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The risk of domino effect associated with the storage of liquefied petroleum gas (LPG) and the safety codes for accident prevention

by

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Abstract

Liquefied petroleum gas (LPG) is among the most common and ubiquitous of the fossil fuelsemployed by us. In contrast to other fossil fuels commonly used by everyone in day-to-day living ─ petrol, diesel, and kerosene ─ which all are a highly flammable, hence hazardous, LPG does not only carry flammability hazard but also the risk of explosion. Due to the very extensive and continuous use of LPG, the risk of LPG─related accident is ever present. This paper deals with the risk associated with the storage of LPG in large installations and reviews the safety codes prescribed by different agencies across the world to minimize the risk. It then presents comparative views of the stipulations of different codes for different site characteristics.

Keywords: Liquefied petroleum gas (LPG), flammability, explosion, domino effect,risk assessment, safety codes

1. Introduction

Liquefied petroleum gas (LPG) is a ubiquitous household fuel which is used even more commonly than petrol, diesel, and kerosene (Tauseef *et al.*, 2011a). Like the three named liquid fuels, LPG is also highly flammable. Additionally LPG carries the risk of explosion because it is stored under pressure and any failure in the storage cylinder may cause the cylinder to suffer a boiling liquid expanding vapour explosion (BLEVE) (Abbasi and Abbasi 2007 a, b; 2008; Tauseef *et al.*, 2010). Such an explosion involving LPG always accompanies formation of fireball. It can also happen that LPG may accidently leak and form a vapourcloud (Khan and Abbasi, 1998a; Eckhoff, 2005; Tauseef *et al.*, 2011; Vasanth *et al.*, 2013). Such a vapour cloud, if partially or fully confined, can get ignited and cause vapour cloud explosion (VCE). Or, if there is no confinement and the vapour cloud has been formed in the open, it may get ignited to cause flash fire (Abbasi *et al.*, 2010). The likelihood of these accidents, which are very destructive ─ especially BLEVE and VCE ─ make the storage and handling of LPG very hazardous.

Worse, any major accident involving large-scale storage or transportation of LPG is seldom a one-off event (Khan and Abbasi, 1997, 1998b, 1999). More often than not the first accident leads to a second major accident and the second accident to a third…and more (Khan and Abbasi, 1997b; 2002). There is thus a cascading or 'domino' effect (Khan and Abbasi, 1998c; 2001), which escalates the first accident manifold. This risk of 'domino' effect makes LPG related installations particularly hazardous.

Numerous precautionary measures are adapted to reduce the risk of LPG−related accidents (Mukhim *et al.*, 2017). The LPG cylinders are designed to withstand much greater pressures than the one at which LPG is filled in the cylinders. The cylinders are also made resistant to mechanical damage. Since LPG vapous are colourless and odourless, mercaptans are added to impart a clearly distinguishable foul smell to the LPG so that its leakage can be detected olefactrily. In refineries and storage depots, where large quantities of LPG is brought, stored, and sent off after repackaging, also, several steps are taken to minimize the risk of accidents (Tauseef *et al.,* 2011b; Abbasi *et al.*, 2013).

But despite these precautions bursting of LPG cylinders is fairly common (Tauseef *et al.*, 2010). Some of the most harmful accidents have also occurred in refineries dealing with LPG. A few examples of such accidents are presented below.

1.1 LPG explosion at Feyzin, France (Abbasi and Abbasi, 2007a; 2008)

A leak in a propane storage sphere occurred on 4 January 1966 at Feyzin, France. It snow-balled into one of the worst incidents involving LPG that has ever occurred, killing 18 people. The accident also was signfnificant because it was the first such accident in which the phenomonon now known as BLEVE was made clear. BLEVE, pronounced *blevy,* is an acronym for boiling liquid expanding vapor explosion. This is a type of explosion that can occur when a vessel containing a pressurized liquid is ruptured (www.firehouse.com).

The facility was a LPG tank farm with eight spheres containing butane and propane. During a routine operation, some propane from one of the spheres leaked out. The propane leak soon formed a visible cloud of vapour, 1 meter deep. It spread for 150 meters and was ignited 25 minutes after the leak by the spark of the spark plug of an automobile which was being started. The fire flashed back to the sphere and engulfed it. The sphere was fitted with water sprays but the supply was inadequate to cool the vessel. When the fire brigade began using their hoses, the water supply to the spheres ran dry. Apparently, the firemen had used off the available water for cooling the neighboring spheres to prevent the fire from spreading, in the belief that the vessel on fire will be protected by a relief valve (Abbasi *et al.,* 2007). But the volve was not functional.

Ninety minutes after the fire started, the sphere went through a BLEVE. Ten out of 12 firemen within 50 meters of the sphere were killed instantly (Tauseef *et al.*, 2010). Men 140 meters away were badly burned by a wave of propane which came over the compound wall. Altogether 18 men were killed and about 80 injured. Flying debris broke the legs of an adjacent sphere which fell over. Its relief valve discharged liquid which added to the fire, and 45 minutes later it also BLEVEd, leading to more BLEVEs. Altogether five spheres and two other pressure vessels burst and three more were damaged. The fire spread to gasoline and fuel oil tanks. It took 48 hours to gain control of the fires.

