and local read-outs should be compared to ensure accuracy;
- calibration of most fixed instruments depends on flow rate, and fluctuations can cause inaccuracy; flows should be kept steady and flows from each point should be balanced;
- the battery voltage of portable instruments should be checked frequently to ensure an instrument will provide accurate readings.

### **A6.8 EQUIPMENT ALARM AND SHUTDOWN CIRCUITS**

The designs and purposes of these circuits vary widely; they may be pneumatic, hydraulic, electrical or electronic. Safe operation of plant and systems depends on the correct operation of these circuits and the following precautions should be observed:

- # where provided, test facilities should be used before cargo operations commence, to check that the circuits and their alarms are operating: any instrument fault revealed should be rectified;
- # wiring inside and outside cabinets should be checked for chafing, condensation, insulation deterioration, bad connections etc.;
- # watchkeepers should be instructed how to distinguish between each audible alarm and what action is necessary;
- # the accuracy of all inputs to alarm circuits should be checked;
- # if an alarm is activated, the cause must be investigated and the necessary remedial action taken.

### **A6.9 INSTRUMENT AND CONTROL AIR SUPPLIES**

Air supplies used for instrument operation and control systems should be leak-tight, and filters and dryers should be checked frequently. Water is a common contaminant leading to corrosion and equipment malfunction; lubricating oil can also cause problems. Both should be drained off regularly.

### **A6.10 FLAME FAILURE DEVICES ON INERT GAS GENERATORS**

This type of equipment is extremely sensitive and should be treated with caution. Any adjustments contemplated should be in complete accordance with manufacturers' instructions.

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## **ELECTRICAL EQUIPMENT IN HAZARDOUS**

# AREAS



## A7.1 ELECTRICAL EQUIPMENT AND REGULATIONS

The electrical installations on gas carriers are subject to the requirements of the flag administration, classification societies, IMO and the International Electrotechnical Commission (IEC). Part of the purpose of these requirements is to minimise the risk of explosion and fire.

Areas and spaces are classified as 'gas safe' or 'gas dangerous', depending on the risk of cargo vapour being present.

Electrical equipment in a place regarded as dangerous has to be of special construction, and certified safe. Portable equipment taken into the area should also be certified safe (see paragraph 3.5.2).

## A7.2 CERTIFIED SAFE ELECTRICAL EQUIPMENT

The types of equipment recognised as safe for dangerous areas fall into the categories described below.

### A7.2.1 *Intrinsically Safe Equipment*

Intrinsically safe equipment relies on low power circuits to limit the maximum energy available to less than that necessary to ignite a flammable mixture under normal and certain fault conditions.

The use of intrinsically safe systems is limited to instrumentation, control and alarm systems because of the very low energy levels to which they are restricted.

### A7.2.2 *Explosion Proof/Flame Proof Equipment*

The equipment is designed with air gaps ('flamepaths')/ between covers or removable parts and the enclosure, closely controlled and so narrow that, if ignition occurred in the equipment, the resulting hot gases or flame would emerge at such velocities that surrounding flammable gas would not be ignited by the explosion. The concept is applicable to motors, junction boxes, circuit breakers and a wide range of other equipment. A certificate for the integrity of the equipment is issued after laboratory testing.

Care is essential in the maintenance and re-assembly of this type of equipment to ensure that the design features are not destroyed. In particular, the flame path should be kept dry and should never be filled with jointing compound.

### A7.2.3 *General Precautions*

Alarm or shutdown circuits which are working correctly should never be bypassed, overridden or isolated; such action could endanger the safety of the ship.

Defective circuits may be bypassed temporarily in case of an emergency but this action should only be taken with the full agreement of the responsible officer, and the decision should be recorded. The defect should be rectified and the circuit repaired as soon as possible, and the bypass removed.

Certified safe equipment should be carefully maintained, preferably by qualified personnel; advice from the manufacturer should be sought in case of doubt.

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# THE PRESSURE SURGE PHENOMENON



## A8.1 INTRODUCTION

A pressure surge is generated in a pipeline system when there is any change in the rate of flow of liquid in the line. The surge can be dangerous if the change of flow rate is too rapid. Pressure surges are most likely to be created during cargo transfer as a result of one of the following actions:

- closure of an automatic emergency shut down (ESD) valve,
- rapid closure or opening of a manual or power-operated valve,
- slamming shut of a non-return valve, or
- starting or stopping of a pump.

If the total pressure generated in the pipeline exceeds the strength of any part of the pipeline system upstream of the valve which is closed there may be a rupture leading to an extensive spillage.

There are similar risks if a valve is opened rapidly to fill a downstream pipeline system.

## A8.2 GENERATION OF PRESSURE SURGE

The pressure at any point in the cargo transfer system while liquid is flowing under normal conditions has three components:

- the hydrostatic pressure;
- the vapour pressure of the product if the tank is closed, or atmospheric pressure if the tank is open;
- the pressure generated by the pump, which is highest at the pump outlet but falls steadily with distance along the line due to frictional losses.

The first two pressure components are constant and will be referred to as the static component. Rapid closure of a valve superimposes an additional transient pressure. This is due to the sudden conversion of the kinetic energy of the moving liquid into strain energy by compression of the fluid and stretching of the pipe.

The cessation of flow of liquid is propagated back along the pipeline at the speed of sound and as each part of the liquid comes to rest the pressure is increased. It is this disturbance that is known as a pressure surge. The height of the surge depends on the density of the liquid, the rate of its deceleration and the velocity of sound through it.

