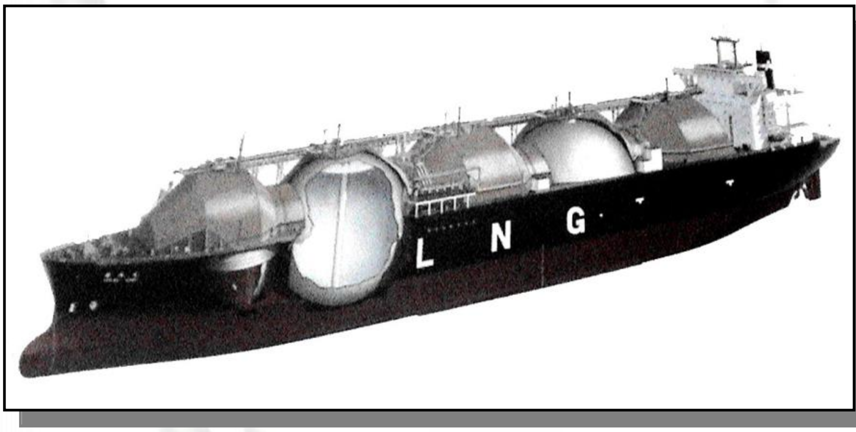


LNG TANKER SAFETY

Version: 05.02.28

I. INTRODUCTION

I.1 Brief History of LNG Ships

In the past, liquefied gas was considered a useless by-product of oil production and was burned off in oil fields as waste. In recent years, liquefied gas pipelines and methane ships were constructed making it possible to transport liquefied gas. Most natural gases are moved through pipelines which started in the United States after World War II. But in the late 1960's, tanker shipment of cryogenic liquefied natural gas began, particularly from producing nations in the Pacific to Japan.

The first ship to carry LNG across the ocean was Methane Pioneer. This vessel was a relatively small tanker reconstructed for this purpose and provided with specially insulated tanks for carrying LNG. She made her first voyage from the Gulf of Mexico to Thames in 1959. This and subsequent voyages proved beyond doubt that the carriage of LNG was feasible and paved the way for the construction of larger carriers.

I.2 Definition of LNG

Liquefied natural gas is the liquid form of a substance, which at ambient temperature and at atmospheric pressure, would be gas. By IMO definition found in the International Gas Carrier Code, liquefied gas are substances carried by ships having a vapor pressure exceeding 2.8 bars absolute at a temperature of
37.8 °C.

When natural gas is chilled to approximately -162°C in atmospheric pressure, it condenses into liquid about one sixth of its original volume in gas state. This colorless, transparent liquid having a weight about one half of water with the same volume is called LNG (Liquefied Natural Gas).

I.3 LNG Business

LNG is becoming increasingly popular as an alternative to petroleum for power generation because its reserves are as plentiful as those of oil, and it is also attractive as a clean source of energy. With LNG carrier services in effect acting as maritime pipelines, the consistent adherence to sailing schedule is of great importance to utility companies, which are responsible for the supply of electric power and gas. As the economies of South Korea, Taiwan and various Southeast Asian nations grow rapidly, so does their energy consumption and demand for LNG. NYK's LNG fleet will therefore expand in parallel with this growing demand as the company diverges into cross trades. This expansion of operations, together with the need to keep the carriers in top condition over very long contract periods, means that vessel maintenance and management will become increasingly important. Also, since LNG is dangerous cargo, safe navigation is of paramount importance.

It is our responsibility to transport goods swiftly, safely and accurately. Loading, handling and unloading are basic to LNG chain of operation and we place safety, accuracy and reliability as top priorities when handling LNG projects. LNG carrier crew members who are to be engaged in these operations are expected to learn necessary techniques in order to carry out their jobs smoothly.

I.4 Source of Natural Gas

Natural gas is made up of various hydrocarbons, which is composed of "inground" petroleum that can be found within the earth's crust. Natural gas may occur in underground wells, in condensate reservoirs and in large oil fields. In case of oil wells, natural gas may occur either in solution with the crude oil or as a gas-cap above it. It contains smaller quantities of heavier hydrocarbons in addition to varying amounts of water, carbon dioxide, nitrogen and other non-hydrocarbon substances. To ensure that the product is in an acceptable condition for liquefaction and for use as gaseous fuel, it requires treatment for the removal of its impurities.

Natural gas is produced on all continents except Antarctica. The world's largest producer is Russia. The United States, Canada, and the Netherlands are also important producers. LNG imports of Japan serviced by NYK ships come from Indonesia, Qatar, Australia and Malaysia.

II. LNG DESIGN AND CONSTRUCTION

II.1 General Description

The overall layout of a gas carrier is similar to that of the conventional oil tanker from which it evolved. The cargo containment and its incorporation into the hull of the gas carrier, however, is very different due to the need to carry its cargo under pressure, or refrigerated or under a combination of pressure and refrigeration. To examine the design of these ships in greater detail, it is convenient to consult the IMO Codes and the rules of the major ship Classification Societies which later in recent years have been rewritten to incorporate all requirements of the IMO Codes.

II.2 IMO Gas Codes and IGC Code

The IMO Gas Code covers ships constructed on or after October 31, 1976. The IMO Gas Code for Existing Ships Carrying Liquefied Gases in Bulk covers ships built before the application date of the new code. These codes are known as the IMO Gas Codes. A further code, the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, with the short title of International Gas Carrier Code (IGC), applies to ships constructed on or after July 1, 1986. With its revised and clarified wording, this IGC Code includes all the updated requirements of the previous Gas Codes for new ships. The IGC Code has been incorporated into the 1974 Safety of Life at Sea (SOLAS) Convention and in 1986 became mandatory for all flags whose governments are signatories to the SOLAS Convention.

Some of the factors to be taken into consideration that affect the design of gas ships are:

a) Types of cargo to be carried;
b) Condition of carriage (fully pressurized, semi-refrigerated, fully refrigerated);
c) Type of trade (determines the degree of cargo handling flexibility); and
d) Terminal facilities available when loading or discharging the vessel.

II.3 Ship Survival Capability And Location Of Cargo Tanks

II.3.1 General (IGC Code 2.1)

Ships are to survive the normal effects of flooding following assumed hull damage caused by some external force. In addition, to safeguard the ship and the environment, the cargo tanks are to be protected from penetration in case of minor damage to the ship resulting, for example, from contact with a jetty or tug, and given a measure of protection from damage in the case of collision or stranding, by locating them at specified minimum distances inboard from the ship's shell's plating. Both the damage to be assumed and the proximity of the tanks to the ship's shell are to be dependent upon the degree of hazard presented by the product to be carried.

II.3.2 Ship Types

Ships are to be designed to one of the following standards:

a) Type 1G ship - is a gas carrier intended to transport products which require maximum preventive measure to preclude the escape of such cargo.

b) Type 2G ship - is a gas carrier intended to transport products which require significant preventive measure to preclude the escape of such cargo.

c) Type 2PG ship - is a gas carrier of 150m in length or less intended to transport products which require significant preventive measure to preclude the escape of such cargo, and where the products are carried in independent type C tanks designed for a MARVS (maximum allowable relief valve setting of a cargo tank) of at least 0.7 MPa gauge and a cargo containment system design 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.

d) Type 3G ship - is a gas carrier intended to carry products which require moderate preventive measures to preclude the escape of such cargo.

Thus, a type 1G ship is a gas carrier intended for the transport 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 is to be designed to survive the most severe standard of damage and its cargo tanks are to be located at the maximum prescribed distance inboard from shell plating. LNG, ethylene and fully refrigerated LPG ships have to comply with type 2G requirements.

II.4 Cargo Containment System

The IMO Code identifies five different types of cargo containment system: (1) independent tanks, (2) membrane tanks, (3) semi--membrane tanks, (4) integral tanks and (5) internal insulation tanks. The independent and membrane types of containment system are of most significant as the majority of liquefied gas carriers built to date utilize one or other of these two types.

II.4.1 Independent Tanks

These types of tanks are completely self supporting and do not form part of the ship's hull and do not contribute to the hull strength. Depending mainly on design pressure, there are three different types of independent tanks for gas carriers, types A, B and C.

a) Type A tanks - are constructed primarily of plane surfaces. The maximum allowable design vapor space pressure in this type of system is, 0.7 bar (g); this means cargoes must be carried in a fully refrigerated condition at or near atmospheric pressure (normally below 0.25 bar (g). The figure 1 below shows a section of this type of tank as would be found on a fully refrigerated LPG carrier.

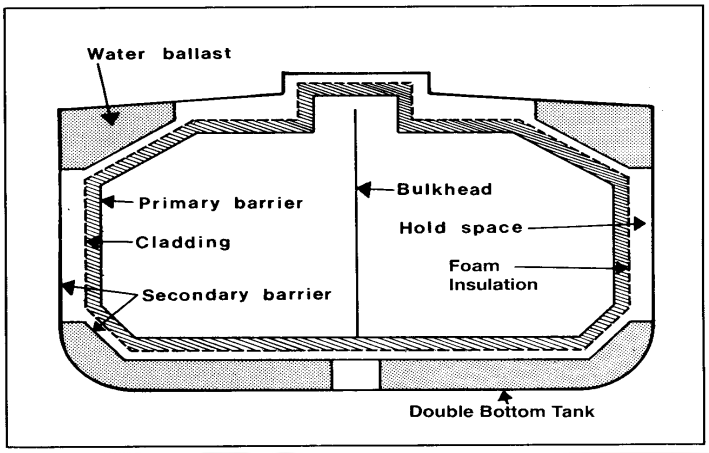


FIG.1: Prismatic self-supporting Type A tank for a fully refrigerated LPG carrier

b) Type B tanks - can either be constructed of plane surfaces or of pressure vessel type. This type of containment system is subjected to a more accurate type of stress analysis test compared to a type A system. Such analysis must include fatigue life and crack propagation analysis. Spherical tanks are well known type B tanks as shown in figure 2 (next page). Type B tank design requires only a partial secondary barrier and this usually consists of a drip tray and a splash barrier. The hold space in this design is normally filled with dry inert gas but may be ventilated with air provided that inerting of the spaces can be achieved in the event of the vapour detection system detecting cargo leakage. A protective steel dome covers the primary barrier above deck level, and insulation is applied to the outside of the primary barrier surface. The type B spherical tank is almost exclusively applied to LNG ships.

