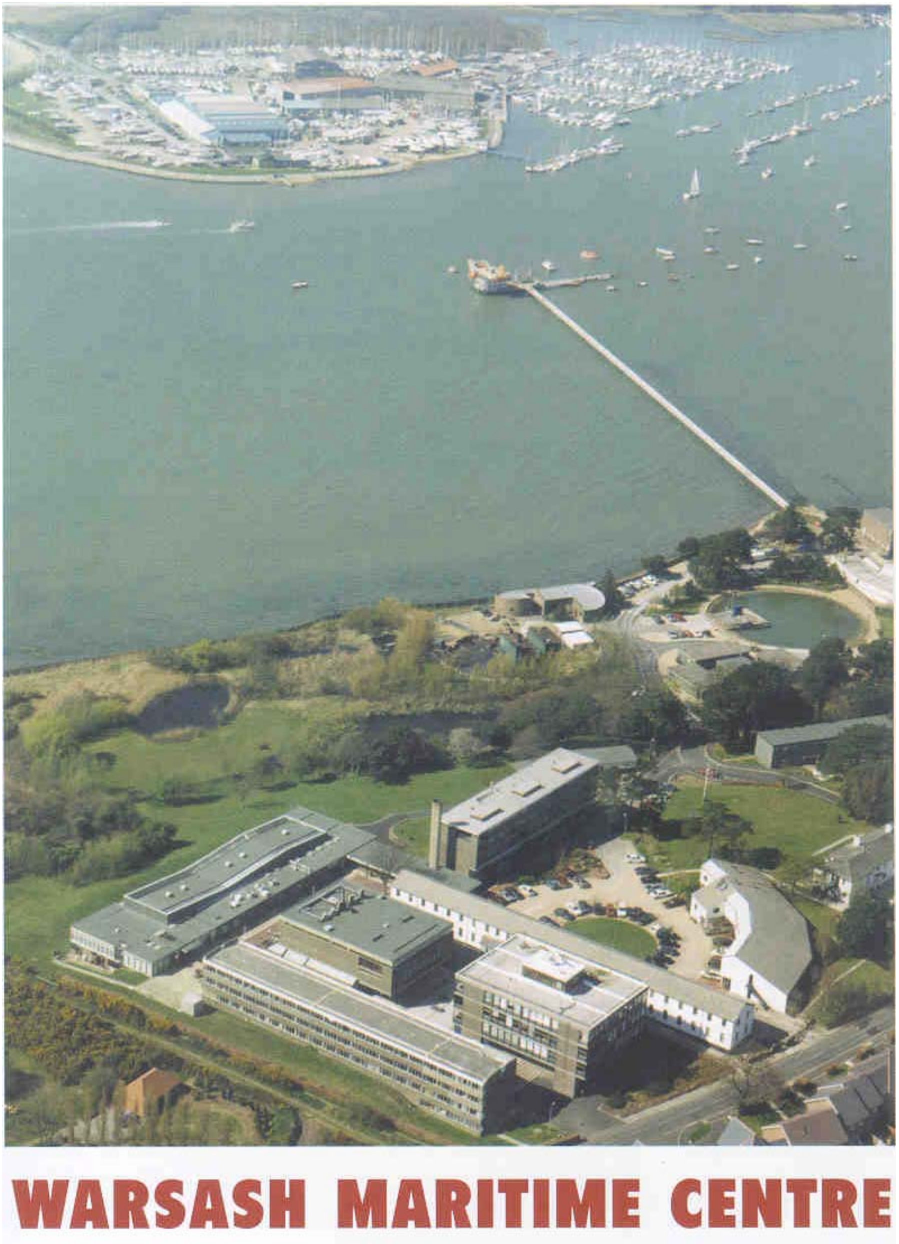

SPECIALISED TANKER TRAINING
(LIQUEFIED GAS)

1 September 2002

ACKNOWLEDGEMENTS

Acknowledgements and thanks are due to many organisations, in particular to the following, from whose publications small extracts and adaptations have been made:-

International Maritime Organisation
International Chamber of Shipping
Department of Transport (U.K.)
Department of Transportation: USCG
Society of International Gas Tanker & Terminal Operators

APPROVAL

The syllabus for this course is in accordance with the recommendations of the Merchant Navy Training Board for training personnel responsible for the handling of liquefied petroleum gas cargoes and satisfies the relevant IMO STCW Convention Regulation requirements.

This course is approved by the UK Maritime and Coastguard Agency for the purposes of the requirements relating to the issue of Tanker Endorsements under the Merchant Shipping (Certification of Deck Officers) and Merchant Shipping (Certification of Marine Engineers) Regulations.

OBJECT OF NOTES

These notes have been prepared by the staff of the Petrochemical Section, Warsash Maritime Centre. They are not intended to form a book. We have included the notes which you might wish to make during the lectures, collated some basic reference material, and provided other references.

OBJECTIVE OF THE COURSE

The course is based on the syllabus given at paragraphs 22 to 34 of Section A-V/1 of the STCW Code. At the end of the course the student will have the relevant technical knowledge to assume the responsibilities of Master, Chief Officer, Chief Engineer, Second Engineer or of any other person having direct responsibility for cargo operations.

WARSASH MARITIME CENTRE **Southampton Institute**
Newtown Road, Warsash, Southampton, SO31 9ZL
Tel: (+44) 1489 576161 **Fax: (+44) 1489 576908**

ASSESSMENT

During the course, we are required to assess your knowledge and understanding of the course materials, as specified in the International STCW Convention. This will be carried out as follows:-

ATTENDANCE.
Full attendance will be expected and **attendance will be recorded on the class Register**. Absence during the course may disqualify you from obtaining a Certificate, or remedial action may be required, for which a fee may be charged.

EXPERIENCE AND PARTICIPATION.
You are expected to support the course by applying your previous experience to discussions and exercises during the course.

EXERCISES.
You may be expected to undertake written exercises, and the work produced will be taken into account when considering the issue of a certificate.

WRITTEN ASSESSMENT.
Part way through the course, you will undertake a written assessment of items already covered. Near the end of the course, you will undertake a further written assessment.

Written assessments will take the form of a number of questions with multiple choice answers, or questions demanding "one word" or "one line" answers.

APPEAL PROCEDURE.
If you are refused a full course certificate you may appeal against the decision. Notification of intention to appeal should be made at the end of the course. If remedial action cannot be taken and agreement cannot be reached, then you may make a written appeal against the assessment, which must be received by WMC within one week. The appeal will be considered within one working week of receipt by a panel including two persons knowledgeable in the subject matter of the course and the WMC Head of Academic Operations or his nominee. You may appear before this panel if you wish. Within one week of the appeal panel meeting, the final decision of the panel will be sent to you.

In the event of a written appeal being received by WMC, copies of all papers, materials and documents relating to the appeal may be sent to the appropriate section at the Maritime and Coastguard Agency.

WARSASH MARITIME CENTRE
(including WMC INDUSTRIAL SAFETY TRAINING)

STANDARD TERMS AND CONDITIONS FOR THE SUPPLY OF BUSINESS SERVICES

1. INTERPRETATION

In these terms and conditions:

"Agreement" means the agreement for Warsash Maritime Centre to provide services to the Client as set out in the Quotation and the Conditions.
"Conditions" shall mean these terms and conditions;
"Client" means the party to whom or which Warsash Maritime Centre has agreed to provide the Services;
"Client's Materials" means the documents and/or other materials referred to in clause 2.3;
"Quotation" means the quotation issued by Warsash Maritime Centre to the Client or in the absence of a written quotation the written correspondence between Warsash Maritime Centre and the Client in respect of the Services;
"Services" means such of the following: training, consultancy, research, accommodation, catering and/or other services referred to in Warsash Maritime Centre's published material, as Warsash Maritime Centre has agreed to supply to the Client in the Quotation;
"Warsash Maritime Centre" means Southampton Institute or Southampton Institute Limited trading as Warsash Maritime Centre, of Newtown Road, Warsash, Southampton, SO31 9ZL.

2. SUPPLY OF SERVICES

2.1 All Services supplied by Warsash Maritime Centre to the Client shall be supplied subject to these Conditions. Any changes or additions to the Services or the Conditions must be agreed in writing between an authorised officer of Warsash Maritime Centre and the Client.

2.2 Warsash Maritime Centre shall supply the Services in accordance with the Quotation and its current brochure or other published literature, subject to these Conditions. In the event of any conflict between the Quotation and these Conditions, the terms of the Quotation shall apply.

2.3 Where the Services require the production and delivery of documents or other materials by the Client, they will be delivered promptly prior to the date specified by Warsash Maritime Centre (acting reasonably) and the Client shall retain duplicate copies.

2.4 If an insufficient number of bookings are received for any course, Warsash Maritime Centre reserves the right to cancel that course and either offer an alternative date, or to refund any pre-paid fees in full.

2.5 Additional conditions shall apply to Clients who book a stay of more than four consecutive weeks in Warsash Maritime Centre's on-campus accommodation. (These are available on application.)

3. PAYMENT AND CHARGES

3.1 The Client shall pay any amounts payable to Warsash Maritime Centre in accordance with this Agreement promptly without any deduction, withholding or set-off.

3.2 Where the Services relate to courses all fees must be paid in advance at time of booking, excepting where the Quotation grants credit terms to the Client in which event payment shall be made 30 days from date of invoice.

3.3 In the event that the Client cancels the agreement at any time then Warsash Maritime Centre's cancellation charges from time to time shall apply, see 7. below.

3.4 Warsash Maritime Centre shall have the right to charge daily compound interest at the annual rate of 5% above the base rate from time to time of Barclays Bank plc upon any sums due but unpaid both before as well as after judgement.

4. WARRANTY AND LIMITATION OF LIABILITY

4.1 Warsash Maritime Centre warrants to the Client that the Services will be provided using reasonable skill and care and as far as reasonably possible within the times referred to in the Quotation or other relevant brochure.

4.2 Where Warsash Maritime Centre supplies any goods in connection with the Services, Warsash Maritime Centre does not give any warranty as to their quality or fitness, but will, where it is able, assign to the Client the benefit of any warranty given by the supplier.

4.3 Warsash Maritime Centre shall have no liability to the Client for any loss or other claims arising from any Client's Materials or instructions supplied by the Client which are incomplete, incorrect, inaccurate or their non-arrival or any other fault of the Client.

4.4 Except in respect of death or personal injury caused by Warsash Maritime Centre's negligence, or as expressly provided in these Conditions, Warsash Maritime Centre shall not be liable to the Client for any losses, damages, costs or other liabilities of the Client whether direct or indirect or consequential including but not limited to any loss of profit or other economic losses which arise out of or in connection with the Services and the Client shall indemnify and keep indemnified Warsash Maritime Centre against claims made by third parties in respect of any such loss or damage. The aggregate liability of Warsash Maritime Centre (except in the case of death or personal injury referred to above) arising as a result of this Agreement shall not exceed the amount paid by the Client to Warsash Maritime Centre in respect of the Services from which the liability arose.

4.5 Warsash Maritime Centre shall not be liable to the Client or be deemed to be in breach of this Agreement by reason of any delay in performing or any failure to perform any of Warsash Maritime Centre's obligations in relation to the Services, if the delay or failure was due to any cause beyond its reasonable control.

5. INTELLECTUAL PROPERTY

5.1 Any intellectual property rights including copyright arising from or in connection with the Services shall, unless otherwise agreed in writing with the Client, belong to Warsash Maritime Centre.

continued:

6. TERMINATION

6.1 Either Warsash Maritime Centre or the Client may at any time (without limiting any other remedy) terminate this agreement by giving written notice to the other if the other commits any breach of these Conditions and (if capable of remedy) fails to remedy the breach within 21 days of being required by written notice to do so, or if the other goes into liquidation, bankruptcy, receivership, administration or proposes any voluntary arrangements with creditors.

6.2 Notwithstanding termination of this Agreement the provisions of clauses 3, 4.3 and 5 shall continue to apply.

7. CANCELLATION CHARGES

7.1 In the event that the Client cancels (by written notice to Warsash Maritime Centre) a confirmed booking with Warsash Maritime Centre, or fails to attend a booked course, the following cancellation charges will apply:

7.1.1 If such notice is delivered less than 2 weeks before commencement of the course (4 weeks for Simulation and Ship Handling), or in the event the Client fails to attend a course without prior notice, the Client shall pay to Warsash Maritime Centre the full course fee. The Client shall also pay the full charge for any associated booking for on-campus accommodation, but only for any period that a room that has been reserved remains unoccupied.

7.1.2 However, if such notice is delivered more than 2 weeks before commencement of the course (4 weeks for Simulation and Ship Handling), the Client shall pay to Warsash Maritime Centre an administration charge of £25 per person per course; and a further £25 cancellation charge for each on-campus room that has been reserved.

7.2 An administration charge of £25 per person per course may be levied if a course is rescheduled at the Client's request within 2 weeks of commencement of course (4 weeks for Simulation and Ship Handling).

7.3 In the event that the Client re-books the cancelled course on an alternative date at the time of cancellation, and provided that more than weeks 2 notice of cancellation (4 weeks for Simulation and Ship Handling) has been given, Warsash Maritime Centre may in its absolute discretion waive any cancellation fees or administration charges.

7.4 Any cancellation charges for research and consultancy services will be levied in accordance with the terms of the Quotation.

7.5 Subject to set-off by Warsash Maritime Centre of any amounts owing to Warsash Maritime Centre in accordance with this Agreement, in the event of cancellation, refunds will be given promptly in accordance with the above cancellation fee policy.

8. CONFIDENTIALITY

8.1 Neither Warsash Maritime Centre or the Client shall divulge or allow to be divulged to any person any confidential information which is identified as such to the other in writing by Warsash Maritime Centre or the Client and which is not in the public domain at the time of disclosure.

9. GOVERNING LAW

9.1 This agreement shall be governed by English law and any proceedings arising from it may be brought in the English courts. The submission by the parties to such jurisdiction shall not limit the right of Warsash Maritime Centre to commence any proceedings arising out of in connection with the provision of the Services in any other jurisdiction it may consider appropriate.

10. NOTICES

All notices hereunder shall be in writing and:

10.1 If given or made by letter sent by first class pre-paid post, and if applicable, by airmail, shall be deemed to have been given 24 hours (in the case of domestic post) and 72 hours (in the case of airmail) after being posted and in proving such service it shall only be necessary to prove that the notice was properly addressed stamped and posted.

10.2 If given or made by facsimile or e-mail transmission shall be deemed to have been given or made when sent unless the notice was sent after 5.00 pm on a business day or on a day other than a business day in which it shall be deemed to have been given or made at 9.00 am on the next business day of the addressee after it was sent.

10.3 Shall be given at the respective address of the other party or at such other address as the other party may have notified in writing as its address from time to time.

11. GENERAL

11.1 Any indulgence granted by Warsash Maritime Centre to the Client and any failure by Warsash Maritime Centre to insist upon strict performance of these Terms and Conditions shall not be deemed a waiver of any of Warsash Maritime Centre's rights or remedies nor be deemed a waiver of any subsequent default by the Client.

11.2 The invalidity in whole or in part of any clause in these Conditions shall not affect the validity of the remainder of the Clauses or these Conditions.

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Useful Web Sites

Web Site	Web Address (URL)
Warsash Maritime Centre	http://www.solent.ac.uk/wmc
Data Sheets	http://hazard.com/msds
Data Sheets (Oxford University)	http://physchem.ox.ac.uk/msds/#msds
Dept. of Environment (Dti)	http://www.shipping.dft.gov.uk/
Health & Safety Executive	http://www.hse.gov.uk
Lloyds List	http://www.llplimited.com
Marine Accident Investigation Branch (UK)	http://www.maib.dft.gov.uk
Maritime & Coastguard Agency	http://www.mcga.gov.uk
Maritime & Coastguard Agency M-Notices	http://www.mcga.gov.uk/publications/mnotice/index.htm
SIGTTO	http://www.sigtto.org/
US Coast Guard	http://www.uscg.mil/
US Code of Federal Regulations (home page)	http://www.access.gpo.gov/nara/cfr/cfr-table-search.html
CFR Title 46 Part 153 (Ships carrying liquefied gases in bulk)	http://www.access.gpo.gov/nara/cfr/waisidx_01/46cfr153_01.html
CFR Title 46 Part 153 (Safety standards for self – propelled vessels carrying bulk liquefied gases)	http://www.access.gpo.gov/nara/cfr/waisidx_01/46cfr154_01.html
CHRIS manual	http://www.chrismanual.com
Merchant Navy	http://www.merchantnavy.com
Warsash Nautical Bookshop	http://www.nauticalbooks.co.uk

Date: 06 Mar 2003

What is a Liquefied Gas?

From the IGC definitions in Chapter 1 a liquefied gas is defined as a liquid having a vapour pressure exceeding 2.8 bar absolute at a temperature of 37.8°C.

Absolute pressures are used in gas calculations and tables giving thermodynamic properties of gases. Absolute pressure is the gauge pressure plus the current atmospheric pressure.

Example

Gauge pressure 3psi Absolute pressure (14.7+3) = 17.7psi

Some Common Gas Ship Cargoes

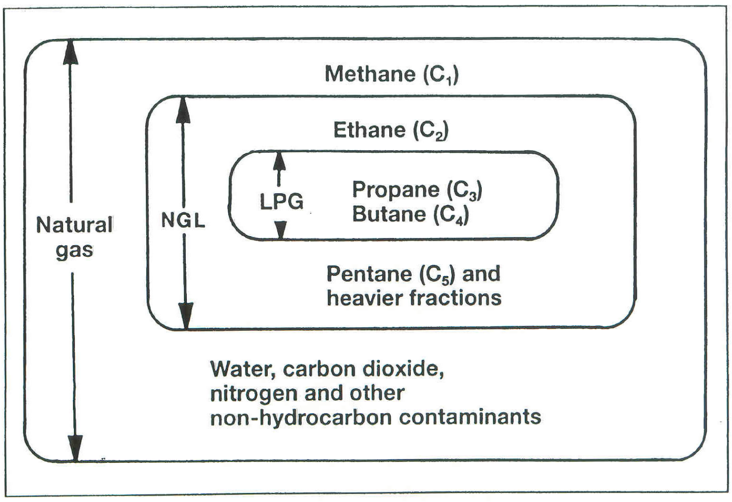
Hydrocarbon Cargoes
These are made up of on hydrogen and carbon molecules.

LNG (Liquefied Natural Gas)
Primarily Methane but also includes Ethane and other heavier components.

Methane
CH_4
Flammable, Colourless, with a faint odour.
Aspyxiant

Flash Point	-175°C
Boiling Point (at atmospheric pressure)	-162°C
Relative Vapour Density	0.55

Uses of LNG, Fuel for power generation, industry and domestic heating.



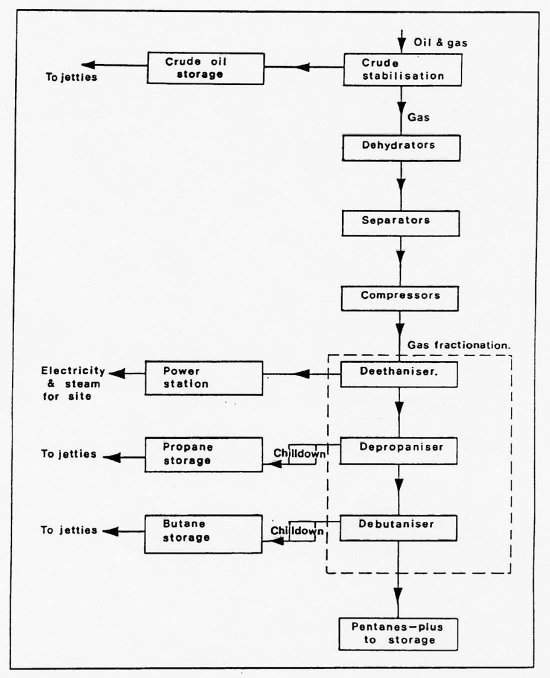
NGL (Natural Gas Liquids)
Natural Gas Liquids found in association with natural gas.
Ethane, Propane, Butane, Pentane and heavier hydrocarbons. Also includes water, CO_2, Nitrogen and other non hydrocarbon substances. Sometimes called Wet Gas.

Ethane
C_2H_6
Flammable, Colourless. odourless
Asphyxiant

Flash Point	-125°C
Boiling Point (at atmospheric pressure)	-89°C
Relative Vapour Density	1.05

Ethane is not a common cargo. It is usually injected back into LNG or is used as a fuel for generators on platforms or shore installations. It is included here since it is an important component of LNG.

LPG (Liquefied Petroleum Gas)
Propane and Butane comes from
1. Oil processing in refineries.
2. Natural gas or crude oil streams.



Propane (C3)
C_3H_8
Flammable, Colourless, odourless (may be stenched)
Aspyxiant

Flash Point	-105°C
Boiling Point (at atmospheric pressure)	-42°C
Relative Vapour Density	1.55

Butane (C4)
C_4H_{10}
Flammable, Colourless, odourless (may be stenched)

Aspyxiant Flash Point	-60°C
Boiling Point (at atmospheric pressure)	-0.5°C
Relative Vapour Density	2.0

C3 and C4 are commonly used as a portable fuel

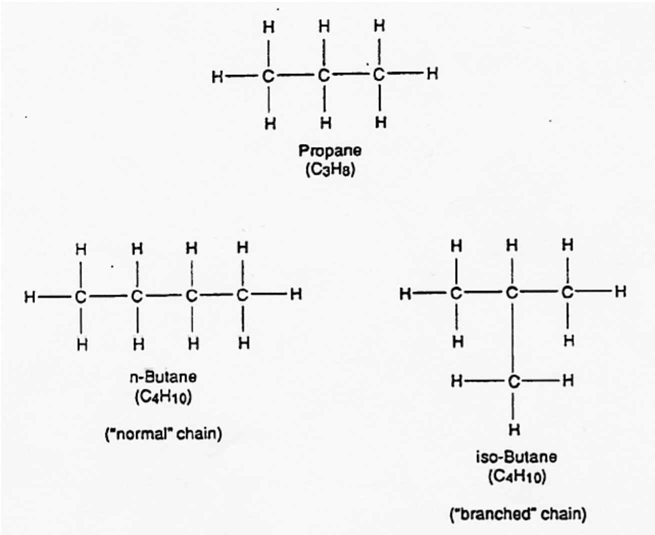
LEG (Liquefied Ethylene Gas)
Ethylene is not found naturally but is produced from the cracking of Naphtha, Ethane or Propane.

Ethylene
C_2H_4
Flammable, Colourless, faintly sweet odour
Aspyxiant

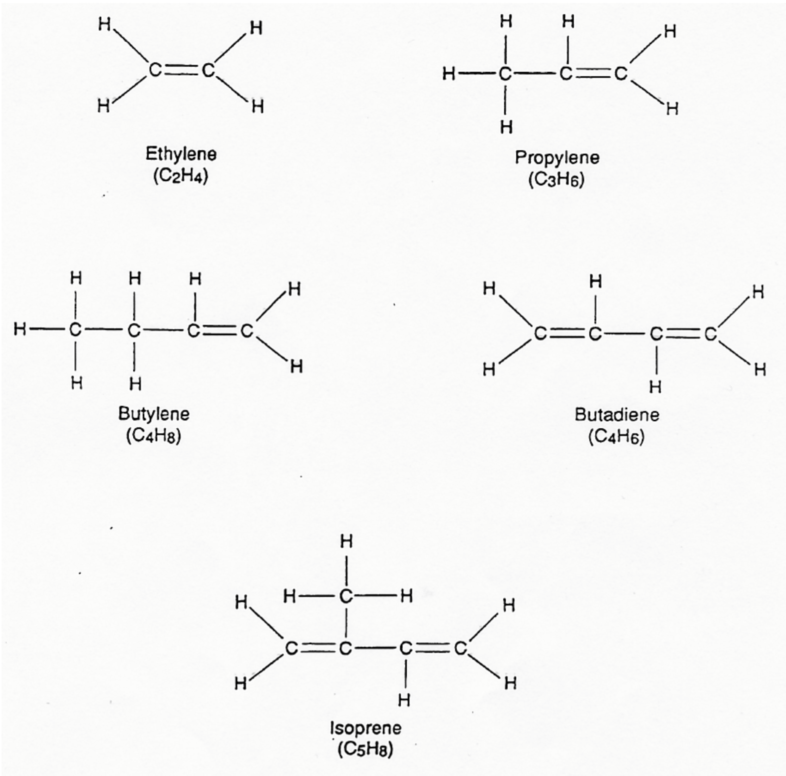
Flash Point	-150°C
Boiling Point (at atmospheric pressure)	-104°C
Relative Vapour Density	0.98

Used as a raw material in the production of plastics, polyethylene foam, styrene etc.

Saturated and Unsaturated Hydrocarbons
For example Methane, propane and butane.



An unsaturated hydrocarbon



Chemical Gases
These contain molecules other than hydrogen and carbon.
Examples of common cargoes are

Ammonia
NH_3
Toxic
Colourless, pungent, suffocating odour

Flash Point	-75°C
Boiling Point (at atmospheric pressure)	-33°C
Relative Vapour Density	0.6

Used for production of fertilizers.

VCM (Vinyl Chloride Monomer)
C_2H_3Cl
Flammable and Toxic
Colourless, pleasant sweet odour

Flash Point	-77°C
Boiling Point (at atmospheric pressure)	-14°C
Relative Vapour Density	2.15

Used in the production of plastics

All of the above cargoes are carried as a liquid by means of refrigeration, pressurisation, or partial refrigeration and pressurisation.

Regulations

Gas Carrier Code

Gas carriers are required to comply with all normal shipping related regulations such as SOLAS, MAPROL, STCW, Loadlines, etc. In addition due to the hazardous nature of the cargoes they carry they must also comply with the IGC code.

Note that from 1986 onwards the code is mandatory. Chapter 7 of SOLAS, carriage of dangerous goods, requires all gas carriers to comply with the code.

Before 1986 compliance is voluntary, however without the certificate of fitness which shows compliance with the code the vessel is unlikely to be chartered or admitted to most ports so compliance is virtually forced upon owners and operators.

IMO Codes

Age of Ship	Code that Applies and Certificate Issued
Pre Oct 1976	The code for existing ships carrying liquefied gases in bulk.
	Certificate
	Certificate of fitness for the carriage of liquefied gases in bulk for existing ships.
Oct 1976 - June 1986	The code for the construction and equipment of ships carrying liquefied gases in bulk. Known as the GCC Code.
	Certificate
	Certificate of fitness for the carriage of liquefied gases in bulk.
July 1986 - Sept 1994	The International code for the construction and equipment of ships carrying liquefied gases in bulk. Known as the IGC code.
	Certificate
	International certificate of fitness for the carriage of liquefied gases in bulk. Known as the IGC code.
Oct 1994 – to date	The International code for the construction and equipment of ships carrying liquefied gases in bulk 1993 edition.
	Certificate
	International certificate of fitness for the carriage of liquefied gases in bulk.

Surveys

For full details of the surveys required for gas carriers refer to IGC 1.5

The following extracts are taken from the code.

1.5.2 **Survey requirements**

1.5.2.1 The structure, equipment, fittings, arrangements and material (other than items in respect of which a Cargo Ship Safety Construction Certificate, Cargo Ship Safety Equipment Certificate and Cargo Ship Safety Radiotelegraphy Certificate or Cargo Ship Safety Radiotelephony Certificate is issued) of a gas carrier should be subjected to the following surveys:

.1 An **initial survey** before the ship is put in service or before the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk is issued for the first time, which should include a complete examination of its structure, equipment, fittings, arrangements and material in so far as the ship is covered by the Code. This survey should be such as to ensure that the structure, equipment, fittings, arrangements and material fully comply with the applicable provisions of the Code.

.2 A **periodical survey** at intervals specified by the Administration, but not exceeding 5 years which should be such as to ensure that the structure, equipment, fittings, arrangements and material comply with the applicable provisions of the Code.

.3 A minimum of one **intermediate survey** during the period of validity of the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk. In cases where only one such intermediate survey is carried out in any one certificate validity period, it should be held not before 6 months prior to, nor later than 6 months after, the half-way date of the certificate's period of validity. Intermediate surveys should be such as to ensure that the safety equipment, and other equipment, and associated pump and piping systems comply with the applicable provisions of the Code and are in good working order. Such surveys should be endorsed on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk.

.4 A mandatory **annual survey** within 3 months before or after the anniversary date of the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk which should include a general examination to ensure that the structure, equipment, fittings, arrangements and materials remain in all respects satisfactory for the service for which the ship is intended. Such a survey should be endorsed in the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk.

.5 An **additional survey**, either general or partial according to the circumstances, should be made when required after an investigation prescribed in 1.5.3.3, or whenever any important repairs or renewals are made. Such a survey should ensure that the necessary repairs or renewals have been effectively made, that the material and workmanship of such repairs or renewals are satisfactory; and that the ship is fit to proceed to sea without danger to the ship or persons on board.

Once surveyed it is a requirement that the vessel and its equipment should be maintained so as to continue to comply with the code. No changes to anything which falls within the survey is permitted without the agreement of the flag state administration. Any accident or defect which affects anything subject to survey should be reported to the flag state administration at the earliest opportunity.

Duration and validity of the certificate (See IGC section 1.5.6)

1.5.6.1 An International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk should be issued for a period specified by the Administration which should not exceed 5 years from the date of the initial survey or the periodical survey.

1.5.6.2 No extension of the 5 year period of the certificate should be permitted.

1.5.6.3 The certificate should cease to be valid:

.1 if the surveys are not carried out within the period specified by 1.5.2;

.2 upon transfer of the ship to the flag of another State. A new certificate should only be issued when the Government issuing the new certificate is fully satisfied that the ship is in compliance with the requirements of 1.5.3.1 and 1.5.3.2. Where a transfer occurs between Contracting Governments, the Government of the State whose flag the ship was formerly entitled to fly should, if requested within 12 months after the transfer has taken place, as soon as possible transmit to the Administration copies of the certificates carried by the ship before the transfer and, if available, copies of the relevant survey reports.

Hazards

Health

Asphyxia

Occurs when the blood cannot take a sufficient amount of Oxygen to the brain.
A reasonably fit person can survive in an atmosphere containing 19.5% Oxygen. Below this level there will be an impairment of activity and a loss of reasoning power. The victim may not recognise this. Below 16% unconsciousness occurs. Lower still and the level of unconsciousness deepens to the point at which breathing stops.

Toxicity

The ability of a substance to cause damage to living tissue, or impairment of the central nervous system, causing illness or death.

Effects of a toxic vapour are irritation to the lungs, throat, skin and eyes.

If the vapour has a narcotic effect, this will effect the nervous system and cause a loss of consciousness and even death.

Toxic effects can be either

LOCAL	At the point of contact
or	
SYSTEMIC	Throughout the body
ACUTE	The immediate effect
or	
CHRONIC	The long term effect

Routes of entry into the body

1. Ingestion – Although ingestion appears unlikely it can occur if the victim is splashed in the face with liquid. This has happen when a connection breaks. A weak connection is common when taking liquid samples from the line with a pump running on re-circulation.

2. Skin Contact – Absorption through the skin is unlikely with gas ship cargoes, however many LPG ships are fitted with a tank of Methanol which is used for de-icing pumps. Methanol is absorbed through the skin and is toxic.

3. Inhalation – The most likely route of entry since the liquids will turn to vapours when released to atmosphere.

Exposure Levels

How much of a gas an individual should be exposed to is defined most commonly as the Threshold Limit Value or TLV. This is defined as the concentration of gas in air to which personnel may be exposed 8 hours per day or 40 hours per week day after day without adverse effects.

Other terms are commonly used. The most common of these are :

- Time Weighted Average (TWA) which is the same as the definition of TLV

- Short Term Exposure Limit (STEL) a figure higher than the TLV or TWA to which an individual can be exposed for a maximum of 15 minutes, up to 4 times per day provided there is a break of at least one hour between exposures. Not given for all gases.

- Ceiling Limit. This figure should never be exceeded and is quoted for the most toxic cargoes only whose action on the body is rapid.

The figures quoted are not a dividing line between safe and hazardous, they are only a guide. Some people will be affected by lower quantities than others. The best practice is to keep as far below these figures as possible.

The information given in the Tanker Safety Guide (Liquefied Gas) is based on US and UK authority figures. Note that these were current only when the guide was published. The figures are reviewed annually in most countries. For example VCM has dropped from 10ppm to 1ppm. It is important to check the most up to date information available. This is often available through data sheets which can be found on the internet.

Cold Burns

Skin contact with materials that are very cold will cause similar damage to skin tissue as contact with materials that are very hot.

There will be associated pain, confusion, shock and possible fainting. Refer to the Medical First Aid Guide (MFAG) now contained within the supplement to the IMDG Code for specific treatment requirements.

Some cargoes will cause a chemical burn in addition to the cold burn, i.e. Ethylene Oxide Ammonia and Chlorine. Reference to the MFAG should be made for individual cargoes. Note at the time of writing the data sheets in the Tanker Safety Guide (Liquefied Gas) and the table in chapter 19 of the IGC give reference numbers to tables in the old MFAG. These references are not correct for the new MFAG in the supplement to the IMDG code.

Hazards - Flammability

For a cargo fire or explosion to occur, there must be appropriate amounts of Oxygen and Cargo Vapour and a Source of Ignition.

The amount of vapour produced by a liquid depends on how volatile the liquid is.

Volatility
The tendency of a liquid to evaporate. The more volatile the liquid the more vapour that may be present and hence the possible hazards of fire and toxicity. Volatility is measured usually measured by one of the following:

- Flash Point (usually by the Closed Cup method)
- Vapour Pressure (usually Reid Vapour Pressure for Oil cargoes, Saturated Vapour Pressure at 20°C for Chemicals)
- Boiling Temperature at Atmospheric Pressure (Gas cargoes)

NOTE: Reid Vapour Pressure (RVP) is expressed in psia at 100°F (37.8°C).

Evaporation
Occurs at the surface of a liquid when molecules with sufficient energy to break free from the intermolecular attractive force that holds them together leave the liquid and become a vapour. Since molecules with high energy levels are leaving the liquid, the overall energy within the body of the liquid is now less. We see this drop in energy as a drop in temperature. Lowering the temperature of a liquid by allowing it to evaporate is the way in which gas ship cargoes are kept cold. The vapour produced by this process is usually reliquefied and returned to the tank as a cold liquid. (Note it is the evaporation process which cools the cargo not the returning of cold liquid to the tank). LNG ships are not currently fitted with reliquefaction plants and the vapour produced by evaporation is burnt as fuel in the ships boilers.