The surge pressure is greatest if the valve closes instantaneously. The sequence of events after instantaneous valve closure is illustrated in Figure A8.1 and is described below.

Diagram I shows the normal flow, and Diagram II the development of the surge as the ESD valve shuts. Diagram III shows that upstream of the surge the liquid continues to move forward and still has the pressure distribution applied to it by the pump. Downstream of the surge, the liquid is stationary and its pressure has been increased at all points by a constant amount. There continues to be a downstream pressure gradient behind the surge, but a continuous series of pressure adjustments takes place in this part of the pipeline to equalise the pressure throughout the stationary liquid. These pressure adjustments also travel through the liquid at the speed of sound.

When the surge reaches the pump (Diagram IV) the flow through it ceases. The pressure at the pump outlet (leaving aside the static component) becomes approximately equal to the sum of the

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surge pressure and the output pressure of the pump at zero throughput. The process of pressure equalisation continues downstream of the pump. If not relieved in any way, the pressure throughout the whole length of stationary liquid reaches approximately the sum of the surge pressure, the pump outlet pressure at zero throughput and the static component. The final pressure adjustment to achieve this correlation leaves the pump as soon as the original surge arrives, and travels back to the valve at the speed of sound.

The time required for the whole process is therefore  $2L/a$  from the instant of valve closure, where  $L$  is the length of the line and  $a$  is the speed of sound in the liquid; this is known as the 'pipeline period'.

Therefore, if the valve closes instantaneously, the liquid upstream in the line experiences an abrupt increase in pressure followed by a slower (but still rapid) further increase until the pressure reaches approximately the sum of the surge pressure, the pump outlet pressure at zero throughput and the static component.

In practical circumstances the valve closure is not instantaneous and there is then some relief of the surge pressure through the valve while it is closing. The pressure front is less steep and as a result the height of the pressure surge is less than if closure had been instantaneous. The pressure rise created will be less and the reflected pressure rise will be relieved through the partially open valve.

At the upstream end of the line some pressure relief occurs through the pump and this also serves to lessen the maximum pressure reached; however if a check valve is fitted it may aggravate the surge. If the effective closure time of the valve is several times greater than the pipeline period then surge pressure alleviation may be significant.

Loss of pressure through the pump continues after the lapse of the time interval  $2L/a$  until the pressure throughout the line between the pump and the closed valve is reduced to the pump output pressure at zero throughput. This is the situation that would have resulted from a very slow closure of the valve, but the pressure surge would not then have occurred.

Downstream of the valve an analogous process is initiated when the valve closes, except that as the liquid is brought to rest there is a fall of pressure which travels downstream at the velocity of sound. However, the pressure drop may be relieved by vapour evolution from the liquid although the subsequent collapse of the vapour bubbles may generate shock waves; for example, if the downstream liquid flows up and down through the transfer arm or hose.

### **A8.3 OTHER SURGE PRESSURE EFFECTS**

The description above refers to the simple case of a single pipeline. In practical cases the design of a possible complex system should be taken into account. For example, the combined effects of valves in parallel or in series have to be examined. In some cases the surge effect may be increased; for instance with two lines in parallel if closure of a valve in one line increases the flow in the other line before this line in its turn is shut down. However, correct operation of valves in series in a line can minimise surge pressure.

The maintenance and regular testing of ESD valve closure times is an important safety procedure.

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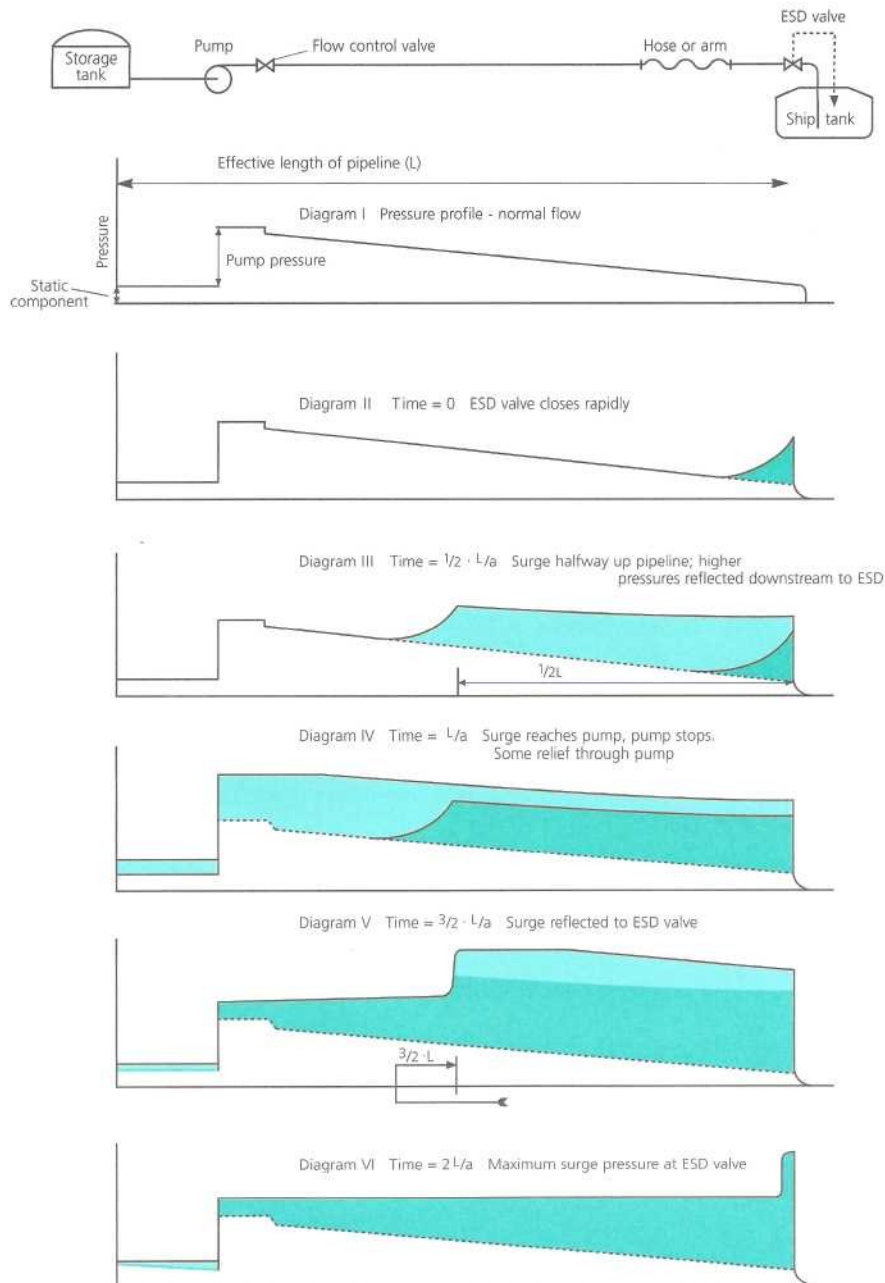