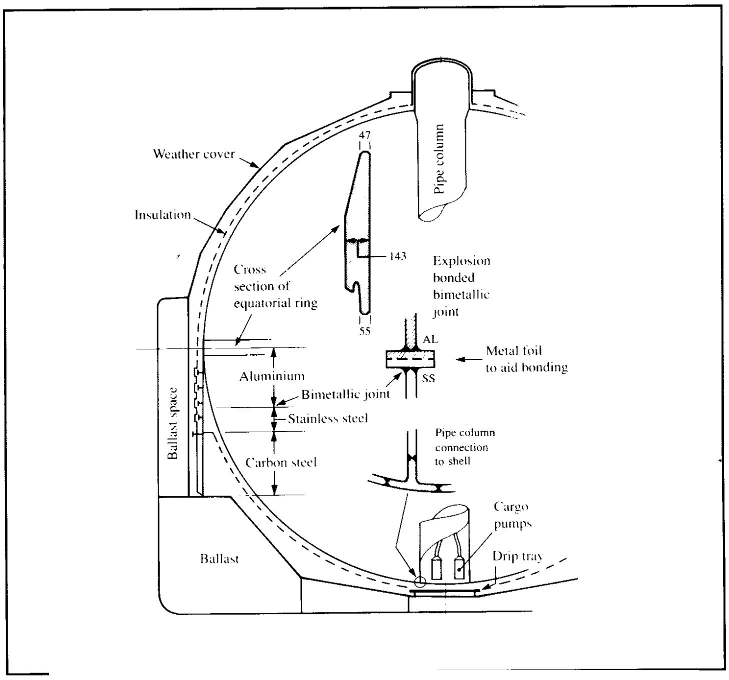
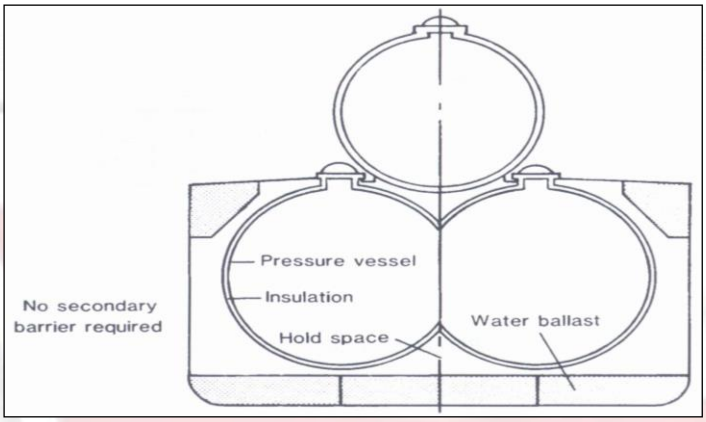


FIG.2: Self-supporting spherical Type B tank

c) Type C tanks - are normally spherical or cylindrical pressure vessels with design vapor pressures higher than 2 bars. Cylindrical vessel types may be vertically or horizontally mounted. This type of containment system is always used in semi-refrigerated and fully pressurized liquid gas carriers; it is also commonly used for fully refrigerated transport provided appropriate low temperature steels are used in the tank construction. Type C tanks are designed and built to conventional pressure vessel codes and, as a result, can be subjected to accurate stress analysis. Furthermore, design stresses are kept reasonably low so, where this type is used, no secondary barrier is required and the hold space can be filled with either inert gas or air. The following figure shows type C tanks in a typical fully pressurized gas carrier. With such an arrangement, there is comparatively poor utilization of the hull volume; however, this can be



improved by using intersecting pressure vessels or "lobe type" tanks which also tapered at the forward end of the ship. This is a common arrangement in semi-pressurized /fully refrigerated ships as shown in the figure below.

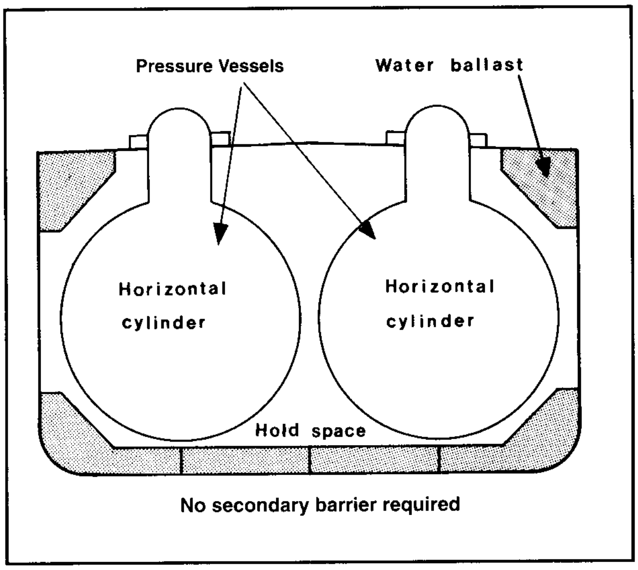


FIG. 3(b): Type C tanks used in fully-pressurized gas carriers

II.4.2 Membrane Tanks

The concept of the membrane system of cargo containment is based on very thin primary barriers, or membranes, which are supported through the insulation by the hull of the ship. They are not self supporting like the independent tanks outlined in the section above in that the inner hull forms the load bearing structure. Membrane containment system must always be provided with a complete secondary barrier to ensure the cargo containment system's overall integrity in the event of primary barrier leakage. The membrane is designed in such a way that thermal or other expansion or contraction is compensated for without undue stressing of the membrane itself. There are two principal types of membrane system in common use both named after the companies who developed them and both designed primarily for the carriage of LNG.

a) Gaz Transport membrane system - the original design comprised a 0.5 mm thick primary barrier (invar membrane) attached to the inner (cold) surface of 200 mm thick perlite-filled plywood boxes for secondary insulation. Invar steel is chosen for the membranes because of its very low coefficient of thermal expansion, thus making expansion joints, or corrugation, in the barriers unnecessary. This type is shown in the figure on the succeeding page.

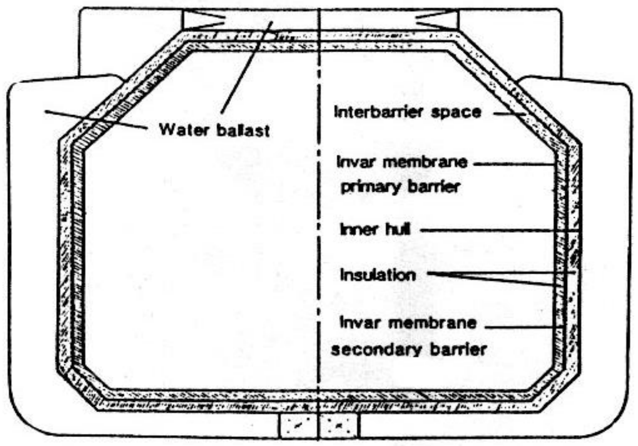


FIG. 4: Gaz Transport membrane containment system as utilized on larger-sized LNG carriers

b) Technigaz (TGZ) membrane system - this system features a primary barrierr of 1.2 mm thick stainless steel with raised corrugation, or "waffles", to allow expansion and contraction. The insulation that supports the primary membrane consists of laminated balsa wood panels between two plywood layers; the inner (cold) plywood layer forms the secondary barrier. The figures below show the detail of its burner and insulation construction.

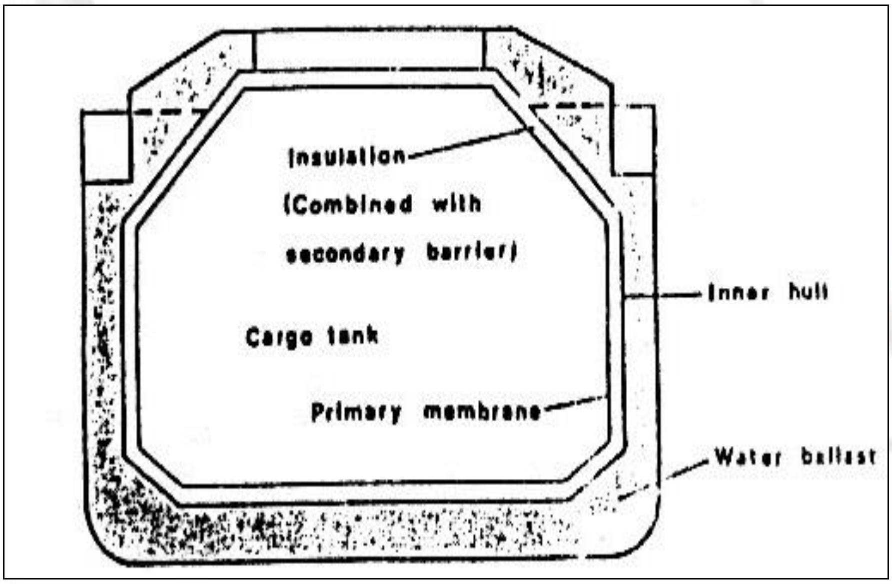


FIG. 5(a) Technigaz membrane containment System as utilized on larger-sized LNG carriers

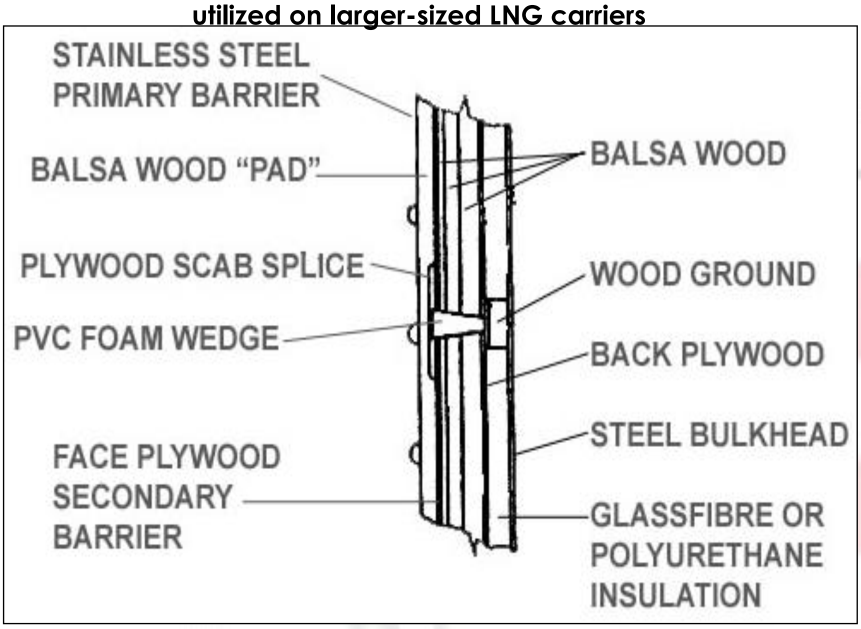


FIG. 5(b) Detail of the Technigaz membrane's barrier and insulation construction

II.4.3 Semi-membrane Tanks

The semi-membrane concept is a variation of the membrane tank system. The primary barrier is much thicker than that in the membrane system, having flat sides and large radii corners. The tank is self-supporting when empty but non-self supporting in loaded condition as the liquid (hydrostatic) and vapor pressure acting on the primary barrier are transmitted through the insulation to the inner hull as the case with the membrane system. The corners and edges are so designed as to accommodate expansion and contraction.

II.4.4 Integral Tanks

The IMO Codes state that "integral tanks form a structural part of the ship's hull and are influenced in the same manner and by the same loads which stress the hull structure". They further state that integral tanks are not normally allowed if the cargo temperature is lower than -10°C.

II.4.5 Internal Insulation Tanks

Sometimes called integral tanks, internally insulated tanks are effectively an integral tank system which utilizes insulation materials fixed to the ship's inner hull plating or an independent load-bearing surface to contain and insulate the cargo.

II.5 Design Philosophy of Moss Rosenberg Containment System

The philosophy involved with this cargo containment system is commonly termed as "leak before failure concept, small leak protection system".

II.5.1 General

The cargo containment system is of the independent spherical tank arrangement in accordance with the patent of Moss Rosenberg. The cargo tanks are equipped to carry liquefied natural gas (LNG), consisting mainly of methane, at cryogenic temperatures and at near atmospheric pressure. Each tank is insulated to reduce cargo loss through natural boil-off. The cargo tank contains a pipe tower, which is fitted with a dome for the purpose of access into the tank and penetration of piping, cables, etc.