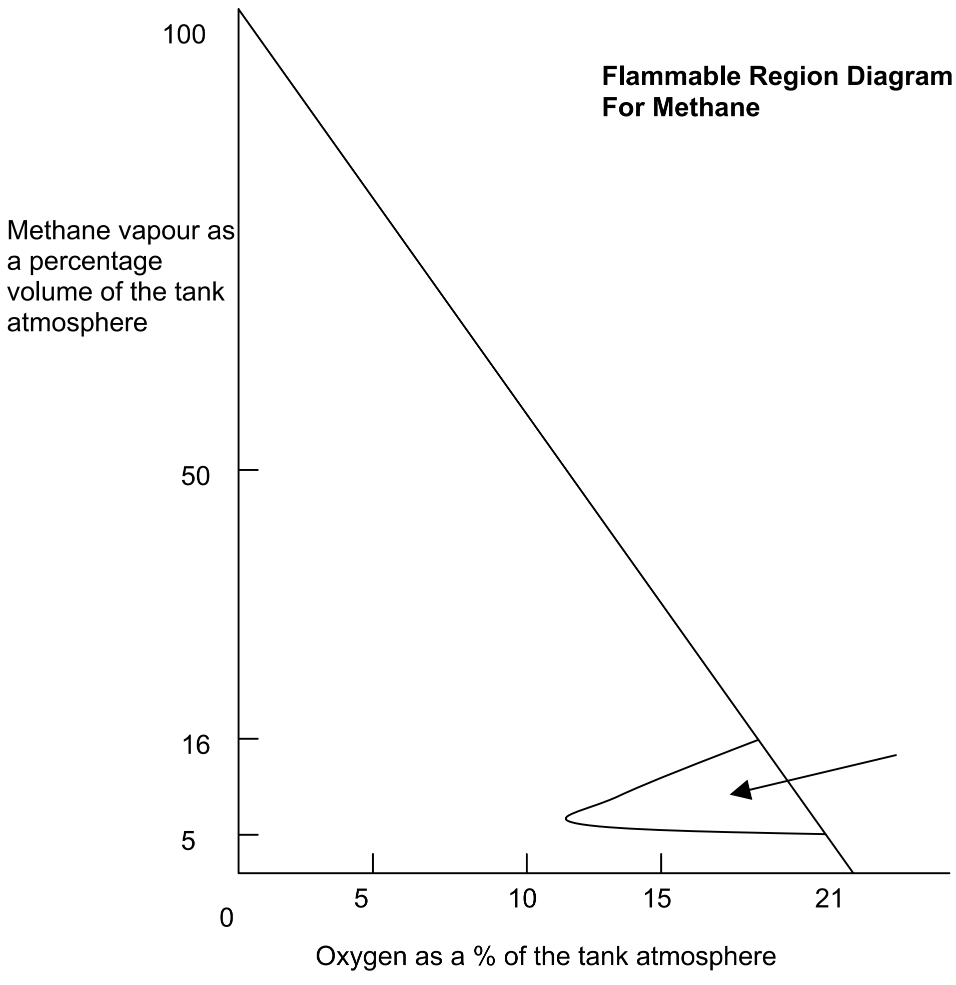
Factors affecting the rate of evaporation

- Temperature
- Surface Area
- Turbulence
- Saturation of the Atmosphere

Evaporation occurs only at the surface of a liquid
Evaporation occurs at all temperatures
Evaporation is greatest at the boiling temperature

Flammable Mixtures
Flammable gases can be ignited and will burn only when mixed with air in certain proportions. If there is too little or too much vapour, the mixture cannot burn. The limiting proportions expressed as percentage by volume of vapour in air are known as the LOWER and UPPER FLAMMABLE LIMITS (LFL and UFL). Note they are sometimes referred to as the Upper and Lower Explosive Limits (LEL and UEL)

For the gas mixtures from the Petroleum liquids encountered in oil tanker practice, the flammable range is from a minimum LFL of about 1% gas by volume in air, to a maximum UFL of about 10% gas volume in air.
For gas tanker (and chemical tanker) cargoes the flammable limits for each cargo can vary considerably. The information can be found in the cargo data sheets in the Tanker Safety Guide (Liquefied Gas).



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. Flash point can be measured as closed cup or open cup. Closed cup gives the lowest reading and is usually quoted.

Volatile and Non-Volatile
Because of the wide range of flash points and vapour pressures found in flammable cargoes there are many different classification systems. The International Safety Guide for Tankers and Terminals (ISGOTT) uses the following definitions which generally used:

Volatile: flash point below 60°C

Non–Volatile: flash point 60°C or above

	Primary Hazard	LFL	UFL	Atmospheric Boiling Point	Unsuitable Materials
Propane	Flammable	2	10	-42	Mild Steel <0°C
n-Butane	Flammable	1.5	9	-0.5	Certain Plastics
Methane	Flammable	5	16	-161	Mild Steel
Ammonia	Toxic	15	30	-33	Zinc, Copper, Aluminium etc
Ethylene	Flammable	2.5	34	-104	Steel
Propylene	Flammable	2	12	-47	Mild Steel, Natural Rubber
Butadiene	Flam + Tox	1	12.5	-5	Copper, Silver, Al
VCM		4	31	-14	Al alloys, Copper

Hazards – Low Temperature

Most metals and alloys (except aluminium) become brittle at low temperatures. For parts of the cargo system exposed to low temperatures such as tanks and pipes selection of the correct steel is important. For temperatures down to –55°C fully killed, fine grain, carbon-manganese steels are used. These are commonly referred to as arctic steel. For the lower temperatures ranges for vessels carrying ethylene (-104°C) or LNG (-163°C) high nickel content steels, stainless steel or aluminium is used.

- Mild Steel down to
- Arctic Steel down to
- Austenitic Stainless Steel, Aluminium, Invar, down to

In the event of a spill

- If the spill is on deck isolate the source. If there is risk of brittle fracture to the deck flood the deck with water. Note that this will produce a large vapour cloud so the risks of ignition and toxic vapours will have to be considered. Note that LNG vessels have a water curtain running continuously across the deck in way of the manifold area from before manifold blanks are removed until they are secured again to protect the deck.
- If the spill is in the drip tray, allow it to boil off naturally. Note that initially the liquid will boil vigorously, but when heat from the surroundings has been consumed the boiling will stop. At this time the liquid will look like water. Keep personnel away until the remaining liquid has evaporated.
- If the spill is on the water around the vessel large quantities of vapour will be produced very quickly. This will appear as a large white cloud which is the water vapour in the air condensing at the low temperatures.

Cooldown

Cargo tanks used for low temperature cargoes have to be cooled down prior to loading. This operation is usually detailed in the ship's operating manual. It is important to observe any cooldown restrictions such as 10°C per hour or limitations on the maximum difference between top and bottom temperatures within a tank to avoid excessive thermal stress.

Cargo pipelines may also have to be cooled slowly. This is particularly important on LNG vessels where the line cooldown operation before loading and discharging usually takes about one hour to complete. Terminals often required loading arms to be cooled slowly before increasing to the maximum agreed rates.

Rollover

Rollover is a temperature related problem. The problem has occurred in a shore storage tank containing LNG. The LNG at the surface evaporates and leaves a layer near the surface whose density increases as the lighter fraction, Methane, evaporates. The bulk of the liquid cannot evaporate and warms slightly as heat leaks in through the insulation. As it expands its density reduces. Eventually the instability of a dense layer on top of a less dense body of liquid cannot be maintained and the surface layer rolls over to the bottom. The warmer body of liquid suddenly evaporates releasing large volumes of vapour which can be more than the relief valves can deal with. This is unlikely to occur on a ship due to constant ship motion. However if a anchor for a long period of time observation of temperatures within the liquid would give a warning of layers forming.
To prevent the problem occurring,

The Tanker Safety Guide (Liquefied Gas) also highlights a similar issue when mixing propane and butane together in a ships tank. The Tanker Safety Guide (Liquefied Gas) recommends that this practice is not carried out unless there has been a thorough thermodynamic analysis of the process.

Hazards – Reactivity

Reference Tanker Safety Guide (Liquefied Gas) 1.4

With water – hydrate formation. Hydrates which resemble crushed ice or slush can block pumps valves or other equipment. The water can come from not drying the tanks properly before loading, changing tank atmospheres with incorrect dew points, water in the cargo system or water dissolved in the cargo (this is most common with LPG cargoes).

Self reaction – polymerisation. Usually affecting certain unsaturated cargoes with double bonds. Can be triggered by heat, small quantities of other cargoes, air or certain metals. Polymerisation can be slowed by the addition of an inhibitor. Most inhibitors are toxic. Inhibited cargoes should not be carried unless there is an inhibited cargo certificate which clearly states the life span of the inhibitor and action to take should the length of voyage exceed the life span of the inhibitor. Temperature trips on the cargo compressor are normally adjusted to be within the maximum temperature stated on the certificate.

Reaction with other cargoes. Data sheets will provide information. Where two different grades are carried physical segregation of the pipelines, usually by removing spool pieces is required. Care should be taken with the reliquefaction system to ensure there is chance of vapour contamination.

Reaction with air. Some cargoes such as butadiene can form unstable compounds when mixed with air which could explode. These are required to have tanks inerted with nitrogen before loading and in some cases to keep a nitrogen blanket over the cargo.

Reaction with other materials. Some cargoes are reactive with materials which may be found in a cargo system such as Ammonia which is reactive with copper and aluminium. Data sheets in the Tanker Safety Guide (Liquefied Gas) give information. Care is required when spare parts are ordered. Ensure the material is suitable for all cargoes the vessel is certified to carry not just the current cargo.

Hazards – Pressure

Liquefied gases have the potential to produce very high pressures even at ambient temperatures in some cases. Refer also to the Tanker Safety Guide (Liquefied Gas) chapter 1 for more information.

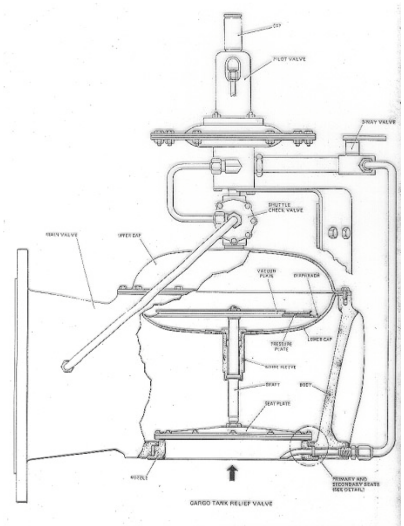
Some pressure related issues;

Cargo tanks. Normally maintained above atmospheric pressure although some pressure vessels can withstand a vacuum for some atmosphere changing operations. Depending on the tank type the maximum pressure can be relatively low for example 0.25 barg is common. Interbarrier space on membrane type LNG ships must be carefully monitored especially during cooldown and warm up operations where pressures can change quickly. Excessive pressure in the interbarrier space has blown the membrane off the insulation in the past resulting in expensive repairs.

Cargo tanks are protected by pressure relief valves. On high pressure tanks they are simple spring loaded valves however on low pressure tanks they are usually pilot operated relief valves. These valves have a poor reputation for re-seating after they have opened resulting in leaking valves constantly discharging small quantities of flammable and or toxic vapour from the vent mast. It is important not to let them lift during cargo operations and this is best achieved by not allowing the tank pressure to approach the relief valve setting. SIGTTO have produced a guide to the operation and maintenance of these valves.

Cargo tank pressure relief valves are covered in the IGC chapter 8.

- Tanks greater than $20m^3$ are required to have two relief valves fitted. (IGC 8.2.1)
- Some relief valves can have different settings. If the setting is changed then it must be under the supervision of the master and in accordance with procedures approved by the flag state. The event must be recorded in the ship's log and a sign posted in the cargo control room. (IGC 8.2.7)
- Vacuum protection is required for most tanks but it is usually in the form of two independent pressure switches to stop cargo pumps and reliquefaction machinery. (IGC 8.4.2) Vacuum relief valves are permitted and should admit inert gas, cargo vapour or air to the tank.



CARGO TANK RELIEF VALVE

Pressure surge. Sudden increase in the pressure within a pipeline caused by a rapid change in liquid velocity within the pipeline. Normally the pressure within a pipeline comes from static and dynamic forces.

Static forces

Hydrostatic pressure
Product vapour pressure.

Dynamic forces

Rapid deceleration of the liquid by closure of a valve or filling of a dead end of pipeline. The kinetic energy of the moving liquid is converted into strain energy by compression of the liquid and stretching of the pipeline.

Cessation of flow is transmitted back up the pipeline at the speed of sound in the liquid.

The size of the pressure surge depends on the density of the liquid, the rate of deceleration, the speed of sound in the liquid and the length of the pipeline.

Severe damage has occurred to pipelines both ashore and on the ship not only because of valves slamming shut, but also because of empty lines with dead ends being filled too quickly. Even opening a valve to relieve the pressure caused by liquid trapped in a section of line, has caused severe structural damage due to the rapid acceleration of the liquid and it's sudden deceleration when it filled an empty section of pipeline.

Cargo Pipelines. It is possible to trap liquid or vapour in the cargo pipelines by isolating sections of the line with closed valves. Any such sections of line should be protected by a relief valve. Liquid lines should relieve back to a cargo tank although they may go to a vent mast provided there is a means to remove any liquid.

CHEMISTRY AND PHYSICS

Syllabus

Structure of an atom
Atoms in combination, molecules.
Inorganic chemistry.
Ammonia, production and use.
Chlorine
Nitrogen
Organic chemistry
Alkanes, Methane, Odorisers
Alkenes, Ethene
Polymerisation, plastics, Inhibitors.
Butadiene, VCM, Ethylene Oxide
Freons

Molecules on the move.
Gas laws.
Vapour density,
Relative vapour density
Condensation
Liquids, density, viscosity.
Vapour pressure
Vapour pressure of gas mixtures.

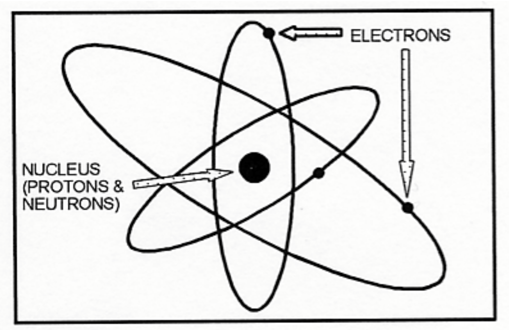
BASICS OF CHEMISTRY

ATOMS contain **PROTONS, NEUTRONS** and **ELECTRONS.**

Protons carry a positive electrical charge. They have a "Relative Mass" of approximately one unit.
Neutrons do not carry an electrical charge. They have a "Relative Mass" of approximately one unit.
Electrons carry a negative electrical charge. They have almost no Mass.

MOLECULES may consist of one or more Atoms of a single **ELEMENT**, or Atoms of more than one Element, chemically combined into a **COMPOUND.**

Normally Protons and Electrons will be in equal numbers in an Atom or Molecule, an imbalance will make it a "charged particle" such as an **ION.**



ATOM.

The **ATOMIC NUMBER** is the number of Protons (and Electrons) in an Atom. The **RELATIVE ATOMIC/MOLECULAR MASS** is the number of Protons plus Neutrons in an ATOM/ MOLECULE. Electrons may be considered as occupying different energy levels. An Atom or Molecule will have its lower energy levels filled before higher levels become occupied.

The lowest energy level can hold 2 electrons.
The second energy level can hold 8 electrons, total 10.
The third energy level can hold 18 electrons, total 28.
The fourth energy level can hold 32 electrons, total 60.

An ELEMENT with 8 electrons in its highest energy level is comparatively stable: Examples Helium (He, 2 electrons), Neon (Ne, 10 electrons), Argon (18), Krypton (36). These are the first four "**Inert Gases**", so called because, having complete shells of electrons, they don't react with anything. (This is nothing to do with Inert Gas in Tankers, which is just something that won't support combustion).

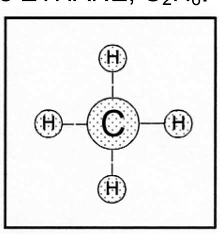
COMPOUNDS are chemical combinations of elements in fixed proportions, e.g.: Salt is made from one Sodium atom (10+1 electrons) and one Chlorine atom (18-1 electrons). They are joined by an **IONIC BOND** and form an Ionic Compound of a Sodium Ion with 10 Electrons and a Chlorine Ion with 18.

CARBON forms a different type of Bond called a **COVALENCY BOND.** Carbon has 6 electrons, and within two electron shells it can therefore combine with atoms supplying 4 more electrons. The study of Carbon compounds is called **ORGANIC CHEMISTRY.**

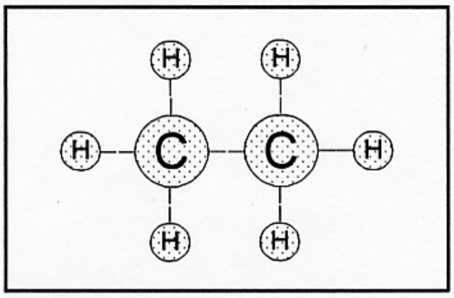
Unlike most other Elements, Carbon atoms can join together with each other. (Some gas atoms such as Hydrogen, Oxygen, and Nitrogen normally exist in pairs: H_2, O_2, N_2).

The simplest **SATURATED ALKANE HYDROCARBON** is METHANE, CH_4.

The next compound in the Alkane series is ETHANE, C_2H_6.



Methane.



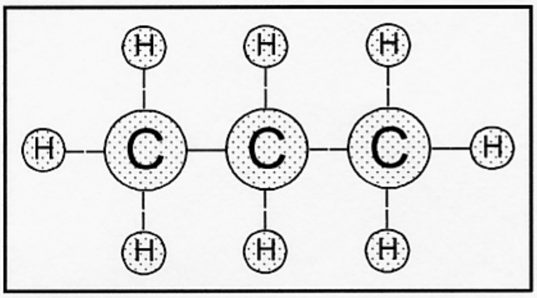
Ethane.

Oil Tanker Cargoes

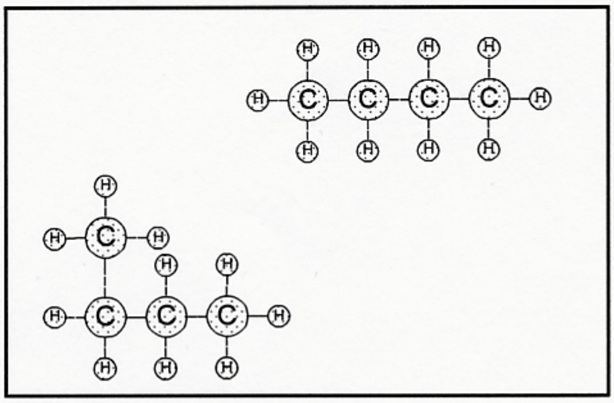
Oil cargoes are **MIXTURES** containing many different hydrocarbons, mostly from the Alkane series, but also Aromatics like BENZENE, C_6H_6, which is linked in a different way.

Gas Tanker Cargoes

LNG is mostly Methane. LPG cargoes include PROPANE (C_3H_8) and BUTANE, (C_4H_{10})

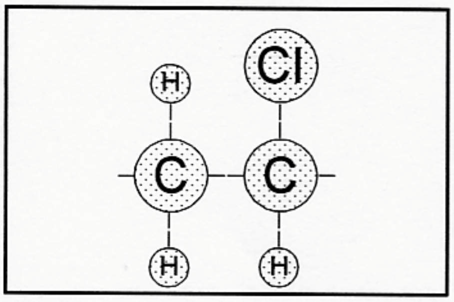


Propane.

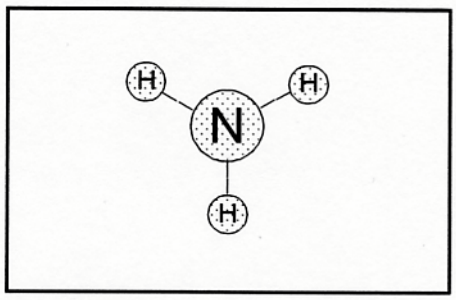


Butane.

Some LPG ships can also carry cargoes such as VINYL CHLORIDE MONOMER (C_2H_3Cl) and AMMONIA (NH_3)



VCM



Ammonia.

PERIODIC CHART OF THE ELEMENTS

(Atomic weights are based on carbon-12.)

Period	GROUP I	II											III	IV	V	VI	VII	Noble Gases
1	1 H 1.01																	2 He 4.00
2	3 Li 6.94	4 Be 9.01											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
3	11 Na 23.00	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 31.00	16 S 32.06	17 Cl 35.45	18 Ar 39.95
	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.71	29 Cu 63.55	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.90	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rh 102.90	46 Pd 106.4	47 Ag 107.88	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.30
6	55 Cs 132.90	56 Ba 137.34	*57 La 138.91	72 Hf 178.49	73 Ta 180.95	74 W 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09	79 Au 196.97	80 Hg 200.59	81 Tl 204.37	82 Pb 207.19	83 Bi 208.98	84 Po (210)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	**89 Ac (227)	104														

* Lanthanide Series 6	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (147)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.92	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
** Actinide Series 7	90 Th 232.04	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (242)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (253)	101 Md (256)	102 No (254)	103 Lr (257)

GAS LAWS

Boyle	1661	$V \propto 1/P$ (T constant)
Gay Lussac	1802	$V \propto T$ (P constant)
Avogadro		$V \propto n$ (P and T constant)

Ideal Gas Law:

$PV = nRT$

Where $R = 8.314\ J\ mol^{-1}\ K^{-1}$

Example

A tank contains $30m^3$ of a gas at a pressure of 1.0 atm and a temperature of -120°C.
How much gas is there in the tank?

If we assume ideal gas behaviour then

$n = (PV)/(RT)$

$P = 1.0\ atm = 1.013\ bar = 1.013 \times 10^5\ Nm^{-2}$

$V = 30\ m^3$

$T = 153\ K$

$n = (1.013 \times 10^5 \times 30) / (8.314 \times 153)$

$= 2.39 \times 10^3$ mole

1 mole of Methane has mass 16 g

Therefore Mass in tank $= 2.39 \times 10^3 \times 16$

$= 3.82 \times 10^4$ g

$= 38.2$ kg

Vapour Density

What is the density of Methane gas at 4 bar pressure and -100°C?
The RMM of Methane is 16.

First find how many moles there are in $1m^3$.

$n = (PV) / (RT)$

$P = 4 \text{ bar} = 4 \times 10^5 \text{ Nm}^{-2}$

$V = 1 \text{ m}^3$

$R = 8.134 \text{ J mol}^{-1} \text{ K}^{-1}$

$T = -100°C = 173 \text{ K}$

$n = (4 \times 10^5 \times 1) / (8.314 \times 173)$

$= 278$ mole

Each mole has mass 16 g

Therefore the mass of Methane in 1 m^3 = 278 x 16 = 4440 g

= 4.44 kg

Therefore Vapour Density = 4.44 kg m^{-3}

LIQUIDS

Density

Most liquids expand on heating. Therefore density goes down as temperature goes up.

e.g. Pure ethyl alcohol:

t/°C	**d/kg m^{-3}**
0	806
10	798
20	789
30	781

Water is unusual

t/°C	**d/kg m^{-3}**
0	999.8
4	1000.0
10	999.7
25	997.1
100	958.4

Relative Liquid Density (Formerly specific gravity)

This is the density of the liquid compared to that of water. Two temperatures should be quoted, first that of the liquid and second that of the water.

e.g. Pure ethyl alcohol.

Relative liquid density = 0.806 @ 0°C/4°C
= 0.789 @ 20°C/4°C
= 0.791 @ 20°C/25°C

Viscosity of Liquids

As temperature rises viscosity falls.

Water

t/°C	Abs.visc./cP	d/g cm^{-3}	Kin.visc./cS
0	1.7921	0.9998	1.7925
4.0	1.5674	1.0000	1.5674
10	1.3077	0.9997	1.3081
20.2	1.0000	0.9982	1.0018
25	0.8937	0.9971	0.8963
100	0.2838	0.9584	0.2961

Ethyl Alcohol

t/°C	Abs.visc./cP	d/g cm^{-3}	Kin.visc./cS
0	1.773	0.806	2.200
10	1.466	0.798	1.837
20	1.200	0.789	1.521
30	1.003	0.781	1.284

Kinematic Viscosity = Absolute viscosity / Density.

Vapour Pressure of Mixtures

Even with extremely good insulation, heat will still be transferred from the surroundings to the liquid cargo. This will cause evaporation. Ideally we would condense all of the vapour produced and return it to the main cargo.

In the case of cargo consisting of only one component, then the vapour will also consist of only that one component. For example, if the cargo is pure propane, then the vapour will also be pure propane. This vapour can be condensed at a temperature of –42°C and returned to the main cargo.

If the cargo is a mixture, such as ethane and propane, then the vapour will **not** have the same composition as the liquid from which it came. The temperature required to condense this vapour will be much lower than that of the main tank. It is possible to calculate the composition of the vapour, and the temperature required to condense it completely. The calculations depend upon the work of Avagadro and Dalton in the early years of the 19th century and of Raoult in 1888.

Raoult's Law states that the partial pressure of a component in the vapour is proportional to its mole fraction in the liquid.

$p = xp_o$ where p is the partial vapour pressure of the component,
x is the mole fraction of the component in the liquid mixture, and
p_o is the saturated vapour pressure, SVP, of the pure component.

To calculate the composition of the vapour, we use the work of Avogadro and Dalton which led to the equation: $y = p / P$ where y is the mole fraction of a component in the vapour, and P is the total pressure of the vapour, and p is the partial pressure vapour of the component.

Example

Suppose a cargo consists of 60 mole % of propane, and 40 mole % of n-butane, carried at a pressure of 1 atmosphere absolute. The temperature of this liquid will be about –33°C.

(1)	(2)	(3)	(4)	(5)
Component	Mole fraction in mixture	SVP of component at –33°C in kPa	Partial pressure of component at –33°C in kPa	Composition of vapour (Partial pressure / SVP of mixture)
	x	p_o	p	y
Propane	0.6	150	90	0.9
n-Butane	0.4	25	10	0.1
	1.0		P = 100	1.0

Raoult's law is used in calculating column (4) from columns (2) and (3). Avogadro's and Dalton's laws are used in calculating column (5) from (4).

We now see that the liquid which contained 60 molecules of propane in every 100 molecules of liquid, has produced a vapour which contains 90 molecules of propane in every 100 molecules of vapour. This is reasonable, because propane is more volatile than n-butane.

Now we put this vapour through the refrigeration system to condense it completely back to a liquid. Obviously this liquid will have the same composition as the vapour from which it condensed. To find the temperature needed, we again use Raoult's equation. We have to guess the temperature, look up the vapour pressures, and calculate the partial pressures. If these add up to more than 101kPa, then the guess is too high.

Try –40°C

Component	SVP, p_o at –40°C	Mole fraction x	Partial pressure, p kPa
Propane	110	0.9	99
n-Butane	18	0.1	1.8
		1.0	100.8

The total pressure, P, at 100.8 kPa is the required 1 atmosphere pressure so the guess was correct.

Summary

The liquid cargo is 60 mole% propane, and will be at –33°C
The vapour leaving the liquid will be at 90 mole% propane at about –33°C
The condensate will be 90 mole% propane at –40°C

A computer, and the appropriate software, would save a lot of time and headaches!

Calculation for Relative Molecular Mass of a Mixture

1	2	3	4	5	6
Gas Component	Percentage by Volume (V_i)	Moles per 100 mole of Mixture = V_i	RMM (M_i)	$\frac{M_i V_i}{100}$	Mass %
Methane	83.2	83.2	16.04	13.35	67.6
Ethane	8.5	8.5	30.07	2.56	13.0
Propane	4.4	4.4	44.09	1.94	9.8
n-Butane	2.7	2.7	58.12	1.57	7.9
Nitrogen	1.2	1.2	28.02	0.34	1.7
	100.0	100.0		19.76 (The mass of 1 mole, i.e. the RMM)	100.0

Conversion of Liquid Volume % to mole % & mole Fraction

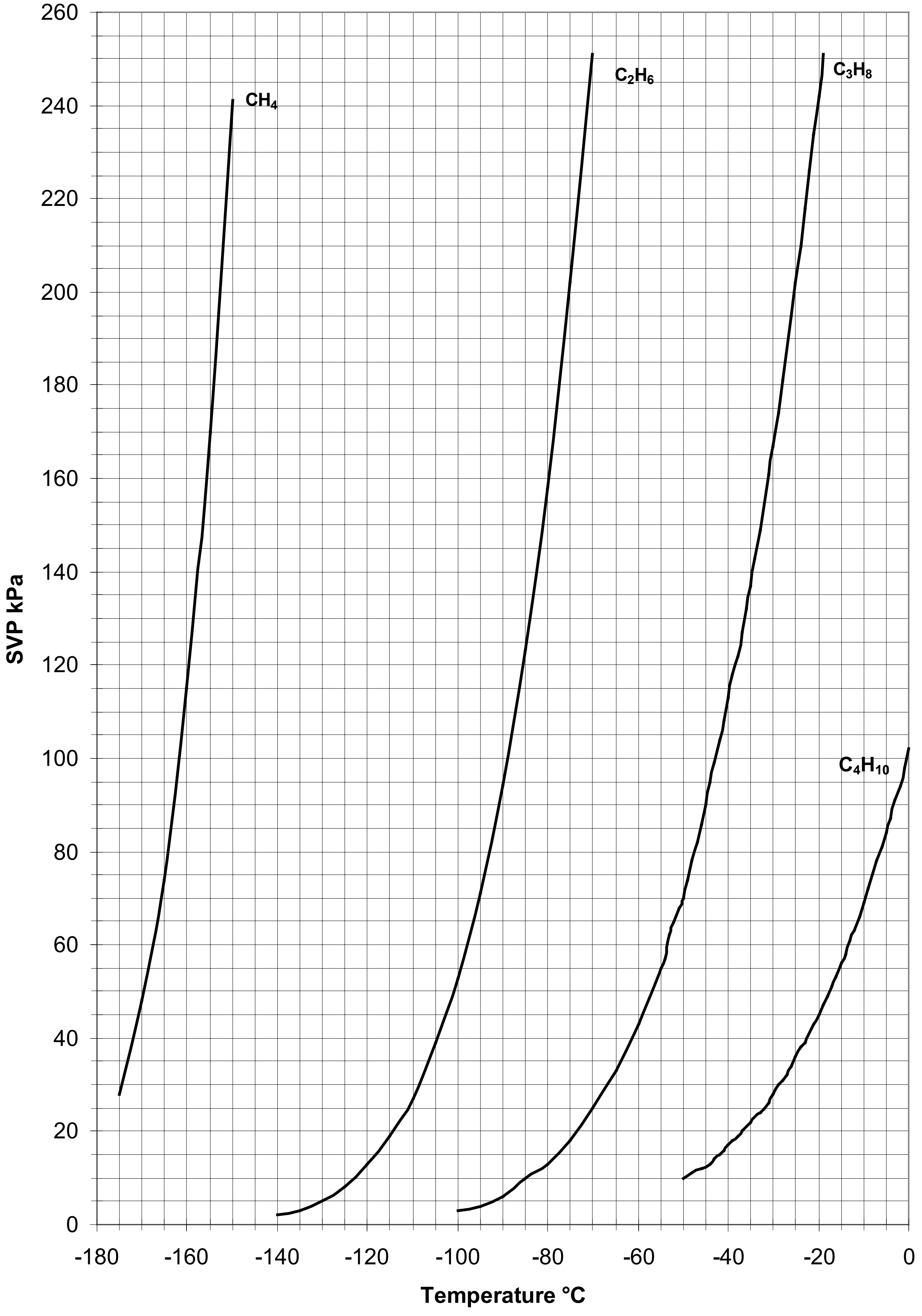
1	2	3	4	5	6	7	8
Component	Volume %	Volume m^3	Density kg m^{-3}	Mass kg	Kilo-moles	Mole %	Mole Fraction
Ethane	0.162	0.162	485	78.57	2.613	0.2	0.002
Propane	94.82	94.82	580	54995.6	1247.35	95.6	0.956
n-Butane	3.544	3.544	642	2275.25	39.15	3.0	0.030
i-Butane	1.474	1.474	617	909.46	15.65	1.2	0.012
	100	100			1304.76	100	1.000

Cargo of 60 mole % Propane, 40 mole % n-Butane

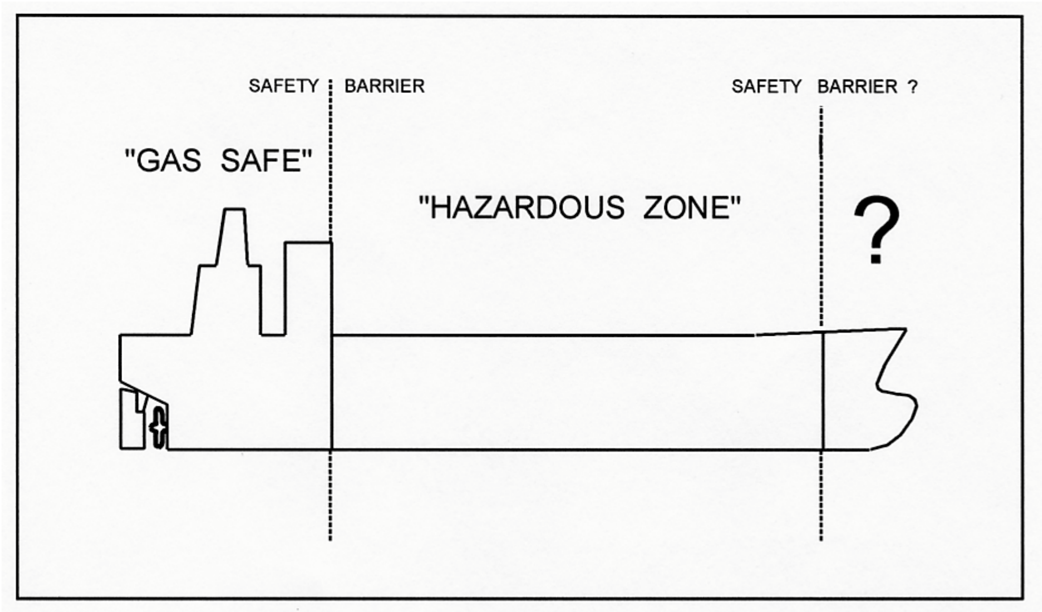
1	2	3	4	5
Component	Mole fraction in mixture	SVP of component at –33°C in kPa	Partial pressure of component at –33°C in kPa	Composition of vapour (partial pressure / SVP of mixture)
	x	p_o	p	y
Propane	0.6	150	90	0.9
n-Butane	0.4	25	10	0.1
	1.0		P = 100	1.0

1	2	3	4
Component	SVP, p_o at –40°C	Mole fraction x	Partial pressure, P kPa
Propane	110	0.9	99
n-Butane	18	0.1	1.8
		1.0	P = 100.8

Saturated Vapour Pressure Graph



Ship Design



Gas Dangerous Areas

Reference IGC Chapter 1.3 Definitions

(IGC) 1.3.17 Gas-dangerous space or zone is:

.1 a space in the cargo area which is not arranged or equipped in an approved manner to ensure that is atmosphere is at all times maintained in a gas-safe condition;

.2 an enclosed space outside the cargo area through which any piping containing liquid or gaseous products passes, or within which such piping terminates, unless approved arrangements are installed to prevent any escape of product vapour into the atmosphere of that space;

.3 a cargo containment system and cargo piping;

.4.1 a hold space where cargo is carried in a cargo containment system requiring a secondary barrier;

.4.2 a hold space where cargo is carried in a cargo containment system not requiring a secondary barrier;

.5 a space separated from a hold space described in .4.1 by a single gastight steel boundary;

.6 a cargo pump-room and cargo compressor room;

.7 a zone on the open deck, or semi-enclosed space on the open deck, within 3 m of any cargo tank outlet, gas or vapour outlet cargo pipe flange or cargo valve or of entrances and ventilation openings to cargo pump-rooms and cargo compressor rooms;

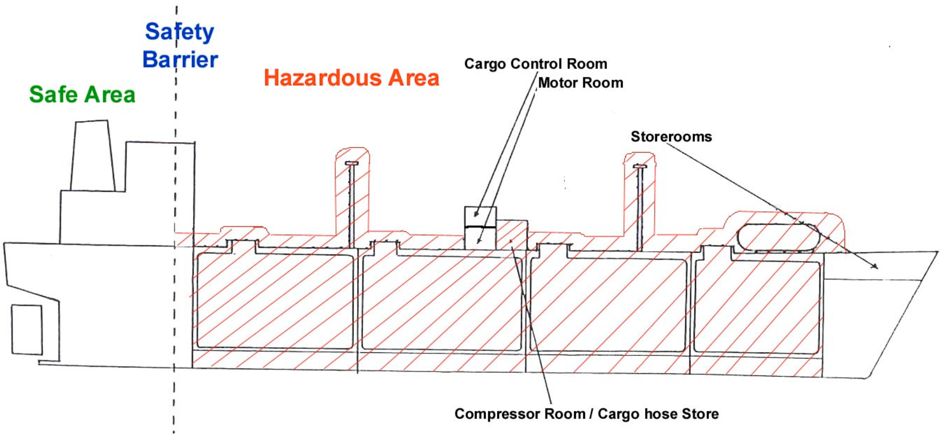
.8 the open deck over the cargo area and 3 m forward and aft of the cargo area on the open deck up to a height of 2.4 m above the weather deck;

.9 a zone within 2.4 m of the outer surface of a cargo containment system where such surface is exposed to the weather;

.10 an enclosed or semi-enclosed space in which pipes containing products are located. A space which contains gas detection equipment complying with 13.6.5 and a space utilising boil-off gas as fuel and complying with chapter 16 are not considered gas-dangerous spaces in this context;

.11 a compartment for cargo hoses; or

.12 an enclosed or semi-enclosed space having a direct opening into any gas-dangerous space or zone.