Figure A8.1 Development of pressure surge in a line after instantaneous valve closure  
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# SHIP/SHORE SAFETY CHECK LIST GUIDELINES

## INTRODUCTION

Before liquid bulk dangerous substances are pumped into or out of any ship, or into a shore installation, the Master of the ship and the berth operator should:

- 1 agree in writing on the handling procedures including the maximum loading or unloading rates;
- 2 complete and sign, as appropriate, the safety check list, showing the main safety precautions to be taken before and during such handling operations; and
- 3 agree in writing on the action to be taken in the event of an emergency during handling operations.

The following guidelines have been produced to assist berth operators and ships' masters in their joint use of the Ship/Shore Safety Check List.

## THE MUTUAL SAFETY EXAMINATION

A tanker presenting itself to a loading or discharging terminal needs to check its own preparations and its fitness for the safety of the intended cargo operation. Additionally, the master of a ship has a responsibility to assure himself that the terminal operator has likewise made proper preparations for the safe operation of his terminal. Equally the terminal needs to check its own preparations and to be assured that the tanker has carried out its checks

and has made appropriate arrangements.

The Ship /Shore Safety Check List, by its questions and requirements for exchange of written agreements for certain procedures, is a minimum basis for the essential considerations which should be included in such a mutual examination.

Some of the check list questions are directed to considerations for which the ship has prime responsibility, others apply to both ship and terminal. It is not suggested that every item should be the subject of personal checking by both representatives conducting the examination.

All items lying within the responsibility of the tanker should be personally checked by the tanker's representative and similarly all items of the terminal's responsibility personally checked by the terminal representative. In carrying out their full responsibilities however, both representatives, by questioning the other, by sighting of records and, where felt appropriate, by joint visual inspection should assure themselves that the standards of safety on both sides of the operation are fully acceptable.

The joint declaration should not be signed until such mutual assurance is achieved.

Thus all applicable questions should result in an affirmative mark in the boxes provided. If a difference of opinion arises on the adequacy of any arrangements made or conditions found, the operation should not be started until measures taken are jointly accepted.

A negative answer to the questions coded 'P' does not necessarily mean that the intended operation cannot be carried out. In such cases, however, permission to proceed should be obtained from the Port Authority.

Items coded 'R' should be rechecked at intervals not exceeding that agreed in the declaration.

Where an item is agreed to be not applicable to the ship, to the terminal or to the operation envisaged, a note to that effect should be entered in the 'Remarks' column.

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While the Ship/Shore Safety Check List is based upon cargo handling operations, it is recommended that the same mutual examination, using the check list as appropriate, be carried out when a tanker presents itself at a berth for tank cleaning after carriage of substances covered by these Guidelines.

#### **DEVIATIONS**

The conditions under which the operation takes place may change during the process. The changes may be such that safety can no longer be regarded as guaranteed. The party noticing or causing the unsafe condition is under an obligation to take all the necessary action, which may include stopping the operation, to reestablish safe conditions. The presence of the unsafe condition should be reported to the other party and where necessary, co-operation with the other party should be sought.

#### **TANK CLEANING ACTIVITIES**

The questions on tank cleaning are provided in the list in order to inform the terminal and the port authorities of the ship's intentions regarding these activities.

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## **GUIDELINES FOR COMPLETING THE SHIP/SHORE SAFETY CHECK LIST**

### **PART A - Bulk Liquid General**

#### **Is the ship securely moored**

In answering this question, due regard should be given to the need for adequate fendering arrangements.

Ships should remain adequately secured in their moorings. Alongside piers or quays, ranging of the ship should be prevented by keeping all mooring lines taut; attention should be given to the movement of the ship caused by wind, currents, tides or passing ships and the operation in progress.

The wind velocity at which loading arms should be disconnected, cargo operations should cease or the vessel should be unberthed should be stated.