II.5.2 Description of Design

a) Four or five cargo tanks are provided and constructed of aluminum alloy. Each tank is protected by a hemispherical steel tank cover which has limited stiffening and no expansion joints. The lower edge of each cover is welded to the deck, forming a watertight seal. A flexible rubber bellows connection is used for sealing where the tank dome protrudes out of the top of the cover. The cover protects the cargo tank insulation from weather and permits control of the hold space atmosphere.

b) Each spherical tank is supported by a metal skirt at its equator, which transmits the entire weight of tank and cargo to the hull.

c) A structural transition joint is fitted between the aluminum and (stainless) steel portions of the skirt. The dissimilar metals are joined together by an explosion-bonding process, as welding is not possible.

d) The cargo tank is fitted with a central pipe tower. The tower supports and contains the cargo pumps, spray pump, discharge and filling lines, CTS (Custody Transfer System), capacitance level gauge, float gauge and gas sampling pipe. Access to the tank is via a manhole fitted on top of the dome.

e) Platforms are fitted inside the tower at regular levels to support the internal equipment and to allow staging points during ascent and descent.

f) Cargo tanks are protected with tank insulation system. There are two types used in NYK ships, the Kawasaki Panel System and the Spiral Generation Log System.

g) Gas carrier construction is currently governed by the SOLAS Convention and International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).

The basis of the "Type B" philosophy is the "leak before fail concept" wherein the primary barrier will fail progressively and not suddenly and catastrophically. In order to meet the requirements, certain conditions have to be met which include:

Stress levels, fatigue life and crack propagation characteristics of the tanks must be determined using finite element model tests and refined analysis methods.

A partial "secondary barrier" must be fitted which must be capable of containing any envisioned leakage from the "primary burner" (tank plating) for a period of 15 days and must prevent the temperature of the ship structure fading to an unsafe level. Failure of the primary burner must not cause failure of the secondary barrier and vice versa.

A "spray shield" must be provided to deflect any leakage down into secondary barrier and away from hull structure.

h) The chances of a crack developing during the life of the ship are remote. In the extreme case of crack propagation occurring in the tank material, a small leakage of LNG within the insulation will be detected at an early stage by the gas detection system fitted at the equatorial ring area.

i) The secondary barrier comprised of an adequately sized aluminum drip pan is installed directly below each cargo tank. The drip pan is provided with temperature sensors to detect the presence of LNG and an eductor system to allow for liquid removal. The spray shield is formed by external aluminum foil surface of the tank insulation. Any LNG liquid leakage will drain by gravity through the insulation to the drip pan via drain tube at the bottom. Any leakage from the northern hemispherical part of the insulation will first pass through drain holes in the skirt and then into the insulation space of the lower hemisphere. The drain at the bottom of the insulation space is sealed in normal service by a thin rapture disc which will fail at cryogenic temperature.

II.5.3 Cargo Tank Insulation

a) Kawasaki Panel System - this system is fitted in Kotokawa Maru, Northwest Swift and LNG Flora.

The prefabricated insulation panels consist of two layers of insulation, the inner layer composed of phenolic resin foam and the outer of polyurethane foam. The panels are attached to the cargo tank by aluminum stud bolts fitted with plastic washers and nut.

A galvanized iron wire net is inserted between the two layers, to act as reinforcement and to prevent the occurrence of cracking in the polyurethane foam layer at low temperature.

The joints between the panels are filled with flexible polyurethane foam in way of the phenol section of the panel. The gaps between the outer polyurethane foam layer of moulded slabs are filled with polyurethane and foamed in place. Polyurethane has a self-bonding property.

The outer surface of the panels is covered with aluminum sheet, which serves as a splash barrier.

There is a small clearance between the inner surface of the insulation panels and the tank surface, in order to provide passage for any leaked cargo and also nitrogen gas flow for cargo leakage detection and maintenance of a dry inert atmosphere.

The insulation way of the skirt is fitted in way of the upper section only and consists of panels similar to those of the tank. The transition part between the lower hemisphere and the skirt is fitted with flexible pre-fabricated U-type insulation blocks.

The external surface of the polyurethane foam at the joint part is covered by synthetic rubber tape and separate aluminum sheets are fixed to the adjoining sheets by pop rivets.

b) Spiral Generation Log System - this system is fitted to Echigo Maru and Banshu Maru.

The spiral generation log system utilizes expanded polystyrene foam which is automatically spun spirally around the sphere. The automatic equipment is designed to fuse adjacent polystyrene strakes (logs) as the machine advances.

The system comprises two polystyrene layers separated by a crack-arresting layer of glass fiber. An aluminum foil vapour (splashy barrier is automatically bonded to the outer surface of the insulation during the log welding process, which butt-welds the prefabricated logs to form a continuous layer.

The insulation is not bonded to the tank surface, to allow passage of nitrogen gas between insulation and tank.

The pole area and the transition areas on the sphere and skirt are insulated with a prefabricated panel made of expanded, rigid and elastified polystyrene foam.

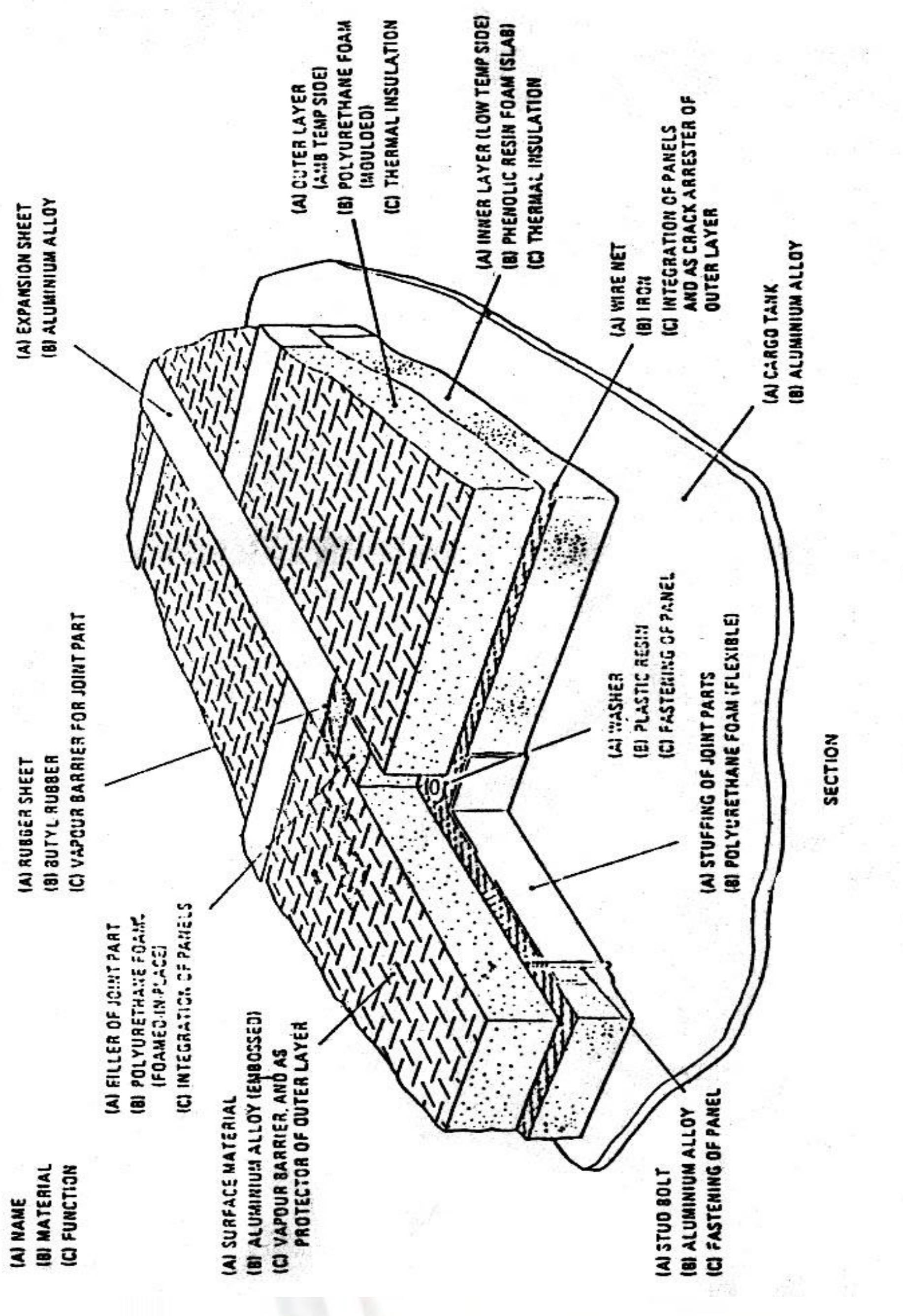


FIG. 6: Polyurethane Foam Insulation

II.6 General Arrangement of LNG Carrier (Moss Type)

The general arrangement of a Moss Rosenberg type of LNG Carrier can be best described by an illustration as shown on the next page. For purposes of instruction, the LNG/C Northwest Swift and the LNG/C Flora are used as examples in illustrating the general arrangement of this type of vessel. General design and construction will include the following notable parts and structures:

1) Accommodation - this structure is located aft of the cargo tanks designed with watertight/gas tight doors and portholes which is common to all gas tankers.

2) Engine room - located below the accommodation and fitted with a dual-fuel system turbine engine. A vapor piping allows boil-off gas from cargo tanks to be supplied to the engine room for fuel.

3) Cargo tanks - four or five spherical shaped tanks numbered from forward to aft. The upper semi-circle of the tank protrudes above deck and the lower semi-circle lies protected within the ship's hull and upper deck.

4) CCR/ECR (CACC) - the cargo and engine control rooms are combined at the accommodation deck below the bridge. The term Centralized Administration and Control Center (CACC) is used on board Northwest Swift. Cargo control and engine control operations through the cargo and engine consoles are performed in this area.

5) Manifolds - pipeline connections to shore arms located on deck at the starboard side and port side between cargo tanks 2 & 3. Normally, there are five manifolds, four for liquid natural gas and one for vapor.

6) Manifold crossovers - pipelines connecting the port and starboard manifolds together. There are separate lines for liquid and vapor.

7) Header lines - main pipelines passing from fore to aft located above deck and branches out to the tank domes. These are classified as liquid header, spray header and vapor header.

8) Flying passage - a walkway from the accommodation to the various tank domes passing above deck at tank dome level. Connected at the forward end is a stairway allowing access from the forecastle to the flying passage or vice versa.

9) Tank dome side - the topside of a cargo tank cover where tank pipes, valves, gauges, etc. are located and monitored during cargo operations.

10) Cargo machinery room -located on deck (starboard side) between no. 3 and no. 4 cargo tanks. It houses various cargo machineries such as compressors and cargo heaters.

11) Main/Upper deck - the deck level which passes from fore to aft of the ship's length.

12) Central pipe tower - fitted vertically inside the tank, supports and contains the cargo pumps, spray pump, discharge and filling lines, CTS (custody transfer system), capacitance level gauge, float gauge system and gas sampling pipe.

II.7 Design Philosophy of The Cargo System (Northwest Swift And LNG Flora)

II.7.1 General

a) Transportation of LNG in ship's cargo tanks is carried out at a pressure that is marginally higher than atmospheric pressure.

b) Four spherical cargo tanks are arranged along the centerline of the vessel. The tanks are within holds and a watertight bulkhead separates each hold. A positive or dry air is maintained in the hold space surrounding each tank.

c) Since the boiling point of the LNG at atmospheric pressure is very low (-162°C), special equipment and procedures must be used whilst handling LNG. Any liquid leakage must be dealt with by spraying the area affected with water by means of the spray system provided, or by the use of a fire hose. This will prevent brittle fracture at the affected steelworks.

d) Before starting any operation involving the liquid cargo, the pipelines and equipment must be cooled to avoid thermal shock and to reduce the rate of boil-off generated at the start of the operation.