Gas Safe Area
Air and sources of ignition are present so the design must be capable of keeping out the gas by ensuring:

- There are no openings in the front of the accommodation or for 3m aft of the front
- Air intakes to the accommodation and engine room are as far aft and as high as possible
- All air inlets and exhausts with fire dampers which can be quickly closed
- The air conditioning can be operated on recirculation

Hazardous Area
Cargo vapour is present in the tanks and occasionally on deck when venting or in case of small leaks from valves. Air is present on deck and sometimes in the tanks. Prevention of a flammable atmosphere and a source of ignition at the same time must be controlled by ensuring:

- The cargo system is designed to operate as a closed system with no release of vapour or liquid during loading, measuring or sampling.
- There is never the possibility of a flammable vapour being present anywhere in the cargo system (Ref IGC 9.1)
- Venting of cargo vapour for gas freeing is only done in controlled circumstances when it is safe to do so
- There are no sources of ignition present on the deck in the defined hazardous area (use of approved electrical equipment)

The Safety Barrier
Is a notional concept forming the division between the gas safe areas of the engine room and accommodation spaces and the hazardous area on deck.

Focsle Area
If the entrance is within the bounds of the defined hazardous area then it is treated as part of that area. Even if it falls outside of the definition care should be taken to avoid the possibility of heavier than air hydrocarbon gases accumulating in this space.

Segregation of Cargo Area

Reference IGC 3.1 & 3.2 (Parts only are summarised here)

- Hold space must be segregated from machinery spaces, accommodation spaces, service spaces etc by a cofferdam. There are exceptions to this refer to the IGC. Hold spaces must be forward of the machinery room.
- When the cargo containment system requires a secondary barrier if the cargo temperature is below –10°C there should be a double bottom fitted. When the cargo temperature is below –55°C there should be a full double hull.
- Cargo piping must not enter accommodation or engine room spaces except when special precautions are taken as in the case of LNG ships.
- Ventilation intakes for gas safe areas should be located so as to minimise the chance of vapours being drawn in.
- Entrances, air inlets and openings to accommodation spaces should not face the cargo area. They should be located on the side of the accommodation at 4% of the length of the vessel but not less than 3m from the front of the accommodation. They need not be more than 5m from the front. Wheelhouse doors are permitted within these limits but must gas tight when closed. (USCG requires a hose test on these doors to prove tightness).
- All air intakes must have closing devises which can be closed from inside the space if toxic cargoes are carried.

Reference IGC 3.4 Cargo Control Rooms

- These may be located within the accommodation space or out on the weather deck.
- If located within the accommodation readings should as far as possible be by indirect means.
- If the fixed gas detector is located in the CCR there should be shut off valves outside the space to isolate it and the exhaust from the detector should be to a safe location outside the space. (IGC 13.6.5)

Reference IGC 3.5 Access to Cargo Tanks and Hold Spaces

- Must be provided so that personnel wearing protective clothing and SCBA can enter and allow an unconscious person to be removed
- The size of the opening into the space must not be less than 600 x 600mm
- Within the space lightening holes should be at least 600 x 800mm and not more than 600mm from the deck unless footholds are provided.

Compressor and Motor Rooms

Reference IGC 3.3 Cargo Compressor Rooms

- Compressor rooms must be located above the weather deck within the cargo area.
- For the purpose of fire protection they must be treated as cargo pump rooms in accordance with regulation II-2/58 of the 1983 SOLAS amendments.
- When the machinery is driven from the motor room there must be a gas tight gland around the shaft where it passes through the bulkhead.
- All valves and equipment for cargo handling must be readily accessible for personnel wearing protective clothing.
- There must be arrangements to deal with drainage of the compressor room.

Reference IGC 3.6 Airlocks

- Only permitted between a gas dangerous zone on the weather deck and a gas safe space (such as the motor room). Should consist of two steel doors between 1.5 and 2.5 m apart.
- The doors must be of closing with no holding back arrangements
- There must be an audible and visual alarm to warn if more than one door is opened

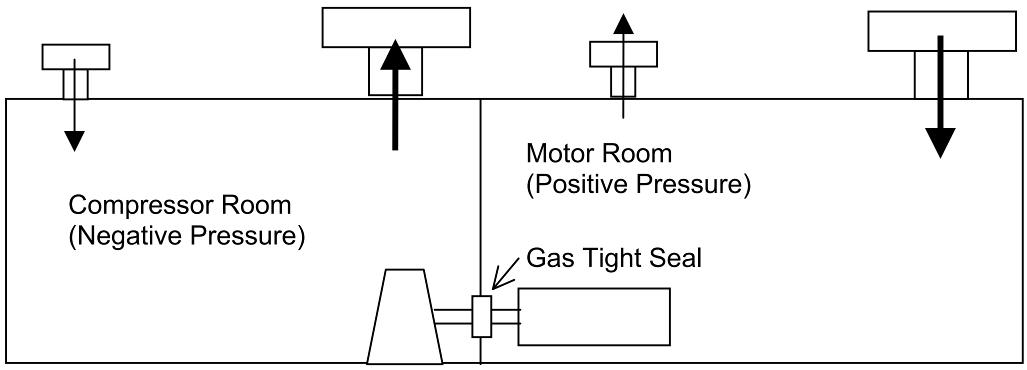
- If the electrical equipment within the space is not of the certified safe type then it should be de-energised if the positive overpressure in the space is lost
- The airlock must be ventilated from a gas safe space and maintained at a positive pressure
- The airlock should be tested for cargo vapour (part of the fixed gas detector system)

Reference IGC 12.1 Ventilation for spaces normally entered during cargo operations

- Compressor rooms and motor rooms must be fitted with mechanical ventilation systems which can be operated from outside the space. The ventilation equipment must be operated before entry to the space and there should be a notice outside the space to this effect.
- Ventilation capacity should be at least 30 changes per hour based on the total volume of the space
- The vent system should be capable of extracting from the top or bottom of the compressor room depending on the density of the cargo vapours carried.
- In gas safe spaces such as motor rooms the ventilation must be of the positive pressure type.
- In gas dangerous spaces such as the compressor room the ventilation must be of the negative pressure type.
-

Reference IGC 12.2 Ventilation of spaces not normally entered.

- Applies to spaces such as void spaces, cofferdams, hold spaces etc.
- Normally there should be a permanent ventilation system to ensure thorough ventilation before entry
- If there is no permanent system then a portable system must be specially approved and used in accordance with the approved instructions.
- Where necessary fixed ducting must be permanently installed to ensure thorough ventilation.



Sources of Ignition

Introduction

This section considers the various sources of ignition which may be present on a gas carrier and describes the relevant precautions. The different sources of ignition have been grouped according to type. This is not an official or approved subdivision, but is introduced here to serve as an aide-memoir.

The References are to the Tanker Safety Guide (Liquefied Gas) Second Ed 1995.

Ignition by heat

Smoking:

Permitted only in specified places. At sea this is often only within the accommodation while in port smoking is typically allowed only in two places, viz. officers and ratings recreation rooms. Further restriction on smoking may be required by port regulations or where the hazard from vapours is increased.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.1).

Welding, burning and other hot-work:

This is prohibited where there is a possibility that flammable gas may be present. In port it is usually prohibited entirely by local regulations. At sea, hot-work may be permitted provided that approval is given by owners or operators and then only after the necessary precautions have been carried out.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.6).

Ignition by mechanical sparks (Impact of two hard substances)

Metal tools: Including hammering, chipping or blast cleaning.

It must be ensured that the area is gas-free before use is allowed and in port, only with the approval of the terminal representative. Note that the use of so-called "non-sparking" (i.e. non-ferrous) tools is not recommended. Particles of hard material may become embedded in the working face of the tool and may then produce an incendive spark on subsequent impact.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.4).

Cigarette Lighters:

The hazard with cigarette lighters arises from the possibility that, if dropped, they may produce a spark. Lighters should never be carried about the ship. Matches and lighters are prohibited from the tank deck or other hazardous area. To discourage the use of lighters it is the practice in many ships to provide safety matches free of charge.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.1).

Ignition by chemical energy

Metallic smears:

If rusty steel is smeared with a lighter metal such as aluminium and then struck, an incendive spark may result. The reaction producing the spark is part chemical and part mechanical. Aluminium equipment (e.g. gangway) should not be dropped or dragged. The Tanker Safety Guide (Liquefied Gas) suggests that extensive experience indicates that the normal use of aluminium paint creates no special hazard. Restrictions are also placed on the material and location of cathodic protection anodes in cargo tanks if fitted.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.5).

Spontaneous Combustion:

Some organic material is liable to decay, with consequent production of heat. If this heat cannot dissipate then the temperature of the material will rise and if the temperature rises to the auto-ignition temperature of the material then it will ignite. Examples include damp laundry or clothing, dirty cotton waste, oil or paint soaked rags and oily sawdust. Prevention of spontaneous combustion is best achieved by cleanliness and good housekeeping.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.8).

Auto-ignition:

In this case the temperature of the material (e.g. vapour) is raised to the auto-ignition temperature by contact with a hot surface such as a steam pipe or exhaust manifold. Whilst this is a major source of fires in machinery spaces it should not be a problem on the tank deck or such areas.
(Ref. Tanker Safety Guide (Liquefied Gas) 3.5.7).

Ignition from electrical equipment
Sparks from any electric motor, faulty insulation, a switch or torch, or any other permanent or portable item of electrical equipment may produce an incendive spark. Therefore all electrical equipment used in hazardous areas should be of an "approved type".
(Ref .Tanker Safety Guide (Liquefied Gas) 3.5.2; & Appendix 7 & IGC chapter 10).

Different gases are grouped according to their ignition properties. In the UK apparatus for use with gases encountered in the surface (as opposed to mining) industries are grouped in one of three groups:

Group IIA (eg propane, butane, benzene, pentane)

Group IIB (eg ethylene, hydrogen sulphide)

Group IIC (eg hydrogen, acetylene, carbon disulphide)

Group IIC gases require less ignition energy than Group IIA gases, e.g. acetylene is more easily ignited (flammable) than propane.

Temperature classification
It is also imperative that the maximum surface temperature that the apparatus can attain under worst case conditions does not exceed the auto ignition temperature of the gases to be encountered. Apparatus are allotted one of six basic temperature (T) classes, the T class being the maximum surface temperature which the apparatus may achieve, related to a 40°C ambient.

Temperature Class	**Maximum Surface Temperature**
T1	450°C
T2	300°C
T3	200°C
T4	135°C
T5	100°C
T6	85°C

Types of protection
Whenever electrical equipment is to be located in a hazardous area some form of protection must be provided to ensure that it will not prove to be a source of ignition. Each method of protection, the more common of which are described below, has its uses and will be more suitable for some situations and less so for others. Different types of protection are suitable for different zones.

Intrinsic safety "a" (Ex ia)
Intrinsically safe (IS) protection relies on limiting the amount of electrical energy available in a circuit under normal or abnormal operation to a level too low to ignite the flammable atmosphere. Two levels of intrinsic safety are recognised in the UK, category "ia" relating to equipment having the

higher level of safety (two faults on the circuit) and "ib" the lower (one fault on the circuit).

Flameproof (Ex d)
Flameproof equipment was developed mainly in the UK and is now a well established and widely used technique. A flameproof enclosure is defined as "an enclosure within which an explosion may occur, but the construction of the enclosure is such that it can withstand the pressure developed during an internal explosion of an explosive mixture, and prevent the transmission of the flame which could ignite the gas in the surrounding atmosphere".

Pressurised (Ex p)
In equipment having type of protection Ex p, the parts of the equipment that could cause an ignition of gas are totally enclosed in a housing that is maintained at a pressure above ambient, the housing being pressurised by air, an inert gas or another safe gas.

Increased safety (Ex e)
The concept of "increased safety" originated in Germany. It is a method whereby measures are applied to electrical apparatus to give increased security against the occurrence of arcs and sparks and excessive temperature. It can only apply to electrical apparatus that does not produce arcs or sparks and does not exceed the limiting temperature in normal service.

Certification standards
A number of bodies are involved in the preparation of new recommendations or standards covering the design, construction, installation and maintenance of equipment in hazardous atmospheres. Some of these are the British Standards Institution (BSI) (UK), the International Electrotechnical Commission (IEC) (worldwide) and the European Committee for Electrotechnical Standardisation (CENELAC) (Europe).

In the UK the British Approvals Service for Electrical Equipment in Flammable Atmospheres (BASEEFA) certifies equipment as meeting the appropriate standard and are the country's testing authority for hazardous area electronic systems and apparatus.

Static

Static Electricity
For an electrical discharge (spark) to occur there are THREE necessary stages which must take place:

(a) Electrostatic separation
(b) Electrostatic accumulation
(c) Electrostatic discharge

(a) Charge Separation

When two dissimilar materials come into contact there is an electron transfer from one material to another, causing charge separation at the interface of the two materials, one becoming negatively charged, the other positively so. If the materials are then separated and the charge retained, a potential difference will exist between the two materials, creating an electrostatic field although of small magnitude. If the contact and separation is repeated continuously, for example, when two materials are rubbing together, the separated charge is considerably increased and a large difference may develop.

Examples of charge separation in gas carrier operations are:

- Flow of liquids through pipelines;
- Flow of liquid/vapour mixtures through spray nozzles; and

(b) Charge Accumulation

The separated charges will attempt to recombine and neutralise each other, a process known as charge relaxation. If the materials are good conductors then there is little restriction to electron movement and the relaxation time will be short with very little charge being accumulated provided there is a path to earth. If there is no path to earth then a good conductor such as a metal will accumulate charge. Where one or both of the materials are poor conductors then the relaxation time will be longer resulting in significant charge accumulation.

(c) Electrostatic Discharge

Single Electrode discharge.

A common example of this would be the discharge of static in the atmosphere to the tip of an antenna in an area with a lot of thunderstorm activity. This is a low power discharge and is unlikely to sufficient to ignite a flammable atmosphere. This may also occur inside a tank where the charged atmosphere discharges to metal projections in the tank. This is not a problem since the discharge is low powered and there is normally no flammable atmosphere present

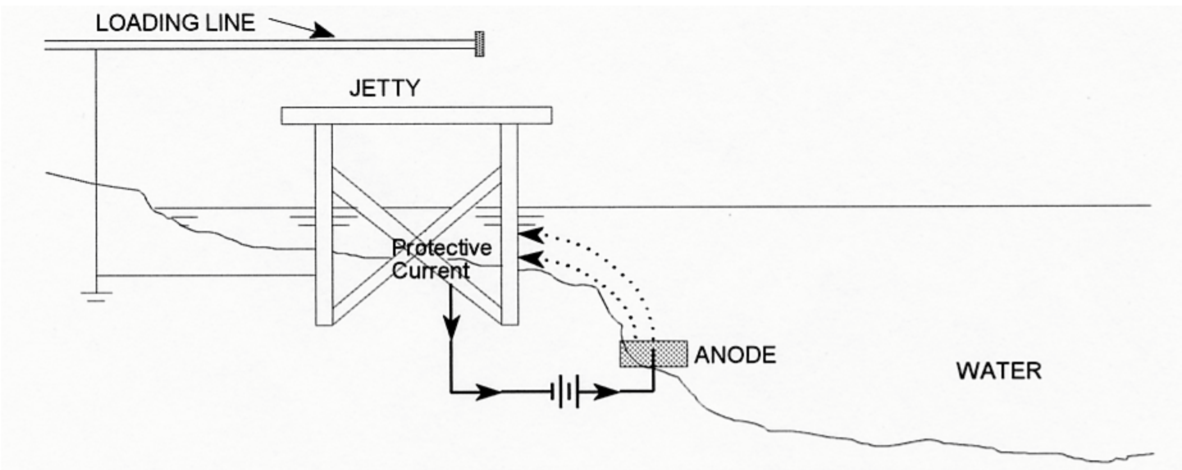
Double Electrode Discharge.

This would be a metal to metal discharge which will produce a powerful spark capable of igniting a flammable atmosphere. This could occur if a section of pipe was insulated, (leaving no path to earth), and a charge was to build up on it do to liquid flow. If another metal object with a path to earth were to come near to the pipe then it is possible for a spark to jump the gap between them. It is for this reason that it is important that all pipes are bonded together on a gas carrier. All gasketed pipe joints and hose connections should be electrically bonded. (IGC 5.2.1.4). On those ships were the tanks are insulated from the hull by way of wooden blocks the tank is earthed to the hull via an earthing strap.

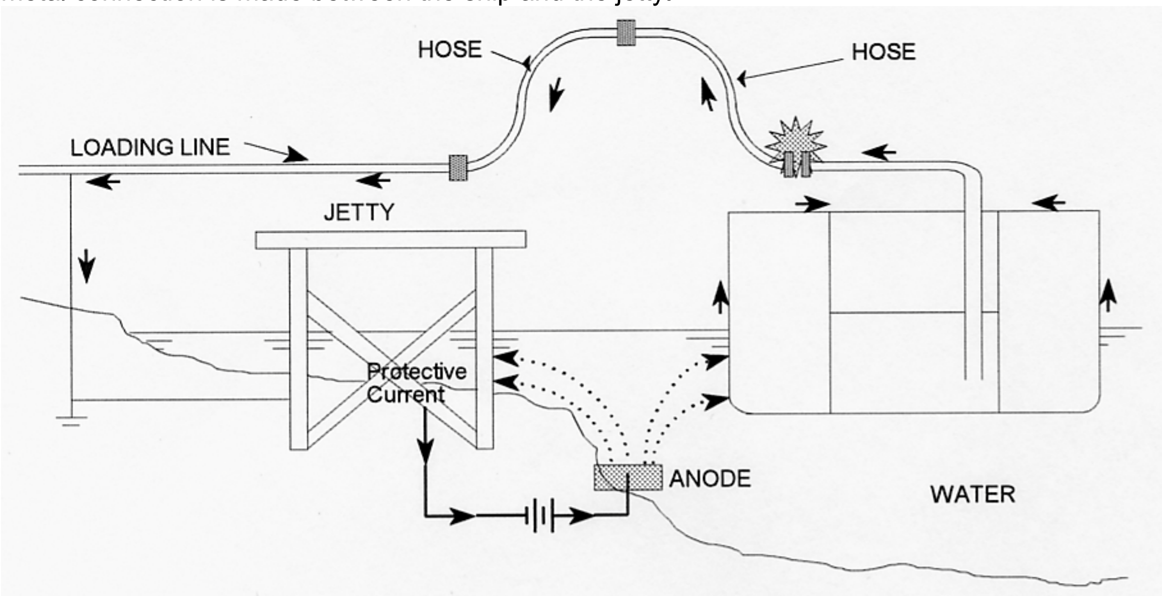
Current Electricity

Ship/Shore Bonding.

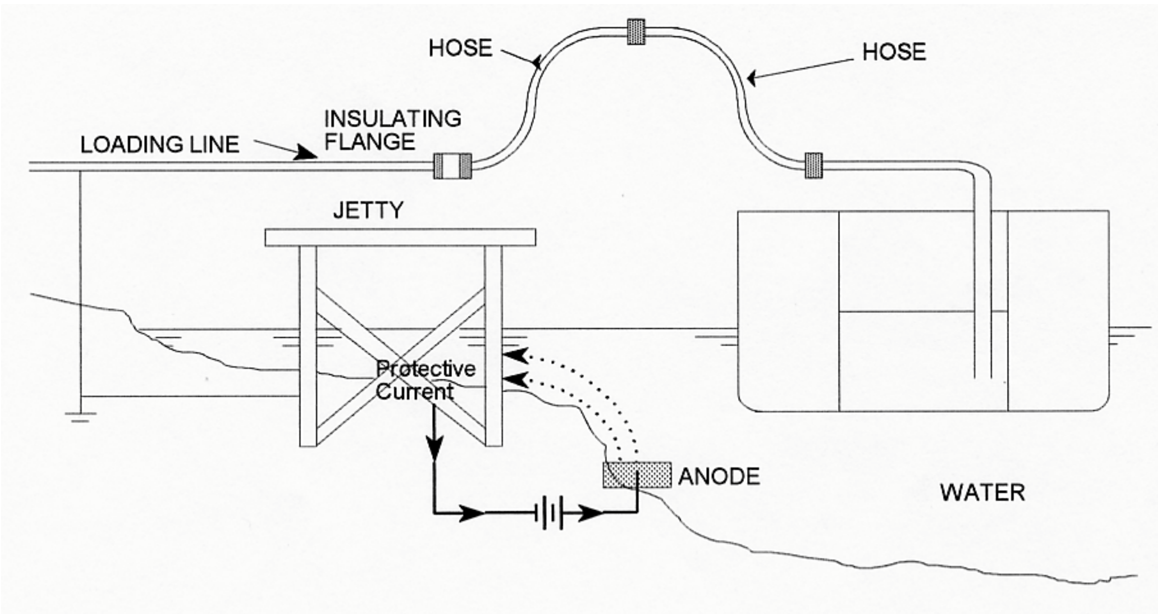
Steel jetty pilings are protected in many cases by impressed current cathodic systems. These systems operate automatically to produce a DC current equal and opposite to that produced by the electrolytic action of steel work in water. Sacrificial anodes made of zinc may also be used.



Both of these methods produce stray currents which may be large enough to cause a spark when a metal connection is made between the ship and the jetty.



In the past, a ship to shore bonding cable has been used to connect the ship to the shore before connecting the hoses or flow booms. However, increased research has shown that this method is quite ineffective and may even create a hazard in itself. Therefore, the bonding cable is **NOT** recommended.



The ship/shore bonding cable is now being replaced by an insulating flange or a length of non-conducting hose to prevent these stray currents arcing between the ship and jetty.

Most countries, including the UK, require this insulating flange to be fitted at the jetty end of the hose string.

Types Of Gas Carrier

The Development of Gas Tankers

LPG Ships

1934 Agnita
First purpose built LPG ship.
12 vertical riveted bottles to carry Butane.

1947 Natalie O Warren
Dry cargo ship converted to carry Propane in 68 vertical cylinders that could withstand a pressure of 18 bar.

1959 Descartes
First semi refrigerated ship.
Tanks can take pressure up to 9 bar.

1962 Bridgestone Maru
First fully refrigerated ship, tanks can take temperatures down to -45°C

1966 Teviot
First Ethylene Ship (Fully Ref / Semi Press)

LNG Ships

1952 Barge Methane
Used on the Mississippi River from Louisiana to Chicago.

1957 Methane Pioneer
First LNG ship, transported cargo across the Atlantic from Louisiana to Canvey Island, London.

1964 Methane Princess
Methane Progress

1960's Development of the Kavaerner / Moss spherical tank system.

General

In the 1950's the first European vessels came into service, in many cases these were existing ships converted to carry LPG cargoes.

These early ships carried all cargo as pressurised cargo in cylindrical tanks.

High tank pressures require strong tanks and this is achieved by using thick and consequently heavy steel.

Above a certain tank size it proves uneconomical to transport by this method alone.

Later developments in welding technology and materials suitable for temperatures led to the development of the following types of gas carrier:

Semi pressurised / semi refrigerated

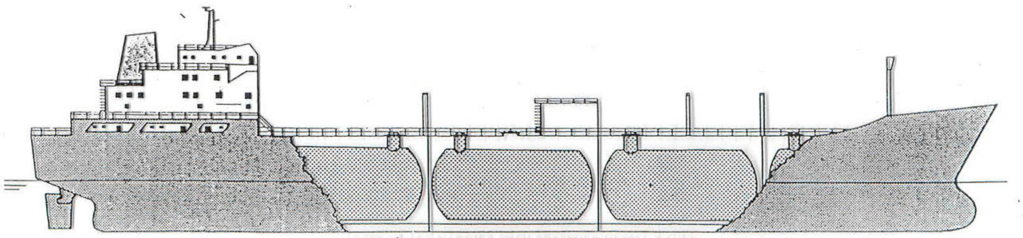
Semi pressurised / fully refrigerated

Fully refrigerated

Fully insulated

Fully Pressurised Gas Carrier

These vessels are small but relatively cheap and simple.



15,000 m^3 LPG CARRIER WITH PRESSURE VESSEL TANKS

The tanks are designed to deal with the highest ambient temperatures prescribed in the IGC code which are 45°C for air and 32°C for seawater. This means that in order to carry cargoes such as Propane and Ammonia the relief valves are set at around 18 barg.

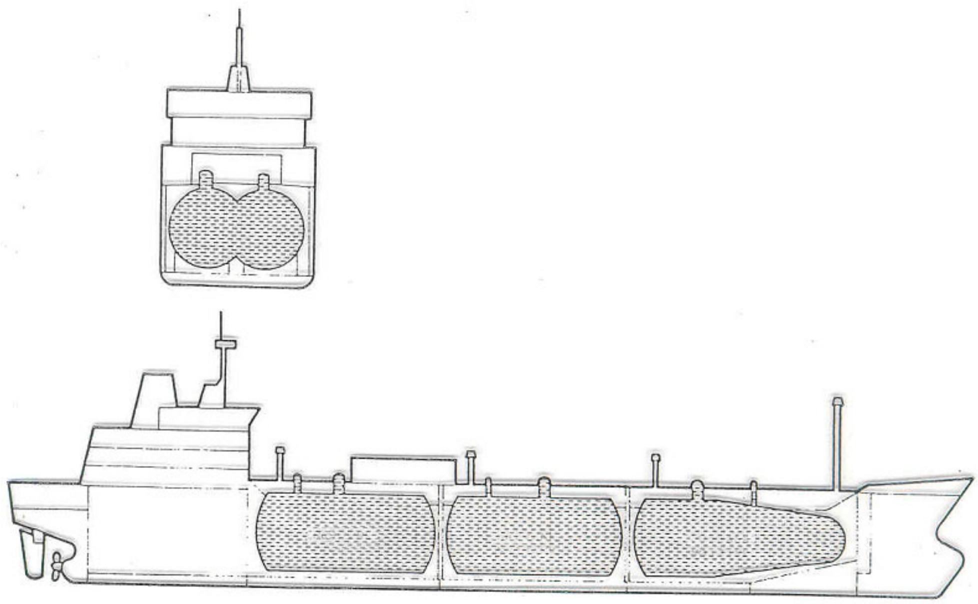
Advantages

- Low cost
- Easy to operate
- No insulation around the tanks
- No reliquefaction plant required
- No low temperature steel required

Disadvantages

- Tank shape doesn't fit well into hull
- Ratio between tank weight and cargo weight is poor
- Small capacity means not very economic

Semi Pressurised / Fully Refrigerated Gas Carrier



These ships developed from fully pressurised ships as low temperature steel technology and refrigeration technology progressed.

Initially they were semi pressurised / semi refrigerated. Reducing the temperature to about –10°C meant that the tank thickness could be reduced or larger tanks could be built. Today a vessel would be semi pressurised / fully refrigerated which would allow a large range of cargoes to be carried giving the owner a very flexible vessel.

A further progression is the semi pressurised / fully refrigerated / ethylene carrier with tanks rated for temperatures of –104°C.

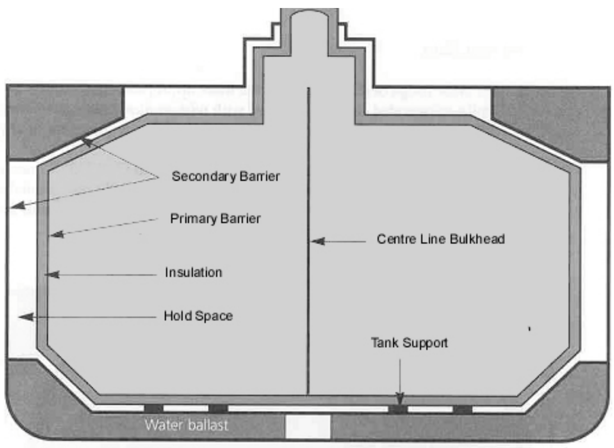
Another more recent progression is that of the semi pressurised / fully refrigerated / ethylene / chemical vessel. This is the ultimate in flexibility. This type of vessel usually has stainless steel tanks and can carry a wide range of chemicals as well as most gas cargoes. It must also comply with the IBC code for chemical ships.

These ships have relief valve settings in the range of 4 to 9 barg. They are usually able to change the relief valve setting.

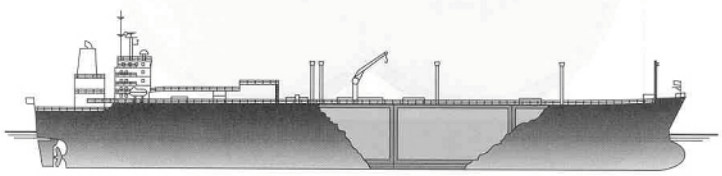
Advantages
- Much more flexible vessel
- Tank shape is bilobe which makes better use of available hull space
- Ratio of tank weight to cargo weight is improved
- Larger than fully pressurised vessels and therefore more economical

Disadvantages
- More complex to operate
- Requires the use of low temperature steel or expensive stainless steel in some cases
- Must have a reliquefaction plant
- Tanks must be insulated

Fully Refrigerated Gas Carrier



Self-supporting independent prismatic tank for LPG/Ammonia



Fully refrigerated 75,000m³ LPG-carrier with independent prismatic tanks

[Diagram from the ICS Tanker Safety Guide (Liquefied Gas)]

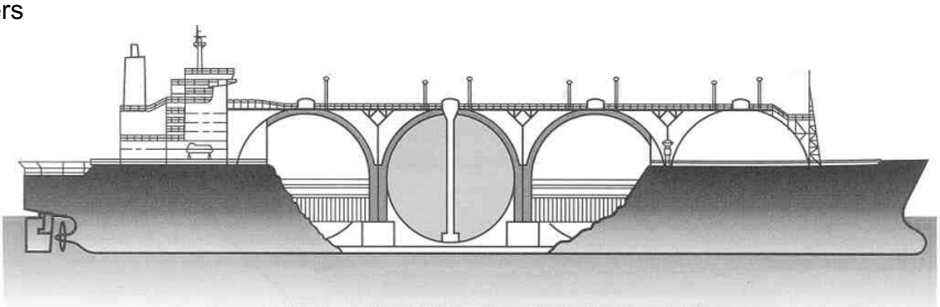
Improvements in refrigeration technology led to the development of fully refrigerated gas carriers. Tank pressure is usually limited to about 0.25 barg.

Advantages
- Ratio of tank weight to cargo weight is now good
- Better use of hull shape with flat sided tank
- Economies of scale ships up to 85,000m^3

Disadvantages
- Limited tank pressure means complete reliance on reliquefaction plant
- Tank type requires a secondary barrier
- Hold space must be inerted when carrying flammable cargoes
- Requires low temperature steel for tank and hull construction

Fully Insulated

LNG Carriers



[Diagram from the Tanker Safety Guide (Liquefied Gas)]

Up to now no LNG ships have been fitted with reliquefaction plants. They rely entirely on the insulation to maintain boil off rates of less than 0.15% per day of the cargo volume. In the future, due to economic changes, reliquefaction plants on LNG vessels are expected. Membrane or spherical tank types are limited to tank pressures of about 0.25 barg.

Advantages
- Large vessels so they are economical
- No reliquefaction plant required
- In some cases very little bunkers are burnt
- When gas burning they are more eco-friendly

Disadvantages
- Very expensive to build due to the tank types and materials used
- Usually limited to full or empty tanks due to free surface and sloshing forces of part filled tanks

IMO Ship Types

The ship type required for a particular cargo can be found in the Tanker Safety Guide (Liquefied Gas) data sheets or chapter 19 of the IGC code.

Reference IGC chapter 2

2.1.2 Ships subject to the Code should be designed to be one of the following standards:

.1 **A type 1G ship** is a gas carrier intended to transport products indicated in chapter 19 which require maximum preventive measures to preclude the escape of such cargo.

.2 **A type 2G ship** is a gas carrier intended to transport products indicated in chapter 19 which require significant preventative measured to preclude the escape of such cargo.

.3 **A type 2PG ship** is a gas carrier of 150m in length or less intended to transport products indicated in chapter 19 which require significant preventive measures to preclude escape of such cargo, and where the products are carried in independent type C tanks designed (see 4.2.4.4) for a MARVS of at least 7 bar gauge and a cargo containment system designed temperature of -55°C or above. Note that a ship of this description but over 150m in length is to be considered a type 2G ship.

.4 **A type 3G ship** is a gas carrier intended to carry products indicated in chapter 19 which require moderate preventive measures to preclude the escape of such cargo.

Thus a type 1G ship is a gas carrier intended for the transportation of products considered to present the greatest overall hazard and types 2G/2PG and type 3G for products of progressively lesser hazards. Accordingly, a type 1G ship should survive the most severe standard of damage and its cargo tanks should be located at the maximum prescribed distance inboard from the shell plating.

Damage Assumptions

Reference IGC 2.5

2.5.1 The assumed maximum extent of damage should be:

.1	Side damage:	
.2	Longitudinal extent:	$1/3L^{2/3}$ or 14.5m, whichever is less
.1.2	Transverse extent: measured inboard from the ship's side at right angles to the centreline at the level of the summer load line	B/5 or 11.5m, whichever is less
.1.3	Vertical extent: from the moulded line of the bottom shell plating at centreline	upwards without limit

.2	Bottom damage:	For 0.3L from the forward perpendicular of the ship	Any other part of the ship
.2.1	Longitudinal extent:	$1/3L^{2/3}$ or 14.5m whichever is less	$1.3L^{2/3}$ or 5m, whichever is less
.2.2	Transverse extent:	B/6 or 10m, whichever is less	B/6 or 5m, whichever is less
.2.3	Vertical extent:	B/15 or 2m, whichever is less measured from the moulded line of the shell plating at centreline (see 2.6.3)	B15 or 2m, whichever is less measured from the moulded line of the shell plating at centreline (see 2.6.3)

2.5.2 Other damage:

.1 If any damage of a lesser extent than the maximum damage specified in 2.5.1 would result in a more severe condition, such damage should be assumed.

.2 Local side damage anywhere in the cargo area extending inboard 760mm measured normal to the hull shell should be considered and transverse bulkheads should be assumed damaged when also required by the applicable subparagraphs of 2.8.1.