1.2 The PEMEX LPG terminal disaster, San Juan, Ixhantepec, Mexico City (Abbasi and Abbasi, 2007; 2008; Kuriechan, 2005)

As recounted by Abbasi and Abbasi (2007a), the "PEMEX LPG terminal in San Juan Ixhuatepec, Mexico City, was a large installation which received supplies from three gas refineries every day. On the morning of 19 November 1984, when the vessels at the PEMEX terminal were being filled with LPG arriving in a pipeline from a refinery 400 km away, a drop in the pipeline pressure was noticed by the control room and a pumping station. It occurred because an 8 inch pipe connecting one of the spheres to a series of cylinders had ruptured. But the operators were not aware of it nor they tried to check it. As a result the release of the LPG from the leaking pipeline continued for 5–10 min".

"The escaping gas formed a 2m high cloud covering an area of 200m×150 m. The cloud then drifted towards a flare tower, caught fire and precipitated the first BLEVE. The explosion hurled vessel fragments wrapped in burning LPG in all directions. Some of the projectiles hit other vessels, damaging them, or caused local fires which engulfed other vessels. This led to the failure of one vessel after another; most exploding vessels caused nearby vessels to fail".

"Four LPG spheres, each containing 1500m^3 of LPG, and several other smaller cylinders holding between 45m^3 and 270m^3 of the liquid suffered BLEVEs. Each BLEVE generated a fireball; such fireballs raged through the streets of Ixhuatepec for about 90 min. A block of 200 houses built mostly of wood, cardboard, and metal sheets was demolished by these fireballs. Masses of fragments of tanks and pipes, some of them weighing 40 tonnes, were blown into air and landed as far as 1200m away. The PEMEX terminal was devastated. The accident was responsible for 650 deaths and over 6400 injuries. Damages due to the explosion and the resulting fire were estimated at approximately $31 million" at the 1984 currency value.

Figure 1 provides glimpses of a portion of storage tank form before and during the accident.

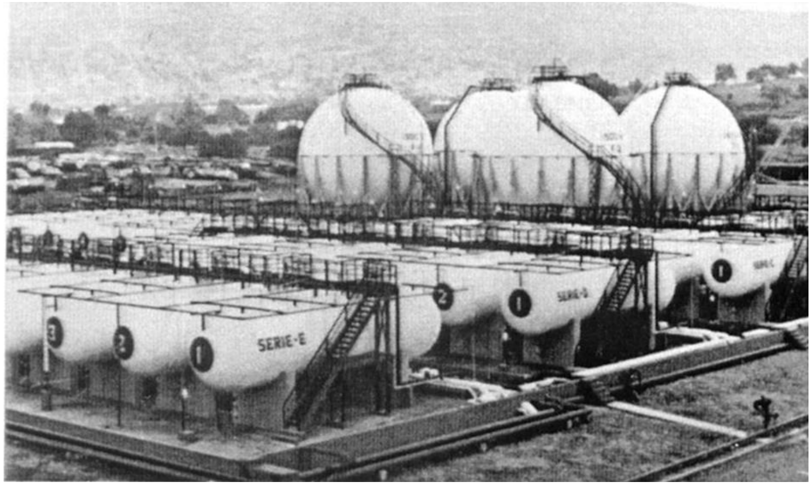
SERIE-E
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Figure 1: Storage spheres and cylinders at the PEMEX plant, San Juan, Mexico before (top) and during the accidents (middle and bottom).

1.3 The Sao Paulo Accident (Khan and Abbasi 1999)

On February 25, 1984, at least 508 people, most of them young children, were killed in Sao Paulo (Brazil) when a 2-ft diameter gasoline pipe ruptured and 700 tons of gasoline spread across a strip of swamp. The cause of the pipe rupture was not reported, though it was said to have been caused due to pressure built up over thesafe limit. It was also stated that there was no way of monitoring the pressure in the pipe line(Khan and Abbasi 1999).

1.4 The Siberian Accident (Khan et al., 1997)

Perhaps the most macabre accident - next only to Bhopal gas tragedy in its severity - occurred on June 3,1989, near Nizhnevartovsk in Western Siberia. Engineers stationed there noticed a sudden drop in pressure at the pumping end of an LPG pipeline. The pipeline was commissioned in 1985 to carry mixed LPG to feed the industrial city of Ufa. Instead of investigating the trouble, the engineers responded by increasing the pumping rate in order to maintain the required pressure in the pipeline. The actual leakage point was about 890 miles downstream between the towns of Asma and Ufa where the pipeline was installed about half a Km away to the side of the Trans Siberian Railway. The smell of escaping gas was reported from the valley settlements in the area but no one did anything about it. The escaping liquefied gas formed two large pockets in the low lying areas along the railway line. The gas cloud then drifted for a distance of 5 miles. Some hours later, after the main leakage had started, a train from Nizhnevartovsk destined for the Red Sea resort of Alder was approaching the leakage area when the driver noticed a fog in the area that had a strong smell. The driver of another train approaching from the opposite direction (Alder to Nizhnevartovsk) saw much the same as he approached the West bound train. Both trains were packed, with a total of 1168 people on board, and as they approached the area, the turbulence caused by them mixed up the LPG mist and vapour with the overlying air to form a flammable cloud. One or the other train ignited the cloud. Several explosions took place in quick succession followed by a ball of fire that was about 1 mile wide and which raced down the railroad tracks in both directions. Trees were flattened within a radius of 2 1/2 miles of the epicentre of the explosions and windows were broken up to 8 miles away. The accident left 462 dead and 796 hospitalised with 70% to 80% burn injuries (Khan *et al.*, 1997).