II.7.2 Description

a) Cargo is discharged through the same manifold, which is located between no.2 and no.3 cargo tanks, and the fore-and-aft liquid header.

b) Pressures are equalized between all cargo tanks by an interconnecting line at fore-and-aft vapor header, which is connected to shore vapor lines via vapor crossover lines when loading or unloading.

c) On loaded and ballast voyage, all boil-off gas will normally be utilized as fuel in the main boilers.

d) A cargo deckhouse is located on the starboard side of the upper deck between no. 3 and no. 4 cargo tanks. The deckhouse contains the cargo machinery room, which is separated by a gas-tight bulkhead from the motor room. The deckhouse contains the following major items of equipment:

(d. l) Low-duty gas compressors - two single stage variable speed, variable vane control electric motor-driven centrifugal compressors used to send boil-off gas to the ship's boilers.

(d.2) High-duty gas compressors - two single-stage, single speed, variable inlet vane, electric motor-driven centrifugal compressors, used to return LNG vapour ashore during loading operations, to return gas/vapour ashore during gassing-up and initial cool-down operation, and to circulate heated cargo vapour through the cargo tank system during warm-up operations.

(d.3) Gas heaters - Two direct steam-heated horizontal shell-and-tube type gas heaters, used to supply warm gas to the boilers for burning, and to supply gas to cargo tanks during warming-up operations prior to inerting, aeration and entry.

(d.4) LNG vaporizer - direct steam-heated horizontal shell-and-tube type, dual mode:

- Hot vapor production mode: to produce gas to purge inert gas from the cargo tanks prior to cool-down.
- Cold vapor production mode: to produce gas to maintain tank pressure when unloading, if shore return gas is not available.

(d.5) Forcing vaporizer - direct steam-heated horizontal shell-and-tube type, used to generate additional boil-off gas for boilers when insufficient naturally occurring boil-off gas is available.

e) Two vertically submerged, electric motor-driven cargo pumps are installed at the bottom of each cargo tank. When all eight cargo pumps are in simultaneous operation, a full cargo can be unloaded in approximately 12 hours.

f) A vertically submerged, electric motor-driven spray pump is installed at the bottom of each cargo tank, discharging LNG to the spray header. Branches are led from the header to spray nozzles inside each tank. Liquid is sprayed into the tanks on the ballast voyage to maintain them at a temperature low enough to prevent excessive stress on each tank’s equatorial ring during loading. The spray pumps are also used for tank stripping prior to warm-up, or during the ballast voyage to generate vapor to satisfy the demand to the ship's boilers.

g) An Inert Gas Generator (IGG) is provided in the engine room for inerting cargo tanks before and after aeration and entry. Dry air is also supplied from the IGG for drying cargo tanks and hold spaces following tank inspections and maintenance.

h) Two nitrogen generators of the membrane permeation type are located in the engine room and provide nitrogen for the following purposes:

(h. l) cargo compressor gland sealing
(h.2) cargo tank insulation space inerting
(h.3) cargo line purging
(h.4) engine room gas line purging
(h.5) vent riser fire extinguishing

i) For cargo quantity measurement, a Custody Transfer System (CTS) is provided. The system includes equipment to measure liquid level, liquid and vapor temperatures and vapor pressure within each cargo tank and it uses these data, together with tank calibration data tables, to perform cargo quantity calculations. A secondary float-actuated by mechanical system is also provided. The calibration of all CTS equipment, including software and the tank calibration, is carried out by an independent firm.

j) An Emergency Shut Down System (ESDS) is provided to the cargo systems on the ship and ashore during loading and unloading operations. The system incorporates ship/shore links so that shut down may be initiated manually or automatically from ship or from shore.

III. CHARACTERISTICS AND PROPERTIES OF LNG

III.1 Composition of LNG

Natural gas consists of several hydrocarbons of which methane is the main component (88% to 95%). Other hydrocarbons making up this compound liquid are ethane (3% to 8%), propane (0.7% to 2%), butane (0.2% to 0.7%) and pentane (0.03% to 0.5%). Other gases present include carbon dioxide (0.6% to 2.0%), nitrogen (0.3% to 3.0%) and helium (0.01% to 0.5%). Useless components in natural gas such as H_2O, HS, CO, heavy hydrocarbons, etc. are removed in the liquefying process. Composition of each hydrocarbon contained in LNG dictates its actual density or specific gravity. If heavier hydrocarbons are present, the higher will be the density of the LNG and the greater will be its calorific value.

As a difference between natural gas and LNG, it can be mentioned that the components of LNG change while in storage in a tank. This change is caused by the evaporation of light components such as methane and nitrogen, which takes place earlier than that of heavier hydrocarbon. Thus, the concentration of heavier hydrocarbons increases while in a prolonged storage.

III.2 General Use of Liquefied Natural Gas

LNG is used for various purposes. It is considered as a clean gas and is becoming increasingly popular as an alternative to petroleum for power generation. Widespread concern about pollution and environmental damage caused by the burning of coal and petroleum has led to greater interests in the utilization of LNG by all concerned entities. Natural gas is used primarily as fuel and as a raw material in manufacturing. Domestically, it fuels furnaces and water heaters, clothes driers, and cooking stoves. It is used in brick, cement and ceramic tile kilns; in glass making; for generating steam in water boilers; and as a clean heat source for sterilizing instruments and processing foods. It is also widely used in petrochemical manufacturing. In recent years, the use of LNG as alternative fuel for power companies was developed to replace the coal and oil-fueled electricity production system. Another development is the use of natural gas as an alternative fuel for vehicles.

III.3 Characteristics of LNG

The following are enumerated as main properties of LNG, characteristics in storage and transportation:

(1) Cryogenic temperature of about -160°C

LNG will require use of suitable materials for cryogenic temperature, consideration towards expansion and contraction due to the changes in temperature, structural design with due regard to thermal stress, effective heat insulation system, precaution against damage caused by low temperature, etc.

(2) Volumetric reduction to about one six hundredth of gas at normal temperature due to liquefaction.

This is advantageous to storage and transportation. However, tank pressure will rise every now and then due to the evaporation of cargo in cargo tanks (boil-off process).

(3) A liquid in the state of boiling

When equilibrium between gas and liquid is destroyed by the rise of temperature or fall of pressure, the liquid will immediately start boiling.

(4) Density is about half of water.

(5) Inflammable but combustion range of its vapor is narrow.

If 5 to 14 volumetric percent LNG is present in air, it forms an explosive gas mixture. In order to prevent such formation, considerations are given to avoid LNG coming into contact with air by, for example, keeping the tank pressure slightly higher than the atmosphere.

(6) Upon leaking into the air, it rapidly evaporates and forms a vapour cloud by the condensation of moisture.

III. 4 Other physical and chemical characteristics:

a. Colorless and odorless liquid

b. Large latent heat of evaporation

c. High volatility

d. Low viscosity

e. High dielectric power and extremely poor electric conductivity. It can easily be charged even by static electricity.

f. No causticity and no toxicity.

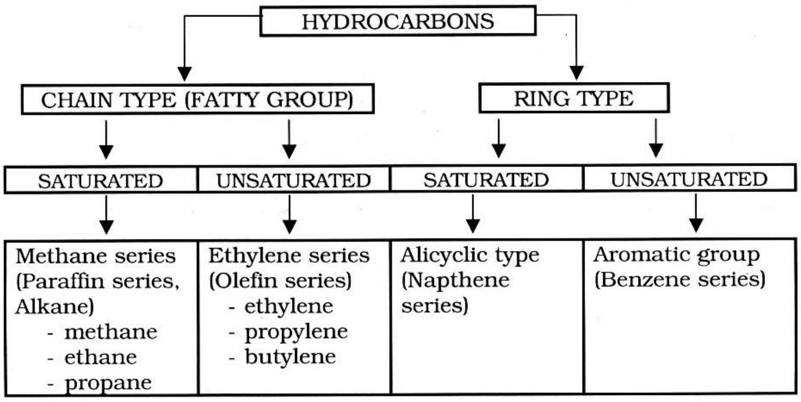
g. Almost no solubility in water.

h. Small surface tension.

III.5 Molecular Formula

III.5.1 Hydrocarbons

Oil and natural gas are made up of different compounds known as hydrocarbons. Hydrocarbon compounds are composed of the elements hydrogen and carbon. These may be in the form of gases, liquids or solids at normal atmospheric temperature and pressure. A hydrocarbon molecule is made up of carbon atoms bonded to one another as nucleus and hydrogen atoms combined together around the nucleus. The hydrocarbon can be classified as follows according to the bonding state of atoms.



The hydrocarbon is first classified into chain type hydrocarbon and ring type hydrocarbon. Molecules of the chain type hydrocarbons are arranged and combined together in series or in the shape of branched chains, and atoms are bonded around the molecules. Then they are classified as either saturated or unsaturated.

One carbon atom can be bonded up to four other atoms. When all carbon valence bonding hands are bonded to other atoms, it is called saturated compound. When a vacancy exists in the carbon valence bonding hands within the molecules, it is an unsaturated compound, which may have a double or triple bond. On the other hand, a hydrogen atom can be bonded to only one other atom.

III.5.2 Methane Series (Paraffin Series, Alkane)

The best characteristic of methane hydrocarbon is its great stability. All hydrocarbons falling under this series have similar chemical properties, and their similar chemical properties also show relatively regular changes with increase in the number of carbon atoms. In atmospheric condition (normal pressure and normal temperature), C_1-C_4 are gases, C_5-C_{14} are liquids, and C_{15} and above are solids.

General formula for the methane series (Paraffins & Alkane) is: C_nH_{2n+2}

Methane	CH_4
Ethane	C_2H_6
Propane	C_3H_8
Butane	C_4H_{10}
Pentane	C_5H_{12}

Hexane C_6H_{14}

III.6 Properties of LNG

III.6.1 Density of Gas

The density is expressed by the mass of a substance per unit volume. The unit and numerical value of density differ depending on the defining units of volume and mass. The density of gas differs depending on the temperature and pressure, even if the gas is of the same substance. As a unit for engineering, kg/cm^3 is principally used, while g/1 and g/cm^3 may also be used. The gas is normally expressed by density under one atmospheric pressure of 0°C, 20°C or 60°C.

III.6 2 Specific Gravity of Gas

The specific gravity of gas is normally expressed by the specific weight of gas to air, or the ratio of the mass of gas to air having the same volume at 0°C and under one atmospheric pressure (the standard state).

a) Avogadro's Law - all gas contains the same number of molecules (6.024 x 10) in the same volume when their temperatures and pressures are the same.
b) Specific gravity of gas - weight of the same number molecules

a. = ratio of weight of one molecule
b. = ratio of molecular weight

c) Composition of air - the main components are oxygen (0_2) and nitrogen (N_2) while there are other components such as argon, carbonic gas, neon and helium, and the ratio of main components are roughly as follows:

	0_2	N_2
Weight ratio	23	77
Volumetric ratio	21	79

Therefore, if the volumetric ratio of N_2 and 0_2 in the air is specified to be 4:1;

Average molecular weight of air = $4N_2+0_2$ = 28.8

Actual molecular weight of air = 28.96

III.6.3 Density of Liquid

The unit used for density is kg/liter or g/cm3. Strictly speaking, the density of liquid also changes with temperature and pressure, but the effect of pressure can be neglected. The effect of pressure is far less than the effect of temperature on the density of gas.

III.6.4 Specific Gravity of Liquid

The specific gravity of liquid is expressed by the ratio of the mass of liquid to the mass of water in the same volume at 4°C. This also indicates the ratio of each density, which corresponds to the numerical value of density expressed in g/cm3 or kg/liter.

It is common practice to use the `numerical value at 15/4°C specific gravity. In England, the specific gravity is originally expressed by the ratio of mass of liquid at 60°C to that of water at 60°C.

III.6.5 Vapor Pressure

The vapor pressure means pressure indicated by the vapor in a state of equilibrium with the liquid of a substance at a specific temperature. The vapor pressure is related to the kind of substance and varies with the temperature of its liquid. The vapor pressure increases with the rise of temperature, and the rate of increase becomes higher as the temperature rises. The value of vapor pressure is not affected by other gases which are presently close to the liquid surface.

