INTERNATIONAL STANDARD

ISO 16903

First edition
2015-06-15

Petroleum and natural gas industries — Characteristics of LNG, influencing the design, and material selection

Pétrole et industries du gaz naturel — Caractéristiques du GNL influant sur la conception et le choix des matériaux

Reference number
ISO 16903:2015(E)

Contents

Page

Foreword iv
1 Scope 1
2 Normative references 1
3 Terms and definitions 1
4 Abbreviated terms 2
5 General characteristics of LNG 2
5.1 General 2
5.2 Properties of LNG 2
5.2.1 Composition 2
5.2.2 Density 2
5.2.3 Temperature 3
5.2.4 Viscosity 3
5.2.5 Examples of LNG 3
5.3 Physical properties 3
5.3.1 Physical properties of boil-off gas 3
5.3.2 Flash 4
5.3.3 Spillage of LNG 4
5.3.4 Expansion and dispersion of gas clouds 4
5.3.5 Ignition 5
5.3.6 Pool fires 5
5.3.7 Development and consequences of pressure waves 5
5.3.8 Containment 5
5.3.9 Rollover 5
5.3.10 RPT 6
5.3.11 BLEVE 6
6 Health and safety 6
6.1 General 6
6.2 Exposure to cold 7
6.2.1 Warning notice 7
6.2.2 Handling, cold contact burns 7
6.2.3 Frostbite 7
6.2.4 Effect of cold on the lungs 7
6.2.5 Hypothermia 7
6.2.6 Recommended protective clothing 7
6.3 Exposure to gas 7
6.3.1 Toxicity 7
6.3.2 Asphyxia 7
6.4 Fire precautions and protection 8
6.5 Colour 8
6.6 Odour 8
7 Materials of construction 8
7.1 Materials used in the LNG industry 8
7.1.1 General 8
7.1.2 Materials in direct contact 8
7.1.3 Materials not in direct contact under normal operation 9
7.1.4 Other information 9
7.2 Thermal stresses 10
Bibliography 11

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

Petroleum and natural gas industries — Characteristics of LNG, influencing the design, and material selection

1 Scope

This International Standard gives guidance on the characteristics of liquefied natural gas (LNG) and the cryogenic materials used in the LNG industry. It also gives guidance on health and safety matters. It is intended to act as a reference document for the implementation of other standards in the liquefied natural gas field. It is intended as a reference for use by persons who design or operate LNG facilities.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

EN 1473, *Installation and equipment for liquefied natural gas — Design of onshore installations*

NFPA 59A, *Standard for the production, storage, and handling of liquefied natural gas (LNG)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
boil-off gas
gas generated during the storage or handling of volatile liquefied gases

3.2
condensate
hydrocarbon liquid that forms by condensation from natural gas, consisting primarily of pentanes (C_5H_{12}) and heavier components

Note 1 to entry: There will be some propane and butane dissolved within the mixture.

3.3
liquefied natural gas
LNG
colourless and odourless cryogenic fluid in the liquid state at normal pressure composed predominantly of methane which can contain minor quantities of ethane, propane, butane, nitrogen, or other components normally found in natural gas

3.4
liquefied petroleum gas
LPG
gaseous hydrocarbons at normal temperatures and pressures, but that readily turns into liquids under moderate pressure at normal temperatures, e.g. propane and butane

3.5
natural gas liquids
NGL
liquid hydrocarbons, such as ethane, propane, butane, pentane, and natural gasoline, extracted from field natural gas

4 Abbreviated terms

For the purposes of this International Standard, the following abbreviations apply.

BLEVE	boiling liquid expanding vapour explosion
LPG	liquid petroleum gas
QRA	quantitative risk analysis
RPT	rapid phase transition
SEP	surface emissive power

5 General characteristics of LNG

5.1 General

It is recommended that all personnel concerned with the handling of LNG should be familiar with both the characteristics of the liquid and the gas produced.

The potential hazard in handling LNG stems mainly from three important properties.

a) It is extremely cold. At atmospheric pressure, depending upon composition, LNG boils at about −160 °C. At this temperature, the vapour is denser than ambient air.

b) Very small quantities of liquid are converted into large volumes of gas. One volume of LNG produces approximately 600 volumes of gas.

c) Natural gas, similar to other gaseous hydrocarbons, is flammable. At ambient conditions, the flammable mixture range with air is from approximately 5 % to 15 % gas by volume. If vapour accumulates in a confined space, ignition can result in detonation and shock wave overpressure.

This International Standard focuses on LNG, its properties, and resultant hazards. When evaluating the hazards at an LNG site, designers need to consider all systems present. Often, the LNG itself does not present the greatest hazard; other systems such as LPG-based refrigeration at the liquefaction plant or high pressure gas send out at a regasification plant can dominate the overall site risk profile.