2.8 **Standard of damage**

2.8.1 Ships should be capable of surviving the damage indicated in 2.5 with the flooding assumptions in 2.7 to the extent determined by the ship's type according to the following standards:

.1 A type 1G ship should be assumed to sustain damage anywhere in its length;

.2 A type 2G ship of more than 150m in length should be assumed to sustain damage anywhere in its length;

.3 A type 2G ship of 150m in length or less should be assumed to sustain damage anywhere in its length except involving either of the bulkheads bounding a machinery space located aft;

.4 A type 2PG ship should be assumed to sustain damage anywhere in its length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage as specified in 2.5.1.1.1;

.5 A type 3G ship of 125m in length or more should be assumed to sustain damage anywhere in its length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage specified in 2.5.1.1.1;

.6 A type 3G ship less than 125m in length should be assumed to sustain damage anywhere in its length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage specified in 2.5.1.1.1 and except damage involving the machinery space when located aft. However, the ability to survive the flooding of the machinery space should be considered by the Administration.

2.8.2 In the case of small type 2G/2PG and 3G ships which do not comply in all respects with the appropriate requirements of 2.8.1.3, .4, and .6, special dispensations may only be considered by the Administration provided that alternative measures can be taken which maintain the same degree of safety. The nature of the alternative measures should be approved and clearly stated and be available to the port Administration. Any such dispensation should be duly noted on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk referred to in 1.5.4.

2.9 **Survival requirements**

Ships subject to the Code should be capable of surviving the assumed damage specified in 2.5 to the standard provided in 2.8 in a condition of stable equilibrium and should satisfy the following criteria.

2.9.1 In any stage of flooding:

.1 the waterline, taking into account sinkage, heel and trim, should be below the lower edge of any opening through which progressive flooding or downflooding may take place. Such openings should include air pipes and openings which are closed by means of weathertight doors or hatch covers and may exclude those openings closed by means of watertight manhole covers and watertight flush scuttles, small watertight cargo tank hatch covers which maintain the high integrity of the deck, remotely operated watertight sliding doors, and sidescuttles of the non-opening type;

.2 the maximum angle of heel due to unsymmetrical flooding should not exceed 30°; and

.3 the residual stability during intermediate stages of flooding should be to the satisfaction of the Administration. However, it should never be significantly less than that required by 2.9.2.1.

Location Of Tanks

Due to the hazardous nature of the cargo there is a requirement in the IGC code to position the cargo tanks in protective locations. The greater the risk from the cargo the greater the degree of protection required.

Reference IGC 2.6

2.6.1 Cargo tanks should be located at the following distances inboard:

.1 Type 1G ships: from the side shell plating not less than the transverse extent of damage specified in 2.5.1.1.2 and from the moulded line of the bottom shell plating at centreline not less than the vertical extent of damage specified in 2.5.1.2.3 and nowhere less than 760 mm from the shell plating.

.2 Types 2G/2PG and 3G ships: from the moulded line of the bottom shell plating at centreline not less than the vertical extent of damage specified in 2.5.1.2.3 and nowhere less than 760mm from the shell plating.

2.6.2 For the purpose of tank location, the vertical extent of bottom damage should be measured to the inner bottom when membrane or semi-membrane tanks are used, otherwise to the bottom of the cargo tanks. The transverse extent of side damage should be measured to the longitudinal bulkhead when membrane or semi-membrane tanks are used, otherwise to the side of the cargo tanks (see figure 2.1). For internal insulation tanks the extent of damage should be measured to the supporting tank plating.

2.6.3 Except for type 1G ships, suction wells installed in cargo tanks may protrude into the vertical extent of bottom damage specified in 2.5.1.2.3 provided that such wells are as small as practicable and the protrusion below the inner bottom plating does not exceed 25% of the depth of the double bottom or 350mm, whichever is less. Where there is no double bottom, the protrusion below the upper limit of bottom damage should not exceed 350mm. Suction wells installed in accordance with this paragraph may be ignored in determining the compartments affected by damage.

Cargo Tanks

Independent

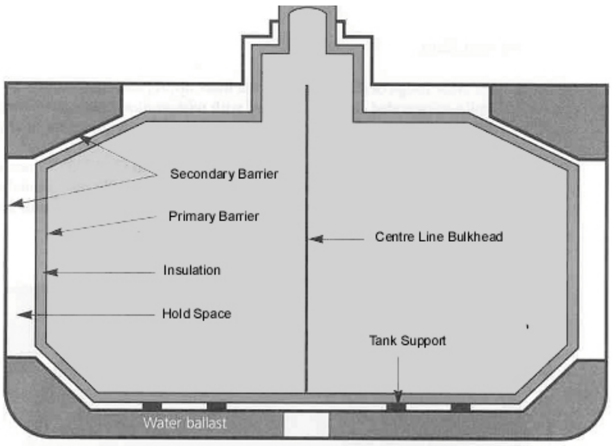
These are independent of the ships hull and can be free standing having the structural strength to support the weight of the cargo, the vapour pressure exerted by the cargo and the loads imparted due to sloshing.

There are three classes of independent tank, A, B and C.

Reference IGC 4.2

Type A
Design employs `classical' ship-structural analysis procedures. These tanks are generally constructed of plane surfaces, the design vapour pressure for such tanks usually being less than 0.7 bar gauge giving a maximum working pressure of about 0.25 barg.

Characteristics
- Flat sides, low pressures so fully refrigerated ships
- Centre line bulkhead to reduce free surface
- Centre line bulkhead is not strong, keep levels even
- Levelling valve at the bottom of bulkhead
- Profile of tank could lead to stress failures and leakage therefore fitted with a secondary barrier
- Hull acts as secondary barrier and is made of low temperature steel
- If cargo is flammable required to have hold space inerted
- Must be means to drain hold space, usually an eductor
- A few ships fill the hold space with perlite insulation material

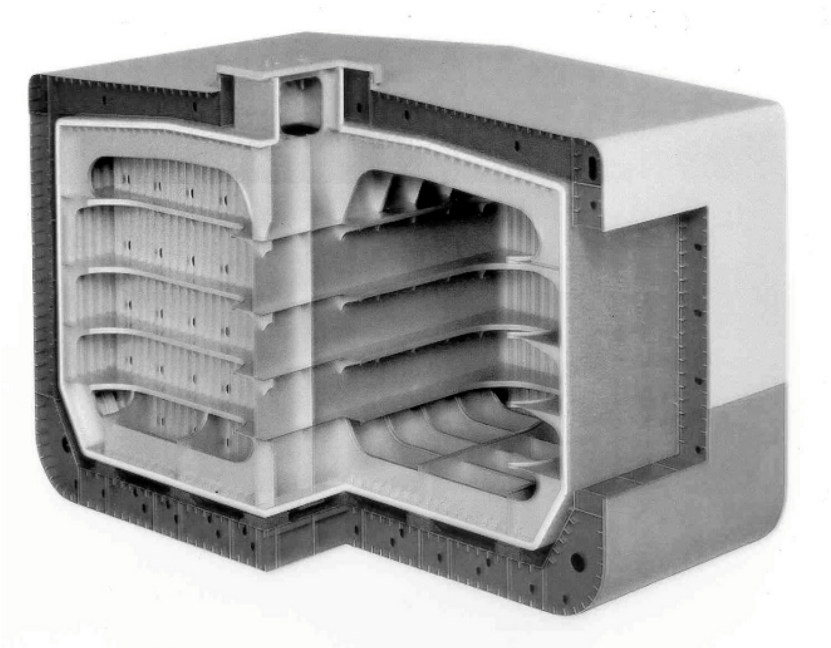


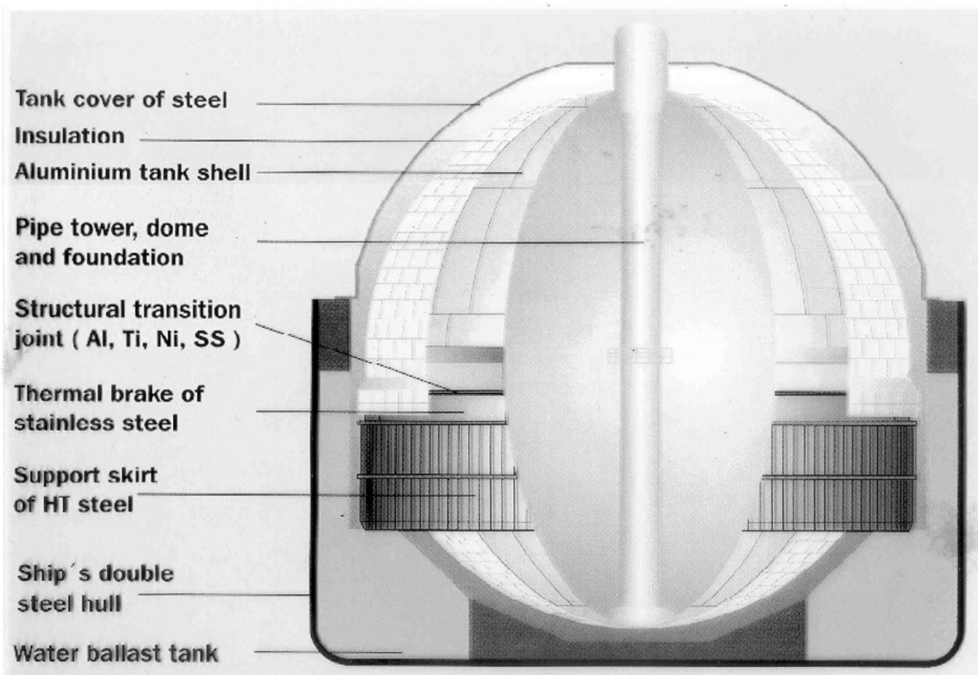
Self-supporting independent prismatic tank for LPG/Ammonia
[Image from the Tanker Safety Guide (Liquefied Gas)]

Type B
Design employs refined design methods and model tests to determine stress levels, fatigue life and crack propagation methods. If such tanks are constructed of plane surfaces, the design vapour pressure is to be less than 0.7 bar gauge giving a normal maximum working pressure of about 0.25barg.

Characteristics
- Low pressure whether flat sided or spherical tank
- Since it is designed and built not to leak no secondary barrier is required

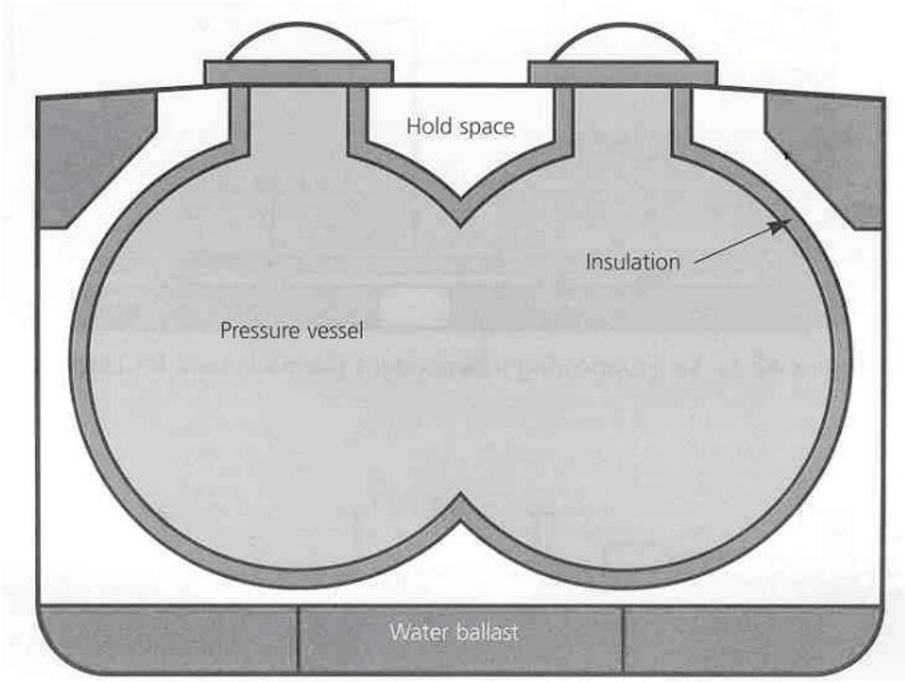
- Spherical tanks do have a partial secondary barrier in the form of a drip tray
- Since no leakage is anticipated from the space the hold space can be kept under dry air, provided there is the means to inert the space quickly should there be a leak
- Means must be provided to drain the hold space of water usually an eductor
- Spherical tanks are the most common of this tank although there are some LPG tanks built to this standard

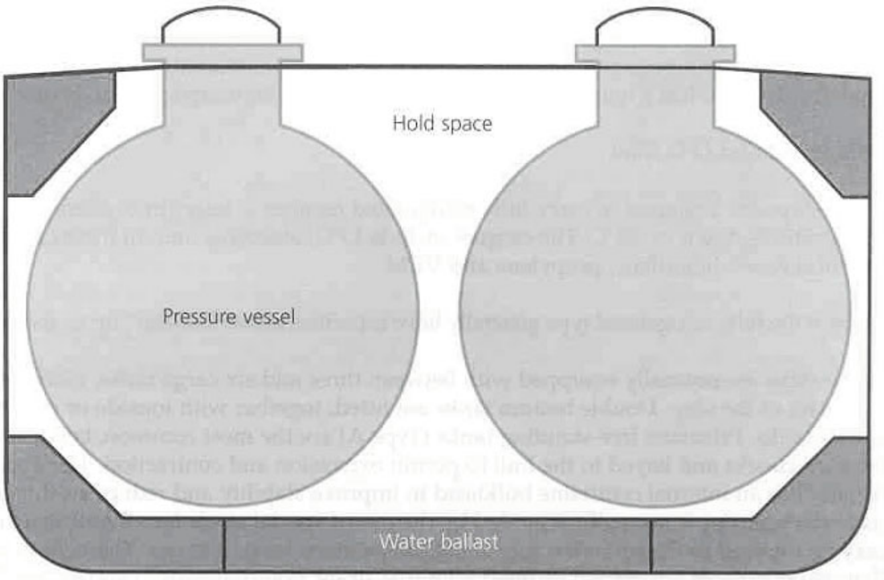




Type C
These tanks are designed to meet pressure vessel criteria and are often referred to as `pressure vessels'.

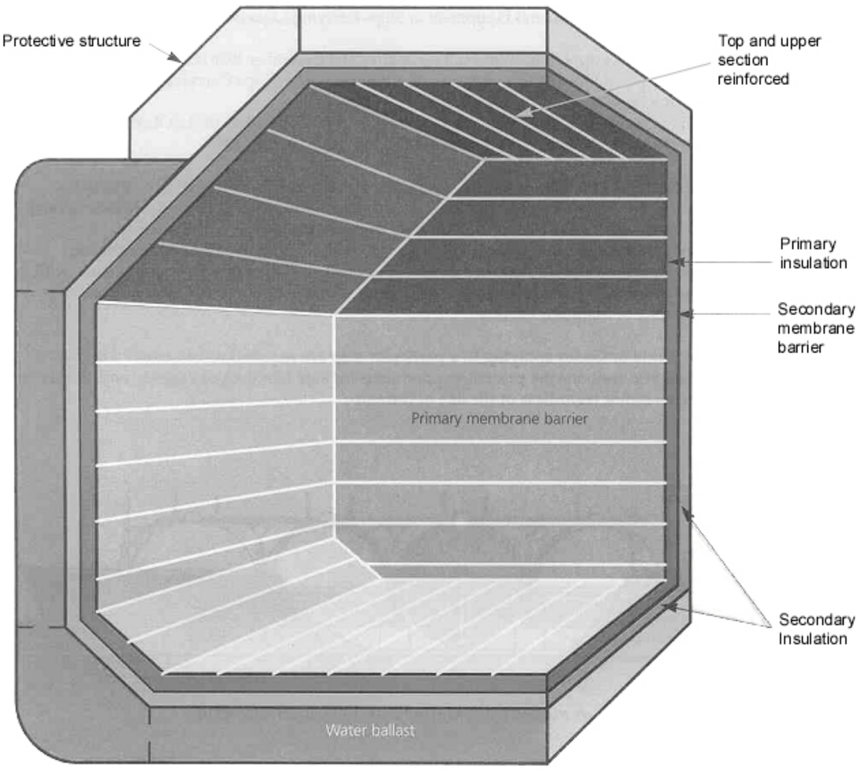
Characteristics
- Normally cylindrical in shape so can stand high pressures
- Medium pressure tanks use bilobe shape
- Fully pressurised tanks have no insulation and are not made of low temperature steel





[Images from the Tanker Safety Guide (Liquefied Gas)]

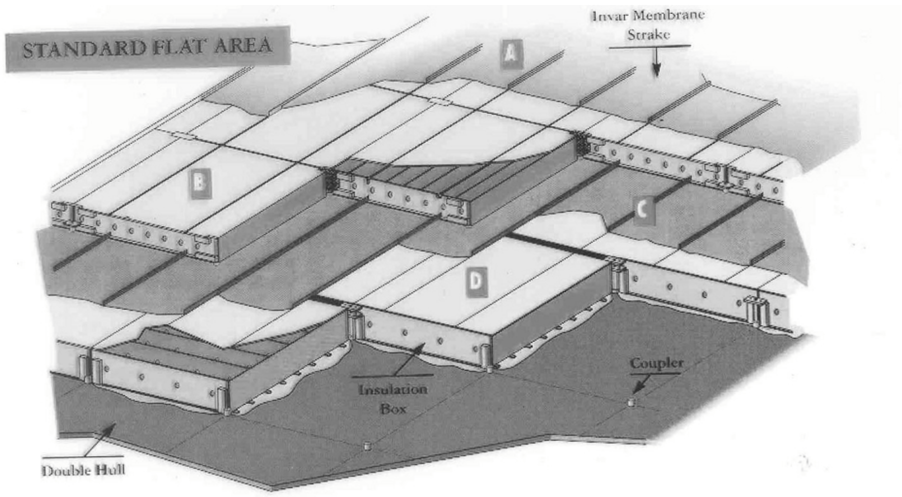
Membrane
Such tanks consist of a thin membrane (thickness usually about 1 mm), which contains the cargo. The membrane and its contents are supported by load-bearing insulation placed between the membrane and the ship's structure. Design pressure does not normally exceed 0.25 bar gauge. It is not possible to construct a centre line bulkhead in the tank hence the angled shoulder region to reduce the free surface effect when the tank is full. Loading restrictions are in the order of less than 10% full or more than 80% full.



[Image from the Tanker Safety Guide (Liquefied Gas)]

There are mainly two types of membrane tank

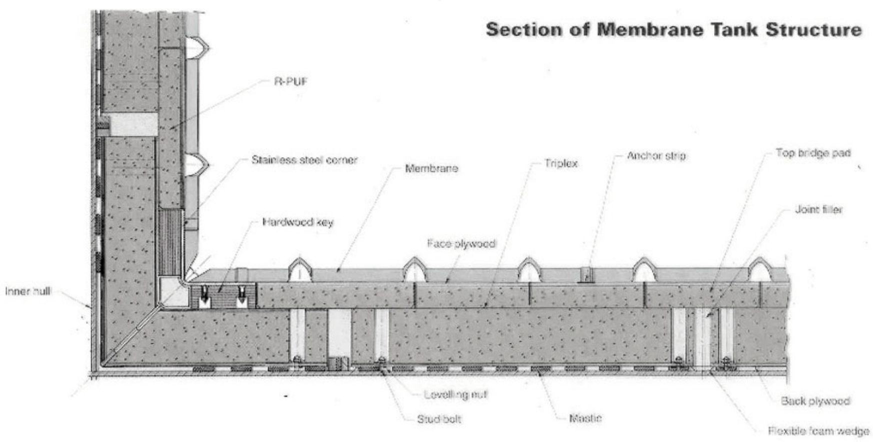
Gaz Transport System



This design uses strips of Invar 0.7mm thick which do not shrink when the tank is cooled. The insulation is made up of plywood boxes filled with perlite insulation. The secondary barrier and insulation is identical to the primary. Nitrogen is passed behind both membranes to help keep the insulation dry and to assist with detection of any leaks in the barrier.

Technigaz System

This system uses a stainless steel membrane. The stainless steel contracts on cooling so a series of folds are made in the plates. On cooling all contraction is absorbed in the fold. The insulation is polyurethane foam stiffened with glass fibre strands. The secondary barrier is a layer of "Triplex", a sandwich of glass cloth and aluminium foil. The secondary insulation is the same material as the primary insulation. Nitrogen is passed under the primary insulation to keep the insulation dry and to help with detection of leaks.



The two companies Gaz Transport and Technigaz have recently joined together and have produced a new membrane system combining the two technologies called CS1. It uses the Technigaz system but replaces the stainless steel "waffle" membrane with the Invar membrane. Since the resultant insulation thickness is less than with the Gaz Transport system the tank volume for a given hull size is greater.

Other Types

There are three other cargo tanks types permitted by the code, however for various reasons they are rarely used.

Integral

These tanks form a structural part of the ship's hull. This tank type is not normally allowed for cargoes below -10°C unless internally insulated.

Semi-Membrane

Such tanks are not self-supporting when loaded. The corners of the tanks are rounded and are free to expand or contract and generally accommodate thermal loads. The loads are transmitted to the ship's structure via load bearing insulation placed between the remaining parts of the tank and the hull structure. Design vapour pressure does not normally exceed 0.25 bar gauge.

Internal insulation

These tanks are non self supporting and consist of thermal insulation materials which contribute to the cargo containment and are supported by the structure of the adjacent inner hull or of an independent tank. The inner surface of the insulation is exposed to the cargo. Normally the maximum pressure should not exceed 0.25 barg, but may be accepted up to 0.7 barg when the tank is supported by the inner hull. If the insulation system is supported by a suitable independent tank then the pressure may be higher than 0.7 barg. There are two types:

Type 1 The insulation and liners form only the primary barrier. The inner hull or independent tank form the secondary barrier should this be required.

Type 2 The insulation or combination of the insulation and liners act as the primary and secondary barriers.

Secondary Barrier
If the cargo temperature at atmospheric pressure is below -10^{o}C a secondary barrier should be provided in order to contain any leakage cargo through the primary barrier. Its construction must be able to contain such leakage cargo for a period of 15 days, allowance being made for a static angle of heel of 30 ^{o}.

The secondary should also prevent the temperature of the vessel's structure from being lowered to an unsafe level in the event of leakage of the primary barrier.

Independent `A', and Type 1 internally insulated tanks are required to be fitted with a complete secondary barrier, (Type 2 internal insulation contains an integral secondary barrier by definition).

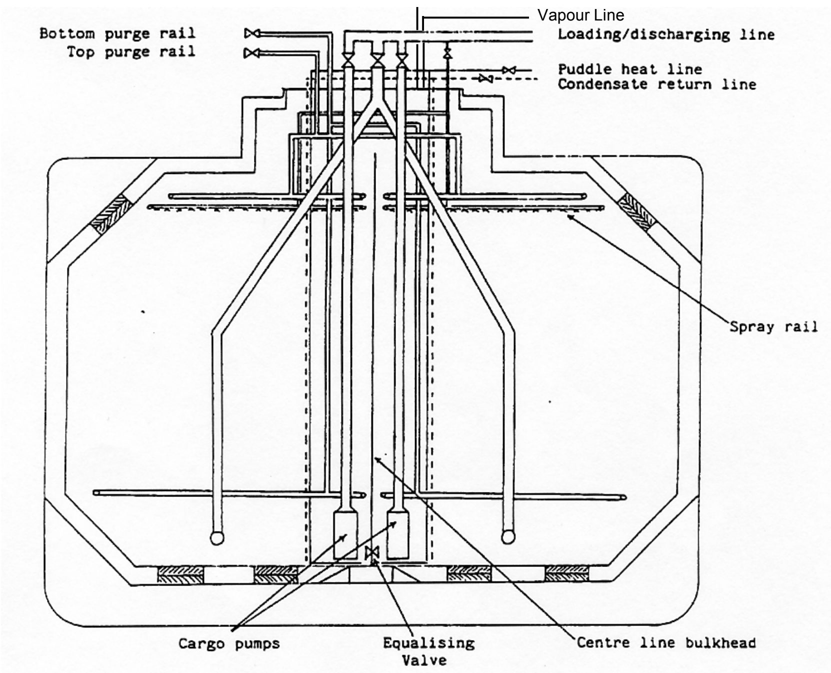
Independent `B' tanks are required to be fitted with a partial secondary barrier.

Independent `C' tanks are not required to be fitted with a secondary barrier.

Membrane tanks require a complete secondary barrier.

Semi-membrane tanks must be fitted with a complete secondary barrier unless the design satisfies the requirements applicable to Independent `B' tanks, in which case the authorities may allow a partial secondary barrier.

It should be noted that the code allows the hull structure to act as a secondary barrier provided:
(i) the cargo temperature is not below -55^{o}C;
(ii) suitably treated carbon-manganese steels are employed.



Liquefaction Plant

Refrigeration / Reliquefaction Fundamentals

Change of State: The Pressure – Enthalpy Diagram (Mollier Diagram)

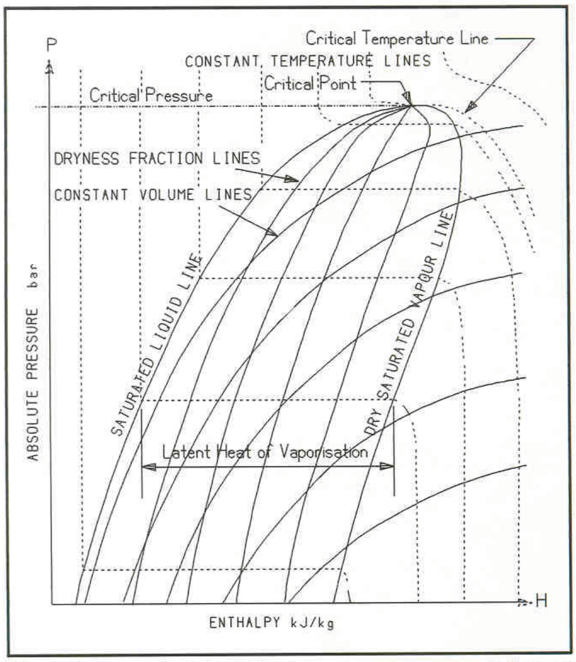


Fig.1 Pressure-Enthalpy Diagram: General Arrangement

The Pressure-Enthalpy diagram is a useful method for presenting the thermodynamic characteristics of refrigerants and other substances which are commonly subjected to change of phase in the liquid-vapour-gas ranges. Fig.1 illustrates the layout of such diagrams.

The vertical axis represents absolute pressure P and the horizontal axis represents enthalpy (heat content) H.

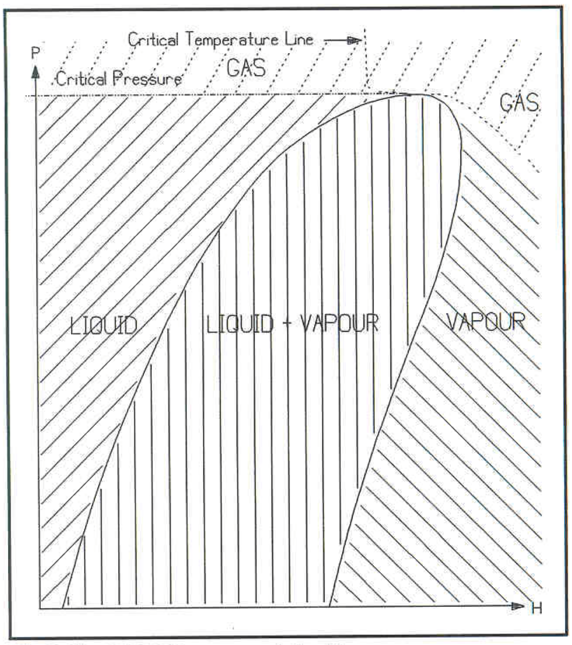


Fig.2 The P-H Diagram and the Phases

Fig.2 shows the ranges of the liquid, vapour and gas phases. Note that the substance is considered to be in the 'gas' state if the pressure is greater than the Critical Pressure and/or the temperature is greater than the Critical Temperature.

Within the saturated liquid and vapour lines, (fig.1) the horizontal lines indicate the value of latent heat and also a constant temperature for a given pressure. Outside this area the substance is either liquid, vapour or gas and the P-T relationship no longer holds constant, (see fig.2).

Note that, for a given temperature, there is only one particular pressure at which a substance will 'boil'. For 'boiling' to occur, the vapour pressure exerted by the H_2O vapour must be equal to the total pressure in the vapour space. This pressure is known as the Saturated Pressure, the corresponding temperature being known as the Saturated Temperature.

Equilibrium Conditions for the Carriage of Ammonia

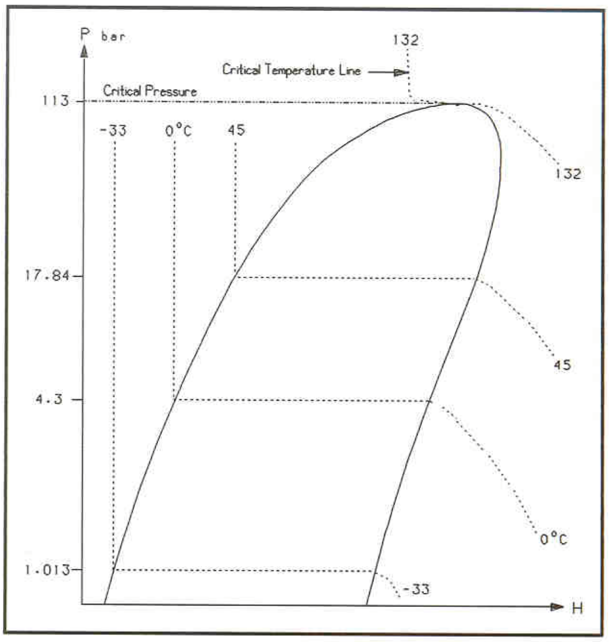


Fig.3 P-H Diagram for Ammonia

Substances which normally exist as a gas (or vapour) under normal atmospheric conditions, can be transported as 'liquefied gas'. The P-H chart for Ammonia (Fig.3) and Figs 4, 5 and 6, illustrate the various conditions under which ammonia can be carried as a liquefied gas.

Note that, in Figs 4 and 5, the low temperature is achieved (noting that is the Saturated Temperature corresponding to the pressure within the container) by controlling this pressure. i.e. by venting the boil-off vapour via the valve in such a manner that equilibrium conditions are maintained within the container.

Fig.6 illustrates the situation if the valve is closed and the temperature of the ammonia is allowed to rise to that of the surrounds. This temperature has been taken to be 45°C.

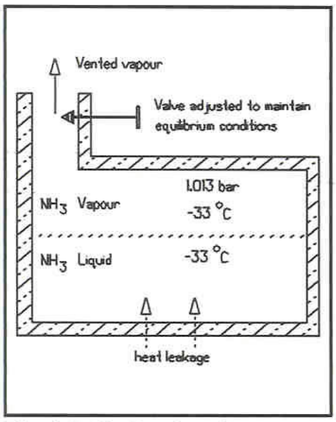


Fig.4 Fully Insulated or Fully Refrigerated

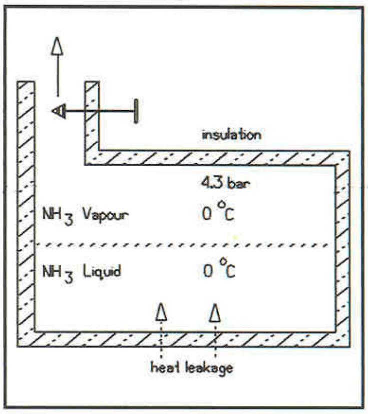


Fig.5 Semi-Pressurized or Semi-Refrigerated

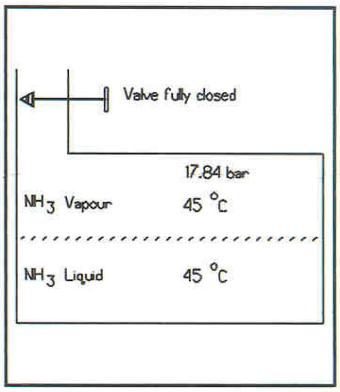


Fig.6 Fully Pressurized

The conditions in figs 4 and 5 can be used to control the temperature of a space. In the example shown, (Fig. 7), the ambient temperature is assumed to be 45°C. and it is assumed that the required temperature of the space is 7°C. In order to achieve this the pressure of the ammonia would be controlled about 4.3 bar, (with a corresponding saturated temperature of 0 °C.), for equilibrium conditions.

If the ambient temperature should fall below 45°C then the heat flow into the space will be reduced. In order to prevent the temperature of the space falling below 7°C the control valve will have to be closed in. This will result in a rise of the ammonia vapour pressure. Also the ammonia temperature will rise since both liquid and vapour are present.

If the ambient temperature should rise above 45°C then heat flow into the space will increase. Equilibrium conditions are restored by opening the control valve and reducing the vapour pressure of the ammonia, thus reducing the temperature of the ammonia.

Liquefaction of Vapours and Gases

2. Vapours can be Liquefied by Compression Alone (at Constant Temperature)

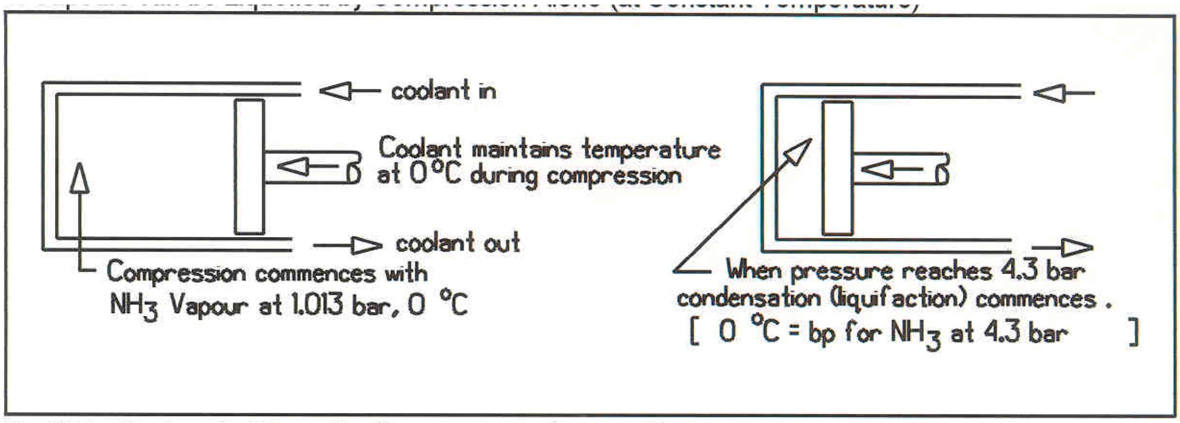


Fig.8 Liquifaction of a Vapour by Compressing at Constant Temperature

2. Gases cannot be Liquefied by Compression Alone (at Constant Temperature)

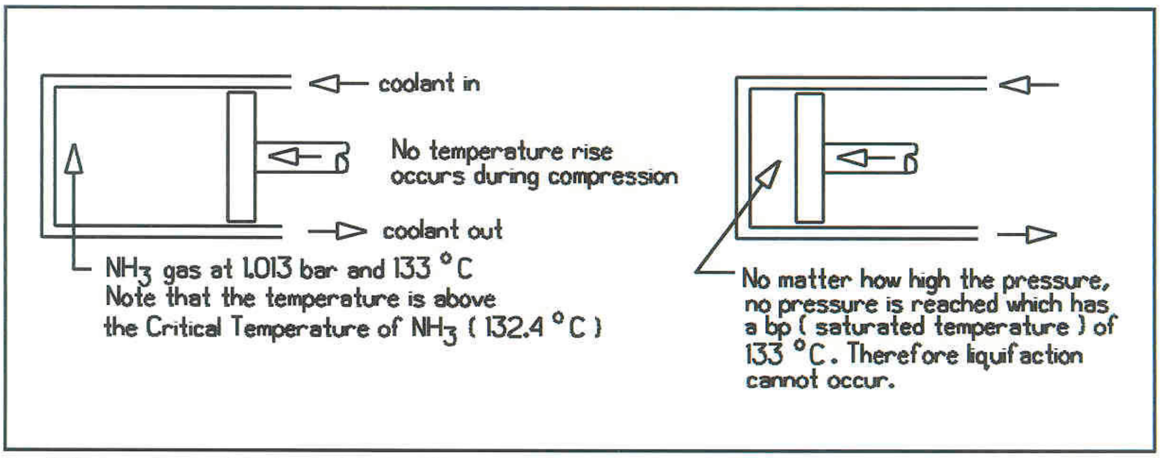


Fig.9 Compression of a Gas at Constant Temperature

Liquefaction of Vapours and Gases (continued)

1. Heat Exchanging

Note that no change in pressure occurs in a heat exchange process within a heat exchanger.

