



## **8 LIQUEFIED NATURAL GAS**

*SIGTTO Definition of Liquefied Gas: A liquid which has a saturated vapor pressure exceeding 2.8 bar absolute at 37.8°C (100°F) and certain other substances specified in Gas Codes.*

Natural gas is a naturally occurring HC gas mixture consisting primarily of methane mixed with minor percentage of the paraffin hydro-carbon family – ethane, propane, butanes and pentane. The non-hydrocarbon constituents in the NG include N<sub>2</sub>, H<sub>2</sub>S, CO<sub>2</sub>, helium and water-vapor. It is formed when layers of decomposing plant and animal matter are exposed to intense heat and pressure under the surface of the earth over millions of years. It is a domestically available, economical, clean burning fuel source.

### **8.1 CHARACTERISTICS**

Physical properties of LNG will change with the change in its composition. The following are the principal characteristics of LNG:

- a) Extremely low temperature range of -155°C to -163°C requires:
  - employment of extremely low-temperature resistant materials
  - appropriate structure to allow expansion/contraction of materials to avoid heat stress caused by the temperature difference
  - effective heat insulating systems for handling and storage
  - protection against low temperature hazards
- b) Vapor pressure for transportation is between 108 to 123 KPa absolute (0.08 to 0.23 bar gauge) and the combination of pressure and temperature indicated above keeps the LNG in boiling state. Any deviation from equilibrium caused by the rise in temperature or fall in pressure will immediately result in the increase of LNG boil-off. The vapor pressure in LNG tank rises very rapidly with the increase in temperature (about 5 bars at -140°C and 12 bars at -120°C).
- c) Density of LNG is in the range of 0.42~0.48 i.e. almost half of that of water.
- d) Density of NG vapor (BOG) varies with temperature. Immediately after the evaporation of LNG, the BOG is almost at the same temperature as the liquid and heavier than air, however, upon warming up, the BOG becomes lighter. Its density is same as the density of air at around -110°C while at ambient temperature, the BOG is twice as light as air and diffuses rapidly into the air.
- e) Volumetric expansion of the BOG at atmospheric pressure and ambient temperature is approximately 600 times the volume of liquid.
- f) Flammable range for NG vapor is 5% to 14%.
- g) Other properties of LNG
  - Colorless liquid
  - Odorless liquid that is normally odorized with a compound called “mercaptan” for detection of a vapor leak



- High latent heat of evaporation
- Extremely volatile
- Low viscosity
- High dielectric capacity
- Poor conductor of electricity
- Easily electrostatically charged
- Corrosion resistant
- Non-toxic
- Scarcely soluble in water

**8.2 LNG COMPONENTS – PHYSICAL & CHEMICAL PROPERTIES**

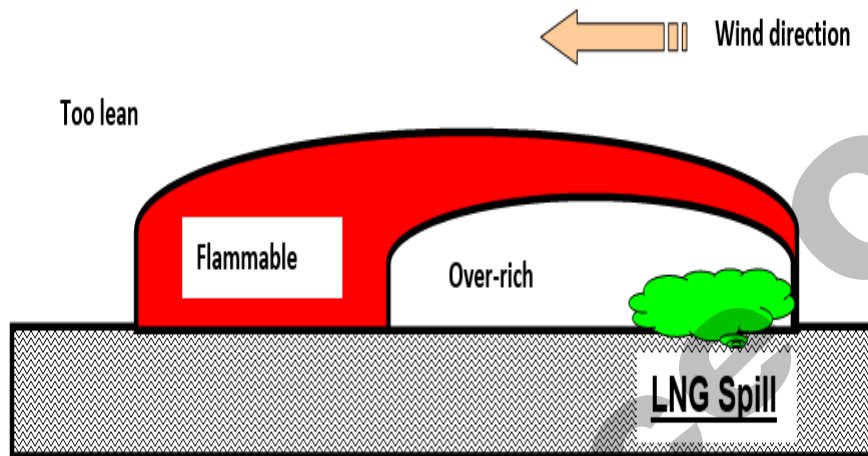
	Methane	Ethane	Propane	Butane	Pentane	Nitrogen
<b>Chemical Formula</b>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>3</sub> H <sub>8</sub>	C <sub>4</sub> H <sub>10</sub>	C <sub>5</sub> H <sub>12</sub>	N <sub>2</sub>
<b>UN No.</b>	1971	1035	1978	1011	1265	1066
<b>Color</b>	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
<b>Odor</b>	Odorless	Odorless	Odorless	Odorless	Gasoline-like	Odorless
<b>Boiling Point</b>	-163°C	-89°C	-42°C	-1°C	36.1°C	-195.8°C
<b>Flash Point</b>	-175°C	-125°C	-105°C	-60°C	-49°C	NA
<b>Auto-Ignition</b>	632°C	472°C	481°C	544°C	260°C	NA
<b>Expansion</b>	1 : 621	1 : 424	1 : 305	1 : 237	1 : 206	1 : 694
<b>Liquid Density</b>	0.4226	0.544	0.505	0.595	0.626	0.808
<b>Gas Sp. Gravity</b>	0.554	1.05	1.55	2.08	2.48	0.9674
<b>Flammable</b>	Yes	Yes	Yes	Yes	Yes	No
<b>Explosive Limit</b>	5 ~ 17%	3 ~ 16%	2.3 ~ 9.5%	1.8 ~ 8.4%	1.5 ~ 7.8%	NA
<b>Toxic</b>	No	No	No	No	Yes	No
<b>Polymerisable</b>	No	No	No	No	No	No
<b>Corrosive</b>	No	No	No	No	No	No



### 8.3 HAZARDS

As noted from its properties, the major hazards associated with LNG are flammability and low temperature.