Wire ropes and fibre ropes should not be used together in the same direction (i.e. breasts, springs, head or stern) because of the difference in their elastic properties.

Once moored, ships fitted with automatic tension winches should not use such winches in the automatic mode.

Means should be provided to enable quick and safe release of the ship in case of an emergency. In ports where anchors are required to be used, special consideration should be given to this matter.

Irrespective of the mooring method used, the emergency release operation should be agreed taking into account the possible risks involved.

Anchors not in use should be properly secured.

#### **2 Are emergency towing wires (fire wires) correctly positioned?**

Emergency towing wires should be positioned both on the off-shore bow and quarter of the ship. At a buoy mooring, towing wires should be positioned on the side opposite to the hose string.

There are various methods for rigging emergency towing wires currently in use. Some terminals may require a particular method to be used and the ship should be advised accordingly.

#### **3 Is there safe access between ship and shore?**

The access should be positioned as far away from the manifolds as practicable.

The means of access to the ship should be safe and may consist of an appropriate gangway or accommodation ladder with a properly secured safety net fitted to it.

Particular attention to safe access should be given where the difference in level between the point of access on the vessel and the jetty or quay is large or likely to become large.

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When terminal access facilities are not available and a ship's gangway is used, there should be an adequate landing area on the berth so as to provide the gangway with a sufficient clear run of space and so maintain safe and convenient access to the ship at all states of tide and changes in the ship's freeboard.

Near the access ashore, appropriate life-saving equipment should be provided by the terminal. A lifebuoy should be available on board the ship near the gangway or accommodation ladder.

The access should be safely and properly illuminated during darkness.

Persons who have no legitimate business on board, or who do not have the master's permission, should be refused access to the ship.

The terminal should control access to the jetty or berth in agreement with the ship.

#### **4 Is the ship ready to move under its own power?**

The ship should be able to move under its own power at short notice, unless permission to immobilise the ship has been granted by the Port Authority and the Terminal Manager.

Certain conditions may have to be met for permission to be granted.

#### **5 Is there an effective deck watch in attendance on board and adequate supervision on the terminal and on the ship?**

The operation should be under constant control both on ship and shore.

Supervision should be aimed at preventing the development of hazardous situations; if, however, such a situation arises, the controlling personnel should have adequate means available to take corrective action.

The controlling personnel on ship and shore should maintain an effective communication with their respective supervisors.

All personnel connected with the operations should be familiar with the dangers of the substances handled.

#### **6 Is the agreed ship/shore communication system operative?**

Communication should be maintained in the most efficient way between the responsible officer on duty on the ship and the responsible person ashore.

When telephones are used, the telephone both on board and ashore should be continuously manned by a person who can immediately contact his respective supervisor. Additionally the supervisor should have the possibility to override all calls. When RT/VHF systems are used the units should preferably be portable and carried by the supervisor or a person who can get in touch with his respective supervisor immediately. Where fixed systems are used the guidelines for telephones should apply.

The selected system of communication together with the necessary information on telephone numbers and/or channels to be used should be recorded on the appropriate form. This should be signed by both ship and shore representatives.

The telephone and portable RT/VHF systems should comply with the appropriate safety requirements.

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#### **7 Has the emergency signal to be used by the ship and shore been explained and understood?**

The agreed signal to be used in the event of an emergency arising ashore or on board should clearly understood by shore and ship personnel.

#### **8 Have the procedures for cargo, bunker and ballast handling been agreed?**

The procedures for the intended operation should be pre-planned. They should be discussed and agreed upon by the ship and shore representatives prior to the start of the operations. These agreed arrangements should be formally recorded and signed by both ship and terminal representatives. Any change in the agreed procedure that could affect the operation should be discussed by both parties and agreed upon. After agreement has been reached by both parties, substantial changes should be laid down in writing as soon as possible and in sufficient time before the change in procedure takes place. In any case the change should be laid down in writing within the working period of those supervisors on board and ashore in whose working period agreement on the change was reached.

The properties of the substances handled, the equipment of ship and shore installation, the ability of the ship's crew and shore personnel to execute the necessary operations and to sufficiently control the operations are factors which should be taken into account when ascertaining the possibility of handling a number of substances concurrently.

The manifold area both on board and ashore should be safely and properly illuminated during darkness. The operations should be suspended and all deck and vent openings closed on the approach of an electrical storm.

The initial and maximum loading rates, topping off rates and normal stopping times should be agreed, having regard to:

- the nature of the cargo to be handled;
- the arrangement and capacity of the ship's cargo lines and gas venting systems;
- the maximum allowable pressure and flow rate in the ship/shore hoses and loading arms;
- precautions to avoid accumulation of static electricity;
- any other flow control limitations.

A record to this effect should be formally made as above.

#### **9 Have the hazards associated with toxic substances in the cargo being handled been identified and understood?**

Many tanker cargoes contain components which are known to be hazardous to human health. In order to minimise the impact on personnel, information on cargo constituents should be available during the cargo transfer to enable the adoption of proper precautions. In addition, some port states require such information to be readily available during cargo transfer and in the event of an accidental spill.

The information provided should identify the constituents by chemical name, name in common usage, UN number and the maximum concentration expressed as a percentage by volume.

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#### **10 Has the emergency shutdown procedure been agreed?**

An emergency shutdown procedure should be agreed between ship and shore, formally recorded and signed by both the ships and terminal representative.

The agreement should designate in which cases the operations have to be stopped immediately.