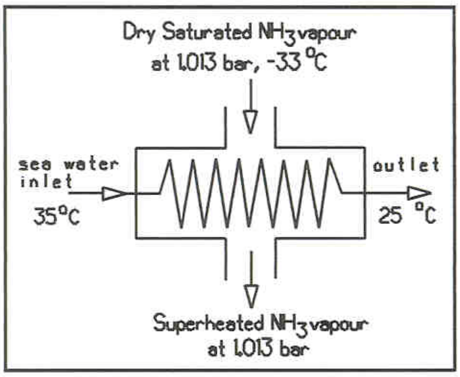
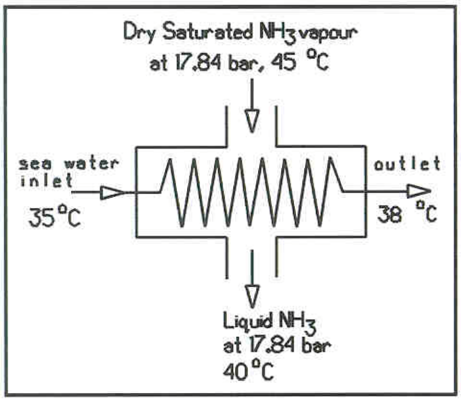


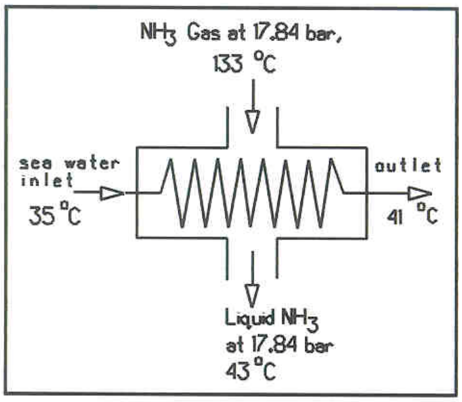
Fig. 10 Heating and Cooling
a)

Fig.10a simply illustrates that, if the temperature of a heat exchange medium is above that of the ammonia vapour, then the vapour will exit from the heat exchanger as 'superheated' vapour. i.e. the temperature of the vapour is above the saturated temperature corresponding to its pressure. (see also Fig.3)



b)

Fig.10b illustrates that, if the temperature of the heat exchange medium is **below** the saturated temperature (corresponding to the pressure) of the ammonia, then the ammonia will be liquefied, assuming that a sufficient quantity of the coolant is flowing through the heat exchanger. The ammonia may even be 'overcooled'. In the figure the temperature of the exiting ammonia liquid is shown to be 40^{o}C, i.e. it has been overcooled by 5 Celsius degrees.



c)

Fig.10c shows that, even though the temperature of the ammonia is above its Critical Temperature, the ammonia can be liquefied (by cooling), provided that the temperature of the coolant is below the Saturated Temperature, (corresponding to the compression pressure), of the vapour or gas.

Gases and vapours can be liquefied by:

compressing to a pressure such that the corresponding saturated temperature is a few degrees above the temperature of the available coolant.

e.g. if the available coolant temperature is 35^{o}C then, for ammonia, the required saturated temperature is 35 + (say) 10 = 45^{o}C. The ammonia must be compressed to 17.84 bar since this is the saturated pressure, condensing pressure), corresponding 45^{o}C.

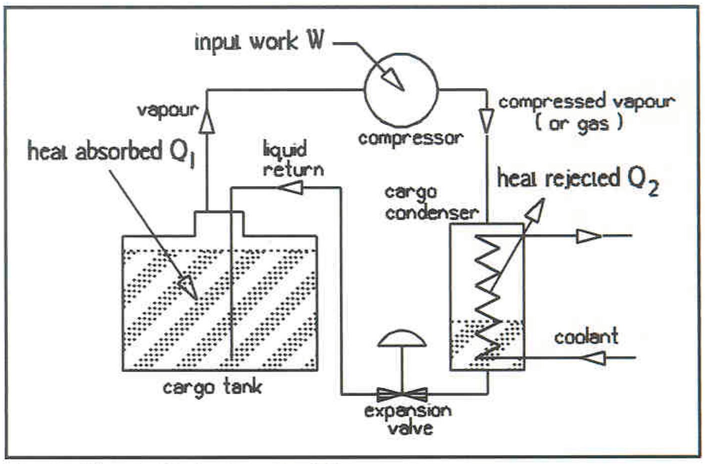


Fig.11 Simple Reliquifaction Plant

In the simple vapour-compression cycles shown the cargo boil-off vapour (fig.13) or refrigerant vapour is compressed, (accompanied by a temperature increase), according to the above principle. The compressed vapour is cooled and condensed at constant pressure, (condensing pressure). The liquid formed is reduced in pressure through an expansion valve where a fraction of the liquid boils off and the temperature drops. This temperature drop is due to heat energy within the liquid being transferred to some of the liquid molecules and converted into kinetic energy. The molecules receiving this energy revert to the vapour phase as a consequence. Thus both liquid and vapour exist on the low pressure side of the expansion valve.

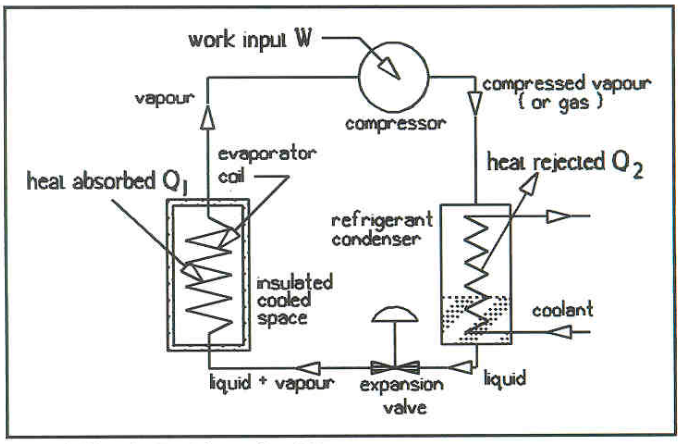


Fig.12 Simple Refrigeration Plant

Under equilibrium conditions, the temperature of `liquid return' or `liquid + vapour' will be the same and is dependent upon the pressure after the expansion valve.

The cargo in the cargo tank or refrigerant in the evaporator coil absorb heat and the phase is changed from liquid to vapour. The cycle is completed.

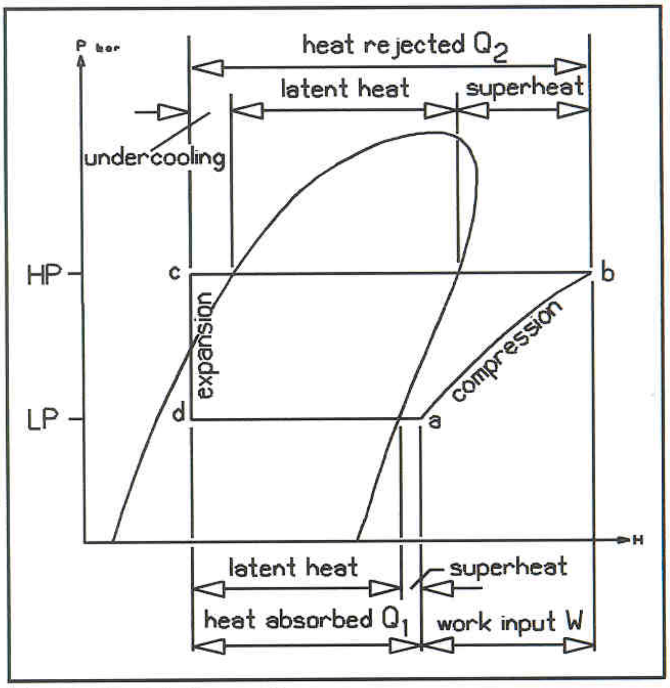


Fig.13 Heat Exchange Processes

P-H DIAGRAM

This is a useful way of illustrating the characteristics of different refrigerants and the refrigeration cycles to which they are subjected.

The `cycle diagram' abcd shown in fig.13 applies to both the reliquefaction and refrigeration plants illustrated in figs. 11 and 12.

The plant efficiency is measured in terms of the `Coefficient of Performance'.

$$\text{Coefficient of Performance} = \frac{Q_1}{W}$$

CARGO REFRIGERATION PLANT
Various refrigeration systems are used in LPG, Ammonia and Mixed Cargo ships for the primary purpose of heat removal, in order to maintain the cargo between narrow pressure limits. The basic refrigeration system operates on the vapour-compression cycle, applied directly or indirectly.

There are two ways in which the principles of refrigeration are applied in LPG ships, namely by direct or indirect reliquefaction. Most liquefied gas ships utilise direct reliquefaction of the cargo vapour. This process may be divided into the following systems:-

1. Single Stage (direct) System [Fig.14]

   This is a simple application of the basic cycle to semi-refrigerated liquefied gas ships.

The LP Cut-out causes the compressor to be stopped in the event of excessively low compressor inlet pressure. The cut-out is self resetting. The HP and HT cut-outs cause the compressor to be stopped in the event of excessively high discharge pressure or temperature. These need to be manually reset once the cause of the malfunction has been The LP Cut-out causes the compressor to be stopped in the event of excessively low compressor inlet pressure. The cut-out is self resetting. The HP and HT cut-outs cause the compressor to be stopped in the event of excessively high discharge pressure or temperature. These need to be manually reset once the cause of the malfunction has been rectified. Causes may be:

- excessively high compressor inlet temperature;
- loss of coolant to the compressor jackets or condenser;
- blocked or fouled condenser tubes;
- air or other incondensibles present in the condenser.

2. Two Stage (direct) System

When the ration of discharge pressure to suction pressure of a compressor exceeds about 6, the reduction in volumetric efficiency is such that two-stage (or even three-stage) compression is required.

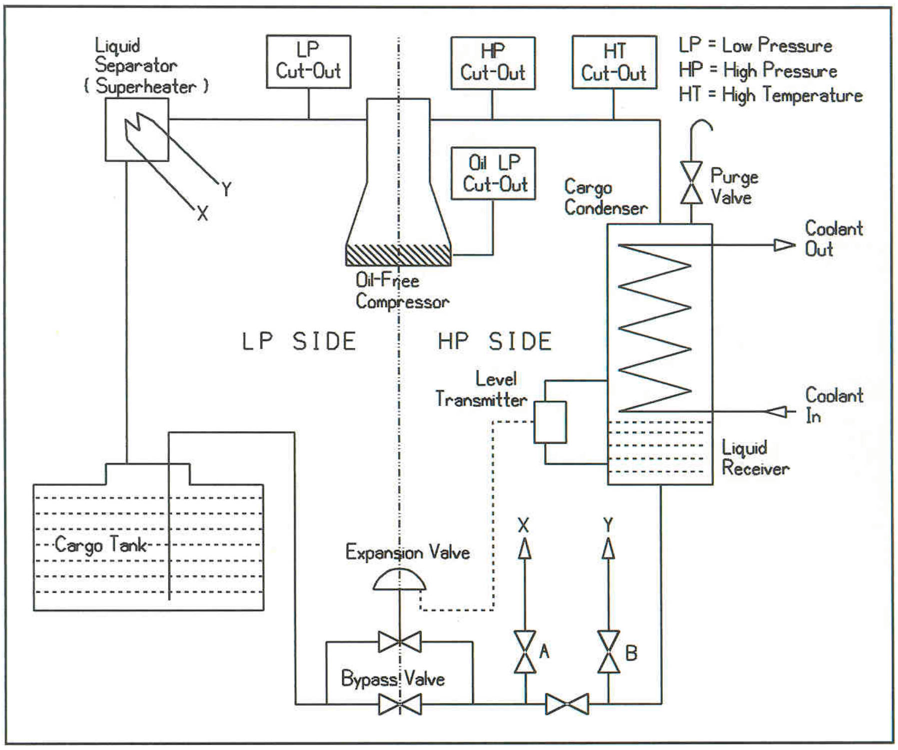


Fig.14 Direct Single Stage Reliquifaction Plant

Most cargo compressors incorporate the compression stages in one machine. The performance is improved and the highest temperature in the cycle (see point 'd', fig.16) is reduced by fitting an intermediate cooler between stages.

The system is particularly relevant to fully refrigerated LPG and Ammonia cargoes.

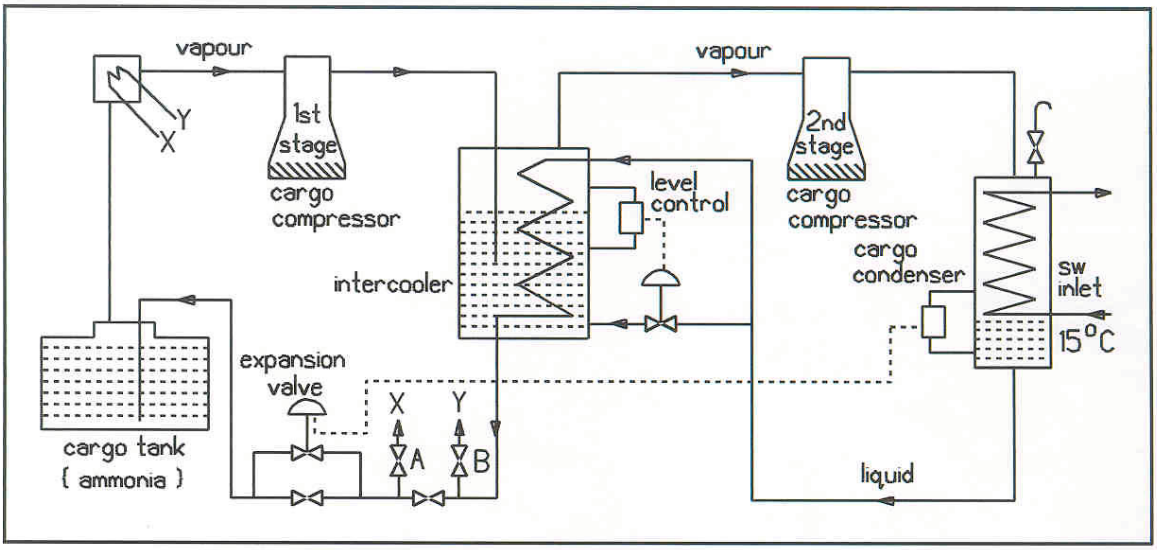


Fig.15 2-Stage Direct System with Inter-cooling

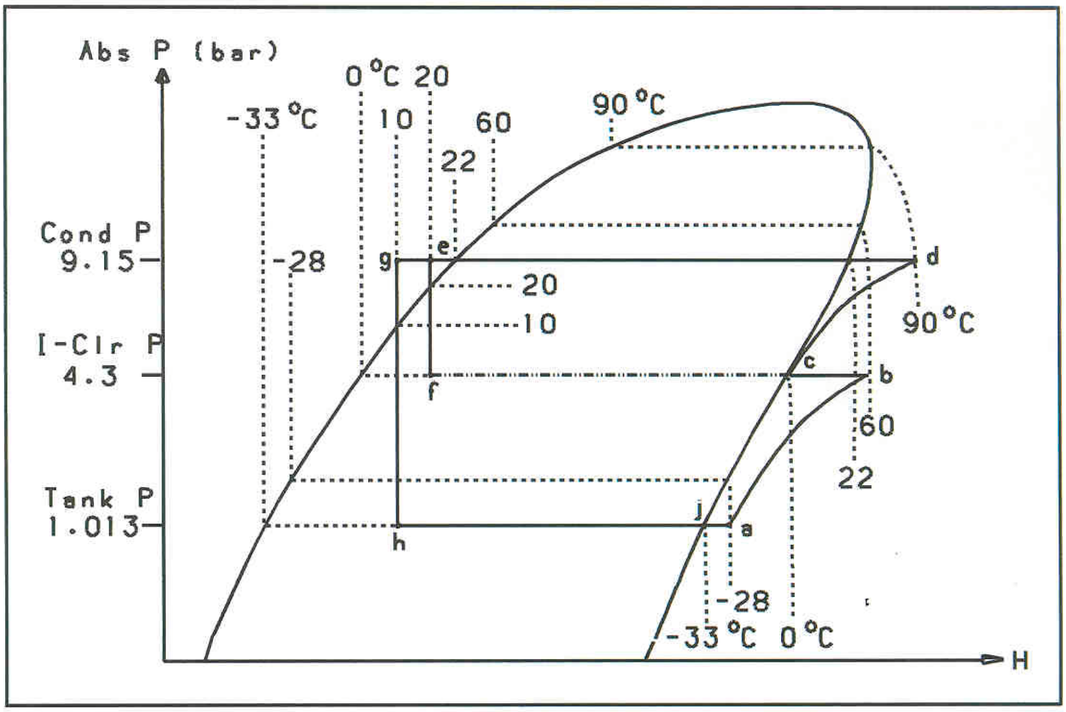


Fig.16 Cycle Diagram for 2-Stage Plant, with Inter-cooling. (Valves A and B shut)

Self Assessment Activity:
Using information given in fig.16, relate the points a, b, c, d, e, f, g, h and j to fig.15 and write in the corresponding pressures and temperatures at the appropriate positions on the figure.

3. Cascade (direct) System

Fully refrigerated liquefied gas ships use this system. It consists of a primary cycle using cargo as refrigerant and a secondary cycle with R22 as refrigerant. Heat absorbed by the cargo is rejected in the cargo condenser to the R22 liquid which evaporates and transports the heat absorbed to the R22 condenser where it is rejected to the sea water used as coolant.

Main advantage of this system is that the cargo condensing temperature and pressure can be kept low despite wide variations in ambient sea and air temperature.

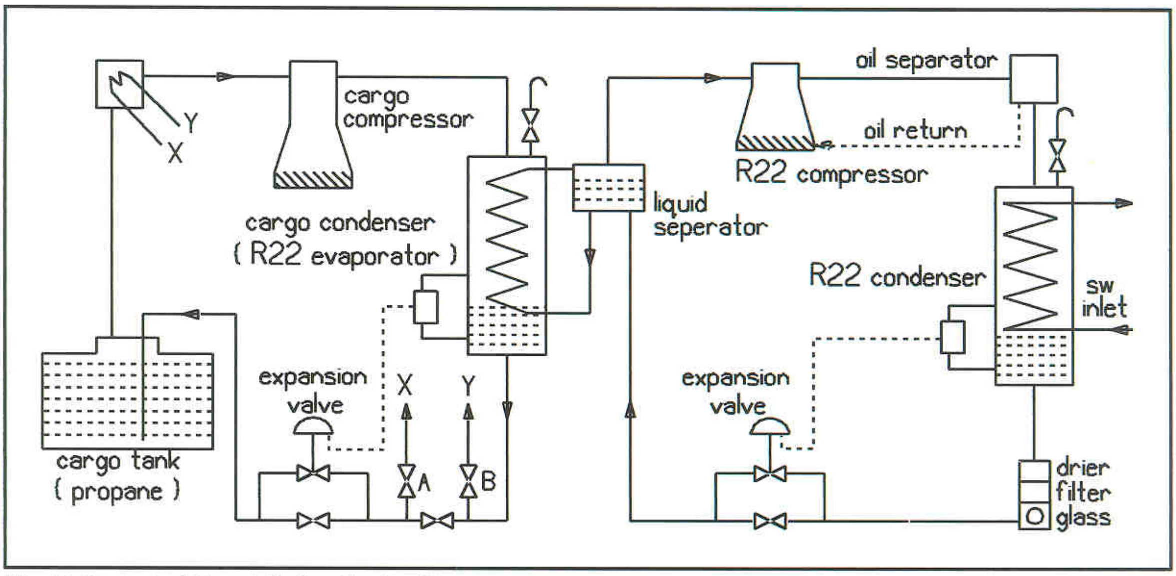


Fig. 17 Cascade (Direct) Reliquifaction Plant

In the system illustrated in fig.17, the liquid separator feeds only liquid (gravity action) to the cargo condenser evaporator coils, the separated vapour being returned direct to the compressor inlet.

Note that the R22 compressor is not normally of the oil-free type. Thus it is normal practice to include an oil separator in the compressor discharge line. Note also the presence of the (hygroscopic) drier, filter and observation glass. The presence of bubbles in the glass indicates the presence of air or insufficient refrigerant charge.

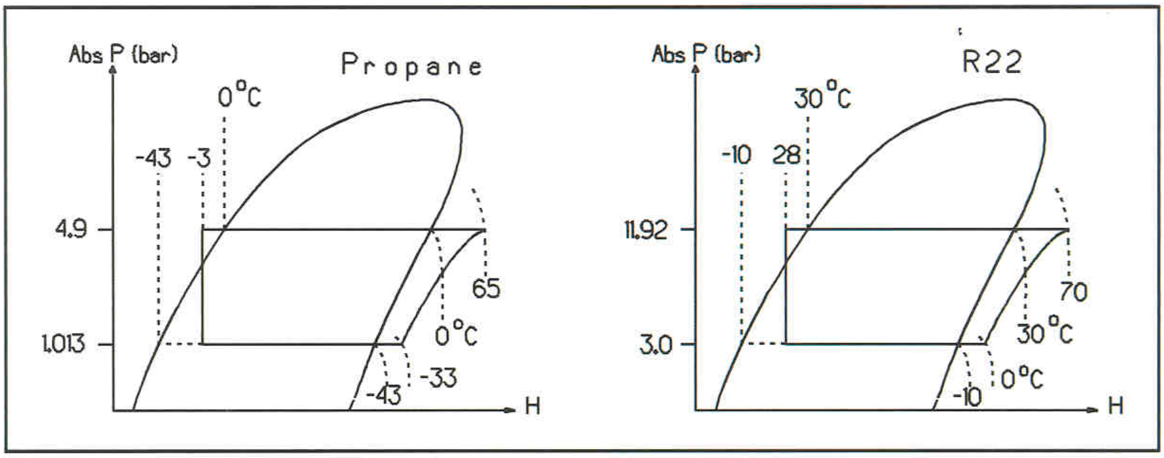


Fig. 18 Cycle Diagrams for Cascade System

COMPRESSORS

Most of the machines used for LPG, Ammonia and R22 compressors are of the reciprocating or screw type, the former being medium speed and the latter high speed. Such machines often have a variable capacity facility. Cargo compressors are usually of the 'oil-free' type, in order to avoid contamination of susceptible cargoes and possible fouling of the system with lubricating oil. Even so, it may be necessary to change the compressor oil if a different cargo is to be loaded. The R22 compressor must be a variable capacity machine to deal with fluctuations in ambient conditions. In this respect, the screw compressor has an advantage.

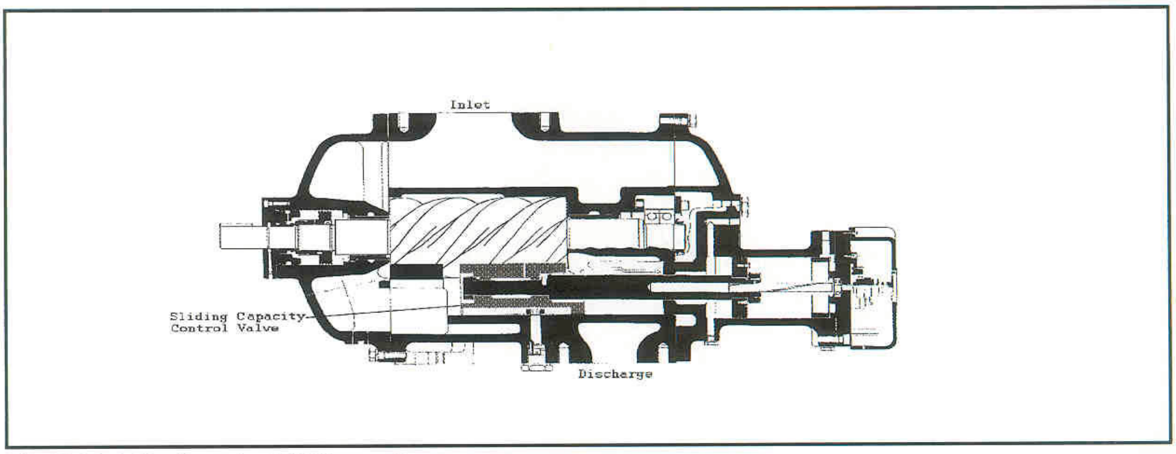
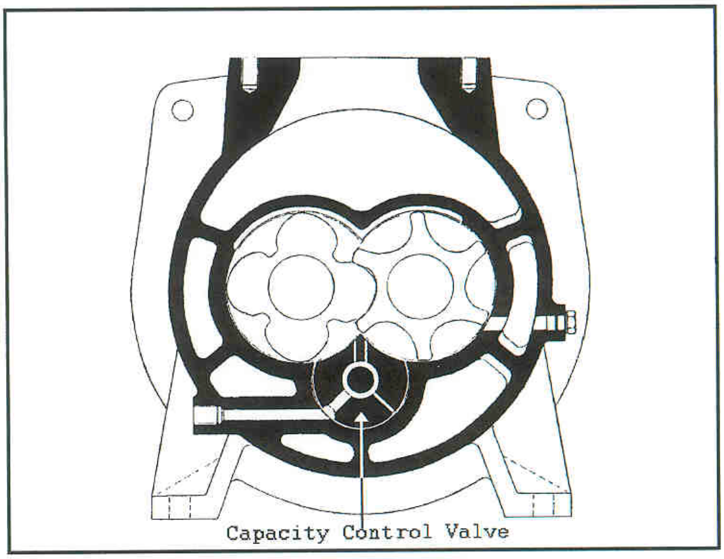


Fig. 19 Variable Capacity R22 Screw Compressor



b) End elevation

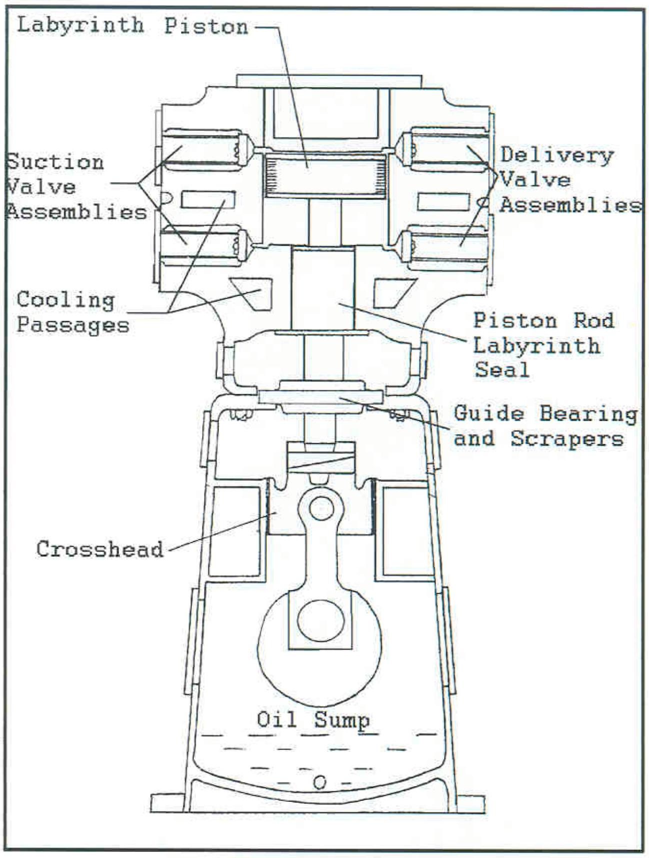


Fig.20 Oil-Free Reciprocating Compressor

Typical reliquefaction Arrangements

Typical fully and semi- refrigerated liquefied gas vessels have three reliquefaction plants, each consisting of LPG and R22 compressor with associated heat exchangers, pressure vessels and pipework. Generally the compressor is driven by an electric motor. The plant is contained in a deck house compartmentalised (by means of a gastight bulkhead) into the compressor room and the motor room to reduce the risk of explosion. Compressor drive shafts pass through the bulkhead via gastight glands which are pressurised by means of an oil header tank.

Two of the three reliquefaction plants would be required to remove the total heat leakage into the full cargo under the worst ambient conditions normally expected. The third plant may be required to deal with excessive demand during cargo handling operations as well as fulfilling the legislatory requirements with regard to the provision of a 'spare' reliquefaction plant.

Reliquefaction plant is used for the following purposes:-

(a) To maintain the correct cargo temperature and pressure.

(b) To reliquefy cargo vapour generated and displaced during liquid loading.

(c) To cool cargo tanks before loading.

(d) To generate cargo vapour for purging tanks, and to prevent vacuum forming during liquid discharge, (although a separate vaporiser is usually provided for this purpose).

(e) To cool inert gas and ventilation air, (to reduce the dew point to about 5^{o}C.

(f) To provide heat for boiling off cargo residues.

LIQUEFIED GASES - SOME PROBLEMS

(i) Ice (solid H_2O)/dry ice (solid CO_2):- mechanical damage, insulation damage, blockages, prevention of valve closure.

(ii) Reactivity

Ammonia + $CO_2 \rightarrow$ Carbamates-hard yellowish white crystals.

Ammonia + $H_2O \rightarrow$ ammonia hydroxide

Hydrocarbons + $H_2O \rightarrow$ Hydrates-white crystalline substances.

Butadiene + $O_2 \rightarrow$ Polymers-rubber like and explosive.

Butadiene + cargo compressor L.O.

Butadiene inhibitor removed if water present.

Uninhibited butadiene in stagnant pockets-dangerous peroxides.

(iii) Solids, Polymers, etc:- mechanical damage, blockages, prevention of closure,

(iv) Incondensables:- Fall-off in cargo reliquefaction/refrigeration plant performance.

(v) Dissolved gases in compressor L.O. Loss of lubricating properties and/or frothing resulting in mechanical damage.

The Effect of Dissolved Gases in LPG/LNG cargoes

All liquids have the ability to dissolve gases and vapours. This ability is temperature dependant among other factors. In general increasing the temperature will cause some of the dissolved gases to be released. Note the implication that the liquid can dissolve substances with a boiling point either lower or higher than the liquid itself at the ambient pressure.
e.g. a LPG cargo of propane may contain (dissolved):- ethane, n-butane, i-butane.

The total pressure in the vapour space above the cargo is made up from the vapour pressures of the individual components of the cargo. e.g.:-

Cargo Component	% vol. of liquid component	% vol of vapour space taken up by vapour component	press of pure component at cargo temp of -40°C (bar)	partial press of component at -40°C (bar)
Propane	95	74	1.13	1.0667
Ethane	4	25.9	7.784	0.3736
n-Butane	1	0.1	0.17	0.0013
		100.0	Total Vapour Pressure	1.4416 bar

For a given cargo temperature the presence of a small percentage of a volatile substance in the liquid body of the cargo has a large effect on both the pressure of the vapour above the liquid and the actual components of the vapour. In the above example the vapour pressure of 'pure' propane would be only 1.13 bar. The presence of a very small amount of ethane has increased the cargo vapour pressure by about 300 mb. In addition, the percentage of ethane vapour in the vapour space above the cargo is considerable, (nearly 26% in the example). The phenomenon increases the load on the cargo reliquefaction plant and may place constraints on the cargo loading rate. Incondensibles entering the cargo condenser will need to be purged if 'high compressor discharge pressure' (or temperature) shut-down is to be avoided.

Lower boiling point fractions (volatile components) either:-

(i) increase the vapour pressure for a given temperature, or

(ii) lower the cargo temperature for a given vapour pressure.

Higher boiling point (non-volatile) components have the opposite effects.

Fig.22 illustrates the phenomenon graphically. The figure also shows the effect on the proportions of the boil off constituents when a commercial cargo of liquid propane contains only 4% mol ethane.

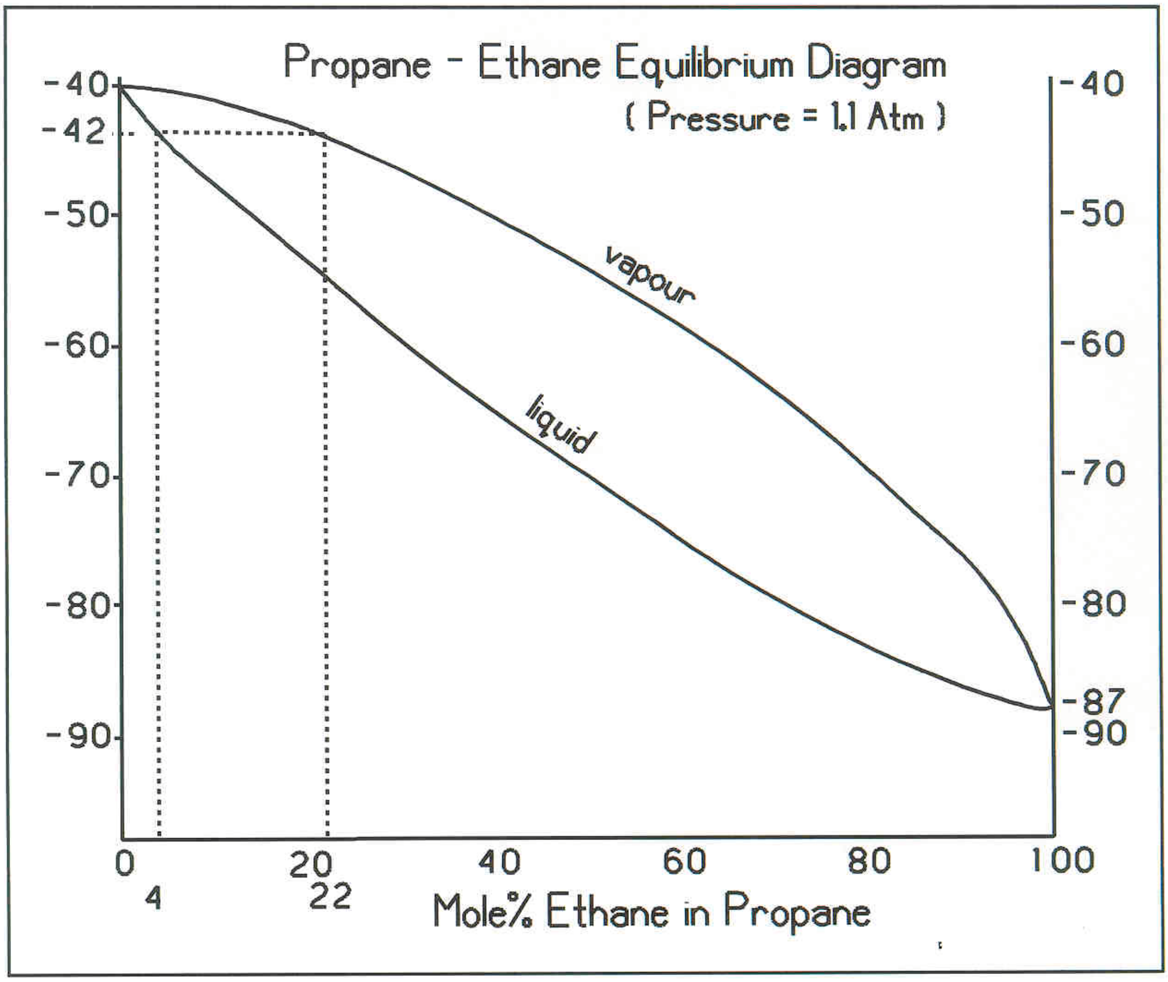


FIG.24

INERT GAS AND NITROGEN SYSTEMS

INERT GAS

"Inert" - (i) Chemically non-reactive;

(ii) Chemically non-reactive with respect to the cargo and cargo containment system;

(iii) Oxygen deficient.