#### 8.3.1 LNG FLAMMABILITY & METHANE FLAMMABILITY GRAPH



Flammable vapor zone – LNG spill

The following flammability characteristics are typical of LNG:

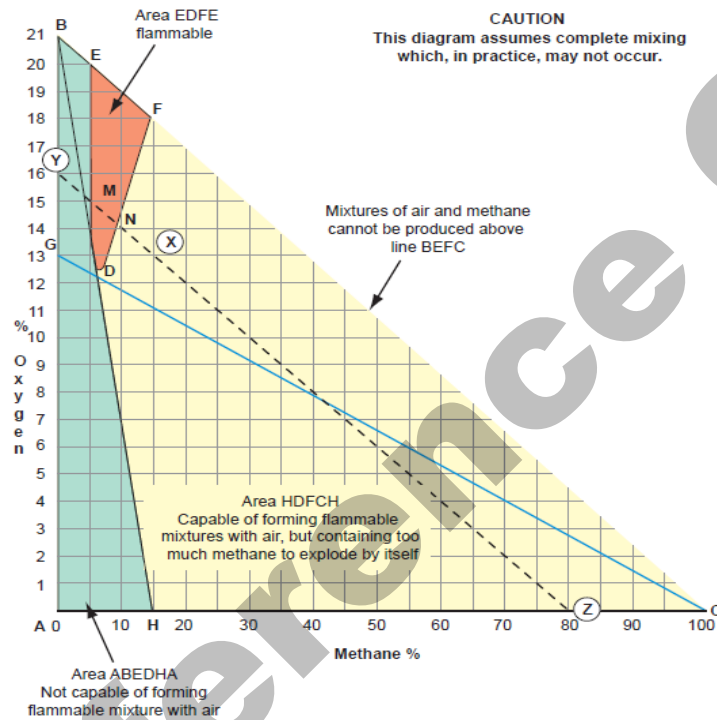
- a) The fire typically results from burning of the vapor rather than the liquid itself.
- b) The vapor can only ignite when mixed with air to form a flammable mixture.
- c) The flammable range for NG is 5.0% to 14.0%.
- d) During the usual service period, the percentage of HC in LNG bunker tank(s) is 100%, hence the ignition cannot take place.
- e) Methane leaking from an LNG bunker tank in a well-ventilated area is likely to rapidly dissipate to less than 5%. Because of this rapid dissipation, only a small area near the leak would have the proper concentration for ignition.
- f) In a closed or poorly ventilated space, the chances of collecting enough fuel in the air for ignition will increase significantly. The heavier hydrocarbons have lower flammability limits than Methane, causing the lower flammability limit of LNG to decrease with increased concentrations of heavier hydrocarbons.
- g) The BOG is lighter than air at vapor temperature above minus (-) 110°C or higher depending on LNG composition, therefore when the vapor is vented to atmosphere, it will tend to rise above the vent outlet and will rapidly disperse. When cold vapor is mixed with ambient air, the vapor-air mixture will appear as a readily visible white cloud due to the condensation of moisture in air. This cloud of LNG vapor and air will likely remain in contact with the ground even after it has substantially warmed-up due to its mixing with cold and heavy air. It is normally safe to assume that the flammable range of vapor-air mixture does not extend significantly beyond the perimeter of the white cloud. This vapor cloud or plume will gradually disperse downwind.
- h) The auto-ignition temperature of CH<sub>4</sub>, the lowest temperature required for its self-sustained combustion without ignition by a spark or flame, is 650°C.
- i) A liquefied gas must be at a temperature above its “flash point” to give off sufficient vapor to form a flammable mixture. Many liquefied gases are shipped at temperatures higher



than their flash points. This includes methane that has a flash point of  $-175^{\circ}\text{C}$  but shipped at  $-163^{\circ}\text{C}$

### 8.3.1.1 METHANE FLAMMABILITY GRAPH

The flammability graph shows relation between the composition and flammability of mixtures of methane, oxygen and nitrogen. This graph is an important tool to ensure against the formation of flammable mixtures of methane and air.



- Description of the flammability graph:

- Vertical axis A-B

- Represents *Oxygen-Nitrogen Mixture with no Methane*
- Point A – 0.0% O<sub>2</sub> (100% N<sub>2</sub>)
- Point B – 20.9% O<sub>2</sub> (79% N<sub>2</sub>)

- Horizontal axis A-C

- Represents *Methane-Nitrogen Mixtures with No Oxygen*
- Point A – 0.0% CH<sub>4</sub> (100% N<sub>2</sub>)
- Point C – 100% CH<sub>4</sub> (0.0% N<sub>2</sub>)

- Triangle ABC

- Any single point within this represents a *Mixture of All 3 Components i.e. CH<sub>4</sub>, O<sub>2</sub> and N<sub>2</sub>* in specific proportion of the total volume
- The proportions of all 3 components represented by a single point can be read off the diagram (e.g. Point D represents 6.0% CH<sub>4</sub>, 12.2% O<sub>2</sub> and 81.8% N<sub>2</sub>)