1.5LPG blast at Visakhapatnam refinery India (Khan and Abbasi, 1999)

On September 14, 1997, at Visakhapatnam, India, a pipeline carrying LPG from a harbor terminal to the refinery developed a leak. The LPG found an ignition source that triggered a large vapor cloud explosion. The resulting fire engulfed 18 storage tanks, destroying seven tanks containing LPG and crude oil (www,marshriskconsulting.com). More than 80 people died. Had the accident not taken place on a Sunday, the death toll would have been several times greater.

1.6 The Skikda disaster

An accident that killed 23 persons and caused property damage worth US $ 800 million occurred at Skikda ─ Algeria's largest refinery handling LPG (Figure2), on 19 January 2004. A boiler ruptured, its explosion damaged nearby vessels containing LPG which began leaking, catching fire and exploding. The initial event rapidly escalated into a frightful disaster (Figure 2).

Figure 2: Blast at the Skikda refinery, Algeria (top) and fires ranging (bottom)

1.7 Typical accidents involving small LPG cylinders (Tauseef et al., 2010)

We present below typical accidents involving small LPG cylinders which have been excerpted from Tauseef *et al.*, (2010). As reported by Tauseef *et al.*, (2010), “one of the worst disasters perpetrated by a portablehousehold-scale LPG cylinder which underwent a BLEVEoccurred in a passenger train going from Cairo to Luxor inEgypt on February 20, 2002. It occurred in the fifth carriageof the 11-carriage passenger train and the resultingfire spread as the train ran. Seven of the carriages wereburnt almost to cinders. According to the official figuregiven at the time, 383 people died. However, consideringthat seven carriages were burned to the ground and eachcarriage was packed with at least double the maximumcarrying capacity of 150, this figure is probably anunderestimate”.

“The Cairo incident was a particularly macabre one, butBLEVEs involving small LPG cylinders is a fairly commonphenomenon as may be seen from illustrativeexamples given below.

A man was killed and three others seriously injuredwhen a cooking gas cylinder exploded in a house in Balasore,India, on 15 February, 2008”.

“Four people were killed when an LPG cylinder beingused for cooking went through a BLEVE near Patna, India,on 10 March, 2008. On the same day at Kolkata, India, theexplosion of an LPG cylinder started a fire which engulfednearby dwellings. One after another LPG cylinders explodedas the fire kept spreading before it was brought undercontrol. Approximately 50 cylinders were thought to beinvolved in the accident”.

“A leaking LPG cylinder exploded on 20 April, 2008 atBangalore, India, killing a four-year-old boy, injuring 11,and damaging houses in the neighborhood”.

“An LPG cylinder exploded in Dimapur, India, on 23April, 2008 causing a devastating fire which led to theexplosion of several more LPG cylinders. As many as 300houses were razed to the ground and two children werekilled”.

“One woman and two children were killed and 10 otherpeople were injured when a cooking gas cylinder explodedin a house in southwest Delhi, on March 2, 2008”.

“At least three people were killed and 20 injured when acooking gas cylinder exploded in Malegaon, India, on29 September, 2008. The cylinder went off in a crowdedmarket and the panic after the blast led to a stampede inwhich 60 people, including three policemen were injured.An LPG tank which underwent a BLEVE in a residentialapartment in Cebu City, Philippines, on 5 November,2008. The explosion blew the kitchen’s roof some 10 maway. The apartment’s second floor also caved in. Threeother apartment units were damaged and four persons werehurt”.

“A 150-kg LPG cylinder at Raymond Terrace, Australia,was engulfed in an accidental bin fire on 3 January, 2009.Soon the engulfed cylinder went through a BLEVE; theresulting explosion sent the fragments of the shatteredcylinder smashing through trees and onto windows andwalls, damaging them. The main body of the cylinder itselfwas propelled 80 m away".

"Two women, trapped in a station wagon which met witha traffic accident near Dalby, Australia, died when an LPGtank in the back of the car suffered a BLEVE. The accidentwhich took place on 19 March 2009, had initially led to afire. The fire then engulfed the LPG cylinder causing it toundergo BLEVE even as rescuers tried frantically to get thetrapped women out".

"A father and son were injured in Melbourne, Australiaon 27 April 2009 when the LPG tank on the vehicle theywere repairing met with a BLEVE".

"A 6-year-old child died while six others were injuredwhen an LPG cylinder suffered a BLEVE in a shop inKolkata, India, on 2 February, 2009".

"At least 13 persons, including two children, werewounded when an LPG cylinder exploded at a roadsidecanteen in Malabon city, Philippines, on 22 June, 2009.Several patrons of the restaurant were also hurt. The blasttriggered a fire that destroyed the ceiling of the canteen".

"Two people were killed in New Delhi when the LPGcylinder in their home underwent a BLEVE on 8 July,2009".

"Four people suffered burn injuries in an LPG cylinderBLEVE at Mumbai on August 25, 2009. The blast alsodamaged two houses nearby".

"In Delhi on October 25, 2009, five people were injuredin an LPG cylinder BLEVE. A fire broke out following theblast".

"On November 17, 2009, more than three dozen pilgrimsand priests were injured when an LPG cylinder blew up ina temple near Agra".

"A gas contract worker was killed and 20 people wereinjured, 6 critically, in an LPG BLEVE on 14 December,2009 at a shopping complex in Malacca, Malaysia".