In both LNG and LPG ships, inert gas is used to provide a safe and dry atmosphere. The risk of fire or explosion is always present when flammable cargo vapour and the correct amount of air or oxygen is exposed to a source of ignition.

An inert gas having a higher quality than that used in crude oil carriers is normally specified, this is necessary to avoid contamination, corrosion, and to ensure greater safety.

In practice, inert gas ranges from pure nitrogen to the following typical composition:-

Oxygen	max. 0.5% Vol.
Carbon Monoxide	max. 0.1% Vol.
Hydrogen	max. 0.1% Vol.
Nitrogen oxides	max. 0.01% Vol.
Sulphur Dioxide	max. Nil Vol.
Carbon Dioxide	approx. 14%-15% Vol.
Nitrogen	the remainder

Some LPG ships also carry anhydrous ammonia which will react chemically with carbon dioxide in the inert gas given above. To prevent the formation of ammonium carbonate, dry air is used in place of this inert gas to displace ammonia vapour from cargo tanks.

Requirements For Inert Gas

Large volumes of inert gas at low pressures are used in cargo tanks for purging prior to gas freeing for survey or maintenance. Similarly, inert gas is used to displace hydrocarbon cargo vapour when changing cargo and to prevent entry of air into the system.

Smaller volumes of inert gas are used to maintain containment or void spaces at a pressure slightly above atmospheric to prevent ingress of moisture and its possible effect on the thermal insulation, as well as ensuring an inert atmosphere in the event of cargo leakage.

In LNG ships, pure nitrogen is used to keep interbarrier spaces inerted. The nitrogen is carried in liquid form in a well insulated storage tank from which it is passed through a vaporiser controlling the gas output.

Production Of Inert Gas

Inert gas may be produced in the ship or it could be supplied from external sources depending on a variety of considerations. LPG ships normally carry an inert gas generating and drying plant of the type shown overleaf, to cover all cargo requirements.

The quality of inert gas depends on the type of fuel burnt, the combustion efficiency, and the effectiveness of the scrubbing arrangements. A light distillate fuel such as gas oil is pumped through the atomising burner into the combustion chamber where it is thoroughly mixed with a rotating flow of filtered air from a blower. Combustion control is automatic following ignition and designed to ensure steady conditions producing very low oxygen content without soot formation.

The gas, partly cooled by the water jacket, then passes into the cooling tower where it is scrubbed by water sprays through which it must pass to the outlet at the top. Scrubbing cools the gas, removes solid particles, unburnt fuel, and sulphur gases (depending on type of fuel) that would otherwise contaminate the system.

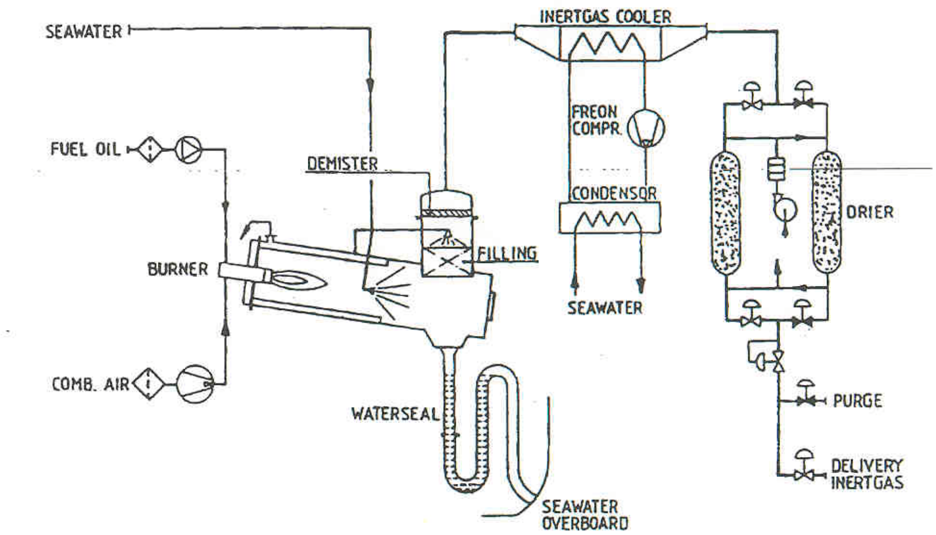
Drying Of Inert Gas

It is essential to minimise the amount of water vapour contained by the inert gas. In the cargo system, the low temperatures inevitably cause ice formation in sumps, cargo pump suctions and reliquefaction plant expansion valves when water is present. In the containment spaces, the inert gas should preferably have even less moisture and a dewpoint lower than the temperature of the cargo, to prevent ice damage to the tank insulation.

Water vapour in inert gas or air can be removed by cooling, freezing, compressing and cooling, absorption drying or a combination of these processes.

In the system shown in the figure below, the inert gas from the cooling tower passes through a demister which removes the entrained water droplets. The saturated gas then enters a refrigerated cooler where the dewpoint is reduced to about 5°C and a large amount of water is removed without causing it to freeze. From the cooler, the gas passes to an absorption drying plant arranged in two units, one of which is in use while the other is being regenerated.

The inert gas at 5°C and saturated with water vapour enters one of the driers at the base through an automatic changeover valve. Some water is precipitated and the gas passes up through a bed of silica gel or other desiccant which absorbs the moisture resulting in dewpoints as low as -55°C. The reaction with silica gel is exothermic and the temperature of the inert gas passing out through the changeover valve to the tanks is about 18°C.



LOW PRESSURE TYPE INERT GAS GENERATOR

One drier unit is being regenerated by circulating gas under a small positive pressure from a blower through an electric heater and into the drier. The absorbed moisture is removed as steam to the cooler where it is condensed, separated and drained out. When the gas temperature before the cooler reaches 180°C-200°C, the heater is switched off by thermostat. Cooling continues until the gas temperature falls to 40°C-45°C when the blower stops and the cooling water is shut off.

The regenerating cycle may take from 5 to 9 hours, this being 60% to 70% of the time taken for the drying cycle.

If heated air is used as the regenerating medium, (rather than inert gas), then it is essential that the drying units are inerted prior to connecting the I.G. system to the cargo system.

Turbo-Inert System

Basically this system (see fig.2), uses the exhaust from a gas turbine electrical generating set as the combustion air for the afterburner using the same distillate fuel as the turbine itself. From the afterburner, the hot gases pass directly into a cooling tower where they are scrubbed and cooled to within 10°C of the seawater temperature. The inert gas then continues through the freezing and drying plant to the cargo tanks.

Additionally, this system produces a supply of dry air for gas freeing cargo tanks by taking an air bleed from the compressor and using it to draw in atmospheric air which then passes through the cooling tower and drying plant.

The system is capable of providing outputs of inert gas or gas-freeing air in excess of 22000 m3/h for LNG ships.

Inert gas can be produced from fuels containing sulphur but this would have to be taken out by using an alkaline gas scrubber which adds to cost and complexity. It is also possible to remove the carbon dioxide with molecular sieves.

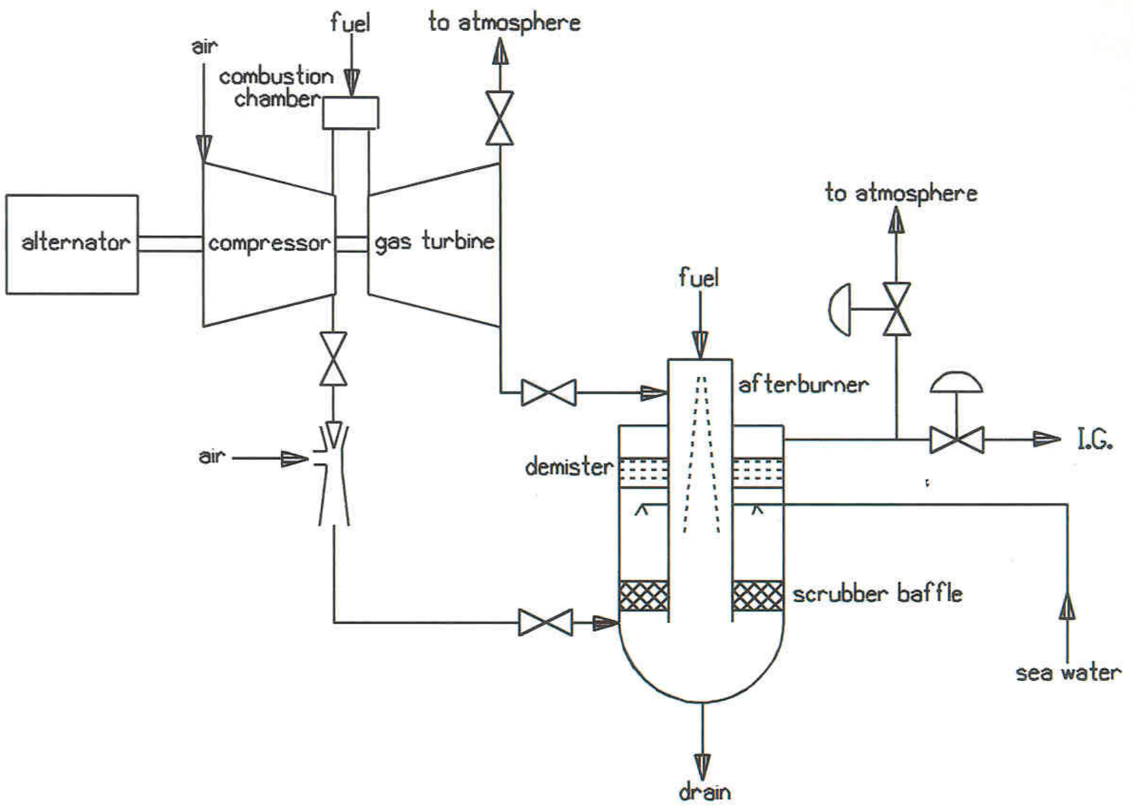


Figure 2 Turbo-Inert Gas System

Alternative IG Production Methods

Nitrogen can be obtained either by purchasing and storing (fully pressurised or fully insulated), or by production onboard using one of the following methods.

(a) liquefaction and separation of air;

(b) membrane Nitrogen Generator - (see figure 3)

(c) preferential adsorption of oxygen from air using carbon molecular sieves. (Pressure Swing Adsorption - see figure 4);

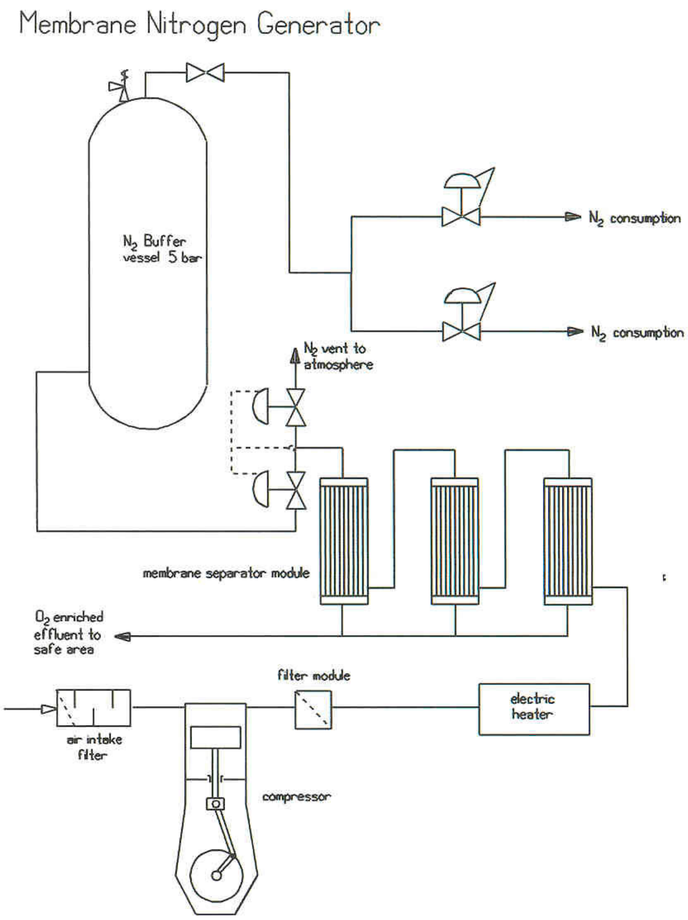


Figure 3

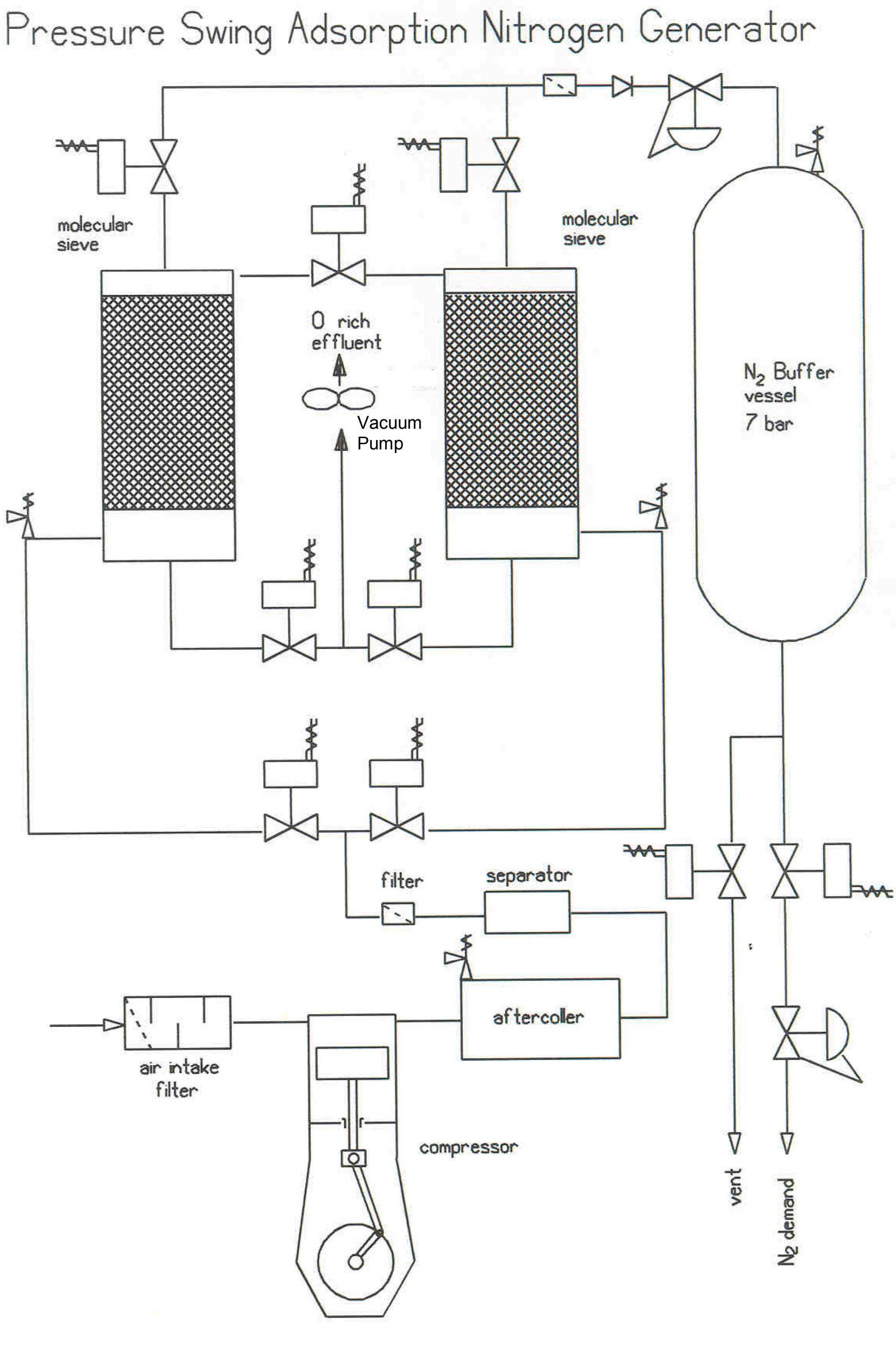
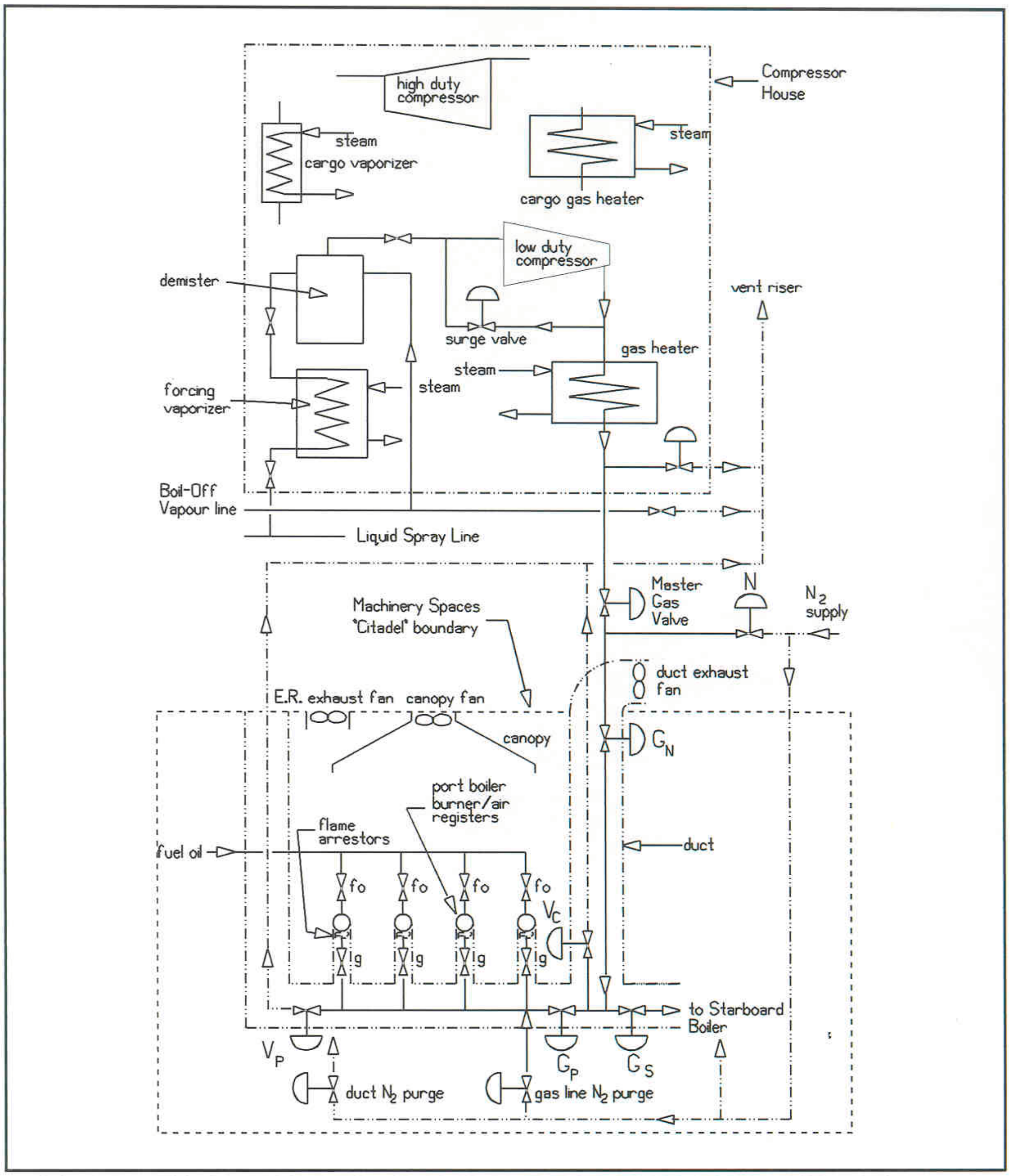

Pressure Swing Adsorption Nitrogen Generator
molecular sieve
molecular sieve
O rich effluent
Vacuum Pump
N2 Buffer vessel 7 bar
filter
separator
aftercoller
air intake filter
compressor
vent
N2 demand

Figure 4

Other Systems

System For Burning Methane Boil-Off



SCHEMATIC OF LNG BOIL-OFF PLANT FOR DUAL FUEL BOILERS

N	Master Nitrogen Purge Valve
G_c	Gas Control Valve (automatically operates for N_2 purging)
V_c	Central Gas Line Vent
V_p	Port Boiler Gas Line Vent
G_p,G_s	Gas Stop Valves - Port and Starboard Boilers
g	Individual Burner Gas Valves at Port Boiler Front
fo	Individual Burner Fuel Oil Valves at Port Boiler Front

LNG BOIL-OFF PLANT FOR DUAL FUEL BOILERS

Gas pressure at furnace about 0.95 mb gauge at temperature 10°C-20°C.
Boil-off rate of order 0.15%-0.3% cargo volume per day.
Cargo Tank pressure about 50mb gauge.

Typical interlocks
Master Gas Valve cannot be opened unless:-

(i) Canopy fan is running;
(ii) E.R./Boiler Room exhaust fan is running;
(iii) Gas Line Casing extraction fan (if fitted) is running;
(iv) Explosive gas reading at canopy and in Gas Line casing is less than 30% LEL;
(v) Main Propulsion Turbine trips are set, (if engaged the turning gear overrides this interlock);
(vi) Gas line pressure is 40mb gauge minimum;
(vii) Gas line temperature is above -10°C;
(viii) Port and Starboard Master fuel oil valves are open;
(ix) Master Nitrogen purge valve is closed.

Gas-Stop Valve (Port boiler G_p; Starboard boiler G_s) cannot be opened unless:-
(i) Main Gas Valve is open;
(ii) Fuel oil valve to boiler is open;
(iii) one oil fired burner is on with a stable flame.

Individual Burner Gas valves cannot be opened unless:-
(i) Gas Stop Valve is open;
(ii) Boiler Gas Line Vent (V_p-V_s) is closed;
(iii) the corresponding Burner F.O. valve is open with a stable flame.

In the event of automatic closure of the Master Gas Valve the gas lines are automatically purged. e.g. on closure of the Master Gas valve:-

(i) G_p and G_s close; individual gas burner lines are purged with N_2, (V_p and V_s closed).
(ii) V_p and V_s open - purging to vent riser.
(iii) N_p and N_s close.
(iv) V_c, G_c open, remaining gas line is purged.
(v) Master Nitrogen purge valve, N, and Gas Control Valve, G_c, close.

N_2 purge should not extinguish the F.O. burner flame.
Change-over from 100% gas firing to 100% F.O. firing is carried out in about 7 seconds.

Note: Boiler Shut-Down may occur during automatic change-over from the 100% 'Gas Fired' mode to 100% 'F.O. fired' mode due to the presence of cold fuel oil in the lines.

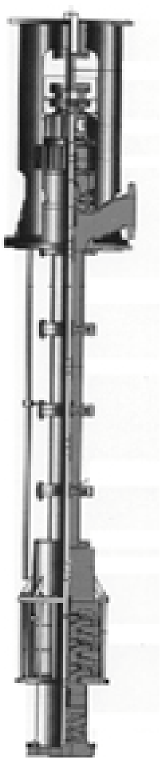
Cargo Pumps

Requirements

When cargo transfer is by pumps which are not accessible for repair with the tank in service then at least two separate means should be provided to transfer cargo from each tank….
Ref IGC 5.8.1

In most cases this means there are two pumps fitted in each tank. However if the cargo tank can withstand pressure then an alternative means of discharge is to pressurise the tank and force the liquid into an empty tank with low pressure. In this case only one pump needs to be fitted to the tank.

Deepwell



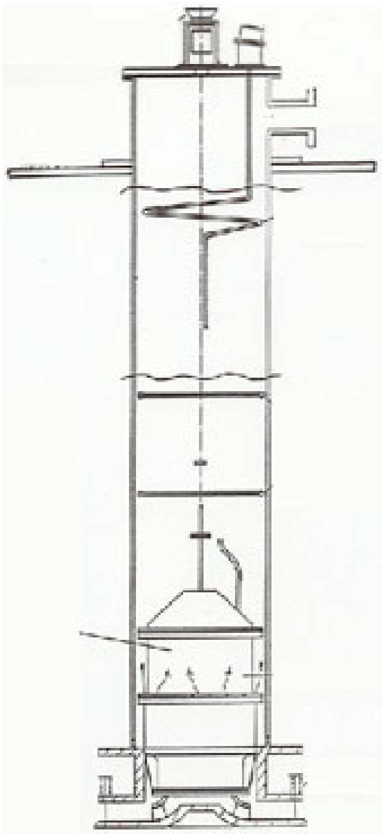
Pump Characteristics

- Motor sits on top of the tank
- Long drive shaft connects the motor to the pump
- Motors usually electric single speed, but can be hydraulic
- Drive shaft is very long and is supported by carbon bearings
- Bearings must not run dry
- Impellers are usually multistage to give the required discharge head
- An inducer is fitted to improve flow to the first stage impeller. This helps to reduce the required NPSH
- Pumps for VCM often have 5 stages

Operational Notes

- Turn pumps during loading to test for freezing
- Turn pumps daily on passage to even out bearing wear
- Turn pumps before starting to ensure they are free to turn

Submerged



Pump characteristics

- Motor and pump are located in one unit at the bottom of the tank
- If the motor or pump fail they can be removed from the tank
- A foot valve located at the bottom of the discharge column is closed to allow removal
- Pump is raised, foot valve closes
- Pump discharge column is inerted
- Lifting tripod set to raise pump and motor
- Cables must not be bent sharply to avoid damage to insulation

Fixed Submerged Pumps

- These are found on LNG ships
- Tank must be entered in order to repair or remove the pump

Operational Points

- Cannot be turned before starting
- There must be a minimum liquid level in the tank before the pump can be started

General Operational Notes

General

All pumps to megger tested before starting
Turn Deepwell pumps during loading, on passage (prevents “brinelling” of bearings) and before starting
Frozen pumps can be de-iced by using hot gas or antifreeze
Never add antifreeze without written permission - cargo could be put off specification and become worthless
Methanol is toxic and is absorbed through the skin

Starting Cargo Pumps

Discharge valve is opened prescribed amount this:

- Reduces the impact at the non return valve
- Keeps the starting load on the motor to a minimum

Pumps usually started on re-circulation by closing tank isolating valve and opening the filling valve
Submerged pumps require a minimum liquid level before starting
Pumps usually have a 20 minute time out period between starts to allow the motor to cool
Fill and cool lines slowly

Emergency Cargo Pumps

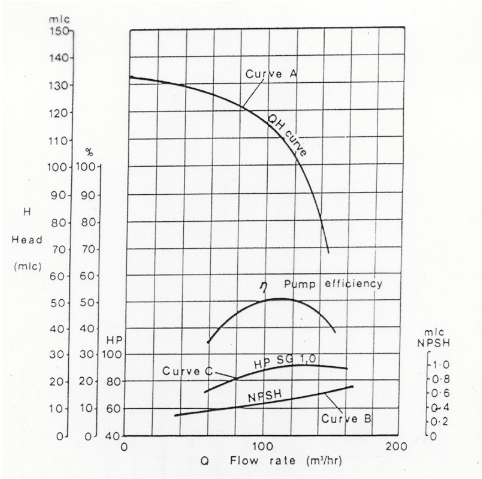
Some ships have a small emergency pump which is lowered through a trunking with a foot valve

LNG ships with spherical tanks can use pressurised discharge if both pumps fail

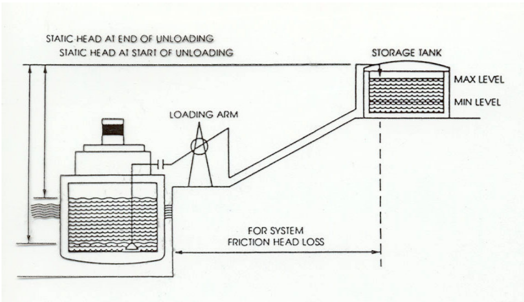
Membrane tanks are usually fitted trunkings for emergency pumps

Pumping Practice

QH Curve is the discharge capacity against head (measured in metre liquid column mlc)



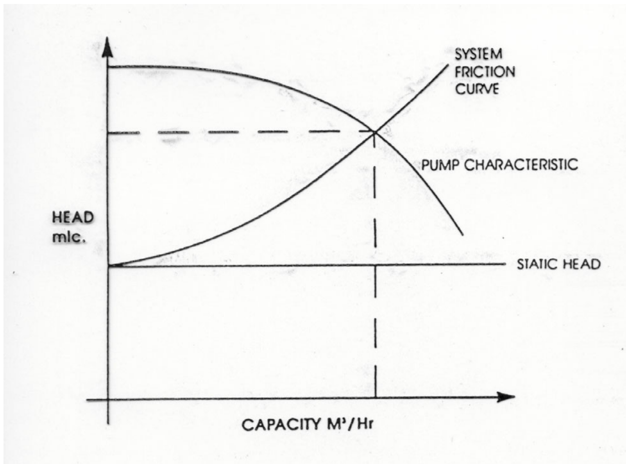
Static Head

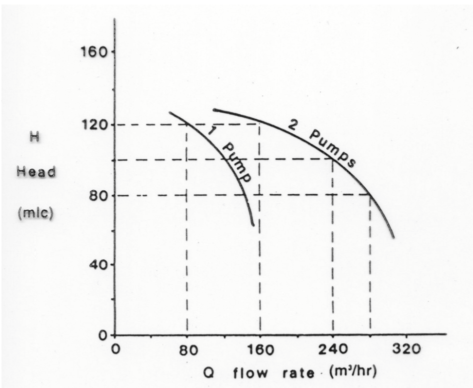


- The height to which the cargo is pumped
- Changes in draft, tide and tank level affect static head

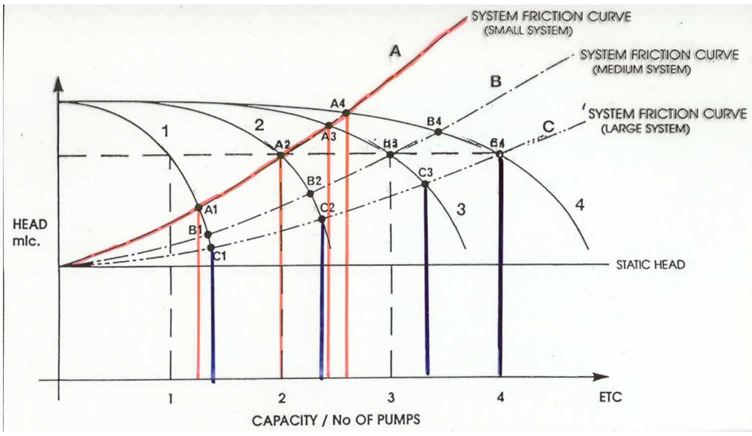
Static and Dynamic Head

- Resistance to flow in the pipeline.
- Depends on size of pipe, length of pipe, and speed of flow





Centrifugal Pumps in Parallel
Theoretically the flow rates are added together. In practice this is not the case.

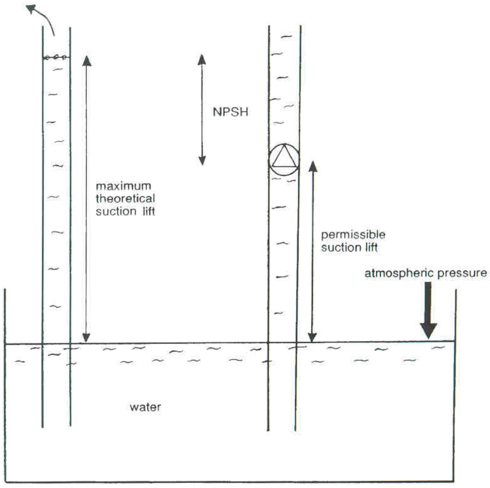


In practice when running multiple pumps against a high back pressure (line A) the increase in flow rate when starting additional pumps becomes very small. The energy to fun them is wasted and converted to heat.
Line C shows a large shore pipeline creating a low resistance to flow. Starting additional pumps in this case is worthwhile.

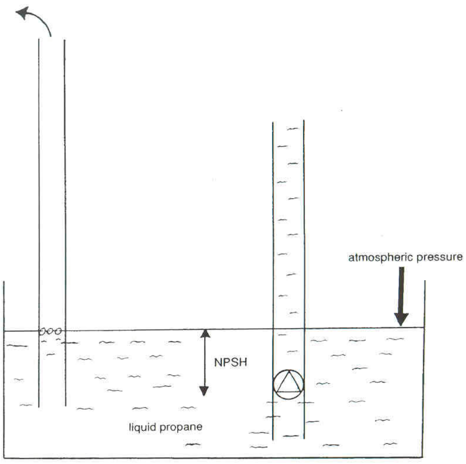
Net Positive Suction Head (NPSH)

With Water

- When pumping water the pump is able to lift the water up to a point
- As the suction pressure drops the water will boil at the inlet to the impeller
- The difference between the two is the NPSH required by the pump.



With Propane



- The pump cannot even be raised to the liquid surface before the liquid begins to boil at the inlet to the impeller
- Pressure required above the pump to prevent the cargo boiling at the inlet to the impeller created by throttling the discharge valve
- Increasing the tank pressure can help reduce the required liquid head
- When the pump is at the bottom of the tank the flow rate must be reduced as the liquid level approaches the bottom to reduce the NPSH requirement. Failure to do this results in the pump gassing up and losing suction.

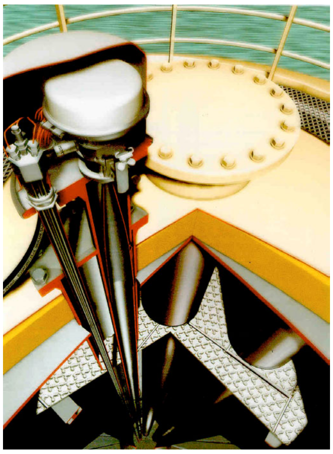
Level Measuring Requirements

Reference IGC 13.2.1, Tanker Safety Guide (Liquefied Gas) 6.2

Each tank must be fitted with at least one liquid level gauge. The specific type of gauge is defined in Chapter 19 of the IGC code. If it is not possible to maintain the gauge while the tank is in service then there should be a back up. Most tanks have two gauges.