Due regard should be given to the possible introduction of dangers associated with the emergency shutdown procedure.

#### **11 Are fire hoses and fire-fighting equipment on board and ashore positioned and ready for immediate use?**

Fire-fighting equipment both on board and ashore should be correctly positioned and ready for immediate use.

Adequate units of fixed or portable equipment should be stationed to cover the ship's cargo deck and on the jetty.

The ship and shore fire main systems should be pressurised, or be capable of being pressurised at short notice.

Both ship and shore should ensure that their fire main systems can be connected in a quick and easy way utilising, if necessary, the international shore fire connection.

#### **12 Are cargo and bunker hoses/arms in good condition, properly rigged and appropriate for the service intended?**

Cargo hoses and metal arms should be in a good condition and should be properly fitted and rigged so as to prevent strain and stress beyond design limitations. All flange connections should be fully bolted and any other types of connections should be properly secured.

It should be ensured that the hoses or metal arms are constructed of a material suitable for the substance to be handled taking into account its temperature and the maximum operating pressure.

Cargo hoses should be properly marked and identifiable with regard to their suitability for the intended operation.

#### **13 Are scuppers effectively plugged and drip trays in position, both on board and ashore?**

Where applicable all scuppers on board and drain holes ashore should be properly plugged during the operations. Accumulation of water should be drained off periodically.

Both ship and jetty should ideally be provided with fixed drip trays; in their absence portable drip trays should be used.

All drip trays should be emptied in an appropriate manner whenever necessary but always after completion of the specific operation.

When only corrosive liquids or refrigerated gases are being handled, the scuppers may be kept open, provided that an ample supply of water is available at all times in the vicinity of the manifolds.

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#### **14 Are unused cargo and bunker connections properly secured with blank flanges fully bolted?**

Unused cargo and bunker line connections should be closed and blanked. Blank flanges should be fully bolted and other types of fittings, if used, properly secured.

#### **15 Are sea and overboard discharge valves, when not in use, closed and visibly secured?**

Experience shows the importance of this item in pollution avoidance on ships where cargo lines and ballast systems are interconnected. Remote operating controls for such valves should be identified in order to avoid inadvertent opening.

If appropriate, the security of the valves in question should be checked visually.

#### **16 Are all cargo and bunker tank lids closed?**

Apart from the openings in use for tank venting (refer to question 17) all openings to cargo tanks should be closed and gastight.

Except on gas tankers, ullaging and sampling points may be opened for the short periods necessary for ullaging and sampling.

Closed ullaging and sampling systems should be used where required by international, national or local regulations and agreements.

#### **17 Is the agreed tank venting system being used?**

Agreement should be reached, and recorded, as to the venting system for the operation, taking into account the nature of the cargo and international, national or local regulations and agreements.

There are three basic systems for venting tanks:

- 1 Open to atmosphere via open ullage ports, protected by suitable flame screens.
- 2 Fixed venting systems which includes inert gas systems.
- 3 To shore through other vapour collection systems.



**18 Have the P/V vents been operated using the checklift facility and the operation of the vent verified:**

The operation of the P/V vents should be checked using the facility provided by the manufacturer. Furthermore it is imperative that an adequate visual, or otherwise, check is carried out at this time to ensure the checklift facility is actually operating the valve. On occasion a seized or stiff P/V vent has caused the checklift drive pin to shear and the ship's personnel to assume, with disastrous consequences, that the vent was operational.

**19 Are hand torches of an approved type?**

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**20 Are portable VHF/UHF transceivers of an approved type?**

Battery operated hand torches and VHF radio-telephone sets should be of a safe type which is approved by a competent authority. Ship/shore telephones should comply with the requirements for explosion-proof construction except when placed in a safe space in the accommodation.

VHF radio-telephone sets may operate in the internationally agreed wave bands only.

The above mentioned equipment should be well maintained. Damaged units, even though they may be capable of operation, should not be used.

**21 Are the ship's main radio transmitter aerials earthed and radars switched off?**

The ship's main radio transmitter should not be used during the ship's stay in port, except for receiving purposes.

The main transmitting aerials should be disconnected and earthed.

Satellite communications equipment may be used normally unless advised otherwise.

The ship's radar installation should not be used unless the master, in consultation with the terminal manager, has established the conditions under which the installation may be used safely.

**22 Are electric cables to portable electrical equipment disconnected from power?**

The use of portable electrical equipment on wandering leads should be prohibited in hazardous zones during cargo operations, and the equipment preferably removed from the hazardous zone.

Telephone cables in use in the ship/shore communication system should preferably be routed outside the hazardous zone. Wherever this is not feasible, the cable should be so positioned and protected that no danger arises from its use.

**23 Are all external doors and ports in the accommodation closed?**

External doors, windows and portholes in the accommodation should be closed during the cargo operations. These doors should be clearly marked, but at no time should they be locked.

**24 Are window type air conditioning units disconnected?**

**25 Are air conditioning intakes which may permit the entry of cargo vapours closed?**

Window type air conditioning units should be disconnected from their power supply.

Air conditioning and ventilator intakes which are likely to draw in air from the cargo area should be closed.

Air conditioning units which are located wholly within the accommodation and which do not draw in air from the outside may remain in operation.

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**26 Are the requirements for the use of galley equipment and other cooking appliances being observed?**

Open fire systems may be used in galleys whose construction, location and ventilation system provides protection against entry of flammable gases.