"Two motor engineers were left with facial and upperbody burns when a BLEVE occurred while they wereworking on the installation of the LPG tank of a car in agarage in Jagodina, Serbia, on 16 December, 2009".

1.8 The present work

The present work explores various codes and standards prescribed for spacing LPG storage tanks by different agencies in India and elsewhere, in such a way that accident in one container does not cause accident in another container. This work, which is specific to LPG, follows our previous report on storage of hazardous materials in general (Abbasi *et al.*, 2017).

2. Common accidents involving LPG

2.1 Falsh fire (FF) and vapour cloud explosion (VCE)

As the above examples indicate, more often than not accidents in refineries or refilling plants involving LPG begin with an accidental spill. If the weather is very cold with ambient temperatures, near zero, the spilled liquid slowly evaporates forming a cloud which initially hugs the ground. In tropical weather as is common in India, the spilled LPG quickly vaporizes to form a vapour cloud. The vapour cloud may then drift in the direction the wind may be blowing till it meets with an ignition source. If, at that stage, it happens to be in partial or total confinement, it can suffer a vapour cloud explosion (VCE). This is what happened at the offshore BPL Refinery rig in 2005 (Mejri and De Wolf, 2013).

If the vapour cloud remains unconfined till it gets ignited, it willlead to falsh fire (FF) as had happened at Feyzin and San Juan Ixhantepec, described in the previous section.

Whether an FF occurs or a VCE, either of it can seriously jeopardize other storage vessels and process units, causing further leaks, massive fires, and/or boiling liquid vapour explosions (BLEVEs). Nearly all the major accidents in LPG processing plants that have occurred in the past, have followed this pattern (Khan and Abbasi, 1998a; Abbasi *et al.*, 2013).

2.2 The boiling liquid expanding vapour explosion (BLEVE)

Abbasi and Abbasi (2007a) have made a detailed exposition of the occurrence, consequence assessment, and management of the BLEVE phenomenon. They have also documented the history of BLEVE (Abbasi and Abbasi, 2008), developed a theory to determine superheat limits associated with BLEVEs (Abbasi and Abbasi 2007b), and explored BLEVE in the context of LPG (Tauseef *et al.*, 2010). The details provided below are based on the extensive material contained in these reports.

2.2.1 Events leading to a BLEVE (www.theenergylibrary.com)

If a vessel containing ‘pressure-liquefied gas’ (PLG),in other words a liquid confined at a temperature above its atmospheric pressure boiling point, gets accidentally heated – say from the heat radiation emanating from a nearby fire – the pressure inside the vessel begins to rise. When this pressure reaches the set pressure of the pressure relief valve, the valve operates. The liquid level in the vessel falls as the valve releases the liquid vapor to the atmosphere(www.theenergylibrary.com).

The liquid is effective in cooling that part of the vessel wall which is in contact with it, but the vapor is not. The proportion of the vessel wall which has the benefit of liquid cooling falls as the liquid vaporizes. After a time, the portion of the metal which is not cooled by liquid also becomes exposed to the heat load, weakens, and may then rupture. This can occur even though the pressure relief valve may be operating correctly(www.theenergylibrary.com).

A vessel may also fail even in absence of fire-engulfment if it is accidentally hit by missiles originating from another vessel exploding nearby – as it happened during the serial explosions in the LPG facility at Mexico City or other forms of mechanical failure such as gland/seal loss, sample line breakage, fatigue, or corrosion(www.theenergylibrary.com).

2.2.2 Consequences of BLEVE involving LPG

Overpressure/ Blast waves

Massive blast wave or overpressure is generated that can hurl people and other objects several meters away.

Missiles

The explosion also sends fragments of the exploded vessel as also nearby objects shooting off as missiles at high velocities. These missiles can, and often, do damage other vessels storing liquefied gas under pressure, causing them to undergo BLEVE as well(www.theenergylibrary.com).

Fireball

A fireball is the kind of fire which is created by large quantity of flammable substance present in an exploding vessel. As noted by Abbasi and Abbasi (2007a), it burns“sufficiently rapidly for the burning mass to rise into the air as a dense cloud or a ball. In all BLEVEs involving flammable material, there is a near instantaneous two-phase release of the materialwhich auto-ignites to form a fireball”.

Toxic releases

It may be mentioned that the abovementioned steps necessarily occur when LPG containers suffer BLEVEs. But BLEVEs are not confined to flammable substances, and, as noted by Abbasi and Abbasi (2007)“BLEVE accidents have occurred involving ammonia (Casal *et al*., 2001), chlorine (Marshall, 1987), chlorobutadiene (Khan and Abbasi, 1997c), and phosgene (Marshall, 1987) wherein the explosion did not cause a fireball but was accompanied by dispersion of toxic material. Indeed of the one-third past BLEVE events not involving flammable liquids, the majority have been associated with toxic gases—chlorine (14%), ammonia (10%), and phosgene (2%) account for 76% of the BLEVEs involving non-flammables" (Abbasi and Abbasi 2007a).