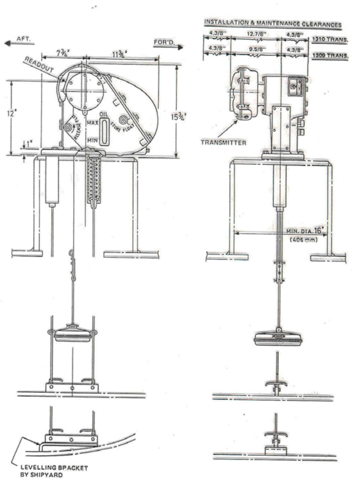
Indirect
Weighing or flow meters – not normally found on gas carriers

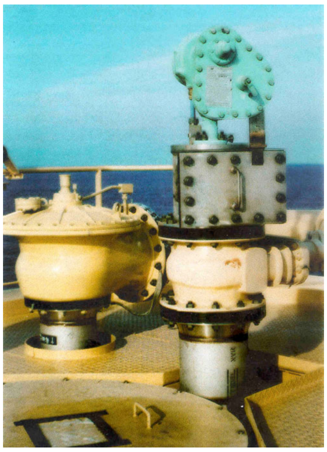
Closed devices which do not penetrate the tank
Radar Gauges



- Transmitter and temperature sensors can be changed without releasing tank atmosphere
- Wave guide is needed to focus radar beam
- The Still Pipe stops boiling inside by transmitting the cold temperature of the liquid to the vapour just above the liquid surface

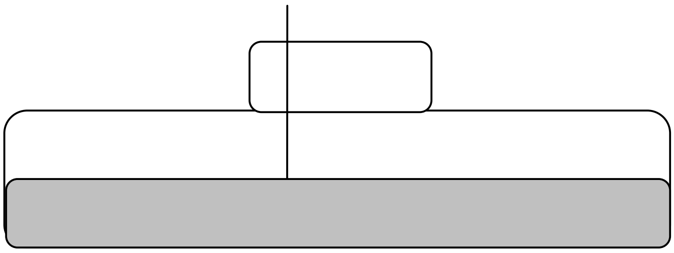
Closed devices which do penetrate the tank
Float gauges, bubble tube indicators and capacitance systems





This design uses a pipe rather than guide wires. A valve at the top allows the float gauge to be completely isolated from the tank preventing release of cargo vapour when maintenance on the gauge is required.

Restricted devices
These penetrate the tank but release a small amount of vapour or liquid. E.g. Slip tubes



Level Measuring - High Level and Overflow

Ref IGC 13.3.1 (page 117)

High Level
…each cargo tank should be fitted with a high liquid level alarm operating independently of other liquid level indicators. This must be capable of being tested manually and must give and audible and visual alarm.

Overflow Protection
Another sensor operating independently of the high liquid level alarm should automatically actuate a shutoff valve in a manner which will both avoid excessive liquid pressure in the loading line and prevent the tank from becoming liquid full. This may be the loading valve to that tank allowing loading to continue to other tanks, or it may be the manifold valve stopping loading to the whole tank.

Temperature and Pressure Measurement

Pressure Measurement
Ref IGC 13.4 Tanker Safety Guide (Liquefied Gas) App. 6.3

- Must have a pressure gauge fitted to the cargo tank, with a remote readout in the cargo control room.
- There must be a high pressure alarm and if the tank has vacuum protection, a low pressure alarm.
- Maximum and minimum pressure must be marked on the gauge.
- If the relief valves have more than one setting the there must be a high pressure alarm for each setting.

General Precautions
- Periodically check for zero calibration
- Avoid using beyond 75% of the gauge range
- Bourdon tubes can be damaged by excessive vibration or excessive pressure pulsations, (these can be eliminated by the use of a flow restrictor).
- Material of construction must be compatible with the cargo
- Don't subject them to violent pressure changes
- When carrying cargoes which polymerise make sure lines and chambers are flushed

Effect of Atmospheric Pressure
- The gauge only compares what is in the tank with what is outside. As the atmospheric pressure changes this will affect the reading given on the gauge. This is most noticeable with cargo tanks which have low pressure limits of about 0.25 barg.
- When taking gauge readings they should be corrected to absolute pressure for a true indication of how the cargo is behaving.

Temperature Indicating Devices
Ref IGC 13.5, Tanker Safety Guide (Liquefied Gas) App. 6.3

Must have at least one in the liquid and one in the vapour. It is usual to have several more to give a good average of the temperature in the tank.

Gauges are used to monitor both the temperature of the liquid and of the tank structure to ensure it is not operated below its design limit. Some tanks have restrictions on the maximum temperature difference between the top and bottom of the tank.

For cargoes carried below -55°C the temperature of the steel around the tank i.e. the inner hull, must also be monitored to ensure the hull structure is not exposed to low temperatures.

Types of Thermometers
- Thermocouples
- Resistance thermometers
- Bi metallic thermometers
- Liquid filled thermometers

General precautions
- Should be suitable for the range of temperatures expected
- Too cold and the metal may become brittle
- The sensor must make good thermal contact with the material to be measured

ENTRY INTO DANGEROUS SPACES

I.C.S. TANKER CASUALTY DATA EXCHANGE SCHEME:

TANKER CASUALTY REPORT NO. 12

This report covers an accident resulting in the death of three Senior Officers.

The Vessel

1. *The vessel concerned was a 54,000.m^3. LPG Carrier built in 1972 with all accommodation aft and four main cargo tanks which were separated from each other by transverse bulkheads. Void spaces extending out to the shipside surrounded each tank. These void spaces were normally filled and kept at a slight over pressure with inert gas when carrying cargo. The inert gas was supplied from a special generator and the normal quality would have contained less than 1% of oxygen.*

2. *Ballast was carried in double bottom hopper tanks situated immediately underneath the void spaces, and in upper hopper tanks which extended over the upper part of the void space. These tanks were not connected with each other. An air pipe was fitted at the after end of each hopper tank to allow the tanks to be filled and emptied without causing a pressure or vacuum build up and a patent valve attached at the upper deck level to prevent water flowing back down the air pipe in heavy weather conditions.*

3. *A duct keel was constructed on the centre line, the bottom of which was the ships hull, the sides being the inboard bulkheads of the double bottom hopper tanks port and starboard, and the top being the centre section of the void space. Three entrances were provided to this duct keel, one forward of No. 1 tank, one between Nos. 2 and 3 tanks, and the after one between Nos. 3 and 4 tanks. A trolley was provided in the duct keel running on fixed angle bars to carry tools and material and also to provide a means of transport for personnel. The trolley was large enough for two persons to ride on in comfort or three at a maximum. A telephone system was also provided from the forward and after sections direct to the cargo control room. This was an intrinsically safe battery powered type instrument.*

4. *A fixed electric driven supply fan was fitted in a ventilator post at the forward end of the duct keel and three outlets were provided one at No. 2 entrance, one at No. 3 entrance and one at the after end of the duct keel. All these outlets were fitted approximately 10 feet above the upper deck level.*

5. *Entry to the double bottom hopper tanks was effected by going down into the duct keel, passing along until in the vicinity of the required tank, where two manhole doors were fitted on the vertical bulkheads, one at the forward end of the tank and one at the after end.*

6. *To ventilate this tank correctly therefore, the forward manhole door would be removed and all other openings to the duct keel shut tight. Air would then pass from the supply fan along the duct keel to the open manhole door and then pass into the tank and leave via the air pipe which was situated at the after end of each tank. Air would then be expelled at the upper deck level.*

General Circumstances

7. *On the morning of the accident the ship was lying alongside the berth waiting to discharge her cargo. Discharge had started the day previously but due to adverse weather conditions during the night all cargo operations had been suspended and the chiksan arms disconnected.*

8. *Prior to arrival at the discharging port, small quantities of water kept appearing in No. 5 starboard double bottom tank (situated furthest aft) and defective valves were suspected. All void spaces had been fully inerted and pressurised one week prior to arrival.*

9. *On the morning of the accident two Senior Deck Officers went into the duct keel to check the suction valve to No. 5 starboard double bottom tank. No defects could be seen and the after door to the tank was removed before the Officers came out for lunch.*

10. *After lunch, having discussed the problem with the Master, it was decided to enter the tank and check if any hull fractures were evident as they had apparently eliminated all other sources of water ingress. A supernumerary Master had been appointed to the ship the previous day for gas training and he also decided to familiarise himself with the duct keel and double bottom tank construction.*

11. *Several Officers knew which tank was being inspected and one had been told to stand by the phone in the cargo control room. The four Officers went down the after entrance to the duct keel and made their way aft and entered the tank through the open manhole door. In fact all entered the double bottom tank; no one remained at the entrance in the duct keel, close to the telephone.*

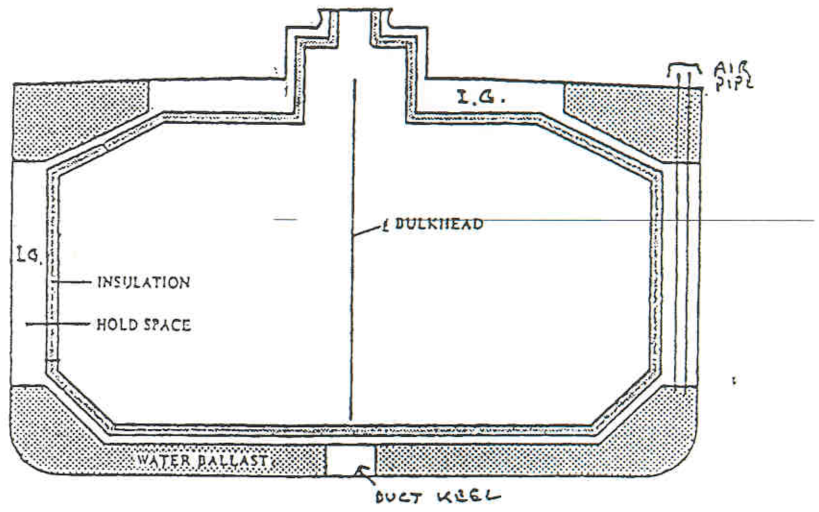
12. *They all passed through the full length of the tank before moving outboard to the ships side. As they started coming aft the Officer in the lead complained of feeling dizzy but at this stage none of the other Officers were experiencing any adverse effects. It was generally agreed that there was an oxygen deficient atmosphere and they should all get out of the tank. After a further two bays had been passed the leading Officer collapsed backwards unconscious and the supernumerary Master was sent out of the tank to raise the alarm while the other two tried to help the unconscious victim.*

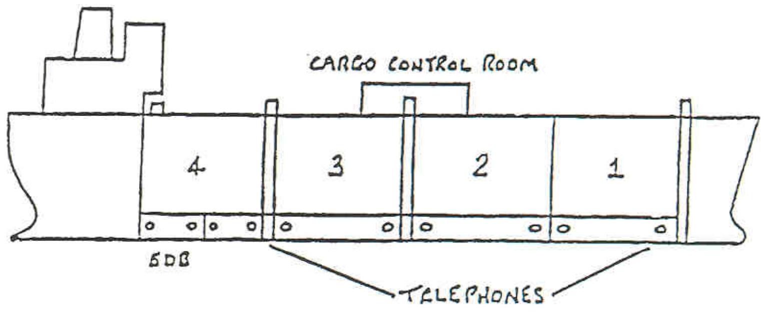
13. *The supernumerary Master managed to get out of the tank, although feeling dizzy by this time, and operated the telephone in the duct keel. Understandably the message that was received in the cargo control room was not completely clear, however, the alarm was raised and the rescue party who had been well trained in rescue procedures of this type went into action. The supernumerary Master was able to reach the upper deck before collapsing. He recovered later.*

14. *Due to too rapid planning and lack of leadership, the members of the rescue team went all the way to the forward entrance and entered the duct keel at this point. As the trolley unit was situated aft they had to make their way over the frames through the full length of the duct keel to the after end. This proved very exhausting and only two members of the original party of four were present at any time throughout the rescue operation. They had unfortunately forgotten to bring the portable VHF sets which could have helped considerably in establishing the exact conditions, and only two compressed air breathing apparatus and a resuscitator were brought to this point.*

15. *Members of the rescue party found the three Officers unconscious but still breathing in the same compartment two bays inboard and one bay forward of the manhole exit. Despite numerous attempts to attach face masks and to carry out the victims all rescue attempts failed.*

16. *One Officer in a confused state, made further attempts to effect entry to the tank from immediately above via the void space; there was, of course, no other means of entering the double bottom tank or the duct keel other than through one of the three entrances mentioned earlier. This resulted in the crew members becoming unconscious from inert gas being released from the void space.*


AIR PIPE
I.G.
I.G.
℄ BULKHEAD
INSULATION
HOLD SPACE
WATER BALLAST
DUCT KEEL


CARGO CONTROL ROOM
4
3
2
1
SDB
TELEPHONES

TANKER CASUALTY REPORT NO. 18

1. All tanker personnel should be thoroughly aware of the potential danger of entering enclosed spaces without first checking that the atmosphere is safe to breathe and can be expected to stay in that condition throughout the duration of the visit. Casualty Report No. 12 described an accident in which three senior personnel died on a gas carrier.

2. Regrettably, deaths and incidents arising from careless or uncontrolled entry into enclosed spaces continue to occur and thus it is felt that inclusion in the scheme of a further example may help to provide further emphasis.

General Circumstances

3. *The following incident resulted in the death of the Boatswain of a refrigerated LPG tanker of 14,000 tons deadweight. The man involved had been on board the vessel for twelve months and, for six months, had been the crew representative on the ship's Safety Committee.*

4. During a ballast voyage the manholes to the pressure tanks were sealed. However, on filling the tanks with inert gas, leakage from the manholes was discovered. The Boatswain was instructed to re-seal the manholes and work commenced in the late morning. Shortly after noon he was discovered lying in one of the pressure tanks. Although brought up quickly, and given oxygen, his life could not be saved.

5. *Subsequent investigations showed that there had in fact been no need to enter the tank to carry out the re-sealing work on the manholes. Why the Boatswain entered the tank was never explained. A ladder was placed into the tank through the manhole (40cm x 60cm) and was clearly how the Boatswain entered. No tool was found in the tank.*

6. *Before starting the work the Boatswain was aware the tank was inerted. However he did not have a man standing by nor did he use the available instruments on board to test the atmosphere either in the tank or immediately outside the manhole.*

Lessons Learnt

7. *The reasons for the Boatswain's actions are not known; however, there can be no question that this and every other similar incident is preventable. A study of many such incidents has emphasised that the people involved are often responsible senior personnel and the only explanation can be that those involved firmly and instinctively believe that "it cannot happen to me".*

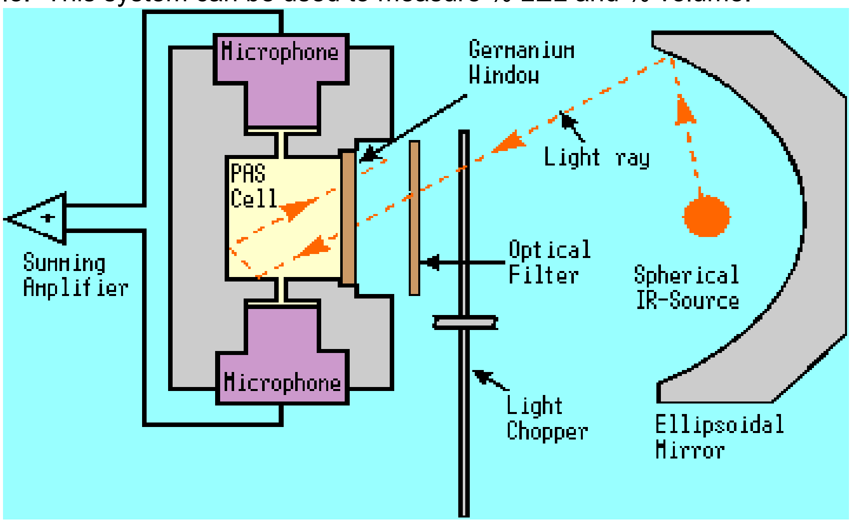
8. *Masters and tanker personnel will all be aware of the dangers. However, regular re-emphasis of the advice in the safety publications on board vessels should help to ensure that correct procedures are invariably followed, otherwise "it could be you next time".*

Gas detection Systems

Requirements
Ref IGC 13.6

- All gas carriers are required to have a fixed gas detection system to cover the spaces listed in the IGC.
- Each space must be sampled within 30 minutes.
- An alarm must sound at 30% LFL.
- On LNG the gas duct and boiler hoods must be sampled continuously when gas burning is in operation due to the increased hazard represented by a leak of methane in the engine room.
- Calibration gas must be carried for the equipment
- Location of sample heads depends on the density of the vapour, this could mean sampling at the top and bottom of a space.
- There must be an audible and visual alarm for the gas analyser in the CCR and on the bridge.
- Every ship must have at least two sets of portable detection equipment for the products carried
- There must be a portable instrument for measuring Oxygen levels in inert atmospheres.

Infra Red Detection
Infra Red detection is used in most fixed analysers. This works on the principle that hydrocarbon gases absorb infra red. Therefore if any hydrocarbon gas is present in the sample chamber less infra red energy is received at the sensing cell. There are several different systems that use this basic principle. This system can be used to measure % LEL and % volume.



Operational points:-

1) Installations should be zeroed and calibrated using a span gas regularly and alarm settings checked. On certain systems installation has to be calibrated for the specific gas to be measured. Others are calibrated using one particular span gas and reference curves are then provided to enable detection of other gases without recalibration.

2) End of line filters should be regularly checked to ensure no blockages.

3) Sample point position in space should be correct for gas to be detected i.e. bottom for hydrocarbons, top for ammonia.

Portable Analysers

Instruments for gas detection fall into 3 main groups

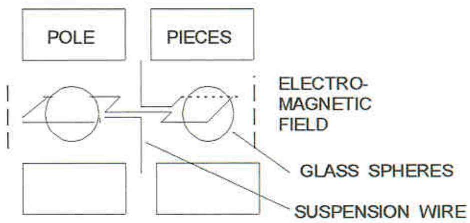
- For testing Oxygen
- For testing flammable atmospheres
- For testing toxic atmospheres

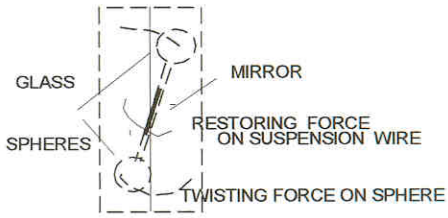
Oxygen Detection

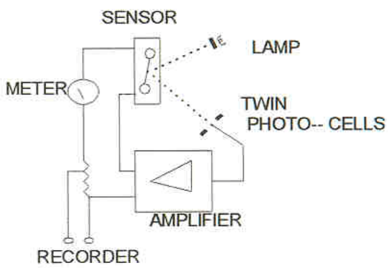
On method of detecting a gas is to look for a unique property that makes that gas different from the other gases in the background.

Paramagnetic Type

Oxygen has a unique property among the most common gases in that it is strongly **paramagnetic**. This allows it to be identified and measured in a variety of gas mixtures. A common type has a lightweight body suspended in a magnetic field where it experiences a torque proportional to the magnetic susceptibility of the gas mixture. A feedback circuit produces an electric current equal and opposite torque and it is this measured current which indicates the magnetic susceptibility of the mixture, that is the proportion of Oxygen in the mixture.







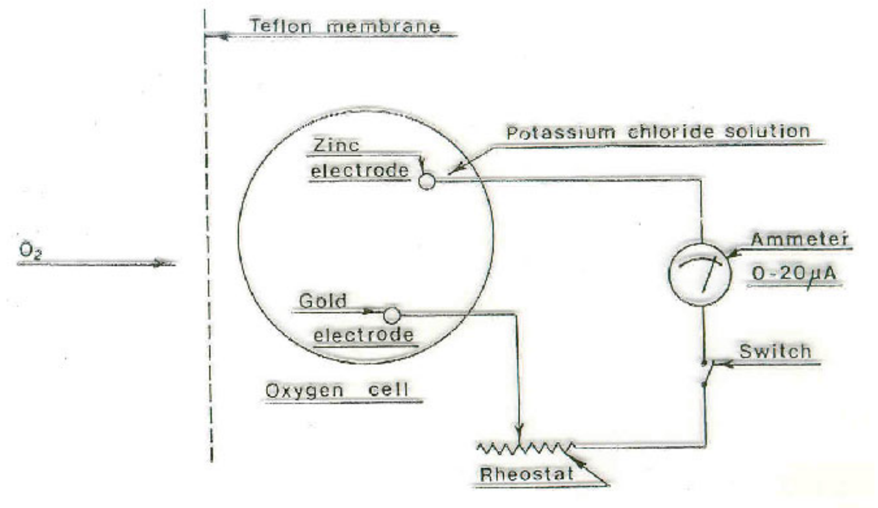
Operational Points

(a) Before use it is important that the instrument is zeroed using Nitrogen or CO_2 and spanned with air for 21% Oxygen.

(b) Atmospheric pressure will affect the readings so it is usual to take readings at atmospheric pressure.

(c) Samples should be directed into the sensor by positive pressure, not vacuum, and the sample should be dry and of uniform flow.

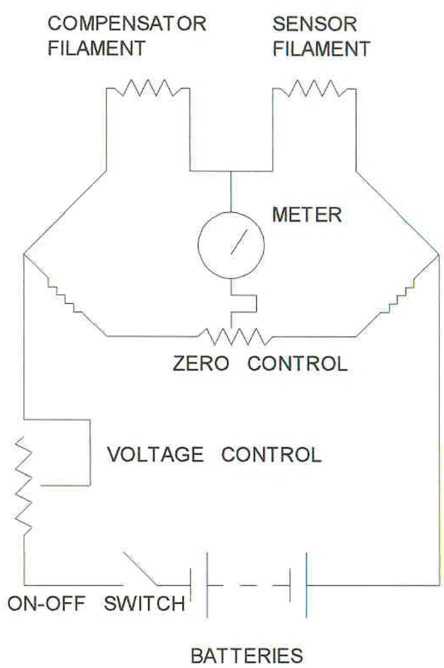
Electrochemical "Fuel Cell"



- Anode & Cathode are different materials
- Oxygen in the electrolyte allows a "galvanic" type action resulting in a small current between electrodes
- The current produced is measured and represents the amount of Oxygen present in the sample.

Measurement of Flammable Gases

Catalytic Type
This is a Wheatstone bridge with a Catalytic filament forming one arm of the bridge and an identical filament which compensates for ambient temperature. The sample gas is drawn across the heated filament where the catalytic reaction makes it hotter. This in turn raises the resistance in the arm reducing the voltage flow in direct proportion to combustible gas concentration. This resistance change is shown on a meter as a percentage of the Lower Flammable Limit. Although the instrument will respond to concentrations 2-3 times the LFL, **the meter will not indicate** such concentrations.



Operational Points
- This type of instrument will not work in an Oxygen deficient atmosphere.
- The filament may become poisoned if exposed to such high gas levels.
- High concentrations of some non-hydrocarbons such as H_2S, CO or gases from lead compounds can affect readings.
- Dusts and combustible mists will not be detected.

- The instrument should be checked and calibrated before use.
- Readings should be taken between squeezes of the bulb.
- The meter is linear.

Non-Catalytic Type (Gascope)
The circuitry is basically the same as the Catalytic type but in this case the heated filament is cooled by the sample gas flow. Since the heat loss is a non-linear function of the gas concentration the meter is non-linear in presentation. This principle of operation enables the meter to indicate % by volume and is not reliant on the presence of Oxygen for operation.

Operational Points

- The instrument should be calibrated by an appropriate gas (say 8% Butane in Nitrogen) before use.
- High pressures can affect readings and it may therefore be necessary to detach the sample line thus allowing the pressure to drop to near atmospheric before taking the final readings.

Note:
It is important that the correct batteries are used and it is recommended that they should be removed if the instruments are not to be used for long periods.

Measurement Of Toxic Gases In Low Concentrations

Currently, the most common method used is the chemical indicator tube. In this method a glass tube is filled with a reagent which will react only to a specific gas or range of gases. The reaction causes a change of colour in the tube according to the concentration which may be read off against a marked scale. The sample gas is drawn through the tube by means of a small hand pump into which the tube is temporarily fitted for the test.

Operational Points

- It is important that all the components used should be from the same manufacturer.
- Should remote sampling be required, the extension hose should be placed between the tube and the hand pump and the tube should be placed in the fitting the correct way round.
- The tubes are designed to measure atmospheres in air.
- If more than one gas is present, other gases can interfere with the reaction.

Personal 0_2 Monitors

These instruments are normally used to continuously monitor the atmosphere during the period of entry and after being tested by one of the types mentioned above. They employ an Electrolytic sensor and usually have an adjustable low level alarm facility. The accuracy of these instruments' readings may be less than those described above.

Important Note.
All these instruments play an important role in the safety of tanker operations. Therefore they must be used in accordance with the Manufacturer's instructions which should be read carefully.

Gas Sampling Procedures

- Sample tubing must be suitable for the gas to be sampled since some materials are absorbent to some gases. It is also important that the tubes are water resistant and are gas tight.

- Tank atmospheres generally do not contain homogenous atmospheres and "dead spots" can be expected, particularly near the bottom of the tank. The method of tank atmosphere changing will also influence the stratification of the atmosphere.

Medical Aspects

Introduction

These notes are a summary of lectures given to students attending the Tanker and Liquefied Gas Tanker Safety courses. These last a week and medical matters take up one and a half hours, so it will be appreciated that this aspect of the subject can only be covered in a limited way.

The main topic dealt with is "gassing" and its treatment, as this is a hazard which applies particularly to tankers (including gas tankers). In severe cases of this kind, immediate resuscitation is vital, so knowledge of the mouth-to mouth method of artificial respiration is vital. This simple skill must be learned, and learned thoroughly, as it is now recognised as the most rapid and efficient way to perform artificial respiration in an emergency. Knowledge of this easy method, which requires no special equipment and can be carried out in almost any situation, may well make all the difference between life and death.

The aim throughout has been to stress general principles, which form the essential basis of a proper understanding of the subject. Tankers today may carry a wide range of petroleum products, chemical solvents and so on, but it is beyond the scope of the lectures (and these notes) to deal with all the special cargoes which may be encountered. The major toxic substances associated with tankers have been discussed individually in some detail, however, and it is hoped that the information given concerning them will help to explain how men can be affected by other substances of similar nature.

It is emphasised that these notes must not be regarded as comprehensive in any respect and it is recommended that they be read in conjunction with the Ship Captain's Medical Guide. Details of the mouth-to mouth method of artificial respiration (and other useful information) may be found in any recent copy of "First Aid", the authorised manual of the St. John and St Andrew's Ambulance Associations and the British Red Cross Society.

Basic Principles

The human body is composed of billions of living cells, all of which need oxygen if they are to survive. The cells derive energy from food, which is "burned" in a rather similar way to fuel in an engine; hence the expression "the fire of life". When oxygen is consumed, carbon dioxide is produced and this has to be removed as it will poison cells if it accumulates. In order to obtain oxygen and lose carbon dioxide, the body is provided with two systems:

(a) the Respiratory system, of which the lungs are the most important part. The lungs function like bellows, moving air in and out, and gas exchange occurs at the same time. The body takes up oxygen from the air which is breathed in and gets rid of carbon dioxide in the air which is breathed out.

(b) The Circulatory System, which is formed by the heart and blood vessels. The blood picks up oxygen from the lungs and carries it to the cells, which take up the oxygen they need and release carbon dioxide in its place. The blood then carries this carbon dioxide to the lungs, where the carbon dioxide is removed and fresh supplies of oxygen are obtained so starting the cycle again.

The cells of the body vary in their oxygen requirements. Brain cells need the most, so they are the first to suffer when oxygen lack (anoxia) occurs. Anoxia can be caused by many factors, and these will be discussed later. The brain can be considered for present purposes in two main parts:

(a) The Higher Centres, which are concerned with thought, judgement, movement of limbs, (Specially skilled work), and the special senses, e.g. sight, hearing and so on.

(b) The Lower (Vital) Centres, which automatically control the body and many of its functions, e.g. breathing, blood circulation and body temperature. The vital centres are so called because life depends on their integrity. They are to a large extent self-regulating and are able to control bodily functions without help from higher centres. In sleep, for example, the higher centres are at rest, but the vital centres keep the body "ticking over" thus acting like an "automatic pilot" in an aircraft.

The brain cells can be disturbed by many factors, some of which will be considered later. In general terms, it can be said that higher centres are affected before vital centres. Consciousness depends on the higher centres, so that when these stop functioning the result is unconsciousness. The next stage, when the vital centres are affected, is more serious as failure of these centres means that the body's vital processes, e.g. breathing and heart action will cease and death will follow. (As a rule, breathing stops first and the heart continues to beat a little longer until death occurs).

Anaesthesia was adopted in order to make surgical operations painless and a general anaesthetic brings about a state resembling deep sleep. The higher centres are "switched off" and the vital centres are left in control of the body.

The effects of anaesthetics follow a broadly similar pattern, rather like the effects of alcohol:

- first, sensation is blunted, so the skin becomes numb and movements are clumsy.
- next, an excitable and emotional phase occurs, as the higher centres become inhibited and primitive emotions are set free.
- a state resembling deep sleep then follows and this becomes deeper and deeper as more anaesthetic is given. at first, "sleep" is light and breathing is normal, but as "sleep" gets deeper the breathing becomes weaker, due to the fact that the anaesthetic is now affecting the vital centres.
- finally, if too much anaesthetic is given, the vital centres become paralysed; breathing weakens and eventually ceases, and death soon results.

Thus, the stages of anaesthesia have been crudely summarised as "awake, asleep, dead". The effects of an anaesthetic depend on concentration and the length of exposure. When the anaesthetic is discontinued, recovery takes place in reverse order to the above. It should be noted that, as with alcohol, people vary greatly in their sensitivity to anaesthetics (and to all other chemicals, for that matter).

Many anaesthetics are very similar in nature to petroleum hydrocarbons; indeed, one modern anaesthetic is a pure hydrocarbon found in petroleum products. This explains why gasoline, for example, acts like an anaesthetic, but rather a dangerous one (for the margin of safety between "sleep" and death is very small, unlike medical anaesthetics).

The brain cells are very sensitive to anaesthetics and similar agents, but they can be affected by many other things as well. Lack of oxygen (anoxia) is particularly serious in this respect and the brain begins to die if deprived of oxygen for more than four minutes, the first cells affected being those of the higher centres. Other harmful agents are excess carbon dioxide, and a large number of poisonous substances. Some poisons act by preventing the cells from using oxygen, so the effects produced are very similar to those caused by anoxia. In such cases, recovery will occur when the poison "wears off", provided the body is kept supplied with oxygen; this is an important fact to remember in the case of hydrogen sulphide poisoning.

It will be apparent that "gassing" on tankers can be due to either of the following, alone or in combination:

(a) lack of oxygen in the air breathed.

(b) toxic gases or vapours, acting as anaesthetics or cell poisons or both.

Therefore, suitable precautions must be taken to ensure that closed spaces are not only free from poisonous gases and vapours, but are also well supplied with fresh air (for oxygen requirements), before entry is allowed. Note that heavy vapours and gases tend to sink and collect in "pools", thus displacing air and forming potential death traps.

Men can be affected by exposure to dangerous situations in two main ways:
(a) Acute Effects, e.g. a man who is suddenly overcome by a high concentration of gas, or by sudden deprivation of air.

(b) Chronic Effects, where prolonged exposure to a fairly low concentration of toxic substance causes gradual damage to certain parts of the body.

In order to define safe working limits, figures are quoted for Threshold Limit Values (T.L.V.). these indicate level so exposure which are generally accepted as a guide to safe practice and are based on a five day (forty hour) working week. They are usually expressed in parts per million (ppm), e.g. the TLV of gasoline is 300 ppm or 0.03%. Other TLVs are given in the Cargo Data Sheets forming part of the Tanker Safety Guide (Liquefied Gas).

The British Health and Safety Executive publish similar Data annually in Guidance Note EH40: Occupational Exposure Limits. This information is in two lists: Maximum Exposure Limits (including suspected Carcinogens such as Butadiene and Vinyl Chloride Monomer) and Occupational Exposure Standards (including gases such as Methane, Propane and Butane).

Example: Gasoline

Under this heading can be included petrol, motor spirit, light distillate feedstock, and the volatile constituents of petroleum in general. Two special substances which are often associated with certain petroleum products - lead additives and benzene - are discussed later.
Gasoline vapour is heavier than air and is detectable by smell. The TLV is 300 parts per million. As a rough guide in terms of figures, the following effects are likely to occur in the "average man":

500 ppm - prolonged exposure is likely to cause mild irritation of the eyes only.

1000 ppm (0.1%) - irritation of the eyes, followed by irritation of the nose and throat after exposure of an hour or so (when some sensitive individuals may begin to feel rather dizzy).

2000 ppm (0.2%) - irritation is worse and symptoms resembling alcoholic intoxication, e.g. dizziness and unsteadiness, develop within thirty minutes.

7000 ppm (0.7%) - "drunk" within five minutes, becoming worse as time passes; will eventually fall into a coma and die if exposure prolonged.

10000 ppm (1%) - effects are produced very rapidly; a few breaths are often sufficient to paralyse all movements, so the victim is unable to save himself and will soon die if not rescued.

The symptoms of gasoline poisoning are very similar to those produced by alcoholic intoxication; mental dullness, dizziness, headache, blurred vision, unsteadiness and staggering, weakness, ringing in the ears, nausea and vomiting. The symptoms often become temporarily worse when the victim is moved into fresh air. If exposure continues, he will become restless, excitable, confused and delirious; he will develop paralysis, followed by coma and death. Death results from failure of breathing; the heart continues to beat a little longer, hence the patient can often be revived by prompt artificial respiration. Rest is essential for the victim, as exertion can often be too much for a weakly beating heart. The details of the treatment will be considered later.

Individual variation is marked and men who are new to such work are particularly at risk. Even the most "hardened" individuals have no resistance to high concentration, however, so familiarity must be allowed to breed contempt and carelessness. Actual cases of gasoline poisoning reveal that the effects come on rapidly and the victim rarely has sufficient warning to escape from danger by his own efforts. Closed spaces containing gasoline vapour are extremely hazardous, especially if free liquid is lying around; anyone foolhardy enough to enter such a compartment without observing all the safety rules (proper breathing apparatus, lifeline, outside assistance and so forth) is virtually committing suicide.

The following examples can be given:

1. A cargo tank carried light distillate feedstock; it was unloaded, washed and ballasted. The ballast was changed during the voyage and, on reaching port, the ballast was emptied and the tank was washed and ventilated once more. It was tested and found to be gas-free, but during mopping-out operations a man was overcome and had to be rescued and resuscitated. The cause was thought to be gasoline fumes from disturbed scale and rust.

2. An escape of gasoline into pump room bilges occurred. A pumpman defied all regulations, entered alone and was overcome. An officer went down with a smoke helmet, but his eyes watered so much that he could hardly see; after fifteen minutes, he had to come out to be sick. The pumpman was stone dead when pulled out.

3. In an incident ashore, a railcar was being entered by a man and a boy. The boy was sent for a spanner. When he returned, he found the operator lying dead in the railcar, in half an inch of petrol. (An equally rapid death from aviation gasoline occurred in USA, when a mechanic entered an aircraft fuel tank which had not been properly gas-freed).

4. **Explosimeter readings of zero are no guarantee of safety**, as the following incident clearly illustrates:
   Two men were removing sludge from a tank, with a fan in operation, when they suddenly collapsed. They had to be rescued and resuscitated. The tank had previously been mechanically ventilated for sixteen hours and machine washed thoroughly for four hours. Explosimeter readings were zero both before and after the occurrence, and again when rechecked twenty minutes later. The cause of the accident was presumed to be gas released from the disturbed sludge.

Benzene

A common and unnecessary source of confusion arises because two words with the same sound have very different meanings. BenzEne is the name for a specific chemical substance which is uniquely dangerous in that it can poison the blood. Benzine on the other hand, is a vague term which is sometimes applied to a type of gasoline, which may contain none of the true benzene at all! To confuse matters further, a crude mixture of benzene and allied substances is frequently termed benzol.