In cases where the galley does not comply with the above, open fire systems may be used provided the master, in consultation and agreement, with the terminal representative, has ensured that precautions have been taken against the entry and accumulation of flammable gases.

On ships with stern discharge lines which are in use, open fire systems in galley equipment should not be allowed unless the ship is constructed to permit their use in such circumstances.

**27 Are smoking requirements being observed?**

Smoking on board the ship may only take place in places specified by the master in consultation with the terminal manager or his representative.

No smoking is allowed on the jetty and the adjacent area except in buildings and places specified by the terminal manager in consultation with the master.

Places which are directly accessible from the outside should not be designated as places where smoking is permitted. Buildings, places and rooms designated as places where smoking is permitted should be clearly marked as such.

**28 Are naked light requirements being observed?**

A naked light or open fire comprises the following: flame, spark formation, naked electric light or any surface with a temperature that is equal to or higher than the minimum ignition temperature of the products handled in the operation.

The use of open fire on board the ship, and within a distance of 25 metres of the ship, should be prohibited, unless all applicable regulations have been met and agreement reached by the port authority, terminal manager and the master. The distance may have to be extended for ships of a specialised nature such as gas tankers.

**29 Is there provision for an emergency escape?**

In addition to the means of access referred to in question 3, a safe and quick emergency escape route should be available both on board and ashore. On board the ship it may consist of a lifeboat ready for immediate use, preferably at the after end of the ship.

**30 Are sufficient personnel on board and ashore to deal with an emergency?**

At all times during the ship's stay at a terminal, a sufficient number of personnel should be present on board the ship and in the shore installation to deal with an emergency.

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**31 Are adequate insulating means in place in the ship/shore connection?**

Unless measures are taken to break the continuous electrical path between ship and shore pipework provided by the ship/shore hoses or metallic arms, stray electric currents, mainly from corrosion protection systems, can cause electric sparks at the flange faces when hoses are being connected and disconnected.

The passage of these currents is usually prevented by an insulating flange inserted at each jetty manifold outlet or incorporated in the construction of metallic arms. Alternatively, the electrical discontinuity may be provided by the inclusion of one length of electrically discontinuous hose in each hose string.

It should be ascertained that the means of electrical discontinuity is in place and in good condition and that it is not being by-passed by contact with an electrically conductive material.

**32 Have measures been taken to ensure sufficient pumproom ventilation?**

Ship's pumprooms should be mechanically ventilated and the ventilation system, which should maintain a safe atmosphere throughout the pumproom, should be kept running throughout the operation.

**33 If the ship is capable of 'closed loading' have the requirements for closed operations been agreed?**

It is a requirement of many terminals that, when the ship is ballasting, loading and discharging, it operates without recourse to opening ullage and sighting ports. Such ships will require the means to enable closed monitoring of tank contents, either by a fixed gauging system or by using portable equipment passed through a vapour lock, and preferably backed up by an independent overfill alarm system.

**34 Has a vapour return line been connected?**

If required, a vapour return line may have to be used to return flammable vapours from the cargo tanks to shore.

**35 If a vapour return line is connected, have operating parameters been agreed?**

The maximum and minimum operating pressures and any other constraints associated with the operation of the vapour return system should be discussed and agreed by ship and shore personnel.

**36 Are ship emergency fire control plans located externally?**

A set of fire control plans should be permanently stored in a prominently marked weathertight enclosure outside the deckhouse for the assistance of shoreside firefighting personnel. A crew list should also be included in this enclosure.

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**If the ship is fitted, or required to be fitted, with an Inert Gas System the following questions should be answered.**

**37 Is the Inert Gas System fully operational and in good working order?**

The Inert Gas System should be in safe working condition with particular reference to all interlocking trips and associated alarms, deck seal, non-return valve, pressure regulating control system, main deck IG line pressure indicator, individual tank IG valves (when fitted) and deck P/V breaker.

Individual tank IG valves (if fitted) should have easily identified and fully functioning open/close position indicators.

**38 Are deck seals in good working order?**

It is essential that the deck seal arrangements are in a safe condition. In particular, the water supply arrangements to the seals and the proper functioning of associated alarms should be checked.

**39 Are liquid levels in P/V breakers correct?**

Checks should be made to ensure the liquid level in the P/V breaker complies with manufacturer's recommendations.

**40 Have the fixed and portable oxygen analysers been checked and are they working properly?**

All fixed and portable oxygen analysers should be calibrated and checked as required by the company and/or manufacturer's instructions. The in-line oxygen analyser/recorder and sufficient portable oxygen analysers should be working properly.

**41 Are fixed IG pressure and oxygen content recorders working?**

All recording equipment should be switched on and operating correctly.

**42 Are all cargo tank atmospheres at positive pressure with an oxygen content of 8% or less by volume?**

Prior to commencement of cargo operations, each cargo tank atmosphere should be checked to verify oxygen content is 8% or less by volume. Inerted cargo tanks should at all times be kept at a positive

pressure.

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**43 Are all the individual tank IG valves (if fitted) correctly set and locked?**

For both loading and discharge operations it is normal and safe to keep all individual tank IG supply valves (if fitted) open in order to prevent inadvertent under or over pressurisation. In this mode of operation each tank pressure will be the same as the deck main IG pressure and thus the P/V breaker will act as a safety valve in case of excessive over or under pressure. If individual tank IG supply valves are closed for reasons of potential vapour contamination or de-pressurisation for gauging, etc., then the status of the valve should be clearly indicated to all those involved in cargo operations. Each individual tank IG valve should be fitted with a locking device under the control of a responsible officer.