Fig. 8 Comparative Properties of Methane and Propane

Property	Methane	Propane
Boiling point (°C at 1atm)	-161.5	-42.2
Critical temperature (°C)	-82.5	96.8
Critical pressure kg/cm	47.4	44.5
S.G. of liquid at boiling point	0.425	0.583
S.G. of gas at atm. pressure	0.555	1.522
Gas density kg/cm, 0°C 1 atm	0.7173	2.0082
Density = air	-112.5	190
Heat of vaporization (kcal/kg)	121.9	101.8
Auto-ignition temperature (°C)	+537	+466
Flashpoint (°C)	-175	-105
Flammable range (%)	5.3~13.9	2.37~9.50
Limiting 0_2 Volume (%)	12.1	11.4

IV. HAZARDS AND PRECAUTION (SAFETY ASPECT OF LNG)

In order to understand the potential hazards associated with storage and sea transportation of LNG, it is necessary to understand and examine its physical and chemical properties. Pure methane data are used to evaluate the potential hazards, as the influence of heavier component is negligible. General properties of methane are shown in the table of comparative properties of methane and propane.

IV.1 Combustion Characteristics

IV.1.1 Auto-ignition Temperature

This is the temperature of a substance to which its vapor in air must be heated for it to ignite spontaneously.

The auto-ignition temperature is not related to vapor pressure or to the flashpoint of the substance and, since most ignition sources in practice are external flames or sparks, it is the flashpoint rather than the auto-ignition temperature of a substance which is generally used for the flammability classification of hazardous materials.

IV.1.2 Flammable Range

This range is expressed in terms of the lower and upper percent by volume of gas in air which is required to support combustion (LEL and UEL). Although methane is flammable over a wider range than propane, the lower concentration limit is higher than propane (5.3 % vs 2.4 %). The greater flammable range for methane is counterbalanced by the fact that methane diffuses much more rapidly than propane. This can be seen by comparing the S.G. values of methane and propane. Consequently, the tendency to maintain combustible mixtures in air is reduced.

IV.1.3 Limiting Oxygen Index

This gives the minimum percent of oxygen to support flame propagation, when a stoichiometric fuel-air mixture is diluted with nitrogen. A stoichiometric fuel-air mixture means that just enough air is available for complete combustion of the fuel. In assessing combustion characteristics of methane, the specific gravity of its vapor has a major significance when evaluating the explosion hazards.

From the table of comparative properties of methane and propane, it can be seen that the specific gravity of methane is greater than air at the boiling point whereas it is less at atmospheric. It can be seen that methane is lighter than air above -112.5°C. From the values given for the specific gravity of propane, it can be seen that it is always heavier than air, and will thus have a tendency to accumulate at low places, whereas methane vapor at temperature normally encountered when venting will be lighter than air.

IV.2 Results of LNG Release

LNG only becomes hazardous if it leaks from its containment system. The result of LNG leakage from a tank can be explained by studying the behavior of methane vapor generated from a spill of LNG.

IV.2.1 Vapourization

If a leak occurs, the low temperature of the LNG will result in a rapid vaporization. Heat will be extracted from the ship steel in contact with the liquid. The steel in contact with the liquid will have its temperature lowered, and will undergo a ductile to brittle transition. A brittle fracture of the plate or the structure will almost certainly follow.

IV.2.2 General Precautions

The rate of vaporization depends upon the heat available in the surroundings. Once the gas temperature rises above -112.5°C, it will rise quickly becoming lighter than air.

IV.2.3 Vapor Dispersion

As explained, LNG vapor tends to rapidly dissipate into the atmosphere. The zone of flammable vapor is restricted to the immediate vicinity of the spill. Because of the lightness of methane, it has no tendency to layer or pocket in the open air, thus avoiding the formation of an invisible explosion hazard.

Vapors such as propane and butane which are heavier than air at ambient temperature, flow next to the ground and settle in low spots as an invisible explosive hazard. The buoyancy and rapid dispersion of methane vapor gives assurance that the flammable region is close to the liquid pool. The cold methane vapors are below the dew point of the ambient air, and they will condense moisture to form a visible cloud. The visible cloud extends far beyond the flammable zone.

Thus, the cloud serves as a conservative definition of the hazard zone. In an enclosed space, the methane vapor will rise to the ceiling because it is lighter than air at ambient temperature, whereas propane will tend to form flammable mixture along the floor.

IV.3 Health Hazards

Certain health hazards of methane are important to understand in order to ensure safe handling of LNG. Methane is a simple asphyxiant possessing only slight inhalation hazards. The limiting factor is the oxygen content available in the gas. The minimum oxygen content should be 18% by volume under atmospheric pressure. Methane is not considered toxic. Natural gas found in pipelines or LNG plant quality may cause some irreversible but non-fatal systematic changes upon low-level inhalation. This is due to impurities.

The prevailing health hazard is low temperature of LNG. While brief contact with LNG may cause slight discomfort, contact maintained for some seconds is sure to result in frostbite. Otherwise, normal skin temperature will cause almost immediate evaporation of any impinging drops or small splashes of LNG. Even short duration exposure to large quantities of LNG can cause severe tissue damage.

Prolonged exposure can embrittle and actually destroy exposed body parts. Tissue damage may result from contact with materials of construction containing LNG. Insulation thus serves a double purpose. It is protecting LNG from heat as well as personnel from cold. Though not all elements containing LNG are insulated, the rapid accumulation of frost on any such element serves to bring the cold hazard to attention.

The following are general precautions to be observed on board an LNG Carrier at all times during cargo operations and other relevant periods.

IV.3.1 Mooring

Mooring should be properly tended so as to keep the ship securely berthed. This is particularly important during cargo transfers when excessive movement could damage loading arms. Personnel on watch should check the mooring periodically to satisfy them that they are properly tended. When tending mooring lines that have been made slack or too taut, an overall view of the mooring system should be taken so that the tightening or slacking of individual lines does not allow the ship to move or place undue stress on the loading arms or other lines. The ship should maintain contact with the fender or mooring should not be slackened if the ship is lying off the fender. Furthermore, personnel on watch should make a review of the ship mooring system and planned cargo ballasting and operations.

IV.3.2 Emergency Towing-Off Wires (Fire Wires)

Towing-off wires should be ready for use without adjustment should the ship need to be towed away from the terminal in case of fire or other emergency. The wire should be made fast to the bollard/bitts on the ship, fore and aft, and their eyes run out and maintained at, or about, the waterline.

In order that sufficient wire to enable the tug to tow effectively, enough slack should be retained between the bollard/bitts and the choke.

IV.3.3 Unauthorized Person

Any person who has no legitimate business on board or do not possess the Master's special permission should be refused access.

IV.3.4 Person Smoking, Intoxicated or Drugged

The personnel on watch should ensure that no one boards while smoking. Special precaution should be taken if persons apparently intoxicated or drugged attempt to board.

IV.3.5 Notices on the Vessel

Notices should be displayed near points of access to the ship and at the entrance of accommodation area.

Example: NO UNAUTHORIZED PERSONS
NO NAKED LIGHTS
NO SMOKING

In addition, INFLAMMABLE, DANGEROUS SUBSTANCE LOADED or HAZARDOUS LIQUEFIED GAS should be displayed on the outboard side handrail.

IV.3.6 Craft Alongside

Unauthorized craft should be prohibited from securing alongside the ship. Regulations against smoking and naked lights should be strictly enforced on any craft permitted alongside. In the event of a breach of regulations, it will be necessary to cease operations.

IV.3.7 Electrical Storm (Lightning)

When an electrical storm is witnessed within the vicinity of the ship, general precautions concerning it should be observed and the cargo operations, if in progress, must be stopped immediately after making arrangements with the terminal representative.

IV.3.8 Openings in Accommodation

All external doors, ports and windows in the accommodation should be kept closed whether at sea or in port. The access door must be limited to one during cargo operations and other doors should be kept shut and prohibited for passage. The doors that are prohibited for passage should be clearly marked with "NO PASSING THROUGH" or "NO ADMITTANCE", but in no case should the door be locked.

IV.3.9 Smoking

Smoking is only permitted under controlled conditions at times and in places specified by the Master. Smoking is strictly prohibited on deck. Smoking in bed is dangerous at anytime especially when tired. Likewise, a person under the influence of liquor can become careless.

IV.3.10 Matches and Cigarette Lighters

The use of matches and cigarette lighters is prohibited on board. A special type of safety lighter is provided for smokers and is available at designated smoking areas.

IV.3.11Portable Electrical Equipment

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

IV.3.12 Galley Precautions

Terminal regulations relating to galley fire limitations must be observed. Cooking pots and other equipment heated by steam may be used at all times. While berthed, galley stoves and cooking appliances with non-immersed elements, such as electric hot plates and toasters, may be used subject to the agreement of the Master and the Terminal Representative that no hazard exists. The above equipment should not be used if there is any possibility of cargo vapor venting or any danger during cargo operations or other special operations. Galley burners should be adjusted to ensure efficient combustion to prevent galley funnel fire and incandescent soot.

Flue and grease filters should be cleaned at regular intervals. Oily rags and fats should not be allowed to accumulate in the galley or its vicinity. Appropriate fire extinguishers should always be available in galleys and personnel should be fully practiced their use.

IV.4 Precautions and Reports During Cargo Deck Watch

IV.4.1 General Precautions

a) At least one person should keep watch near the manifold and turnover his watch on sight.

b) When transferring your watch, hand over events during your watch, the present state of the operationn, precautions and schedule in detail.

c) If you are not sure or in doubt, report to or check with the officer of the watch.

IV.4.2 Duties of Deck Watch

The deck watch should monitor and report the following items to the cargo control room at regular intervals and at the same time check and adjust various devices in use as advised by the officer on watch:

a) Condition pipelines and any leakage of LNG or oil;

b) Pressure of manifold in use and loading arm condition;

c) Ship's mooring line condition. The ship should remain adequately secured in their moorings. Ranging of the ship should be prevented by keeping all mooring lines taut. Attention should be given to the movement of the ship caused by currents or tides and the cargo operation in progress;

d) Condition of emergency towing wires. Emergency towing wires should be positioned both on the offshore bow and quarter of the ship. The eyes of these wires should be maintained at or about the waterline and regularly checked and adjusted against the change in draft during the cargo operation;

e) Any oil spill on the sea surface around the vessel at all times;

f) State of weather and sea condition;

g) Unauthorized craft approaching the ship;

h) Arrangement of fire fighting equipment and instruments for coping with oil pollution, etc.;

i) Visitors to the ship. Persons who have no legitimate business on board, or who do not possess the Master's special permission should be refused access;

j) Unauthorized photography;

k) Status of loading/unloading of ship's stores;

l) Smoking and/or use of open flame in non-designated areas.

m) Confirm that all ports and doors leading to the accommodation are closed

IV.4.3 Operation of Cargo Manual Valve

Communication between Cargo Control Room (CCR) and on deck watchman must be properly established:

a) To ensure the safe control of cargo valve operation at all times. It is very important to establish a reliable operational procedure. The valve operation should be carried out according to the instructions of the responsible officer in the CCR. Valves should never be handled freely by the judgment of persons on watch on deck.

b) The order from the responsible officer should be repeated before handling the valves. Only then can the valves be handled and after completion should be reported. This procedure is vital to prevent wrong operation.

c) Correct flow of valve operation

o Order at CCR (name of valve, valve no., open/shut...)
o Repeat on deck (on the spot, valve side)
o Report on deck (after handling and confirming the valve)
o Answer at CCR

Example:

o CCR: Open - Spray crossover valve - VS057
o ON DK: Open - Spray crossover valve - VS057 - Roger.
o ON DK: Spray crossover valve - VS057 - Open, Sir.
o CCR: Spray crossover - VS057 - Open, Roger.