3. The challenges of locating LPG storage units at 'safe distances' from each other

From the foregoing it is clear that any major accident in one of the LPG storage units in a tank farm can cause accidents in adjacent units thereby escalating the original accident manifold. To prevent such happening all hazardous units should be kept so far away from each other that each unit is out of the zone of influence of likely accidents happening in the nearby units. But such luxary siting of hazardous units is not practicable due to the limited availability and high cost of land area. Additionally, farther the units from each other, greater the cost of piping and transportation. In other words, cost considerations make it impossible to have a no-risk arrangement. What is possible are arrangements that seek to minimize the risks while maximizing land-use. 'Safe distance' norms and codes have been developed to meet this challenge of finding the best balance between the cost and the risk, as described below.

4. Standards and codes for siting LPG storage units at 'safe distances' from each other

4.1 The National Fire Prevention Association (NFPA) NFPA, 2008 (www.nfpa.org; www.zakatinst.net)

In the USA, National Fire Prevention Association (NFPA) has developed the code, NFPA 58 for LPG. In general NFPA codes (www.nfpa.org), standards, recommended practices, and guides for five prevention are developed through a consensus standards development process approved by the American National Standards Institute.

NFPA (www.nfpa.org) brings together volunteers representing varied viewpoints and interests to achieve consensus on fire and other safety issues. While the NFPA administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its codes and standards.

NFPA 58, Liquefied Petroleum Gas Code, was prepared by the Technical Committee (www.bookmarki.com) and approved as an American National Standard. These requirements are part of federal law in the United States and are added to help make users of NFPA 58 aware of them.

The Committee in the NFPA has primary responsibility for documents on the design, construction installation, and operation of fixed and portable LPG gas systems which include (documents.mx):

a) installation, and operation of fixed and portable LPG systems bulk plants and commercial, industrial (with specified exceptions), institutional, and similar properties;
b) truck transportation of liquefied petroleum gas;
c) engine fuel systems on motor vehicles and other mobile equipment;
d) storage of containers awaiting use or resale;
e) installation on commercial vehicles; and
f) liquefied petroleum gas service stations.

According to NFPA, LPG isdefined as that material which has(www.nfpa.org) a vapor pressure not exceeding that allowed for commercial propane that is composed predominantly of the following hydrocarbons, either by themselves or as mixtures: propane, propylene, butane (normal butane or iso-butane), and butylenes.

Structures such as fire walls, fences, earth or concrete barriers, and other similar structures are not permitted around or over installed non refrigerated containers unless specifically allowed (www.nfpa.org). Structures partially enclosing containers are permitted if designed in accordance with a sound fire protection analysis. Each group of containers it to be separated from the next group in accordance with the degree of fire protection required.

4.2 Oil Industries Safety Directorate guidelines (OISD, 2005; documents.mx)

In India, Oil Industries Safety Directorate Standard, OISD, 144, have beenprepared by the Functional Committee on LPG, Oil Industry Safety Directorate, Government of india, Ministry of Petroleum and Natural Gas.

According to OISD (documents.mx), LPG is a mixture of light hydrocarbons primarily C_3 & C_4 derived from petroleum, which is gaseous at ambient temperature and atmospheric pressure. It is liquefied at ambient temperature with application of moderate pressure. LPG is susceptible to fire, explosion and other hazards. Such hazards can have an impact on the property, equipment, plant personnel and public.

This standard lays down the minimum safety requirements on design, layout, storage, loading / unloading operations, inspection and maintenance, fire protection, emergency planning and safety audit systems of LPG Installations(documents.mx).

This standard does not cover(documents.mx):

i) Process plants
ii) The distribution of LPG to domestic and non-domestic consumers and pipeline operations

iii) Road / rail transportation
iv) Refrigerated and mounded storage facilities for LPG

According to OISD, it is necessary that the fire protection facilities shall have firefighting access, means of escape in case of fire, and also segregation of facilities so that the adjacent facilities are not endangered during the fire(documents.mx).

4.3 Occupational Safety and Health Administration code (OSHA, 2007; www.ccohs.com)

In United States Occupational Safety and Health Administration (OSHA) has developed a code for the storage and handling of liquefied petroleum gases, which is named OSHA - 1910.110

This code has been prepared by United States Department of Labour, of whichOSHA is an agency. Its mission is to prevent work-related injuries, illnesses, and deaths by issuing and enforcing rules (called standards) for workplace safety and health. The agency is headed by Deputy Assistant Secretary of Labor.

According to OSHA, LPG is defined as any material which is composed predominantly of any of the following hydrocarbons, or mixtures of them; propane, propylene, butanes (normal butane or iso-butane), and butylenes.

4.4 FM Global guidelines (FM Global, 2001; www.organize-email.info)

Factory Mutual Global (FM Global) is a U.S.-based insurance company (*www.organize-email.info)*, with offices worldwide, that specializes in loss prevention services primarily to large corporations throughout the world in the Highly Protected Risk (HPR) property insurance market sector. FM Global is the communicative name of the company, whereas the legal name is "Factory Mutual Insurance Company".

The FM global data sheet covers:

1) The properties and hazards of LPG
2) Construction, location, and arrangement of storage tanks and accessory equipment
3) Pipe and fittings
4) Safeguards for unloading stations, transfer methods, vaporizers, dilution
5) equipment, etc.
6) Small tank and cylinder, installations
7) Refrigerated LP-gas tanks.

FM global data sheet does not cover small cylinders such as those used for camp stoves, torches or cigarette lighters.

According to FM Global, LPG may be defined as a compressed or liquefied gas obtained as a byproduct in petroleum refining or natural gas manufacturing.