**44 Are all persons in charge of cargo operations aware that in the case of failure of the Inert Gas Plant, discharge operations should cease and the terminal be advised?**

In the case of failure of the IG plant the cargo discharge, de-ballasting and tank cleaning should cease and the terminal should be advised.

Under no circumstances should the ship's officers allow the atmosphere in any tank to fall below atmospheric pressure.

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## GUIDELINES FOR COMPLETING THE SHIP/SHORE SAFETY CHECK LIST

### PART C - Bulk Liquefied Gases

**1 Is information available giving the necessary data for the safe handling of the cargo including, where applicable, a manufacturer's inhibition certificate?**

Information on each product to be handled should be available on board the ship and ashore before and during the operation.

Cargo information, in a written format, should include:

- cargo stowage plan;
- full description of the physical and chemical properties necessary for the safe containment the cargo;
- action to be taken in the event of spills or leaks;
- counter-measures against accidental personal contact;
- fire-fighting procedures and fire fighting media;
- procedures for cargo transfer, gas freeing, ballasting, tank cleaning and changing cargoes;
- special equipment needed for the safe handling of the particular cargo(es);
- minimum allowable inner hull steel temperatures; and
- emergency procedures.

When cargoes required to be stabilised or inhibited are to be handled, ships should be provided with a certificate from the manufacturer stating:

- name and amount of inhibitor added;
- date inhibitor was added and the normally expected duration of its effectiveness;
- any temperature limitations affecting the inhibitor; and
- the action to be taken should the length of the voyage exceed the effective lifetime of the inhibitor.

**2 Is the water spray system ready for use?**

In cases where flammable and/or toxic products are handled, water spray systems should be regularly tested.

Details of the last tests should be exchanged.

During operations the systems should be kept ready for immediate use.

**3 Is sufficient suitable protective equipment (including self-contained breathing apparatus) and protective clothing ready for immediate use?**

Suitable protective equipment, including self-contained breathing apparatus, eye protection and protective clothing appropriate to the specific dangers of the product handled, should be available in sufficient quantity for operations personnel both on board and ashore.

Storage places for this equipment should be protected from the weather and be clearly marked.

All personnel directly involved in the operation should utilise this equipment and clothing whenever the situation requires.

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Personnel required to use breathing apparatus during operations should be trained in its safe use. Untrained personnel and personnel with facial hair should not be selected for operations involving the use of breathing apparatus.

**4 Are hold and inter-barrier spaces properly inerted or filled with dry air as required?**

The spaces that are required to be inerted by the IMO Gas Carrier Codes should be checked by ship's personnel prior to arrival.

**5 Are all remote control valves in working order?**

All ship and shore cargo system remote control valves and their position indicating systems should be regularly tested. Details of the last tests should be exchanged.

**6 Are the required cargo pumps and compressors in good order, and have maximum working pressures been agreed between ship and shore?**

Agreement in writing should be reached on the maximum allowable working pressure in the cargo line system during operations.

**7 Is reliquefaction or boil off control equipment in good order?**

It should be verified that reliquefaction and boil off control systems, if required, are functioning correctly prior to commencement of operations.

**8 Is the gas detection equipment properly set for the cargo, calibrated and in good order?**

Span gas should be available to enable calibration of gas detection equipment. Fixed gas detection equipment should be calibrated for the product to be handled prior to commencement of operations. The alarm function should have been tested and the details of the last test should be exchanged.

Portable gas detection instruments, suitable for the products handled, capable of measuring flammable and/or toxic levels, should be available.

Portable instruments capable of measuring in the flammable range should be calibrated for the product to be handled before operations commence.

**9 Are cargo system gauges and alarms correctly set and in good order?**

Ship and shore cargo system gauges should be regularly checked to ensure that they are in good working order. In cases where it is possible to set alarms to different levels, the alarm should be set to the required level.

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**10 Are emergency shutdown systems working properly?**

Where possible, ship and shore emergency shutdown systems should be tested before cargo transfers.

**11 Does the shore know the closing rate of ship's automatic valves; does the ship have similar details of shore system?**

Automatic shutdown valves may be fitted in the ship and the shore systems. Among other parameters, the action of these valves can be automatically initiated by a certain level being reached in the tank being loaded either on board or ashore.

Where valves are fitted and used, the cargo handling rate should be so adjusted that a pressure surge evolving from the automatic closure of any such valve does not exceed the safe working pressure of either the ship or shore pipeline system.

Alternatively, means may be fitted to relieve the pressure surge created, such as recirculation systems and buffer tanks.

A written agreement should be made between the ship and shore supervisor indicating whether the cargo handling rate will be adjusted or alternative systems will be used; the safe cargo handling rate should be noted in this agreement.

**12 Has information been exchanged between ship and shore on the maximum/ minimum temperatures/pressures of the cargo to be handled?**

Before operations commence, information should be exchanged between ship and shore representatives on cargo temperature/pressure requirements.

This information should be agreed in writing.

**13 Are cargo tanks protected against inadvertent overfilling at all times while any cargo operations are in progress?**

Automatic shutdown systems are normally designed to shut the liquid valves, and if discharging to trip the cargo pumps, should the liquid level in any tank rise above the maximum permitted level. This level must be accurately set and the operation of the device tested at regular intervals.