V. EMERGENCY PROCEDURES

In this section, general outline of actions to be taken are given emphasis with regard to the liquefied gas cargo. Such actions are explained for common guidance appropriate for emergency situations.

V.1 Liquefied Gas Fires

Fires involving escaping liquefied gas should, where possible, be extinguished by stopping the gas flow. If the flow of gas cannot be stopped, it may be safer to allow the fire to burn, and at the same time using water spray or fog to cool adjacent structures and control the effect of radiant heat. Extinguishing the flame may result in re-ignition, and a wider spread of flame due to continued flow of gas will follow.

In order to reach valves to shut off the flow of gas, it may be required to extinguish smaller flames in the vicinity of the valves. In this case, dry powder extinguishers should be used. Water jets should never be used directly on LNG pool fire as the water will act as a heat reservoir and enhance evaporation with correspondingly increased burning rate. The fire over a pool of LNG should be extinguished, after which, the fire hoses should be used in an attempt to wash the LNG away and increase its evaporation.

V.1.1 Pressure or Jet Fire

Leaks from pump glands, relief valves, masthead vent headers, etc. will initially produce vapor and/or liquid which rapidly vaporize. When this vapor mixture is ignited, it will give rise to a jet flame or pressure fire as gas leaks are normally pressurized. One situation where pressure persists is in a closed pipeline and in the case of a pressure-leak fire, the best course of action is often to allow the fire to burn until the pipeline is depressurized.

When pressure fire is allowed to burn out, the surroundings should be protected with cooling water. An alternative to this method is to extinguish the fire. However, this method has a high risk of further vapor cloud production that may result to a greater explosive fire when re-ignited.

As a preventive measure to avoid ignition of a gas cloud or vapor released in the atmosphere, all openings to hazardous ignition areas should be closed. Furthermore, the vapor cloud should be directed or dispersed away from ignition sources by means of fixed or mobile water sprays.

V.1.2 Pool Fire

Large leaks and spillage of LNG may accumulate on drip pans/trays, on deck or within other enclosures on board and ashore. A liquid spillage on shore from a tank or pipeline rupture can easily be contained within bounds just like on a ship. Should the vapor of either type reach an ignition source, a resultant pool fire will burn like petrol. Evaporation will maintain the liquid temperature at or slightly below its boiling point. It is important to remember that the addition of water will increase the rate of vaporization and the intensity of fire. When using water to disperse liquid spill and in order to prevent brittle fracture, the water should never be directed into the burning liquid gas as this will cause a violent increase in flame.

V.1.3 Enclosed Space and Compressor Room Fires

Fire in an enclosed space is very imminent particularly where cargo vapor may exist. Leaking gases may form a flammable mixture within an enclosed space which may cause an explosion if a source of ignition is found. The supply of oxygen to the enclosed space should be minimized by closing openings where possible, and by shutting down mechanical ventilations.

Enclosed spaces containing cargo machineries such as compressors, heat exchangers or pumps will normally be provided with a fixed and remotely activated fire extinguishing system, example carbon dioxide. It is also necessary to shut down the ventilation system, dampers and entrance openings if situations permit. External surfaces would also require cooling.

V.1.4 Riser Fire

Cargo vapor being released to the atmosphere through the ship's masthead vent riser can be ignited to become a riser fire. Normally, gas is never released through the vent riser but in emergency cases, the pressure relief valve can be activated or a relief valve can be opened. If during venting the released gas is ignited by any means, a decision must be made to control or extinguish the fire. If the fire is extinguished and venting continues, a gas cloud would roll to and along the main deck being initially heavier than air. If ignition occurs, the cloud will burn and flash back to the source. If, however, the decision is made to control rather than to extinguish the fire, then the source of fuel should be cut-off or diverted by suitable means and the fire will be allowed to burn itself out preventing the formation and potential hazard of gas cloud.

One method of dealing with the fire is injecting a smothering agent at the base of the riser which can snuff out the fire or allowing nitrogen gas or inert gas to exit through the riser to extinguish the fire. This will not however stop the emission of gas and if the riser top is hot, a re-ignition may occur. The masthead should therefore be cooled down by water spray.

V.1.5 Unconfined Spillage Fire

Direct spillage of liquefied gas on deck aboard ship or on the ground ashore can become a big open fire when ignited. This will although depend on the quantity of LNG spilled. This type of fire can be dealt with by means of common techniques such as direct fire extinguishing at the base of the fire using dry chemical or CO_2 gas. Once the fire is extinguished, water spray should be used to disperse and vaporize the remaining spill on deck and prevent possible brittle fracture effect. Any source of ignition should be identified and isolated or eliminated by any means to prevent re -ignition of vaporized gases.

V.1.6 Action on Discovering Fire

There is a well-known reminder of the action to be taken in successfully fighting a **FIRE**.

Find → **Inform** → **Restrict** → **Extinguish**

a) ***Find*** - the start of a fire emergency action always begin when someone has found out a fire. Finding out the fire can be made in various manners as long as there is evidence determined by the witness to suspect or declare the existence of fire in an area. Such evidence maybe include the presence of one or more of the following; flames, smoke, abnormal temperature, odor of burning materials, etc.

b) ***Inform*** - the first action of a person upon discovering fire must be to inform everybody of an emergency situation by raising the alarm and immediately alerting others who maybe in the vicinity. The duty officer or duty engineer should also be informed about the discovery of fire including relevant information such as location of fire and initial observations. The duty officer will then inform the Master, sound the appropriate alarm if it is not yet made, and make the necessary public address to inform everybody onboard of the emergency.

c) ***Restrict*** - the succeeding action of the person who found out the fire should be to conduct initial action while the ship's crew are organizing their respective teams in accordance with the emergency procedure. If the fire is manageable, he may extinguish the fire by using an appropriate portable fire extinguisher. Usually, dealing with the fire would require a team effort especially if the fire is already in an advanced stage and the best action to take prior to the arrival of the emergency team is to restrict the spread of fire.

During cargo operations, activation of the ESDS and limiting further supply of fuel to the fire by shutting-off valves are necessary to restrict the intensity of fire. Activation of water spray systems on board and on the terminal will also help restrict the spread of fire to other parts of the ship and to the terminal.

d) ***Extinguish*** - Extinguishing an LNG fire depends on various circumstances such as location, intensity and type of fire. Aspects of these items were discussed earlier in the types of liquefied gas fires. One of the important considerations to remember in extinguishing LNG fires is the behavior of gas when the fire is put out. There is always a possibility of building a gas cloud which would re-ignite when a source of ignition is reached. Therefore, extinguishing a liquefied gas fire does not just end when the fire is put out but requires management of the vapor in the vicinity and the sources of ignition.

V.2 Control and Extinguishment of Fire

Liquefied gas fires must be dealt with using fire control and extinguishment techniques different from ordinary fires. The decision to allow the fire to burn in controlled conditions or to extinguish the fire must be employed by the person in charge. This requires proper assessment on various factors such as the possibility of re-ignition, the controllability and extent of fire, the source of fire, the proximity of dangers, the capability of fire fighting teams and other factors.

V.2.1 Control of Fire Techniques

a) **Isolation of Fuel** - One of the first actions to be taken when fire occurs is to activate the ESDS. This will automatically stop the ongoing transfer of LNG from ship to shore or vice versa. Hence, if the source of fire is a leaking pipeline, this will be considered as the initial action to control the fire by pressure reduction on the line. The next step is to isolate the pipeline by shutting the necessary valves and allowing the remaining liquid in the pipeline to vaporize and burn. This is known as starvation.

b) **External Cooling and Protection** - In order to prevent the spread of fire to nearby affected areas which are considered as proximity of danger, boundary cooling and protection is necessary. An LNG Carrier is designed with water spray system for this purpose. The accommodation and cargo tanks for example will be protected from heat arising from a pipeline pressure fire by means of water spray or curtain barrier. This can also be reinforced by using fire hoses and nozzles in the spray mode. In such case, the expansion of contained boiling liquid will be prevented and the possible spread of fire will be avoided.

c) **Flame Bending** - If a pressure flame is impinging in other pipelines, cargo tanks, accommodation, surrounding steelwork or pressure vessel, it can be slowly bent away using a spray jet. Care must be taken to avoid extinguishing the flame. Another technique would be to use the wind to one's advantage if possible. Ice forming may also extinguish the fire if the pressure is limited, which may later break and give off un-ignited vapor when pressure is developed.

d) **Control of Un-ignited Leak** - The danger of un-ignited leak is a critical matter. Vapor clouds must be dispersed using water spray. All possible sources of ignition must be isolated and gas checks must be conducted to assess presence of gas in certain areas.

V.2.2 Fire Extinguishing Methods

a) **Cooling.** In fire involving liquids such as fuel oil, extinguishing method may include cooling the liquid below its flashpoint. This however, is not possible in the case of liquefied gases. On the contrary, water increases the burning rate by inducing heat which causes vaporization of the liquefied gas. This method may only be for the purpose of surface cooling of metal surfaces for the prevention of spreading the fire.

b) **Smothering**. This method is only effective in certain conditions for liquefied gas such as in a compressor room where fire suspension maybe achieved by CO_2 or halon. Smothering a mast riser fire is also possible using inert gas. However, foam which is a popular smothering agent is unlikely to extinguish a liquid gas fire.

c) **Starvation**. This self-extinguishing method is done by shutting off the fuel source and allowing the fire to consume the gas until it is extinguished. A common example is allowing the content of a pipeline to be depressurize by closing the valves.

d) **Flame Inhibition** - Inhibiting the flame is the most effective method to extinguish a free burning liquefied gas fire. Dry powder does not starve, smother or cool at any extent. What it does is it absorbs the energy in the flame. Dry chemicals attack the flame by the absorption of free radicals in the combustion process. Gas carriers are required by regulations to be fitted with fixed dry powder systems capable of delivering powder to any part of the cargo area by means of fixed monitors and hand held hoses.

V.3 Large Leaks

Leaks in containment spaces must be dealt with immediately in order to prevent the ship's structural steel from becoming brittle. Provisions are usually made for dumping the cargo in the tank affected, normally through a stern jettison line. During this operation, the ship should steam against the wind in order to avoid being enshrouded in the evaporating LNG.

Furthermore, the LNG leaked into the containment space should be pumped out using eductors powered with LNG. At the same time, the ballast tanks should be filled to provide a source of heat. In the event of large leaks, the void space safety valves and hatches will open, and LNG vapor will be discharged. As the void space is in the inerted condition, these spaces should be free from fire hazard.

V.4 Collision and Grounding

The extent of damage inflicted on a tank by grounding or collision will vary with the type of containment system. Extensive damage such as rapture of the primary barrier is very unlikely with a spherical tank. In most cases, the sphere will tend to float away from the supporting structures. In the event of a collision that splits a tank wide open, both ships are likely to be enveloped in a cloud of gas as the heat available in the hull and sea causes the LNG to vaporize.

In the area of collision, the atmosphere may well be over rich and sparks from tangled steelwork would not cause ignition. However, cold gas traveling at sea level outwards from the breach is likely to be ignited from sources in the engine room and accommodation spaces.

There is not likely to be an explosion, but the fire might prevent the normal procedure of turning the stern into the wind and going astern to assist in keeping the gas and flames forward. It may be possible to fight such a fire, particularly if it is in the forward tank that is breached, by water spray on the adjacent tanks and a curtain of spray to prevent the heat from traveling aft. Extinguishing such a flame would be impossible, thus, the full tank volume of LNG will have to be burned out.