4.5 National Standards Authority of Ireland (NSAI) standard (NASI, 2009)

In Ireland, a Code of Practice for the Bulk Storage of Liquefied Petroleum Gas has been developed (inforstore.saiglobal.com) in the name of I.S. 3216:2009.This code is prepared in exercise of the power conferred by section 16(5) of the National Standards Authority of Ireland (NSAI) Act, 1996 (No. 28 of 1996).

This standard has been drafted by the Gas Technical Standards Committee (GTSC) TC 8. The representatives of the following organizations took part in its preparation(inforstore.saiglobal.com):

1) Chief Fire Officers Association,
2) Dublin City Council,
3) Department of Environment, Heritage and Local Government,
4) Dublin Institute of Technology
5) Irish Liquefied Petroleum Gas Association,
6) The Health and Safety Authority,
7) The National Standards Authority of Ireland.

This standard represents a code of good practice but compliance with it does not confer immunity from relevant legal requirements, regulations and local by-laws.

The standard provides a general guide to safe practice in storing and handling LPG at fixed storage installations. It provides a guide to safe practice both for people storing LPG and those enforcing safety requirements. This standard is intended to minimise the risks of fire and explosion from escaping LPG and from a fire at or near LPG storage(inforstore.saiglobal.com).

The storage of LPG may be subject to additional legal requirements, for example(inforstore.saiglobal.com):

1) Safety Health and Welfare at Work Act 2005 and associated regulations
2) Dangerous Substances Act 1972
3) Dangerous Substances (Liquefied petroleum gas) Regulations 1990
4) European Communities (Control of major accident hazards involving dangerous substances) Regulations 2006
5) Fire Services Act 1981 and 2003 (as amended)
6) Building Control Act 1990

7) Planning and Development Act 2000

4.6 Health and Safety Executive code (HSE 2002; www.theiclinquiry.org; www.hse.gov.uk)

In London,Health and Safety series booklet HS (G) 34 has been developed for guiding the storage of LPG at fixed installations.

According to the Health and Safety Executive (HSE), LPG is a generic term used to describe liquefiable gases consisting predominantly of C_3 and C_4 hydrocarbons.

HSE provides a general guide to safe practice in storing and handling LPG at fixed storage installations both for the people storing LPG and those enforcing safety requirements. This guide may be used where people have duties under the Health and Safety at Work Act (HSWA) and may also be used as good practice in other circumstances such as storage vessels at domestic premises.

The recommendations are intended to minimize the risks of fire and explosion from escaping LPG and from a fire at or near a store. The storage of LPG is usually subject to major hazard controlthe general duties of the HSW Act. It is alsosubject to additional legal requirements:

(a) At the premises subject to the Factories Act 1961, the Highly Flammable Liquids and Liquefied Petroleum Gases Regulations 1972 (HFL Regulations) will apply;

(b) The Notification of Installations Handling Hazardous Substances Regulations 1982 (NIHHS) requires that all premises at which 25 tonnes or more of LPG are kept should be notified to the Health and Safety Executive (HSE). Guidance on these regulations can be found in HSE booklet HS(R) 16.

(c) The general requirements of the Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH) apply to all premises where LPG in any quantity is produced or processed or where 50 tonnes or more are stored. Guidance on the CIMAH Regulations can be found in HSE booklet HS(R)21 and on the emergency plans required by the regulations in HSE booklet HS(G)25 (hillsborough.independent.gov.uk).

(d) At premises subject to the Fire Certificates (Special Premises) Regulations 1976, enforced by HSE, and the Fire Precautions Act 1971, enforced by the Fire Authority, the presence of LPG may be taken into account when considering the general fire precautions (hillsborough.independent.gov.uk).

(e) The operation of loading and unloading road tankers and tank containers with a capacity greater than $3m^3$ when they are loaded or unloaded while still on a vehicle, is subject to the requirements of the Dangerous Substances (Conveyance by Road in Road Tankers and Tank Containers) Regulations 1981.

(f) If LPG is supplied through a pipeline, the Pipeline Act 1962 may apply. However the Act does not apply to certain specified pipelines including those wholly within factory premises, mines, quarries and petroleum depots. This Act is enforced by the Pipelines Inspectorate of the Department of Energy to whom enquiries should be made;

(g) Where LPG is supplied as a gas through pipes to the premises, the supply must be authorised by or under the Gas Act 1986, subject to certain exceptions. It is an offence for any person to supply gas through pipes without authorisation in circumstances where authorisation is required.

4.7 Canadian Standards Association Code (CAN/CAS, 2007; www.novascotia.ca; www.shopcsa.ca)

The Canadian Standards Association (CSA), has developed a propane storage and handling code, which is named as CAN/CSA-B149.2. CSA is a not-for-profit membership-based association serving business, industry, government and consumers in Canada and the global marketplace (*www.novascotia.ca).*

Thecode applies to (www.shopcsa.ca):

(a) The storage, handling, and transfer of propane.

(b) The installation of appliances, equipment, components, accessories, and containers on highway vehicles, recreational vehicles, mobile housing, outdoor food service units, and wash-mobiles when propane is to be used for fuel purposes.

(c) The installation of containers and equipment to be used for propane in distribution locations and filling plants.