- Sector EDF

- Represents *Flammable Zone*
- Any mixture with its composition represented by a point that lies within this sector is flammable



- Sector HDFC
  - i. Represents *Over-rich Mixture*
  - ii. Any mixture with composition represented by a point that lies within this sector can form flammable mixture when mixed with air but contains too much CH<sub>4</sub> to ignite
- Sector ABEDH
  - i. Represents *Too-lean Mixture*
  - ii. Any mixture whose composition is represented by a point that lies within this sector is not capable of forming flammable mixture when mixed with air
- Use of flammability graph during operations:
  - The LNG bunker tank's initial atmosphere content is represented by point Y on A-B axis and the final by point Z on A-C axis, hence,
    - i. If mixture Y is now mixed with mixture Z, the resulting mixture will always be represented by point X, that will move from Y to Z by increasing the quantity of mixture Z in the tank
    - ii. The point X will pass through flammable zone EDF between point M (CH<sub>4</sub> 5.5%) and point N (CH<sub>4</sub> 9.0%)
  - Pre-docking operation (inerting prior to aeration)
    - i. Initial condition: Point C (CH<sub>4</sub> 100%)
    - ii. Final condition required: Point B (O<sub>2</sub> 20.9%)
    - iii. N<sub>2</sub> is added to tank until CH<sub>4</sub> content reduces to 15% at point H
    - iv. Addition of CH<sub>4</sub> will cause the mixture to change along the line HDB, hence, the mixture will not pass through flammable zone EDF but will be tangential to it at point D
    - v. If the CH<sub>4</sub> content had earlier been reduced to less than 15% (any point between A and H), the change in composition with the addition of air will not pass through the flammable zone EDF throughout the operations
    - vi. Theoretically, therefore, it is only necessary to add N<sub>2</sub> to CH<sub>4</sub> tank when inerting to reduce the CH<sub>4</sub> content to 15%
    - vii. However, complete mixing of N<sub>2</sub> and CH<sub>4</sub> may not be achieved, hence as a measure of safety, the CH<sub>4</sub> content must be reduced to 2% or less during inerting
    - viii. The reading of 2% or less CH<sub>4</sub> prior to introducing O<sub>2</sub> shall be ensured at all sampling points of LNG bunker tank and piping system
  - Post-docking operation (inerting prior to cool-down)
    - i. Initial condition: Point B (O<sub>2</sub> 20.9%)
    - ii. Final condition required: Point C (CH<sub>4</sub> 100%)
    - iii. N<sub>2</sub> is added to tank until O<sub>2</sub> content reduces to 13% at point G
    - iv. Addition of CH<sub>4</sub> will cause the mixture to change along the line GDC, hence, the mixture will not pass through flammable zone EDF but will be tangential to it at point D
    - v. If the O<sub>2</sub> content had earlier been reduced to less than 13% (any point between A and G), the change in composition with the addition of CH<sub>4</sub> will not pass through the flammable zone EDF throughout the operations
    - vi. Theoretically, therefore, it is only necessary to add N<sub>2</sub> to air when inerting to reduce the O<sub>2</sub> content to 13%



- vii. However, complete mixing of N<sub>2</sub> and air may not be achieved, hence as a measure of safety, the O<sub>2</sub> content must be reduced to 2% or less during inerting
- viii. The reading of 2% or less O<sub>2</sub> prior to introducing CH<sub>4</sub> shall be ensured at all sampling points of LNG bunker tank and piping system

### **8.3.2 FIRE HAZARD DUE TO STATIC ELECTRICITY**

*QHSE Manual Section-9.7.5* shall be referred for additional guidance on static electricity.

The LNG bunker system is electrically bonded to the ship's hull to prevent the build-up of static charge. It is important to maintain the bonding connections in good condition. The risk of causing ignition by static electricity is reduced if the system is correctly bonded or the flammable mixtures are avoided.

A significant static electrical charge may be caused by

- high fluid velocities
- change from liquid to vapor/liquid droplet flow
- small particles carried in vapor

In an un-bonded system, static electrical charge may generate due to

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

### **8.3.3 EXPLOSIVITY**

Ignition of LNG vapors in a *confined space* can result in an explosion from excessive pressure built-up due to heat. In an *unconfined space*, an explosion may result from the rapid spread of the flame through a large vapor cloud.

### **8.3.4 BOILING-LIQUID EXPANDING-VAPOR EXPLOSION (BLEVE)**

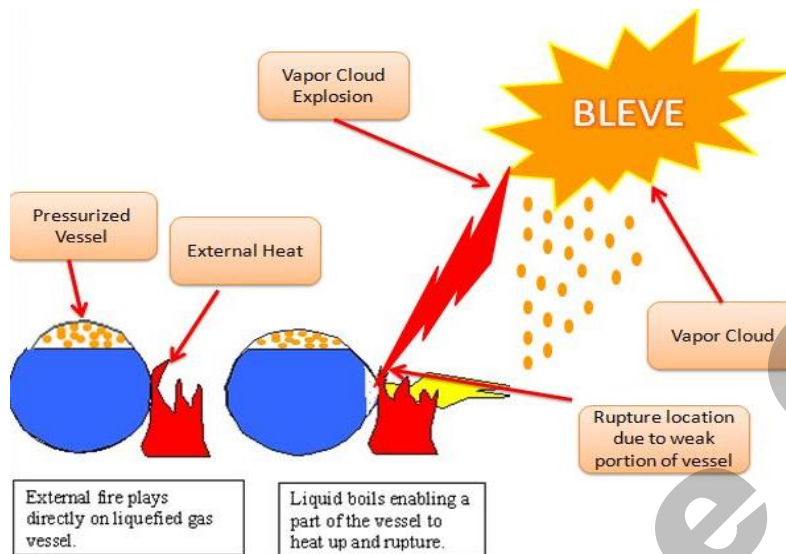
BLEVE is an explosion resulting from the catastrophic failure of a pressurized LNG containment system containing a liquefied gas significantly above its boiling point at normal atmospheric pressure. The pressure vessel (LNG bunker tank) may fail due to mechanical damage, corrosion, excessive internal pressure, flame impingement or metallurgical failure.