V.5 Failures in Cargo Handling Plant or Boil-Off System

In the event of ruptures in cargo pipes, all valves may be shut by releasing the air pressure in the emergency valve-closing loop. This is done with manual valves located in strategic positions throughout the cargo tank areas, as well as outside it. Leaked out cargo is washed away immediately. Failure in the boil-off system will trigger automatic safety devices, which will cut off the gas supply to the engine room. If gas alarms occur in the engine room, the valve shutting off gas supply will be automatically operated.

V.6 Methane (LNG) Data Sheet

A data sheet provides a summary of useful information and guidelines regarding a particular cargo for the safety of all concerned persons. The following are facts and information about methane gas extracted from its data sheet. Methane is the main component of LNG described as colorless, odorless and in the liquid state. Its main hazard is its flammability.

V.6.1 Emergency Procedures

a) **Fire** - Stop gas supply. Do not extinguish flame until gas or liquid supply has been shut off, to avoid possibility of re-ignition. Extinguish with dry powder, halon or carbon dioxide. Cool tanks and surrounding areas with water spray.

b) **Liquid in eye** - Do not *delay*. Flood eye gently with clean fresh water. Force eye to open if necessary. Do not rub affected area. Continue washing for at least 15 minutes. Obtain medical advice or assistance as soon as possible.

c) **Liquid on skin** - Do not delay. Remove contaminated clothing. Flood affected area with water. Handle patient gently. Do not rub affected area. Immerse frostbitten area in warm water until thawed. Obtain medical advice or assistance as soon as possible.

d) **Vapor inhaled** - Move victim to fresh air. Remove contaminated clothing. If breathing has stopped or is weak or irregular, give mouth-to-mouth/nose resuscitation or oxygen, as necessary. Obtain medical advice or assistance as soon as possible.

e) **Spillage** - Stop the flow. Avoid contact with liquid or vapor. Extinguish sources of ignition. Flood with large amounts of water to disperse the spill and to prevent brittle fracture. Inform port authorities or Coast Guard of the spill.

V.6.2 Health Data

a) Particulars
- Asphyxiant.
- TLV is 1000 ppm.
- Odor threshold is 200 ppm.

b) Effect of liquid
- On eyes: Tissue damage due to frostbite.
- On skin: Tissue damage due to frostbite.
- By skin absorption: Not absorbed through skin.
- By ingestion: Not pertinent. No hazard in normal industrial use.

c) Effect of vapor
- On eyes: No hazard in normal industrial use. Tissue damage due to frostbite.
- On skin: No hazard in normal industrial use. Tissue damage due to frostbite.
- When inhaled: (Acute effect) Vapor has narcotic effect. Because of very rapid evaporation rate, there is possibility of total air replacement and danger of asphyxiation. (Chronic effect) No chronic effect known.

d) Personal protection
- Protective clothing covering all parts of the body such as gloves, boots, goggles or face shield, all insulated against cold temperature attack.

V.6.3 Fire and Explosion Data

a) Flashpoint: - 175°C approx.

b) Auto-ignition temperature: 595°C
c) Flammable limits: 5% to 14% by volume
d) Explosion hazards - Vapor can form a flammable mixture with air which, if ignited, may release explosive force causing structural damage.

VI. BASIC LNG CARGO OPERATIONS

VI.1 Loading Operation

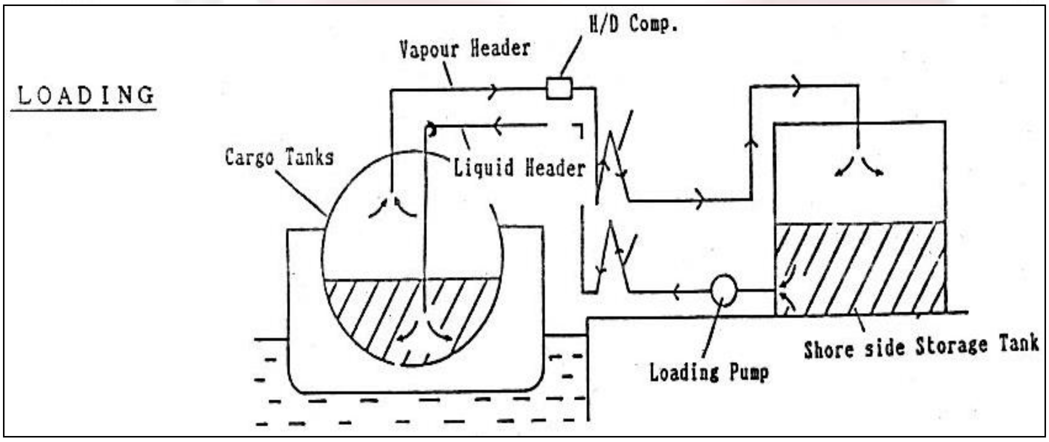


Fig. 9 Cargo loading using a vapor line

Cargo loading is carried out using a vapor line (vapor header) and a liquid line (liquid header). When loading is carried out with vapor return facilities, liquid is taken on board through the liquid header and directed into the cargo tanks. Vapor generated is returned ashore via the vapor return connection using the cargo compressor of the LNG/C in order to control the cargo tank pressure. Close watch should be kept on ship's cargo tank pressure. This operation is done on the closed cycle so as not to dispose LNG vapor to the atmosphere.

VI.2 Unloading Operation

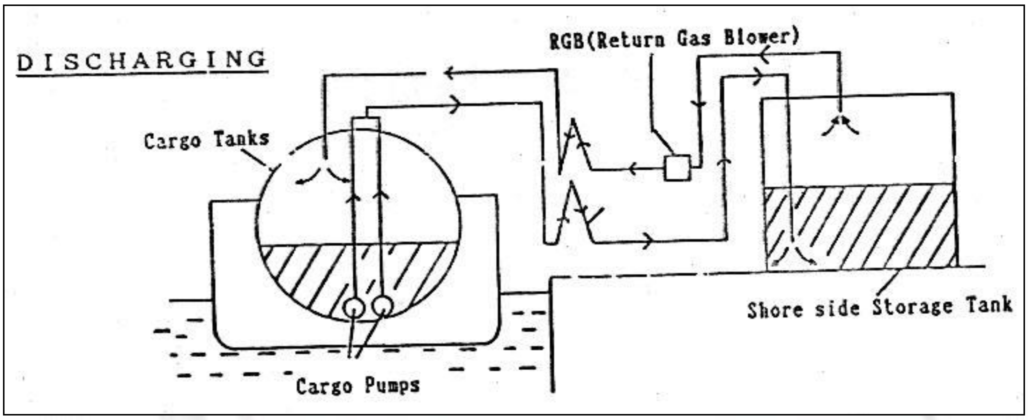


Fig. 10 Cargo discharging using a vapor line

Cargo unloading can be carried out using a vapor line (vapor header) and a liquid line (liquid header), similar to that of loading operation. However, unloading operation is carried out using the ship's submerged pumps fitted in each tank to discharge its cargo. In order to control tank pressure during the operation, LNG in cargo tanks is pumped-out to the shore side storage tank while BOG from ashore is directed to the ship's tanks by the shore side return gas blower. This operation is illustrated in (Figure 10) in a simple diagram.

VI.3 Loaded Voyage

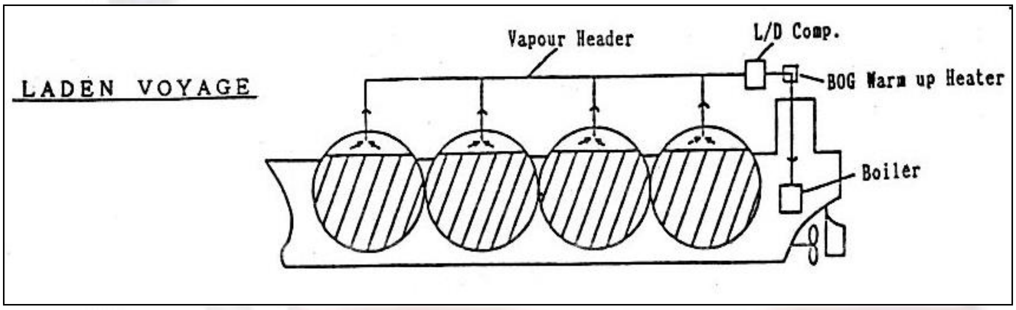


Fig. 11 Loaded voyage with vapor to boiler

The loaded voyage commences upon departure at loading port until arrival at discharge port. During this period, it is important to maintain strict control of cargo temperature and pressure by proper monitoring. Due to the thermal effect of the atmosphere on the cargo tanks, LNG would boil-off creating a continuous release of vapor and an increase of vapor pressure in the cargo tanks. In order to keep the tank pressure within acceptable limits, the boil-off gas is continuously directed to the ship's boilers to be utilized as fuel. At no circumstance should the BOG be released in the atmosphere unless in extreme emergency cases where all other safe options have already been taken. Figure 11 illustrates this process.

During the loaded voyage, other operational procedures are undertaken relevant to the safe operational upkeep of the vessel. Regular checks should be made to ensure there are no defects in cargo equipment and no leaks in nitrogen or air supply lines. It may also be necessary to carry out visual cold-spot inspections of cargo tank insulation's outer surfaces inside hold spaces. The following procedures are carried during loaded voyage.

(1) Control and monitoring of cargo temperature and tank pressure.
(2) Operation and control of L/D compressor and gas heater.
(3) Measurement of oxygen content and dew point in the hold and annular spaces.
(4) Aeration and re-pressurizing of hold spaces.
(5) Testing of cargo pumps and spray pumps.
(6) Checking and testing of valves.
(7) Preliminary meeting for discharging.
(8) Preparations for cargo handling, arrival in port.
(9) Line cooldown.

VI.4 Ballast Voyage

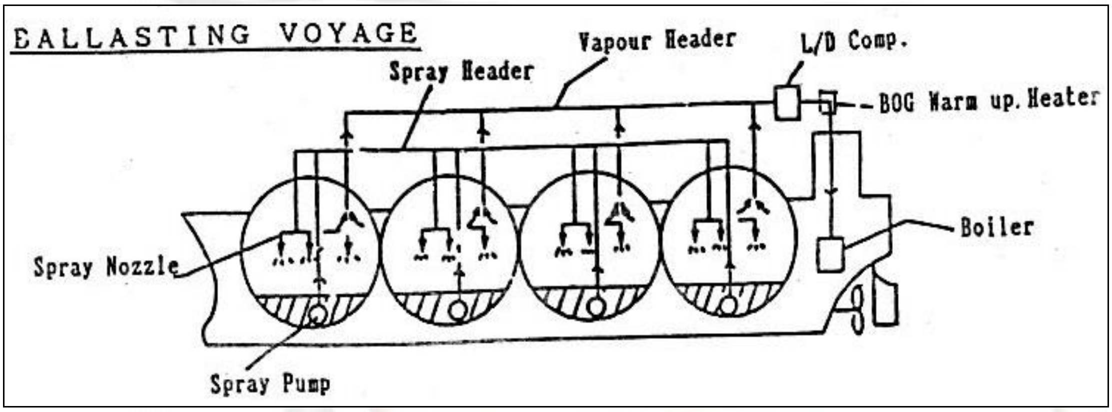


Fig.12 Ballast voyage with cooldown spray system.

The ballast voyage is from the discharge port to the loading port. During this voyage, it is normal practice to retain a small quantity of cargo on board after discharge. The amount retained is known as "heel". This is used to maintain the tanks at low temperature and to supply BOG to the boilers for fuel during ballast voyage. The quantity of the heel therefore depends on the length of the voyage and the ship's management of speed and fuel consumption. The process of BOG being sent to the boilers for fuel is similar to the BOG operation during loaded voyage.