The Code does *not* apply to (www.shopcsa.ca):

(a) Marine or pipeline terminals
(b) Petroleum refineries
(c) Propane when used as a feedstock in chemical plants
(d) Utility pipeline distribution and transmission pipelines

(e) Refrigerated storage or underground reservoirs for propane
(f) Propane used on boats
(g) Propane used as a propellant in aerosol containers
(h) Butane fuel cylinders of 5.3 oz (150 g) capacity or less and
(i) The installation of appliances, equipment, components, accessories, and containers other than those on highway vehicles, recreational vehicles, mobile housing, outdoor food service units, and wash-mobiles when propane is to be used for fuel purposes.

According to this code, LPG is the material that is composed predominantly of any of the following hydrocarbons or mixtures of them: propane, propylene, butanes (normal butane or isobutane), and butylenes.

4.8 Gas Cylinder Rules (GoI, 2004; www.scribd.com; explosives.nic.in)

In India, The Gas Cylinders Rules were published as required by section 18 of the Explosives Act, 1884 (4 of 1884) in the Gazette of India (www.scribd.com).

According to these rules, LPG means (explosives.nic.in) any material, which comprises predominantly of any of the following hydrocarbons or mixture of them with vapour pressure not exceeding 16.87 kg/cm^2 (gauge) at 65^o C:- Propane (C_3H_8), propylene (C_3H_6), butane ((C_4H_{10}), (n-butane and iso-butane), and butylene (C_4H_8).

According to these rules, every person storing compressed gas cylinders and every person in charge of or engaged in the storage, handling and transport of such gas cylinders, shall at all times-

a) Comply with the provisions of these rules and the conditions of any license relating thereto;

b) Observe all precautions for the prevention of accident by fire or explosion

4.9 Guidelines for facility sitting and layout (CCPS 1989; www.ishn.com)

The Center for Chemical Process Safety (CCPS) was established in the USA (www.ishn.com) in 1985 by the American Institute of Chemical Engineers for the express purpose of assisting industry in avoiding or mitigating catastrophic chemical accidents.

CCPS has issued a manual which outlines methods for finding an optimal location for a chemical or petroleum processing site and then arranging the units and equipment. It provides comprehensive guidelines on how to select a site, how to recognize and assess long-term risks, and how to lay out the facilities and equipment within that site. A survey guide is provided to aid site selection teams in obtaining necessary data to select a new site. Site layout and equipment spacing guidelines are provided based on historical and current data including industry practices and standards. Spacing tables are provided which can be used as a starting point in laying out a site.

The manual is applicable to the following types of facilities:

1) Large and small
2) Petroleum and chemical facilities and other industries using petroleum or chemical products
3) Within and outside of the US
4) Grassroots sites, brownfield sites, and expansions within a site
5) Open air sites
6) Processes enclosed in a building (in terms of siting the building, not in terms of process equipment layout inside of the building)

Typical separation distances between various elements in open-air process facilities are cited throughout the manual. These distances are based on historical and current data from refining, petrochemical, chemical, and insurance sectors. The data were developed based on experience and engineering judgment and were updated based on incident learning. The separation distances cited are based on potential fire consequences. Highly reactive and exotic chemicals, such as alkyls or hydrazine, may require greater spacing or protection. Explosion concerns will also require further analysis and possibly increased spacing to meet specific design goals and to limit explosion damage.

These typical separation distances assume a minimal level of site fire protection such as fire hydrants, manual firefighting capabilities, and adequate drainage to prevent flooding during a major firefighting effort. Distances may be reduced or increased based on risk analysis of site-specific conditions or when additional fire protection, safety measures, or other layers of protection are implemented. Fire protection measures include: fireproofing, automatic water-spray systems, fire detection systems, emergency shutdown systems, and mobile firefighting equipment. Utilize consequence analysis of potential fire, explosion, and toxic impacts to determine the adequacy of substituting additional layers of protection for spacing. As stated in previous chapters, applicable codes, standards, and local regulations should be researched. If they contain more stringent spacing requirements than those quoted in these guidelines, then they take precedence.

Many companies, as well as industry insurers, trade associations, and standards organizations, have developed specific criteria for spacing between plants, buildings, equipment, and property lines. These criteria are meant to reduce the impact of explosions or fires on major equipment and facilities, including adjacent units and buildings.The decisions on site lay-out have to be necessarily site- specific and no single spacing standard can be appropriate for all situations.

4.10 American Petroleum Institute document (Lei et al., 2017; ballots.api.org; documents.mx; law.resource.org)

TheAPI (American Petroleum Institute) STANDARD 2510,has been developed for the design and construction of LPG Installations.

The document was produced under API standardization procedures that ensured appropriate notification and participation in the developmental process and is designated as an API standard (documents.mx).

The API standard (law.resource.org) covers the design, construction, and location of LPG installations at marine and pipeline terminals, natural gas processing plants, refineries, petrochemical plants, or tank farms. The standard covers storage vessels, loading and unloading systems, piping, or and related equipment.

This standard does not apply to the following installations (ballots.api.org):

1) Those covered by NFPA 58 and NFPA 59.
2) U.S. Department of Transportation (DoT) containers.
3) Gas utility company facilities; refinery process equipment; refinery and gas plant processing equipment; and transfer systems from process equipment upstream LPG storage.
4) Those tanks with less than 2000 gallons of storage capacity.

The provisions of this standard are intended for application to new installations. The standard can be used to review and evaluate existing storage facilities. However, the feasibility of applying this standard to facilities, equipment, structures, or installations that were already in place or that were in the process of construction or installation before the date of publication, must be evaluated on a case-by-case basis considering individual circumstances and sites.