Benzene is one of the aromatics, but it is the only one which attacks the blood. However, all aromatics can act as anaesthetics, i.e. like gasoline. Aromatics occur naturally in crude oil, and high octane gasolines usually contain considerable quantities.

Benzene vapour is heavier than air and has a characteristic smell which is detectable at 100 ppm. Note that this is far greater than the TLV of 5 ppm. The latter concentration should never be exceeded.

There are two hazards with benzene:

(a) ACUTE - it has an anaesthetic action, like gasoline but only about half as powerful. This effect will normally be overshadowed by other volatile constituents of the cargo, except when pure benzene is being carried.

(b) CHRONIC - this is a serious hazard and explains the low TLV. Continuous exposure to fairly low concentrations can damage the bone marrow and give rise to various blood disorders. The effects are cumulative, so the only safe course is to avoid all exposure to benzene as far as possible. Symptoms of chronic benzene poisoning are vague and difficult to recognise without special medical tests, but the condition is unlikely to occur on tankers in normal circumstances. Occasionally cargoes of pure benzene are carried and special precautions are necessary. The potential hazard associated with low concentrations of benzene emphasises the importance of thorough gas-freeing of tanks before entry is allowed.

Butadiene And Vinyl Chloride Monomer

These two cargoes, which may be carried in suitable LPG ships, also have **Chronic** health hazards in addition to their **Acute** anaesthetic properties.

Anoxia (Oxygen Lack)

Shortage of oxygen will affect all the cells in the body, but the brain is the first to suffer and is more easily damaged by anoxia than any other part of the body. The brain may suffer from anoxia due to:

(a) lack of oxygen in the air breathed

(b) respiratory failure (cessation of breathing)

(c) circulatory failure (the blood fails to carry oxygen to the brain)

(d) the fact that the brain cells are unable to use the oxygen owing to the effect of specific poisons, e.g. hydrogen sulphide.

The air in compartments which have been closed for a long time is often deficient in oxygen, especially if rusting has occurred. Cargo tanks may contain a large amount of heavy vapour and gas, which can kill a man indirectly by suffocation (the air having been displaced by the other gas). The effects depend on the severity of the oxygen lack. If a man is suddenly deprived of oxygen altogether, e.g. if he descends into a "pool" of heavy gas or enters a compartment totally devoid of oxygen, he will fall unconscious with little or no warning and will die if not rescued quickly (the brain cells start to die after 4 minutes without oxygen).

When oxygen lack is less severe, the picture is quite different. Normal air contains 21% oxygen, but this can fall to 14% before effects begin: breathing tends to become faster and slightly deeper. Below this level the brain begins to be affected and the first sign is that the victim becomes "thick-witted". He is slow, stupid and obstinate, and loses his common sense and judgement. Vision is affected (the light seems to fade) and movements become weak and clumsy. The man does not realise what is happening, however, so he will blunder on at great risk to himself and others. He will not listen to reason and may well turn nasty if attempts are made to rescue him at this stage.

As the anoxia gets worse, he will become "drunk" and may sing, shout, laugh, cry or "see red" for no apparent reason. He loses all sense of time and distance; he does not know where he is; he stumbles and falls to the ground, becomes unconscious and eventually dies.

Recovery is rapid and complete after a short period of mild anoxia, but is can be a slow and difficult process after a severe episode. The victim is often very confused and may remain irritable and unstable for a while. He may appear to be a changed person.

The sudden effect of total oxygen lack is illustrated by the case of an employee of an engineering firm, who wore an airline helmet while shot-blasting. Unfortunately, someone connected the airline to pure nitrogen (a non-poisonous gas) with the result that the unfortunate shot-blaster was deprived of oxygen and died of suffocation. It should be noted that he became unconscious so quickly that he did not have time to remove his helmet.

Carbon Dioxide CO_2

This gas is often used in fire fighting appliances. It extinguishes fires by depriving them of oxygen and it can kill people in the same way. Therefore, its effects are mainly those of anoxia. It is a colourless gas with no smell, but it has a slightly acid taste (it is the "fizz" in soda water). It is heavier than air, so it can collect in "pools" and cause suffocation in the same way as other heavy gases.
It does have some effects of its own at low concentrations and these are mentioned briefly, although they are not of much practical importance in the present context:

Up to 2%	- no effects are likely
3%	- breathing is deeper and slight headache may occur
5%	- breathing is strenuous, with sweating and bad headaches
10%	- severe headache and breathlessness develops rapidly, perhaps with ringing in the ears, dim vision and twitching, unconsciousness and death follow if exposure continues.

Caustics

This is not a "gassing" hazard, but caustic cleaning materials are dangerous and deserve special mention. The liquid is highly caustic (corrosive) to the tissues, especially the eye. It will rapidly destroy skin and is much worse than strong acids in this respect.

If it splashes in the eye, only **immediate action** can save sight:

THE EYE MUST BE FLOODED WITH WATER AT ONCE AND THIS MUST BE CONTINUED UNTIL ALL THE CAUSTIC SODA HAS BEEN FLUSHED AWAY

If there is no running water to hand, the victim's head should be pushed in a bucket of water and his eyelids opened - by force if necessary. It is truly a case of being cruel to be kind, as this is the only possible way to prevent blindness. After prolonged washing, the eyes may be rinsed with clean water to which a little vinegar has been added,(not more than 1 teaspoonful to a pint of water). Then apply eye pads and bandages to keep the eyes closed, referring to the Ship Captain's Medical Guide.

Splashes on skin should be treated in the same way, with floods of water.

Note: **As splashes are so dangerous, those exposed to this hazard must wear goggles and suitable protective clothing.**

Treatment Of Gassing

If the victim is unconscious, check whether he is breathing and, if he is not, **START MOUTH-TO-MOUTH ARTIFICIAL RESPIRATION IMMEDIATELY**. Remember, you only have four minutes before the brain starts to die. **DO NOT WAIT** while someone fetches a special gadget. (A "Minuiteman" Resuscipac or similar machine may be useful later, when it is brought if the victim is still not breathing, but check that the machine is working properly before using it. If you are in any doubt, continue with mouth-to-mouth resuscitation.

It is essential to make sure that the victim's airway is clear, as stressed in the training given in the mouth-to-mouth method. Keep head tilted back, remove dentures and any foreign material which may be present in the mouth.

Be on guard for vomiting, especially during the recovery phase; if it occurs, turn the head to one side and keep the mouth clear. If he is unconscious, but breathing (or when the victim has been resuscitated to this state), ensure that his breathing is adequate. When it is, turn him over onto his side in a sleeping position - the three-quarters prone position - so that he is lying with his face turned towards the deck (reference should be made to the books previously mentioned for full details).

It should be noted that drugs are of no value in these cases; it is pointless breaking capsules under the victim's nose.

If is clothes are saturated with gasoline, etc, remove them and dry the skin off quickly. The victim should then be wrapped in a blanket.

When consciousness is regained, reassure the patient and make him rest in bed. Keep him ward, but do not overheat him. **DO NOT GIVE ALCOHOL**. If his eyes are sore, wash them gently with clean, lukewarm water; then apply eye pads and bandage the eyes in the closed position.

Keep the man in bed after the incident and observe him carefully; he should be seen by a doctor as soon as possible. He must not be allowed back to work until fully recovered and it seems certain that no complications will occur. If signs of chest trouble develop, treat in accordance with the advice given in the Ship Captain's Medical Guide.

Conclusions

Safety is mainly a matter of sound routine and safe working habits. The proper safety precautions must always be taken. **Never take chances**, many people have died because they thought they would be able to get away with it.

The same considerations apply when someone else is in danger; think carefully before you rush to his assistance. For his sake as well as your own, make sure you follow the proper safety procedures, or you will just add yourself to the casualty list and make the problem twice as bad for somebody else.

Be sure you are thoroughly familiar with all rescue gear and safety equipment, so that no time is lost in an emergency. A thorough knowledge of the mouth-to-mouth method of artificial respiration is a vital factor in saving life: **make sure you know it**. The method is equally valuable in other situations, e.g. electrocution.

These notes do not cover the various safety measures which are laid down, and reference should be made to such sources as the International Safety Guide for Oil Tankers and Terminals, I.C.S. Tanker Safety Guide (Liquefied Gas) and Ship Captain's Medical Guide.

Cargo Operations

Only the basic principles can be outlined in these notes. Reference should be made to the Tanker Safety Guide (Liquefied Gas) and to ship operating procedures for detail.

Considering a voyage cycle starting with a vessel which has just left dry-dock

Inspection of Tanks
Why?
Important to remove any debris in the tank since the pump is located at the bottom of the tank

Drying tanks
Why?
During the inspection puddles of water should be removed. It is also important to remove all water moisture from within the tank. Failure to this at this stage will cause problems with icing later.
How?
Air is dried usually with an R22 air drier and then silica gel to obtain a dewpoint of around -45°C. In some cases the air is also heated before being passed back into the tank.

Inerting
Why?
To prevent a flammable atmosphere within the tank in which case inert gas from the ships IGG is used. For some cargoes the Oxygen must be removed to prevent reaction. In these cases the Oxygen content is usually required to be in the order of 0.1% by volume. This can only be achieved by the use of Nitrogen which is supplied from the shore.

The Tanker Safety Guide (Liquefied Gas) recommends that the Oxygen content after inerting should be in the order of 2% by volume.

How?
Inert gas is introduced into the bottom of the tank and air is discharged from the top of the tank.

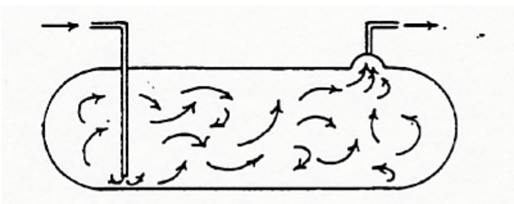
Atmosphere Changing

When changing the atmosphere there are two methods which may be used.:-

i) **Dilution**

This method comprises of a mixing process where the incoming vapours mix with and gradually dilute the existing atmosphere to a homogenous state similar to that of the incoming vapour.

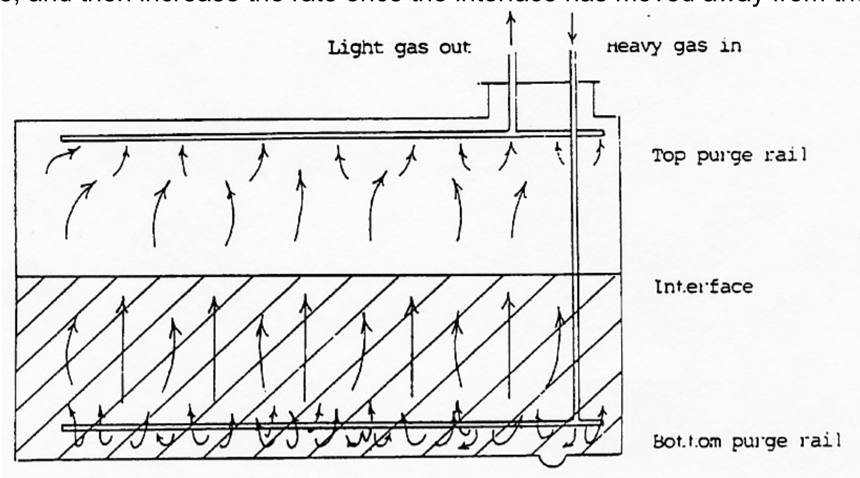
Depending on the ship type there are a number of different ways in which the vapour can be introduced into the tanks to ensure a good mix and to reduce the amount required to a minimum. It is the method sometimes adopted on pressurised and semi-pressurised vessels where the pipeline layout does not allow the second method of 'Displacement' to be used successfully.



ii) **Displacement**

This method relies on stratification within the cargo tank of the two different gases due to the difference in densities of each. The heavier gas is kept below the lighter. The effect is similar to that of a piston.

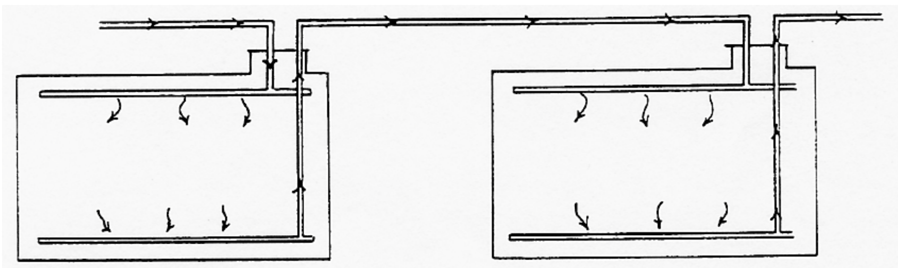
It relies on a good interface being achieved between the two gases. This depends on the difference in density between the two, and also how much turbulence is created within the tank, especially when the operation is being commenced. Hence when undertaking the operation it is better to commence the introduction of the new gas slowly to minimise the turbulence, and then increase the rate once the interface has moved away from the inlet. A



slight positive pressure on the tank will also help to maintain the interface.

In theory, if a good interface can be maintained only one tank volume of incoming gas would be required the change the tank vapour. However, in practise some mixing does occur due to the slight differences in density and pipe layouts within the tank, hence a larger volume will be required.

If more than one tank has to be purged with the incoming gas, to further reduce the quantity required to complete the process, instead of purging each tank individually it is sometimes possible to link two or more tanks together. This allows the gas coming out of the first tank to be fed into the second etc. In this way if any mixing does occur it can be used to commence the operation in the following tanks instead of being wasted.



In deciding which gases are heavier or lighter the best method is to enter the thermodynamic tables for the particular gases concerned and compare the respective vapour densities at the particular temperature.

However for general applications the word NAIL can be used as an *aide memoir* to decide the best method to change a tank atmosphere. If it is written as follows the different likely gases can be readily seen in descending order of density.

N	Nitrogen / NH_3
A	Air
I	Inert Gas
L	LPG

Therefore LPG vapour is heavier than I.G., hence it would be fed into the bottom of the tank and the I.G. removed from the top. Methane has a density equal to air at a temperature of about -100°C.

Once the tanks are inerted the pipelines and machinery must also be inerted to avoid the possibility of a flammable atmosphere anywhere.

Gassing Up

Why?

Before loading LPG liquid the tanks have to be purged with LPG vapour. This is because the ships reliquefaction plant cannot condense inert gases due to them being above their critical temperatures. Also if ships I.G. has been used the solids it contains can do serious damage to the cargo compressors. In the case of LNG ships it is important to remove all of the CO_2 contained in the inert gas (about 14%) as this will freeze at about -75°C. Removing the inert gas also removes the water vapour contained within it even though this quantity is small.

How?

The operation is undertaken in a similar way to the inerting with the LPG vapour being passed into the bottom of the tank and the inert gas taken from the top.

The LPG vapour is either obtained from shore or from liquid in a deck storage vessel. In both cases the liquid is delivered slowly to a vaporiser which turns the liquid to vapour, which is then passed to the tanks.

The expelled I.G. / LPG vapour can be used to purge the pipeline system and is then sent out via the vent mast or to a shore flare. In some ports neither of these methods is allowed in which case only one tank is purged, the expelled mixture being contained in the other tanks until the vessel is clear of the berth. The remaining tanks are done at anchor and the vessel returns to the berth once all tanks are cooled down ready to load.

Regular % gas readings should be taken throughout and once 90 - 95% gas is obtained in the top of the tank (actual figure depends on refrigeration plant operations manual) the reliquefaction plants may be started and purging stopped. Initially the plants may not run correctly due to the remaining incondensibles in the tank atmosphere. These are vented off via the purge condensers.

Once the tanks are gassed up the pipelines and machinery must also be gassed up.

Cool Down

Why?

In a lot of refrigerated ships the cargo tanks must be cooled down to the carriage temperature of the cargo slowly, to minimise thermal stresses within the steelwork. The actual rate of cooldown will vary with tank design but is generally around 10C/hr with a maximum difference allowed between top and bottom readings. In addition if the tanks were not cooled and cold liquid was introduced there would be so much vapour produced that the ships reliquefaction plant, or high duty compressors in the case of an LNG ship, would not be capable of dealing with it.

How?

Cooling is achieved by putting liquid into the tanks via spray rails. Initially the liquid will vaporise and in doing so it will take heat from the surrounding atmosphere. The excess pressure generated is controlled by either returning to shore via the vapour return or by using the ships reliquefaction plants. The operation is complete when a puddle of liquid forms within the tank and the required temperature gradient has been achieved. Monitoring the tank pressure is also a good indicator of the amount of heat energy trapped in the tank structure.

On some ships the tank construction is such that they will withstand the thermal stresses imposed without a slow cooldown operation. Therefore, on these ships, once the tank has been gassed up a quantity of liquid is placed in each tank in turn, usually sufficient to cover the bottom steelwork so the amount of boil off is kept to a minimum. The pressures which are obviously produced are controlled by using the cargo reliquefaction plants and the operation is complete when the tank pressures have been reduced to a level where loading can be commenced. At this time it is possible to have ambient temperatures in the top of the tank and -42 (Propane) in the bottom. This should only be carried out on vessels where the operations manual clearly states that the tank structure can withstand the thermal gradients produced.

Loading

Prior to commencing the load the tank pressures should be reduced to the minimum possible with at least one reliquefaction plant running, with the others either running if sufficient pressure in cargo tanks, or ready to be started at short notice. LNG ships should have HD compressors ready for starting to return vapour to the shore.

Loading is commenced at a slow rate to cool the lines and so that the pipeline system can be checked for leaks. On LNG ships there is a separate operation to cool the lines before loading which takes about an hour. The rate can then be increased gradually to a maximum where the tank pressures can be maintained steady at a working level sufficiently below the relief valve setting.

Loading can be undertaken using a vapour return line (VRL), ships plant for LPG ships), or both. Usually if the VRL is available then the "both" option is used as it enables the fastest loading rate to be achieved and also provides a safety back up if for some reason either the VRL is lost or the ships plant stops.

However in many ports a VRL is not available and hence the loading rate has to be restricted. It may also necessitate the rate being reduced considerably as the tank becomes full due to the rapidly reducing vapour space and consequent increase in pressure.

Note that many terminals connect a VRL but will not permit the ship to use it. This is due to concerns about contamination of the shore tanks. The VRL is there only for emergency use should there be a problem with the ship reliquefaction plant. LNG ships can only return the vapour to the shore.

Loaded Passage

As heat leaks in through the insulation the tank pressure will rise. On an LNG ship the natural boil off is sent to the engine room where it is burnt in the boilers. A LPG ship will run the reliquefaction plant to allow the cargo to boil and evaporate which will cool it. The vapour drawn off is reliquefied and returned to the cargo tanks. It is better to return condensate to one tank at a time and rotate the tanks to ensure an even distribution while the float gauges are raised at sea.

Discharging

During the discharge as the tank level drops so does the pressure in the tank. This will cause the boiling point of the cargo to go down and so the cargo will evaporate and boil more producing vapour. However as the cargo temperature drops boiling may stop and pressure will continue to fall. If the discharge is fast natural boil off in this way may be insufficient to maintain a positive pressure in the tank. In this case it will be necessary to inject more vapour into the tank. This may come from the terminal (which is usually the case on an LNG ship), or the vessel may create vapour by bleeding off some liquid from the discharge line and passing it through the vaporiser.

If the ship is going to load the same grade on the next voyage then it is normal practice to leave a small quantity of liquid in the tank in order to keep the tank cold on the ballast voyage. On an LNG ship this may be quite a large parcel of cargo if the ship is required not to burn bunkers only cargo vapour in the boilers.

If the vessel is to gas free the tanks as much as possible should be discharged however it is never possible to completely empty a tank since the volume in the discharge pipe will always fall back to the sump when the pump is stopped.

Ballast Passage
During a normal ballast passage the cargo tanks are kept cold ready for arrival at the next port by spraying. On an LPG ship as the pressure rises the reliquefied vapour is sent back to the tanks via the spray lines. On a LNG ship it depends on whether the ship has been instructed to burn mostly bunkers or gas. If it is to burn gas then a small spray pump supplies a “forcing vaporiser” which produces gas for the engine room. To minimise use of cargo the tanks will normally only be sprayed a few days before arrival at the loading port in order to obtain the minimum temperature acceptable for loading.

Boil Off
If the ship is to be gas freed as much liquid as possible will have been discharged at the last port. Since there is always some liquid left in the tank this must be removed.

How?
LPG Ship
On fully refrigerated ships this is achieved by evaporating the liquid from the sumps. The cargo compressors are run without the cooling medium so producing hot gas. This is fed into the tank sumps either directly or via heating coils. The heat in both cases is transferred to the remaining liquid causing it to evaporate.

If the hot gas is returned directly the resulting vapour in the tank is vented to atmosphere via the vent mast, or through another plant to be turned into condensate which is then put in a deck storage vessel. If heating coils are used the hot gas, on passing through the coils will be cooled to the extent that it condenses. This condensate can then be passed over the side or fed into a deck storage tank as before.

If using heating coils the puddle has been removed when the discharge from the coils becomes hot and the discharge pressure on the compressor increases. In both cases the bottom temperatures should be monitored and when the puddle has gone the temperature will rise rapidly.

LNG Ship
On LNG ships vapour is passed through the HD compressors and the HD heater to warm it to about 70°C before returning to the bottom of the tank via the liquid line. Excess vapour can be burnt in the boiler or vented depending on the amount of time available for the operation.

Indication that liquid has gone?
Change in bottom temperature and pressure in the tank.

Warm Up
Why?
Once the puddle of liquid has been removed, hot gas should be continued to be returned into the tanks. This is to begin heating the tank.

How warm?
This part of the operation may be limited by time, but tank temperatures should be as high as possible before purging is commenced. In any case the tank temperature (not the atmosphere) should be warmer than the dewpoint of the inert gas to avoid moisture in the tank. If possible the tank structure should be warmed to atmospheric temperature to avoid moisture when ambient air enters the tank.

Purging
Why?

This operation is carried out similar to the purging operation prior to loading but in the reverse sequence, the objective again being to avoid a flammable atmosphere in the tanks.

How?
Dry inert gas is blown into the top of the tanks with the LPG vapour being expelled via the bottom (or the other way around for LNG which is lighter than air). If the displacement method of atmosphere changing is used all the hydrocarbon gas will be removed. However the hydrocarbon content should always be less than 2% by volume before any air is introduced into the tank. Cargo pipelines and machinery must also be purged.

Aerating
How?
Once the hydrocarbon concentration in the tanks has been reduced to less than 2% by volume, aerating can be commenced, (in via top out via bottom). Once the cargo tanks have been aerated the pipelines and machinery must also be aerated. Series purging can be used is pipeline layout allows.

For Repairs To One Tank

The above procedures are followed in the tank to be gas freed. However, instead of venting the LPG or returning the condensate from the coils over the side, the gas can be transferred into either a deck storage vessel if fitted or into another tank. To save as much vapour as possible, it is usually possible to link either the loading line or lower purge rail to the vapour suction on the compressors. The plants are then run with the condensate returned to another tank. The outlet from the tank is carefully monitored and the plant is left in operation until the % gas from the tank drops below 95%. The plant is then stopped and the remaining gas is vented to atmosphere. The gas "saved" to another tank can then be used to gas up the tank being worked on when the repairs are complete.

Once tanks are gas freed and safe for entry a tank inspection should be conducted and any dirt etc removed. Likewise before the tank is closed another inspection should be carried out to ensure all tools and materials have been removed and that the tank is clean. This avoids damage to the pumps and aids in future gas freeing ops.

TO LOAD AMMONIA (NH_3) INTO TANKS UNDER AIR AT AMBIENT TEMPERATURE

This operation is conducted in a similar way to that for loading LPG except for the following differences caused by the different characteristics of Ammonia.

i) Ammonia is the lightest of the gases likely to be used. Therefore when purging, instead of introducing Ammonia into the bottom of the tanks which would cause mixing to occur, Ammonia is always introduced and extracted via the top of the tank.

ii) Ammonia will react with CO_2 to form solid carbamates. Therefore if ammonia was introduced into a tank containing inert gas formed by a combustion process i.e. ships generator, this reaction would take place causing a large problem with the tank.

However, in many places it is recognised that although Ammonia vapour is flammable it is not easily ignited and therefore can be introduced directly into an air atmosphere. Therefore, in general no inerting of tanks is required. In some ports tanks will require to be inerted in which case Nitrogen has to be used.

iii) When Ammonia is passed through sprays it is possible for a large static charge to be created. Therefore liquid ammonia should never be sprayed into a tank which contains air.

To Gas Free After Ammonia

Ammonia can present particular difficulties during the gas freeing operation.

i) it is very soluble in water
ii) it becomes trapped within tank surfaces and dirt
iii) very low ppm concentrations are required on completion

The operation is commenced by removing all the liquid from the tank as with LPG, except that once the liquid has been removed hot gas should be returned to the tank for as long as possible. The objective is to heat the tank to above the dew point temperature of the air, which will be used to remove the ammonia.

This is very important, because if the water within the air condenses when put into the tank it will absorb ammonia and hence will make gas freeing the tank impossible until that water is removed.

For the same reason it is preferable to start purging with "dry" air. The air should be introduced into the bottom of the tank with the NH_3 taken from the top either to the vent mast or to another tank via the reliquefaction plants.

% gas readings should be taken regularly throughout the tanks. As the concentrations reach less than 5% the amount of air through-put in the tanks should be increased as much as possible, usually by by-passing the drier and increasing the number of fans in use. This will help to remove the remaining gas and warm the tank up faster so encouraging the ammonia to be released from the tank surfaces.

Once below 700 ppm the tank lids can be opened. Checks should then be made to ensure there is no free water around the sumps or tank bottom. If so this has to be removed as soon as possible along with any dirt / dust build up.

Air purging should be continued for as long and fast as possible. Many ports require final concentrations of Ammonia to be below 10 ppm prior to loading LPG.

As with LPG, all pipes, valves and equipment in cargo system has to be blown through, including all dead ends in pipes. In addition, Ammonia contaminates the lube. oil in cargo compressors and consequently this should be changed. Up to three changes are sometimes required to reduce ammonia concentrations in compressors sufficiently.

Cargo Operations On Pressurised And Semi Pressurised Vessels
The general procedures to change grades on this type of vessel are the same as on refrigerated vessels. However, the way in which certain stages are undertaken differ due to the construction of the tanks and equipment on board.

Liquid Freeing
Usually there is sufficient cargo left on board after discharge to allow the tanks to be pressurised using the cargo compressors. Once sufficient pressure has been obtained within the tank (this depends on the density of the liquid and height of the tank) the valves on all the lines are opened to overboard or to another tank. The stripping line valve on the pressurised tank is then opened. This results in the remaining liquid being blown out of the tank. If any does remain after this operation, it has to be evaporated by re-circulating hot vapour from the compressors.

Gas Freeing / Purging
Due to the construction of the tanks on this type of vessel it is usually possible to draw a large vacuum (up to 80%)on the tanks without fear of damage. This is used to reduce the amount of vapour required to complete an atmosphere change in the tanks. Once all the liquid has been removed, the remaining pressure is vented, and then a large vacuum is draw on the tanks using the cargo compressors. There are no inert gas generators on such vessels so to remove the gas in the tank the vacuum is broken by air. This method removes the bulk of the remaining gas in the tank.

If LPG, after the first vacuum is broken the tank is ventilated, using the compressors on air, until the tank atmosphere is below the flammable limit. Another vacuum is then drawn and broken to ensure that there are no large concentrations of gas remaining within the system.

If Ammonia, another vacuum is drawn immediately and again broken with air. This will reduce the atmosphere remaining to below the flammable limit. The tank is then ventilated by dilution using the cargo compressors. To remove the final traces of ammonia and to speed up the operation the tanks are sometimes water washed. When being undertaken large vacuums can be drawn in the tank so care has to be taken to ensure tank can be readily ventilated. Once complete it is very important to ensure all water is removed and tanks are dry.

Gassing Up
Many ports require vessels to be inerted before loading cargo hence inert gas has to be supplied from shore before gassing up. However prior to each a large vacuum is again drawn on the tanks before being broken with either the I.G. or vapour. Sometimes cargo vapour is not available from shore so has to be obtained either via ships vaporiser or by spraying directly into the tank.

Jettison of Cargo

When would you do it?

- Small quantities as part of gas freeing operation
- Large quantities to lighten the vessel after stranding

What are the Hazards?

- Large vapour cloud will be produced, flammable and toxic danger
- Damage to the hull
- Ships sea suctions, (Ammonia)
- Possibly use a flexible hose over the side just above the water

Personal Protection Equipment

Reference IGC Chapter 14.1

General
There is a requirement for suitable protective equipment to be provided for all crew working with the cargo. What is suitable depends on the nature of the product.

Safety Equipment
Similar to standard fireman's outfit and includes SCBA.
Why is it required?

Air Supply
Most ships have an air compressor but it if not it there must be at least 6000 litres of compressed air for each safety equipment set (5 standard air bottles equals 6000 litres).

Storage
Equipment must be in a clearly marked easily accessible locker.

Maintenance
The compressed air equipment must be inspected monthly by a ships officer and recorded in the ships log. In addition it must be inspected by an expert at least once a year.

Medial Equipment
In addition to the normal requirements there must be Oxygen resuscitation equipment and antidotes if appropriate for the cargoes carried.

Special Equipment for Certain Products
Check in the table in chapter 19 to see if any of the paragraphs in section 14.4 apply.

14.4.2 requires escape BA with a 15 minute duration to escape from the vessel in case of a large gas cloud.

14.4.3 requires decontamination showers on deck. They must work in all ambient conditions.

14.4.4 requires an additional 2 sets of safety equipment.

Emergency Shut Down (ESD)

Activated by

- Manual pushbuttons
- Loss of control air
- Loss of electrical power
- Loss of hydraulic power to valves
- Fusable plugs
- Low tank pressure
- Movement of vessel on berth

Problems with ESD

Can lead to pressure surges in the pipelines. IGC code requires that the valves close in not more than 30 seconds (5.6.4). At high loading rates this may cause a pressure surge. Many terminals have surge protection devices fitted. The best way to avoid problems is to link the ship and shore ESD systems together. SIGTTO have produced a paper on this subject which recommends that ships and terminals use a standard interface for common connection of ESD systems. In practice this rarely happens except n LNG ships which have usually been built to run between designated ports. Loading terminal often supply a remote ESD control at the ships manifold and if possible ships should supply terminals with a means of operating the ship’s ESD while at discharging ports. The most important point to avoid an ESD is to trip the pump before the valve has closed.

Note that ESD valves must be of the fail-closed type (closed on loss of power) and also capable of local manual closing operation.

Powered Emergency Release Coupling (PERC)

Fitted on some loading arms to allow emergency disconnection from the ship. Two ball valves are fitted close together on the loading arm with a release coupling fitted between them. The ball valves close on ESD activation and if vessel movement is extreme the coupling will release leaving the end of the loading arm attached to the ships manifold while the arm swings back to the stowed position by virtue of the counter weight fitted.

Fire Fighting

Fire Water Main (IGC 11.2)
- Fire main
- Fire pumps
- Emergency fire pump
- Hoses

All as per SOLAS

Water Spray System (IGC 11.3)
To cover
- To cover
- Tank Domes
- Deck Pressure Vessels
- Manifolds
- Bridge Front
- CCR
- Compressor Room
- Motor Room

Dry Powder (IGC 11.4)
- Must be able to deliver at least two jets of dry powder to any part of the deck
- Be pressurised by an inert gas such as Nitrogen stored next to the dry powder tank
- Ships greater than 1000m^3 must have two separate dry powder units
- System should be capable of being activated locally at the discharge hose box
- There should be at least one hose at the front of the accommodation

Compressor Room CO_2 (IGC 11.5)
- Similar to the engine room flooding system
- Not to be used for inerting the space due to the electrostatic hazard created on discharge
- Capacity of CO_2 must be equal to 45% of the volume of the space.

Fireman's Outfits
- 5000m^3 and below 4 sets
- above 5000m^3 5 sets
- Specification of fireman's outfit is the same as in SOLAS

Action in the event of fire
- Raise the alarm
- Do not try to extinguish a gas fire.
- Isolate the source and cut off the fuel to the fire.
- Gas fires are very hot especially if they are under pressure. Use water to control the heat.
- Use fixed water spray, or hoses for cooling.
- In an extreme case the flame can be extinguished by either a water cone entrained from behind which cuts off the supply of air to the flame, or dry powder using the same approach from behind.
- The danger with extinguishing a flame is the large cloud of gas which could be ignited and flash back to the source.

Conclusions from Tanker Casualty Report No. 12

A searching inquiry into the accident revealed a number of points and these are sub-divided into action taken before and after the initial accident.

Before

1. No attempts were made by any of the four Officers concerned to monitor the atmosphere inside the double bottom tank before entry was effected.

(b) Ventilation of the tank was not carried out in the designed matter.

(c) No communication link was set up between the entry team and a responsible Officer on deck.

(d) No safety equipment was kept ready for immediate use in the event of a situation of this type developing.

(e) People initially unaffected by the oxygen deficient atmosphere stayed behind to assist the one victim, without first making use of compressed air breathing apparatus. This finally resulted in three fatalities.

After

2. The team who had been trained in the correct rescue procedures acted independently with no one person taking control and co-ordinating the rescue attempt.

(b) It became apparent that a number of senior key personnel were not acquainted with the layout of the duct keel and entrances which resulted in additional confusion.

(c) The ship had on board sufficient breathing apparatus for eight persons yet only two sets reached the scene of the accident. In addition a further seventy small escape compressed air breathing sets were carried which were not utilised. Portable VHF sets were also forgotten in the initial rush and not utilised.

(d) Instead of attaching an air supply direct to each victim, artificial resuscitation was tried on the unconscious persons during the rescue even though they were found to be breathing.

3. During the Company's inquiry it was found that a 50 millimetre crack in the tank top resulted in inert gas entering the double bottom tank and in fact this crack was known to the three Officers who died in this tragic accident. The slight pressure in the void space forced the inert gas into the double bottom tank through this small crack which resulted in an oxygen deficient atmosphere in the immediate area underneath. Over a long period of time there is no doubt that the whole of the double bottom tank could have been filled with inert gas.

Lessons Learnt

4. As a result of this accident a number of modifications and changes were carried out to those procedures and regulations already laid down by the Company and the most important are as noted.

(a) Telephones from spaces similar to the duct keel have been modified to give a positive indication at the master unit to indicate which phone has been operated. It should be noted that the two telephones in the duct keel were connected to a single unit in the cargo control room and it was not evident which phone had actually been utilised.

(b) Suitable warning notices have been placed on all entrances to potentially dangerous areas such as void spaces.

(c) Exits from spaces like the duct keel have been clearly marked. During the rescue attempts some of the rescuers missed the nearest opening and valuable time was wasted carrying on to the next opening.

(d) Rescue procedures have been modified to put more accent on planning rather than wholly on speed. Speed of action must obviously be tempered with a plan of action.

(e) All exits from such spaces should be closely investigated during the building of new tonnage to make the best possible use of clear areas.

(f) New procedures have been drawn up for implementation before entering a potentially dangerous space. An action plan will be drawn up to include a number of safety procedures re-emphasising the need to ventilate and monitor the atmosphere of spaces prior to entry. Although this had been Company standing policy, it had not been followed on this occasion.

(g) The Company's safety procedures have been critically examined and modified where necessary.

(h) A special small light weight working escape set is being developed which will be supplied to all vessels for each person to carry before entering a potentially dangerous space, so that in the event of a similar situation developing a short time supply of good air will be immediately available.