An LNG/C is fitted with a spray cooldown system utilized for cooling down of tanks. Each cargo tank has a built-in spray pump used to pressurize the spray line and spray nozzles for the conduct of tank cooldown operation. LNG is sprayed in a cargo tank through the spray nozzles thereby gradually reducing the tank temperature.

VII. SAFETY IN GAS CARRIERS

This subject area will focus on some safety procedures included in the Safety Management System (SMS) of NYK Line with regard to the Company's standard on safety of work on gas carriers.

VII.1 Hot Works

Hot work means welding work, fusing and melting work, heating work using fire, and other types of work that generate sparks and/or heat that could lead to fire or explosion.

VII.1.1 Hot Work Precautions

a) When carrying out hot work outside the engine room area, the presence of flammable gas around the work place and of the existence of a potential fire source must be fully taken into consideration.

b) When berthed at a terminal, no hot work whatsoever must be carried out on board ship **without** the approval of the terminal or port authority.

c) Hot work outside the engine room area must **not** be carried out during cargo work, tank cleaning, gas purging and other similar operations.

VII.1.2 Execution of Hot Work

When executing hot work outside the engine room area, it shall be done in accordance with the following procedures:

a) The Master shall judge the necessity and safety of hot work and decide whether or not to carry out the work.

b) The Master, when hot work is executed, shall report the method and nature of work to the Company and obtain approval in writing for the execution of the work in question.

c) The Master shall hold a safety meeting with the person responsible for the work as well as necessary person/s, and shall ensure that everyone has a thorough understanding of the work methods and safety measures.
d) Execution of the work shall only commence after the issuance of a "Hot Work Permit".

VII.1.3 Hot Work Permit

Before the start of the hot work, the chief of the hot work site should obtain a "Hot Work Permit" after ensuring that the work safety measures were undertaken. He must also enter specific instructions or words of caution for the work in question in the applicable space of the hot work permit and sign it. The necessary requirements for safe hot work outside the engine room area shall be checked by the Chief Engineer and the Chief Officer, and for the work inside the engine room area, by the Chief Engineer, and then the Hot Work Permit shall be issued by the Master.

The Hot Work Permit shall be valid for the scope of the time and conditions given in the permit. When the time is exceeded or the condition had changed, another Hot Work Permit is to be issued prior to work continuance. An effective permit shall not exceed eight hours.

When the work in question is finished, the Chief of the work site shall report the fact to the Chief Engineer or the Chief Officer and enter the time the work was finished in the filled permit and sign the entry. The permit posted at the work site shall be discarded and a copy filed.

VII.1.4 Work Safety Measures

When executing hot work, the Chief of the work site must ensure the safety of the work by taking the following measures:

a) The work site and vicinity areas shall be cleaned and checked to see that it is free of oil, rags and other flammable substance.

b) The work site and adjacent areas shall be checked to see that there are no flammable or explosive gases.

c) Easily flammable articles shall not be placed in the work site or adjacent areas.

d) The work site should be thoroughly ventilated.

e) Portable fire extinguishers, fire hoses and other appropriate fire equipment should be ready for use near the work site.

f) Safety for approaching the work site shall be ensured.

g) Persons engaged in the work should be provided with safety glasses and gloves, and other protective gear.

h) Welding and other equipment to be used shall be checked for freedom from abnormalities.

The Chief of the site must, during the execution of work, and as occasion demands, station a lookout for fire in the work area and adjacent areas and other areas that will become dangerous due to the transmission of heat from work. The Chief Engineer or the Chief Officer must pay careful attention to the possibility of an outbreak of fire near the work place for an ample length of time after hot work is finished.

<S-091003-01FRM>

HOT WORK PERMIT

This permit is to be completed before any welding or burning operation being performed outside of the engine room workshop (and in the room associated with fuel tank and fuel oil piping).

Ship's Name: ______________________ Date: __________________

1. Description of Work: ____
   ____

2. Location of Work: ____

3. Equipment To Be Used: ______________________________________

4. Precaution
   a) Working area is free from combustible materials .... YES/NO
   b) Combustible gas test is taken and area is free from gas .... YES/NO
      (Combustible gas % LFL Reading: ______________)
   c) Has the equipment or pipeline been gas freed? YES/NO
   d) Has the equipment or pipeline been blanked? YES/NO
   e) Is the equipment or pipeline free from liquid? YES/NO
   f) Is the equipment isolated electrically?... YES/NO
   g) Is the surrounding area safe? YES/NO
   h) Adjacent area and space are free from combustible materials .... YES/NO
   i) Ventilation of the working area is adequate .... YES/NO
   j) Firefighting equipment is provided at the working location and any other risky area .... YES/NO
   k) Safe access is provided .... YES/NO
   l) Special condition/Precaution: ________________________________
      ____
   m) Test for combustible gas must be conducted immediately before commencement of hot work and at frequent intervals during the work.

5. This Permit Is Valid from: ______________ Hrs Date: ______________
   to: ______________ Hrs Date: ______________

6. Personnel To Carry Out Work: ____________________________________
   ____

7. Responsible Officer in Charge of Work Area

   Name: ______________________ Signature: ______________________

8. This Permit Certifies that Safety Is Secured.

   ______________________ ______________________
   Department Head ( ) Master

   ....

9. Work Has Been Completed and All Persons under My Supervision, Materials and Equipment Have Been Withdrawn.

   ______________________ ______________________
   Responsible Officer Time and Date

10. This Permit Is Hereby Canceled.

   ______________________ ______________________
   Department Head( ) Master

Fig. 13 Hot Work Permit form

VII.2 Enclosed / Confined Spaces

VII.2.1 General

The Chief Officer and/or the Chief Engineer are responsible for the safety of work in the following enclosed or confined spaces and must instruct the crew on proper work methods.

a) Space where oxygen concentration is liable to be deficient.
b) Space where harmful gases are present.
c) Space where explosive gases are present.

VII.2.2 Oxygen Deficiency

Oxygen deficiency is liable to occur in the following places:

a) Tanks and cofferdams that have been disused for a long time.
b) Holds of coal and ore carrier.
c) Tanks, holds and storerooms which have just been painted.
d) Tanks treated for cathodic protection.
e) Laid-up boilers.
f) Spaces that have vegetable beginning to decay, chips and steel materials with advance rust.
g) Spaces where carbon dioxide gas and halon gas fire extinguishers have been used.

VII.2.3 Entry Permit to Enclosed/ Confined Spaces

An entry permit must be secured prior to entry into confined spaces such as cargo holds, tanks, cofferdams, etc.

The Chief Officer or Chief Engineer must not issue an entry permit until he has checked that the space in question has been fully ventilated so that the oxygen concentration in the space is normal (21%). Measuring oxygen must be done several times and in several places.

Generally, the effect of oxygen concentration is said to be as follows:

18% - 23% ....No negative influence
less than 17% ....Not suitable for work

less than 11% ....Difficulty in breathing, loss of consciousness, danger to life

Illumination inside enclosed/ confined spaces when work is to be carried out.

a) Measures must be taken for ample illumination for the work place, passageways and ladders.

b) Explosion proof lighting equipment must be in space where flammable and explosive gases are liable to be generated.

c) Persons entering the space in question must commence work only after giving themselves time to get used with the illumination of the space.

VII.2.4 Entry Procedures

The following procedures must be strictly observed when entering an enclosed/ confined space.

a) Notify the duty officer or the duty engineer of the names of the person who will enter the space, the name of the space and to estimated time of work completion.

b) Pose a lookout at the entrance of the space.

c) Work inside the space with two or more persons.

d) Station a lookout with a communication device at the entrance.

e) Ready an emergency breathing apparatus at the entrance.

Once every 30 minutes, take measurement of toxic gases and oxygen concentration.

f) Apply appropriate ventilation during the periods of work.

g) When abnormality is noticed, stop work immediately and do not resume work until the atmosphere in the space is checked and found to be normal.

<S-091004-01FRM>

ENCLOSED SPACE ENTRY PERMIT

This permit is to be issued for entry into any hold, tank, and void or similar enclosed space.

It is to be completed in duplicate, the original permit should be posted at the entrance of the space concerned and the duplicate should be retained at the Ship's Office or in the Engine Control Room by the Safety Officer for future reference.

This permit becomes invalid if for any reason, accidental or otherwise, an operation is carried out which may release toxic or explosive vapors into the space. In such cases the place should be retested by the Safety Officer and if found safe a new permit would be issued.

Location/Name of Enclosed Space: ______________________

Reason for Entry: ______________________

This Permit Is Valid from: __________hrs Date __________ (See Note 1)

to: __________hrs Date __________

Section 1 — Pre-Entry Preparations

(To Be Checked by Master or Responsible Officer)

1. Has the space been segregated by blanking off or isolating all connecting pipelines? YES／NO
2. Have valves on all pipelines serving the space been secured to prevent their accidental opening? YES／NO
3. Has the space been cleaned? YES／NO
4. Has the space been thoroughly ventilated? YES／NO
5. Pre-entry atmosphere tests: (See Note 2)
   Readings: Oxygen __________% vol. (21%)
   Hydrocarbon __________% LFL (Less than 2%)
6. Have arrangements been made for frequent atmosphere checks while the space is occupied, or after work breaks? YES／NO
7. Have arrangements been made for the space to be continuously ventilated throughout the period of occupation and during work breaks? YES／NO
8. Is adequate illumination provided? YES／NO
9. Are breathing apparatuses available for immediate use at the entrance to the space? YES／NO
10. Has a responsible person been designated to stand by the entrance to the space? YES／NO
11. Has the Officer of the Watch (bridge, engine room, cargo control room)been advised of the planned entry? YES／NO
12. Has a system of communications been agreed and tested?
    Inside of the space ←——→ The person at the entrance YES／NO
    The person at the entrance ←——→ Bridge/ECR/CCR YES／NO
13. Is there a system for recording who is in the space? YES／NO

Section 2 — Pre-Entry Checks

(To Be Checked by Person Authorized as Leader of Team Entering Space)

Section 1 of this permit has been completed fully.
I am aware that the space must be vacated immediately in the event of ventilation failure or if atmosphere tests change from agreed safe criteria.
I have agreed the communication procedures.
I have agreed upon a reporting interval of ______minutes.

To Be Signed by:

Master or Responsible Officer __________Date________Time__________

Authorized Team Leader __________Date________Time__________

Responsible Person Supervising Entry __________Date________Time__________

Fig.14 Enclosed space Entry Permit form

VII.3 Rescue

When one or more of the workers inside the enclosed space becomes a victim of toxic gases or lack of oxygen, the lookout at the entrance or the deck officer or engineer on duty shall request assistance. Nobody must commence or attempt rescue until rescue assistance arrives. When entering the space in question for the purpose of rescue, it must be done in accordance with the following procedures:

a) Put on a properly checked and inspected breathing apparatus.

b) Wear protective glasses, clothes, gloves and other protective gear.

c) A deck officer or engineer at the space entrance with a communication device shall supervise the rescue.

d) Prepare an oxygen breathing apparatus (resuscitator) at the space entrance.

e) Wear a lifeline. If possible, carry a communication device.

The success or failure of the rescue depends on how quickly the victims will be taken out of the space and administered with oxygen or fresh air rather than giving first aid to their injuries.

VII.4 Shipboard Signs

The chief officer shall display posters in conspicuous places in the living quarters with the following warning language and the native language of the crew.

"No one is to enter the cargo hold, tanks, cofferdams and other enclosed/ confined spaces without the permission of the Chief Officer or the Chief Engineer".