If ship and shore shutdown systems are to be inter-connected then their operation must be checked before cargo transfer begins.

**14 Is the compressor room properly ventilated, the electrical motor room properly pressurised and the alarm system working?**

Fans should be run for at least 10 minutes before cargo operations commence and then continuously during cargo operations.

Audible and visual alarms, provided at airlocks associated with compressor/motor rooms, should be regularly tested.

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**15 Are cargo tank relief valves set correctly and actual relief valve settings clearly and visibly displayed?**

In cases where cargo tanks are permitted to have more than one relief valve setting, it should be verified that the relief valve is set as required by the cargo to be handled and that the actual setting of the relief valve is clearly and visibly displayed on board the ship. Relief valve settings should be recorded on the check list.

# Conversion Tables

## Temperature

### Use of the table

- 1 Find the temperature needing conversion in central column (bold figures).
- 2 The corresponding figure in the left or right hand columns is the equivalent temperature in °C or °F respectively.



"C	V	F	"C	T	F	(3	T	F	C	T	F	
-2	-		-294	<b>-2</b>	-5-8	100	<b>50</b>	122	0	049-4	<b>12</b>	2
73	<b>459</b>			<b>1</b>							<b>1</b>	49-8
-2	-		-289	<b>-2</b>	-40	106	<b>51</b>	123-8	0500		<b>12</b>	2
68	<b>450</b>			<b>0</b>							<b>2</b>	51-6
-2	^		-28-3	<b>-1</b>	-2-2	11-1	<b>52</b>	125-6	0506		<b>12</b>	2
62	<b>440</b>			<b>9</b>							<b>3</b>	53-4
-2	-		-27-8	<b>-1</b>	-0-4	11-7	<b>53</b>	1274	051-1		<b>12</b>	2
57	<b>430</b>			<b>8</b>							<b>4</b>	55-2
-2	-		-27-2	<b>-17</b>	14	12 2	<b>54</b>	1292	051-7		<b>12</b>	2
51	<b>420</b>										<b>5</b>	570
-2	-		-26-7	<b>-16</b>	3-2	128	<b>55</b>	131-0	0522		<b>12</b>	2
46	<b>410</b>										<b>6</b>	58-8
-2	-		-26-1	<b>-15</b>	5-0	133	<b>56</b>	132-8	052-8		<b>127</b>	2
40	<b>400</b>											60-6
-2	-		-256	<b>-14</b>	68	13 9	<b>57</b>	134-6	053-3		<b>128</b>	2
34	<b>390</b>											62-4
-2	-		-250	<b>-13</b>	8-6	14-4	<b>58</b>	136-4	053-9		<b>129</b>	2
29	<b>380</b>											64-2
-2	-		-24-4	<b>-12</b>	10-4	150	<b>59</b>	138-2	0544		<b>13</b>	2
23	<b>370</b>										<b>0</b>	660
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-3	-	-	238	4.4	<b>40</b>	104-0	43-9	<b>111</b>	231 8	168	<b>370</b>	698
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4												
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39	<b>29</b>										<b>0</b>	0
-3	-	-	18-4	6-1	<b>43</b>	109-4	456	<b>114</b>	237-2	204	<b>40</b>	75
3-	<b>28</b>										<b>0</b>	2
3												
-3	-	-	16-6	6-7	<b>44</b>	111-2	46-1	<b>115</b>	2390	210	<b>410</b>	770
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00	<b>22</b>							<b>0</b>			<b>0</b>	0

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### Pressure

Use of the table

- 1 Find the units in which the pressure is known in the left column.
- 2 Find the units in which the pressure is required along the top row.
- 3 Multiply known pressure by figure shown at intersection.

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	Kpa	Bar	Std Atm	kg/cm	lb/inch (psi)	lb/ft	mm Hg	inches Hg	inches H <sub>2</sub> O	ft H <sub>2</sub> O	metres H <sub>2</sub> O
Kpa	1	<b>0.01</b>	0.009 9	0.0102	0-1450	20-88 ~i	1 7- 50	0-2953	4-015	0-3346	0-1020
Bar	100	i	0-9869	1-020	14-50	2,089	750-1	2953	401-5	33-52	10-22
Std Atm	101- 325	1-013	1	1-033	14-70	2,116	760	29-92	407-5	33-96	10-35
kg/cm	98039	0-9807	0-9678	1	14-22	2,048	7356	28-96	394-4	32-87	10-02
lb/inch <sup>2</sup> (psi)	6-8966	006895	006805	0-07031	1	144	5172	2036	2773	2-311	07044
lb/ft <sup>2</sup>	0-0479	0- 0004788	00004725	0000488 2	0-006944	1	0-3591	001414	0.1926	001605	0004891
mm Hg	0-1333	0-001330	0001316	0001360	0-01934	2785	1	0-03937	0.5362	004469	001362
inches Hg	33864	003386	003342	003453	0-4912	70-73	25-4	1	13-62	1-135	0-3459
inches HzO	0-2491	0002456	0002456	0- 002535	003606	5-193	1-865	007342	1	0-0833	0-02540
ft H <sub>2</sub> O	29886	002984	002944	003042	04327	62-31	22-38	0-8810	12	1	0-3048
metres H*O	9-8039	0-09789	009660	00998	1-420	204-4	73-42	2-891	39-37	3-281	1

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**OCIMF:** Oil Companies International Marine Forum

**SGTTO:** Society of International Gas Tanker and Terminal Operators

**IMO:** International Maritime Organization

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