The most common cause of a BLEVE is fire as it causes an increase in the tank pressure while the flame impingement reduces the tank steel's mechanical strength; particularly in the part of the pressure vessel that is not cooled by the liquid. The resulting explosion may be catastrophic in nature with pieces of tank's shell thrown in all directions to a considerable distance. The tank rupture causes an immediate drop in pressure and produces a blast.

The liquid, that is at a temperature much higher than its boiling point, boils off spontaneously; thereby creating large quantities of vapor, carrying liquid droplets, being thrown upwards. The flammable gas/air mixture (contained in the escaping vapor cloud) will ignite from

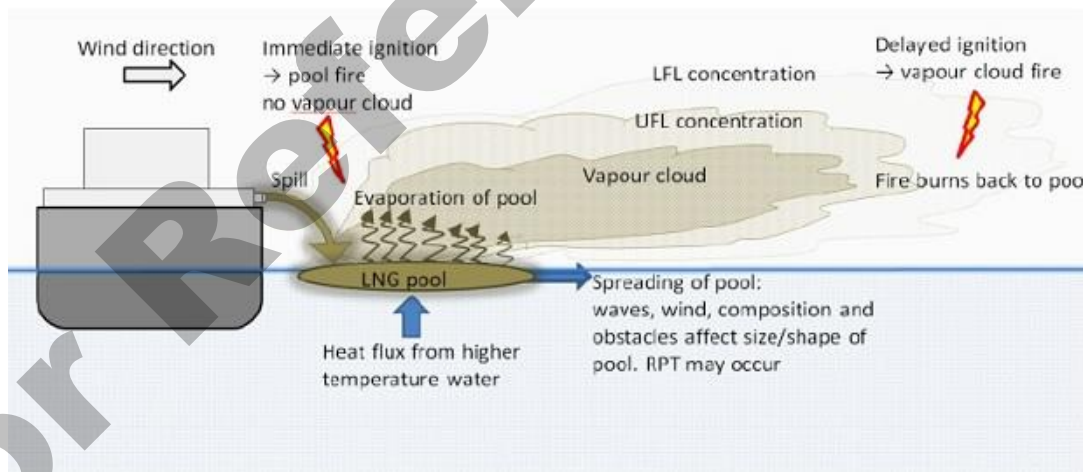


existing fire or the rendering metal to create a fireball that may reach gigantic proportions. The rapidly expanding vapor will produce a further blast and intense heat radiation.



### 8.3.5 FLAMELESS EXPLOSION OR RAPID PHASE TRANSITION (RPT)

LNG vaporizes violently in contact with water, thereby, causing a physical explosion that is sometimes referred as *Cold or Flameless Explosion*. Such explosions are not caused due to combustion but involve transfer of excessive amounts of energy in the form of heat from water (at room temperature) to the LNG with temperature difference of about 175 Kelvins.



### 8.3.6 STRATIFICATION

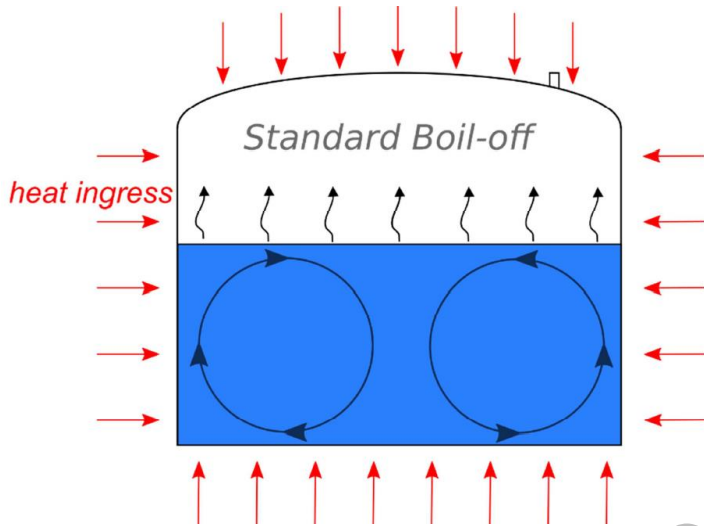
*Stratification* is the process of formation of LNG layers of differing densities inside a storage tank. It may occur when fresh LNG is loaded in a tank through

- bottom-filling arrangement below the existing LNG heel that is lighter, or
- through top-filling arrangement above the existing LNG heel that is denser heel.