5.2 Properties of LNG

5.2.1 Composition

LNG is a mixture of hydrocarbons composed predominantly of methane and which can contain minor quantities of ethane, propane, butane, nitrogen, or other components, normally found in natural gas. The physical and thermodynamic properties of methane and other components of natural gas can be found in reference books (see Annex A) and thermodynamic calculation codes. Although the major constituent of LNG is methane, it should not be assumed that LNG is pure methane for the purpose of estimating its behaviour. When analysing the composition of LNG, special care should be taken to obtain representative samples not causing false analysis results due to distillation effects. The most common method is to analyse a small stream of continuously evaporated product using a specific LNG sampling device that is designed to provide a representative gas sample of liquid without fractionation. Another method is to take a sample from the outlet of the main product vaporizers. This sample can then be analysed by normal gas chromatographic methods, such as those described in ISO 6568 or ISO 6974.

5.2.2 Density

The density of LNG depends on the composition and usually ranges from 420 kg/m^3 to 470 kg/m^3, but in some cases can be as high as 520 kg/m^3. Density is also a function of the liquid temperature with a gradient of about 1,4 kg/m^3/K. Density can be measured directly but is generally calculated from composition determined by gas chromatographic analysis. The method as defined in ISO 6578 is recommended.

NOTE This method is generally known as revised Klosek-McKinley method.

5.2.3 Temperature

LNG has a boiling temperature depending on composition and usually ranging from −166 °C to −157 °C at atmospheric pressure. The variation of the boiling temperature with the vapour pressure is about 1,25 × 10^{-4} °C/Pa. The temperature of LNG is commonly measured by using copper/copper nickel thermocouples or using platinum resistance thermometers such as those defined in ISO 8310.

5.2.4 Viscosity

The viscosity of LNG depends on the composition and is usually from 1,0 × 10^{-4} to 2,0 × 10^{-4} Pat −160 °C, which is nearly 1/10 to 1/5 of the water. Viscosity is also a function of the liquid temperature.

5.2.5 Examples of LNG

Three typical examples of LNG are shown in Table 1 below which demonstrates the property variations with different compositions[1].

Table 1 — Examples of LNG

Properties at boiling temperature at normal pressure	LNG Example 1	LNG Example 2	LNG Example 3
Molar content (%)			
N_2	0,13	1,79	0,36
CH_4	99,8	93,9	87,20
C_2H_6	0,07	3,26	8,61
C_3H_8	—	0,69	2,74
i C_4H_{10}	—	0,12	0,42
n C_4H_{10}	—	0,15	0,65
C_5H_{12}	—	0,09	0,02
Molecular weight (kg/kmol)	16,07	17,07	18,52
Boiling temperature (°C)	−161,9	−166,5	−161,3
Density (kg/m^3)	422	448,8	468,7
Volume of gas measured at 0 °C and 101 325 Pa/volume of liquid (m^3/m^3)	588	590	568
Volume of gas measured at 0 °C and 101 325 Pa/mass of liquid (m^3/10^3 kg)	1 392	1 314	1 211
Mass heat of vaporization (kJ/kg)	525,6	679,5	675,5
Gross heating value (MJ/m^3)	37,75	38,76	42,59

5.3 Physical properties

5.3.1 Physical properties of boil-off gas

LNG is stored in bulk as a boiling liquid in large, thermally insulated tanks. Any heat leak into the tank causes some of the liquid to evaporate as a gas. This gas is known as boil-off gas. The composition of the boil-off gas depends on the composition of the liquid. As an example, the boil-off gas could contain 20 %

1) Values are given from simulations.

nitrogen, 80 % methane, and traces of ethane; the nitrogen content of the boil-off gas could be about 20 times that in the LNG.

As LNG evaporates, the nitrogen and methane are preferentially lost leaving the liquid with a larger fraction of the higher hydrocarbons. Boil-off gases below about –113 °C for pure methane and –85 °C for methane with 20 % nitrogen are heavier than ambient air. At normal conditions, the density of these boil-off gases is approximately 0,6 of air.

5.3.2 Flash

As any fluid, if pressurized LNG is lowered in pressure below its boiling pressure, for example by passing through a valve, then some of the liquid evaporates and the liquid temperature drops to its new boiling point at that pressure. This is known as flash. Since LNG is a multi-component mixture, the composition of the flash gas and the remaining liquid differ for similar reasons from those discussed in 5.3.1.

As a guide, a 10^3 Pa flash of 1 m^3 liquid at its boiling point corresponding to a pressure ranging from 1×10^5 Pa to 2×10^5 Pa produces approximately 0,4 kg of gas. More accurate calculation of both the quantity and composition of the liquid and gas products of flashing multi-component fluids such as LNG are complex. Validated thermodynamic or plant simulation packages for use on computers incorporating an appropriate database should be used for such flash calculations.