According to API, LPG defined as any material in liquid form that is composed predominantly of any of the following hydrocarbons or of a mixture thereof: propane, propylene, butanes (normal butane or isobutane), and butylenes (law.resource.org).

5. Comparative view of the recommendations of the different codes

Table 1 presents a comparative view of the recommendations of different codes for the minimum to be maintained between LPG containers and buildings/property. Similar information on separation distances to be maintained between LPG containers is presented in Table 2. As may be seen the standards often, though not always, run parallel. Table 3 presents a summary of the CCPS recommendations for locating LPG containers in the context of the industry's boundary and the availability of mitigation measures.

Ongoing research by the authors shows that in several contexts the minimum distances prescribed are not adequate to substantially reduce the risk (Mukhim *et al.*, 2018; Tauseef *et al.*, 2018).

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Table 1: A comparative view of the minimum distances between LPG containers of different capacities and important buildings/property proposed as 'safe' by different agencies

Volume of the container (m^3)	*Distances in meters (m), as proposed by*															
	NFPA		*OISD*	*OSHA*		*FM Global*	*NSAI*				*HSE*				*CAN/ CSA*	*API*
	Mounded or underground container	*Above ground container*	*	*Mounded or underground container*	*Above ground container*	*	*Mounded or underground container*		*Above ground container*		*Mounded or underground container*		*Above ground container*		*	*
							Without dispersion wall	*With dispersion wall*	*Without fire wall*	*With fire wall*	*Without dispersion wall*	*With dispersion wall*	*Without fire wall*	*With fire wall*		
< 0.5	3	0	-	3	0	-	2.5	1.5	2.5	0.3	2.5	1.5	2.5	0.3	1	-
0.75	3	3	-	3	3	-	3	1.5	3	1.5	3	1.5	3	1.5	3	-
1.5	3	3	-	3	3	-	3	1.5	3	1.5	3	1.5	3	1.5	3	-
7	3	7.6	-	7.6	7.6	7.6	3	1.5	7.5	4	7.5	4	7.5	4	7.5	-
15	15	15	15	15.3	15.3	-	7.5	7.5	15	7.5	7.5	4	15	7.5	7.5	15.3
30	15	15	20	15.3	15.3	-	7.5	7.5	15	7.5	7.5	4	15	7.5	7.5	15.3
100	15	15	30	15.3	15.3	-	7.5	7.5	15	7.5	7.5	4	15	7.5	§	15.3
200	15	23	30	15.3	23	23	11	11	22.5	11	11	6	22.5	11	§	23
300	15	30	40	15.3	30.5	46	11	11	22.5	11	11	6	22.5	11	§	30.5
400	15	38	40	-	-	40	15	15	30	15	-	-	30	15	§	38
650	15	61	60	-	-	61	15	15	30	15	-	-	30	15	§	61
2750	15	91	90	-	-	91	-	-	-	-	-	-	-	-	§	61
>3785	15	122	120	-	-	122	-	-	-	-	-	-	-	-	§	61

** Container type is not mentioned in the standards*

§ At the discretion of the authority having jurisdiction

Table 2: Separation distances between LPG containers of different capacities recommended by different agencies

Volume of the container (m^3)	*Distances in Meters (m), as proposed by*										
	NFPA	*OSHA*	*FM Global*	*NSAI*		*HSE*		*CAN/CSA*	*API*		
				Mounded vessels	*Above ground vessels*	*Mounded vessels*	*Above ground vessels*		*Other pressure vessels #*	*Vessel containing material with a flash point of ≤100F*	*Vessel containing material with a flash point of ≥100F*
< 0.5	0	None	-	0.3	0.3	1	1	None	Three quarters of the larger tank diameter	One diameter of the larger tank	Half the diameter of the larger tank
0.75	0	None	-	1	1	1	1	1			
1.5	1	1	-	1	1	1	1	1			
7	1	1	1.5	1	1	1	1	1			
15	1.5	1.5	1.5	1	1	*	1	1			
30	1.5	1.5	1.5	1	1	*	1	1			
100	1.5	1.5	1.5	1	1.5	*	1.5	§			
200	¼ of sum of dia of adjacent containers	-	1.5	1	¼ of sum of diameters of 2 adjacent containers	*	¼ of sum of diameters of 2 adjacent containers	§	Three quarters of the larger tank diameter	One diameter of the larger tank	Half the diameter of the larger tank
300		-	1.5	1				§			
650		-	1.5	-				§			
2750		-	-	-				§			
>3785		-	-	-				§			

** The spacing between adjacent vessels should be determined by site conditions and the need for safe installation, testing and maintenance.*

 # Volume of the container is not specified.

§ At the discretion of the authority having jurisdiction

Table 3: Stipulations of the Centre for Chemical Process Safety (CCPS) forseparation distances between LPG containers and buildings, public places, public roads or adjoining property

Quantity of compressed gas in the container (Kg)	*Distances in Meters (m), as stipulated by CCPS*			
	Property boundary and public access (road, rail lines, parks)	*Battery limits*	*Fire water pumps*	*ESD and mitigation system activation points*
100	-	-	-	-
200	3	8	30	15
400	15	15	61	15
2000	-	-	-	-
3000	-	-	-	-
4000	-	-	-	-
7000	-	-	-	-
9000	-	-	-	-
11000	-	-	-	-
18000	-	-	-	-
Over 20000	30	30	61	15