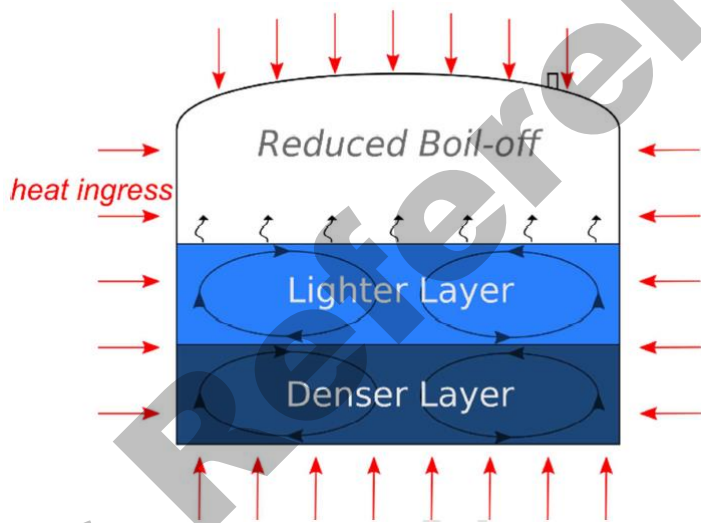
When heat enters the LNG tank through tank walls and warms up the LNG, the warmer liquid rises as convection current along the tank walls and changes direction to horizontal on reaching the top part of the tank. As the current moves along the surface, the LNG cools and



sinks. In the top part of the tank, the evaporation results in the formation of a thin chilled layer of LNG. Further evaporation takes place as the current passes its heat to this thin layer while travelling along the surface and the layer is maintained at low temperature. This layer now acts as a buffer between the warm current and the vapor.



*Diagram representing natural convection current in homogenous LNG*



*Diagram depicting Stratification process in a tank with LNG parcels of differing densities*

The process maintains vapor at SVP till the BOG is continuously retracted from the tank. However, if the tank is sealed, the evaporation gets suppressed and the thin layer at the top is destroyed thereby exposing the warm current. The result is a sudden rise in the tank pressure. Stratification can be prevented by thoroughly mixing new LNG parcel with the existing heel by either injecting the lighter LNG below denser heel or adding the denser LNG above lighter heel.

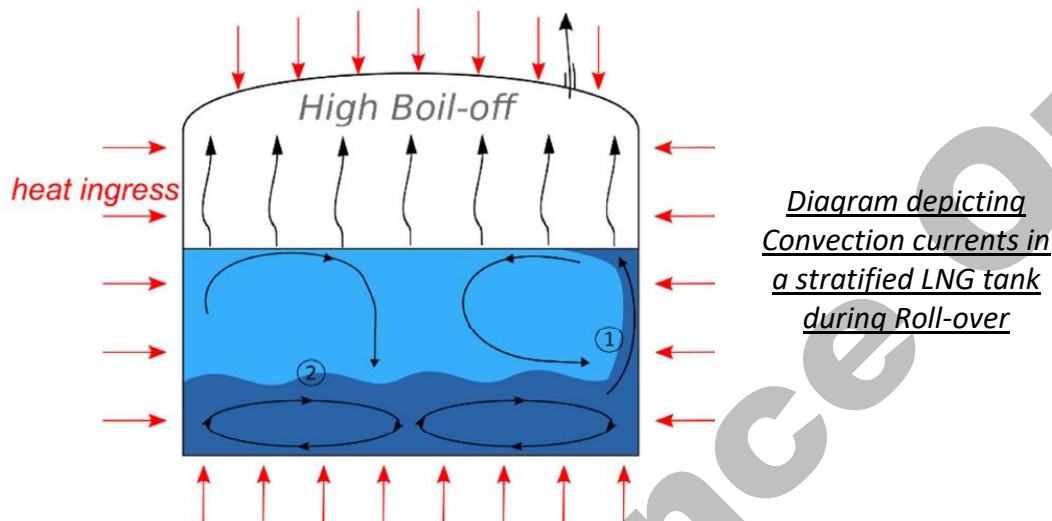
**8.3.7 ROLL-OVER**

LNG layers of differing densities (e.g. two LNG parcels with different specific gravity) inside a tank may lead to unstable stratification; with the lighter liquid on top of the heavier. If heat enters the tank now, it will cause weathering at the top layer so that the lighter components evaporate away thereby increasing the specific gravity of the top layer. However, due to



absence of weathering in the intermediate and lower layers, there is no evaporation of components at these layers.

If this process continues, the two layers will reach the same specific gravity and, when disturbed, the layers will tend to correct this instability by spontaneous mixing. This process is called as *Roll-over*.



Due to roll-over of the two layers, the evaporation, which was so far suppressed in lower layers, will take place and result in generation of large quantities (as much as 10 times the normal) of BOG, also known as *flash-gas*. The resulting BOG may cause the pressure to rise beyond the capacity of the LNG bunker tank safety relief valve. This may result in the tank sustaining damages along with uncontrolled venting thereby creating extremely hazardous conditions on the vessel and surroundings. To prevent roll-over, the two-layer phenomenon must be avoided. This is achieved by ensuring homogeneity of the liquid or by thorough mixing.

In general, roll over is not a concern in an LNG bunker tank due to mixing caused by ship's motion. However, ageing of unused bunker or weathering and heat expansion that may occur during long voyages, may result in roll-over in an LNG bunker tank.

### **8.3.8 HEALTH HAZARDS ASSOCIATED WITH LNG & ITS VAPORS**

There are severe health hazards associated with exposure to LNG and/or its vapors. Though LNG is non-toxic and non-anaesthetic, it presents health hazards due to its unsuitability for breathing and extremely low temperature.