5.3.3 Spillage of LNG

When LNG is poured on the ground (as an accidental spillage), there is an initial period of intense boiling, after which the rate of evaporation decays rapidly to a constant value that is determined by the thermal characteristics of the ground and heat gained from surrounding air. This rate can be significantly reduced by the use of thermally insulated surfaces where spillages are likely to occur as shown in Table 2. These figures are given for examples, but should be checked when used for QRA or detail engineering.

Table 2 — Rate of evaporation

Material	**Rate per unit area after 60 s** kg / (m^2h)
Aggregate	480
Wet sand	240
Dry sand	195
Water	600
Standard concrete	130
Light colloidal concrete	65

Small quantities of liquid can be converted into large volumes of gas when spillage occurs. One volume of liquid produces approximately 600 volumes of gas at ambient conditions (see Table 1). When spillage occurs on water, the convection in the water is so intense that the rate of evaporation related to the area remains constant. The size of the LNG spillage extends until the evaporating amount of gas equals the amount of liquid gas produced by the leak.

5.3.4 Expansion and dispersion of gas clouds

Initially, the gas produced by evaporation is at nearly the same temperature as the LNG and is denser than ambient air. Such gas is, at first, subjected to gravity spreading by flowing in a layer along the ground until it warms sufficiently by absorbing heat from the soil and mixing with the ambient air.

The dilution with warm air increases temperature and decreases the molecular weight of the mixture. As a result, the cloud is in general denser than ambient air until diluted well below the flammable limit. Only in case of high water content of the atmosphere (high humidity and temperature) can the condensation of water during the mixing with the cold LNG vapours heat-up the mixture as such that it becomes lighter than air and results in a buoyant cloud. Spillage, expansion, and dispersion of vapour clouds are complex subjects and are usually predicted by computer models. Such predictions should only be undertaken by a body competent in the subject. Following a spillage, 'fog' clouds are formed by condensation of water vapour in the ambient air. When the fog can be seen (by day and without natural fog) and if the relative humidity of the ambient air is sufficiently high, the visible fog is a useful indicator of the travel of the vaporized gas and the cloud gives a first indication of the extent of flammability of the mixture of gas and air as the visibility of the cloud is a function of the humidity and ambient temperature, not a function of the natural gas release.

In the case of a leak in pressure vessels or in piping, LNG sprays as a jet stream into the atmosphere under simultaneous throttling (expansion) and vaporization. This process coincides with intense mixing with air. A large part of the LNG is contained in the gas cloud initially as an aerosol. This eventually vaporizes by further mixing with air.

5.3.5 Ignition

A natural gas/air cloud can be ignited when the natural gas concentration is in the range from 5 % to 15 % by volume.

5.3.6 Pool fires

The surface emissive power (SEP) of a flame from an ignited pool of LNG with greater diameter than 10 m can be very high and shall be calculated from the measured values of the incident radiative flux and a defined flame area. The SEP depends on pool size, smoke emission, and methods of measurement. With increased footing, the SEP decreases. The Bibliography contains a list of references which can be used to ascertain the SEP for a given circumstance.

5.3.7 Development and consequences of pressure waves

In a free cloud, natural gas burns at low velocities resulting in low overpressures of less than 5×10^3 Pa within the cloud. Higher pressures can occur in areas of high congestion or confinement such as densely installed equipment or buildings.

5.3.8 Containment

Natural gas cannot be liquefied by applying pressure at ambient temperature. In fact, it shall be reduced in temperature below about −80 °C before it liquefies at any pressure. This means that any quantity of LNG that is contained, for example between two valves or in a vessel with no vent, and is then allowed to warm up increases in pressure until failure of the containment system occurs. Plant and equipment shall therefore be designed with adequately sized vents and/or relief valves.

Designers need to pay attention to eliminating the potential to shut in even small volumes of cryogenic liquid, including attention to details such as cavity venting of ball valves.

5.3.9 Rollover

The term rollover refers to a process whereby large quantities of gas can be emitted from an LNG tank over a short period. This could cause over pressurization of the tank unless prevented or designed for. It is possible in LNG storage tanks for two stably stratified layers or cells to be established, usually as a result of incomplete mixing of fresh LNG with a heel of different density. Within cells, the liquid density is uniform but the bottom cell is composed of liquid that is denser than the liquid in the cell above. Subsequently, due to the heat leak into the tank, heat and mass transfer between cells and evaporation at the liquid surface, the cells equalize in density and spontaneously mix. This spontaneous mixing is called rollover and if, as is often the case, the liquid at the bottom cell has become superheated with respect to the pressure in the tank vapour space, the rollover is accompanied by an increase in vapour evolution. Sometimes, the increase is rapid and large. In a few instances, the pressure rise in the tank has been sufficient to cause pressure relief valves to lift.