**Exposure to LNG:** All shipboard personnel must be fully conversant with health hazards described in this section. In case of exposure to LNG and/or its vapors, refer to the medical first aid schedule provided in the SDS. In addition, refer to the information provided in The Ship Master's Medical Guide and the International Medical Guide for Ships. Seek shore medical assistance at the earliest.

For serious injuries and medical conditions, the shipboard personnel should immediately seek shore medical advice and request for earliest medical assistance, if possible. Immediate first-



aid, applicable to the type of medical emergency, shall be administered to the patient till shore medical assistance is available. Record of the medical emergency, patient's condition and the nature of treatment shall be maintained in the medical log. Medical first-aid equipment including oxygen resuscitation equipment shall be available on board and kept in a readily accessible location. Resuscitator operating instructions should be conspicuously displayed near the location of its storage.

**8.3.8.1 ASPHYXIA**

Asphyxia or suffocation is a condition in which the functioning of brain is impaired due to low O<sub>2</sub> level (below 19%) in the blood. Although LNG vapors are non-toxic, they may reduce the O<sub>2</sub> content in the vapor cloud. A person inhaling pure LNG vapors would rapidly become unconscious and die in a few minutes, if not immediately treated. The following information is pertinent to Asphyxia:

- a) When asphyxia develops slowly by gradual reduction of the O<sub>2</sub> content in the atmosphere, the victim has little warning and is generally unaware that anything is wrong until it is too late.
- b) Deficiency of O<sub>2</sub> can be due to the presence of NG vapor or N<sub>2</sub>.
- c) Oxidation or rust formation in enclosed spaces may lead to dangerously low O<sub>2</sub> levels.
- d) It is recommended that entry is never made in an NG vapor cloud.

Products	Symptoms	Treatment
<ul style="list-style-type: none"> <li>• LNG</li> <li>• Nitrogen</li> </ul>	<ul style="list-style-type: none"> <li>• Increased rate and depth of respiration</li> <li>• Blueness of skin (Cyanosis)</li> <li>• Torturous breathing with a snoring sound</li> <li>• Headache, dizziness &amp; inability to concentrate</li> <li>• Mental confusion followed by complete loss of consciousness</li> <li>• Paralysis of respiratory centre</li> </ul>	<ul style="list-style-type: none"> <li>• Remove from exposure</li> <li>• Apply artificial respiration if required</li> <li>• Apply external cardiac massage</li> <li>• Loosen clothing</li> <li>• Give oxygen if cyanotic or breathing laboured</li> <li>• Give non-alcoholic drinks if desired</li> <li>• Keep at rest</li> <li>• Unless symptoms are minor, seek shore medical advice</li> </ul>

**8.3.8.2 LOW TEMPERATURE EFFECTS ON HEALTH**

LNG is handled and stored at extremely low temperature; hence it presents health hazards from accidental exposure to cold. These hazards are described below.

a) Hypothermia

Prolonged exposure to temperatures below 10°C without adequate protection can result in a decrease in the body temperature or *Hypothermia*. As the body temperature falls, capability to perform physical and mental tasks decrease. Cardiac disturbance can occur if the body temperature falls below 27°C and death may result if it falls further.



b) Effect of contact with cold surface on skin

When bare skin comes in contact with a cold surface, the moisture on the skin freezes, thereby bonding the skin to the surface. The skin and underlying frozen flesh are then easily torn off leaving an open wound. It may be possible to heat a localized area sufficiently to thaw and release the frozen flesh. This procedure may work on valve handle wheels and pipe hangers but will generally be unsatisfactory on cold piping or other large objects. Cold contact and cryogenic burns result from exposure of insufficiently protected skin areas to LNG, cold vapor, cold pipes or equipment. The severity of burns varies with the length of exposure, the temperature of the source, and the rate at which heat is transferred from the skin to the source. This rate is high for contact with liquid and cold metal objects than it is for vapor.

c) Effect of contact with cryogenic liquids

Direct contact with a cryogenic liquid generally produces rapid freezing of tissues because of the high rate of heat transfer. Keeping the liquid confined within piping and storage vessels and wearing adequate protective apparel are the two best ways to avoid exposure of the skin to liquid. To avoid spillage or leakage, the LNG containment and handling system should be designed, constructed, and operated safely. Contact with cold gas will usually affect a higher portion of body area than that affected by cold liquid contact. When cold gas is released in a jet, the high rate of heat transfer can result in rapid freezing of large exposed portions of the body.

d) Frostbite

Continued exposure to cold atmosphere, such as would be found within the vapor cloud, can result in *Frostbite* of exposed skin in addition to breathing discomfort. Since frostbite is accompanied by pain, it serves as a warning of the presence of cold atmosphere. In most cases, the direct physical contact with extremely cold LNG vapor, and pipes or equipment without insulation causes frostbite at the affected area, a condition, in which body tissues become frozen. If the affected body area is not treated in time, the frostbitten tissues will die and may result in the onset of Gangrene; a potentially life threatening condition caused by the lack of blood supply to body tissues.

Products	Symptoms	Treatment
<ul style="list-style-type: none"> <li>• LNG</li> <li>• Nitrogen</li> </ul>	<ul style="list-style-type: none"> <li>• Skin initially becomes red, but then turns white</li> <li>• Usually painless (before thawing)</li> <li>• Extremely painful (after thawing)</li> <li>• Affected area is hard to touch</li> <li>• Confusion or agitation</li> <li>• Fainting</li> <li>• Shock</li> </ul>	<ul style="list-style-type: none"> <li>• Warm the area rapidly but gently with the hand or woollen material</li> <li>• Affected part should be placed in warm water at about 42°C</li> <li>• Keep the patient in a warm room</li> <li>• Do not massage the affected part</li> <li>• No movement of the affected joints unless sufficient warming or thawing has been carried out</li> <li>• Give painkiller or morphine if the pain is serious upon thawing</li> </ul>



		<ul style="list-style-type: none"> <li>• Blisters should never be cut, nor clothing removed if adhering firmly</li> <li>• While warming up, the patient should not be allowed to have alcohol or smoke</li> <li>• Dress the affected area with sterile dry gauze</li> <li>• Seek shore medical assistance at the earliest</li> </ul>
--	--	--

**8.3.9 REACTIVITY OF LNG WITH WATER TO FORM HYDRATES**

The NG extracted from a gas field contains some impurities such as moisture, H<sub>2</sub>S, CO<sub>2</sub> and heavy hydrocarbons. These impurities adversely affect pipelines and nozzles of liquefaction plants through corrosion and choking, hence must be removed before the gas is subject to the liquefaction process. This is called the pre-processing of natural gas.

Though the processed LNG is extremely clean and refined, the presence of moisture in pipelines and tanks may lead to the formation of fine white powder called as *hydrate*. High dewpoint temperature of the N<sub>2</sub>, insufficient drying-up of LNG bunker tank prior first bunkering after delivery or docking, dissolved water in LNG bunker are a few probable causes for the presence of water in the bunker containment system. The powdery hydrates are not readily decomposable, and their formation is similar to that of salt associated with crystallization of water. There is no convincing explanation on the mechanism by which these hydrates are formed. The powdery substance may cause choking of pipelines and nozzles and the problem, though mainly seen in shore liquefaction plants, may exist in LNG bunker containment system, especially at nozzles on spray lines inside LNG bunker tanks. To prevent the formation of hydrates in LNG fuel containment system, its dew point shall be lowered to -40°C or less using dry air prior to inerting.

**8.3.10 HAZARDS OF VENTING**

Small volumes of LNG expand to produce large quantities of vapors that are highly flammable. Hence, venting operations present a very high degree of hazard to the safety of the vessel, personnel and the environment. Refer to *Section-9.8.2* for detailed guidance on venting of NG.

**8.3.11 LOW TEMPERATURE HAZARDS**

**8.3.11.1 BRITTLE FRACTURE**

A vessel’s structure or fitting that is not fabricated with low temperature steel will turn brittle if sprayed with extremely low temperature LNG bunker. The combination of static, dynamic and thermal stresses can cause the steel structure to crack due to its brittle condition. Personnel on LNG fuelled vessels shall be guided by the following procedures:

- a) Open deck near LNG bunker containment system
  - LNG bunker lines and flanged joints should be periodically inspected for leakages.



- Maintenance and/or renewal should be planned for effective arrest of leaks. Shore workshop assistance should be considered for major repairs.
- LNG bunker manifold connections should be checked for leaks to ensure that LNG does not spill on to the ship's steel structure.
- Unused manifold connections should be isolated and blanked.
- Manifold disconnection or removal of blanks should be carried out only when the manifold pressure gauge shows "zero" reading and all liquid content in the line has been cleared by purging with N2 and draining to a bunker tank. Complete de-icing of pipelines does not provide full surety of the pipelines being liquid free.
- Drip tray should not be filled with water during LNG bunkering.
- Charged fire hoses should be kept ready near the LNG bunker manifold in use.
- Manifold water curtain shall be operated during LNG bunkering.
- In the event of a spillage or leakage, water spray should be directed at the spill to disperse and evaporate the liquid and to protect the steelwork. The leak must be rectified at the earliest and bunkering operation shall be suspended, if necessary.

***Scupper on LNG bunkering deck:*** During LNG bunker transfer operation, no scupper in the vicinity of LNG tanks & pipelines shall be plugged. In case of LNG spill, the formation of LNG pool shall be prevented by hosing down the spill with seawater and allowing it to be drained through scuppers.

- b) Bunker pipelines – Though bunker pipelines are constructed with low temperature grade steel (stainless steel), rapid cool-down may result in excessive thermal stresses. To prevent brittle fracture of LNG bunker pipelines, cool-down of bunker pipelines should be carried out at a gradual rate that is less or equal to the design cool-down rate. Information on pipeline cool-down rates is usually provided by the shipyard/maker.
- c) LNG bunker tank – Information on LNG bunker tank cool-down procedure and rate will be provided by shipyard/maker. Cool-down of LNG tanks shall be carried out at a rate that is less than or equal to the design cool-down rate.

### **8.3.11.2 COLD SPOTS DUE TO DAMAGE OF LNG BUNKER TANK INSULATION**

The insulation provided on LNG bunker tank prevents the temperature of adjacent steel structure from falling below the permitted levels. Cold spots and icing at these locations indicate local breakdown of the insulation. Where applicable, the LNG bunker tank insulation shall be periodically inspected to determine the presence of insulation breakdowns. If cold spots are located, arrangements shall be made to maintain the temperature of surrounding area either by direct hosing of water or by filling the adjacent water ballast space.

***Checks for cold spots:*** As a measure of precaution, void spaces, cofferdams and ballast tanks adjacent to LNG bunker tanks, where applicable, must be physically inspected for cold spots after the first bunkering post yard delivery or dry-docking. Thereafter, these spaces shall be checked for cold spots at least once every 3 months.



### **8.3.11.3 ICE FORMATION IN PIPELINES ADJACENT TO LIQUID LINES**

Control air pipelines, provided for operating pneumatic LNG bunker system valves, should be protected against icing when located in close vicinity of LNG bunker pipelines. Any moisture in such pipes will freeze and cause LNG bunker system to shut down.

### **8.3.12 PRESSURE RELATED HAZARDS**

The following information relates to the design pressure of LNG bunker system:

- a) LNG bunker lines are usually designed to sustain pressure upto 10 bars.
- b) Specific operational parameters, construction profile of LNG bunker tank including wall thickness and shape, insulation, and the vessel's capability to control tank temperatures guide the high and the low-pressure alarm settings.
- c) The safety relief valve setting for LNG bunker tank will vary basis construction.
  - Membrane type tank = 0.25 barg (pressure) & 0.01 barg (vacuum)
  - Type-C tank = 4.0 barg (pressure) & 0.1 barg (vacuum)
- d) Extreme pressures that are higher or lower than the design pressure range, may result in uncontrolled venting or severe structural damage to the containment system.
- e) Rise in temperature of LNG that is trapped in a closed system (e.g. between 2 valves in an LNG bunker pipeline) may result in the developing of leak in the system. Where presence of trapped liquid is ascertained, the liquid should be drained to an LNG tank by slowly opening the intermediate valve(s).
- f) When LNG is introduced in a tank for cool down, a sudden increase in the tank pressure will be experienced due to excessive production of BOG. To keep the tank pressure within nominal limit, the BOG is either returned ashore or consumed in the ship's machinery.

#### **8.3.12.1 PRESSURE SURGE**

Sudden closing of remotely controlled or automatic shut-down valves located in LNG bunker pipelines may generate a pressure surge that can cause hose burst, shore pipeline failure and severe damage to the shore bunker facility. The following precautions shall be observed to avoid the generation of pressure surge:

- a) Closing rate of the remotely controlled LNG bunker system valves should be periodically checked under actual operating conditions. If found operating too rapidly, the closing time should be suitably adjusted. It must be remembered that valves have different torque characteristics at service and ambient temperatures.
- b) The power-pack (hydraulic or pneumatic) system for the remote operation of LNG bunker system valves should be closely inspected for leaks. The system should be maintained in good operational condition so that it is able to generate sufficient pressure in the power pack unit during automatic operation. Manual operation of valves shall be identified, and the manual pump shall be stored in a readily accessible location.
- c) Automatic shut-down valves operated by level sensors are known to shut prematurely due to internal faults or power failure. The system should be periodically checked under actual operating conditions to ensure fault free operation at correct set values. Upon activation of ESD, the time taken by an automatic valve to close from fully open position shall be between 24 and 30 seconds.
- d) Required valves should be suitably lined-up prior commencing LNG bunker transfer.



- e) During the LNG bunker transfer, valves in the liquid system should never be *SHUT* suddenly.
- f) When changing over between tanks during LNG bunkering, if applicable, the valve(s) to line up the new tank should be opened prior shutting the valve(s) to the tank being isolated. If required, the bunker facility shall be asked to reduce the pumping rate when changing the line-up.

### **8.3.12.2 PRESSURE IN LNG BUNKER TANK & INTERBARRIER SPACE**

LNG bunker tank pressure shall always be maintained above atmospheric pressure to prevent the ingress of air and possible formation of flammable mixtures. The tank shall be maintained at a positive pressure even if it contains only NG vapor or N2. A vessel shall arrive at LNG bunker facility with tank pressure at or below the facility's requirement.

Membrane tanks are vulnerable to damage from vacuum or incorrect differential pressures owing to the thin barrier material. IBS shall be filled with dry N2 or dry air, as applicable. Pressure in LNG bunker tank(s) and IBS should be closely monitored, especially during LNG bunkering. The following factors affect pressure in IBS:

- a) Change in LNG tank shell temperature
- b) Atmospheric temperature variation during the day
- c) Change in climate/weather conditions
- d) Change in sea water temperature
- e) Atmospheric pressure
- f) Vapor sampling in the fixed gas detector

### **8.3.12.3 HAZARDS ASSOCIATED WITH PRESSURE RELIEF VALVE**

Section-10.5 of this manual shall be referred for guidance on hazards related to safety relief valves.

### **8.3.13 SLOSHING**

Within a defined range of a tank's filling levels, the pitching and rolling motion of the ship in combination with the free surface of liquid can create high impact pressure on the tank surface. This phenomenon is called *Sloshing* and may cause heavy structural damage to membrane type LNG bunker tank. LNG bunker may be safely carried only within the filling range specified for a system, if the sloshing is permissible. Safe tank loading limits are provided by the shipyard/maker and vessel's classification society. The ship's motion that may generate sloshing in LNG bunker tank(s) shall be avoided. Continuous repeat of the motion in a seaway that causes sloshing may become significantly dangerous. The shipboard personnel shall stay alert to the fact that it is very difficult to predict the kind of sea conditions that will cause sloshing; hence the ship's movement may be changed by altering ship's heading, speed or trim.