BULK LIQUID OXYGEN, NITROGEN, AND ARGON STORAGE SYSTEMS AT PRODUCTION SITES

Doc 127/23

Revision of Doc 127/20

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As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites*. This publication was jointly produced by members of the International Harmonisation Council.

This publication is intended as an international harmonised publication for the worldwide use and application by all members of the International Harmonisation Council whose members include the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Regional editions have the same technical content as the EIGA edition, however, there are editorial changes primarily in formatting, units used and spelling. Regional regulatory requirements are those that apply to Europe.

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Table of Contents

Amendments to 127/20

Section	Change
4.4	Additional text
5.2.5	Minor changes
5.4.1	Minor changes
5.4.2	Entirely reworked section
5.4	Minor changes
7.3	Minor changes
9.3	Several changes
Appendix C	New

NOTE Technical changes from the previous edition are underlined

1 Introduction

The increase in recent years in the size and production capacity of air separation plants has led to a corresponding increase in the capacity of cryogenic liquid storage installations at production sites. Therefore, it has become more important to consider the potential hazards associated with cryogenic liquid, the consequences and effects on the local environment of a major release of liquid, and the preventive measures required.

2 Scope and purpose

2.1 Scope

This publication specifically covers storage installations on production sites where the storage tank is flat-bottom constructed, is connected to the production process plant, and the individual tank capacity is greater than 125 000 litres.

See Appendices A and B, for bulk liquid storage installations on production sites where the storage tank(s):

- is vacuum-insulated constructed with an individual capacity greater than 125 000 litres;
- are manifolded vacuum-insulated tanks with a combined capacity greater than 125 000 litres;
- are cluster tanks where the tanks have a combined capacity greater than 125 000 litres; or
- are combinations of vacuum-insulated tanks and cluster tanks that are manifolded together and have a combined capacity greater than 125 000 litres.

The information contained in this publication applies only to new installations designed after the publication of this document and not to existing installations. However, the information contained in this publication may benefit existing installations or those in the project phase.

Specific requirements for loading systems can be found in EIGA Doc 179, *Liquid Oxygen, Nitrogen, and Argon Cryogenic Tanker Loading Systems* [1].[1]

For flat-bottom storage tanks not connected to a production process plant, the requirements of this publication shall be met. For vacuum-insulated tanks or other storage configurations, see Appendices A and B.

2.2 Purpose

This publication provides guidance for those persons directly associated with the design, installation, operation, and maintenance of bulk cryogenic liquid storage systems. The intent of this publication is to ensure that a minimum, uniform level of safety is provided throughout the industrial gas industry for the protection of the public and industry employees. Users of this publication should recognise that it is presented with the understanding that it cannot take the place of sound engineering judgment, training, and experience.

The information presented does not supplant, but is intended to complement, national and local regulations and codes of practice such as the British Compressed Gases Association publications, (BCGA) CP20, *Bulk liquid oxygen storage at production sites* and BCGA CP22, *Bulk liquid argon or nitrogen storage at production sites* [2, 3].

This publication presents recommendations to reduce the possibility of large releases of stored cryogenic fluids from a storage system through installation of protective equipment and instrumentation, equipment inspection and testing, and storage system design criteria.

It is the intent of this publication to emphasise prevention of releases. However, this publication provides basic information about mitigation of releases even if they are unlikely.

[1] References are shown by bracketed numbers and are listed in order of appearance in the reference section.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

Is used only to indicate the future, not a degree of requirement.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Bulk liquid storage installation

Total fixed assembly of liquid storage tank(s) integrated with other equipment such as pumps, filling equipment, pressure build-up vaporisers, pressure relief devices (PRDs), controls, and other related ancillary equipment that are connected to it.

3.2.2 Freeboard

Additional height, which is greater than the maximum liquid level that is required for seismic sloshing height or upset case liquid inventories, whichever is greater, and any additional margin as specified by design code. See Figure 1.

3.2.3 Full tank contents

Liquid volume at maximum liquid level.

3.2.4 Maximum allowable working pressure (MAWP)

Maximum gauge pressure permissible at the top of a tank when the tank is in operation.

NOTE—This is identical to the term “design pressure” used in codes such as API 620, *Design and Construction of Large, Welded, Low-pressure Storage Tanks* [4].

3.2.5 Maximum liquid level

Highest allowable liquid level of the tank under normal operating conditions, which is the 100% level of the tank.

3.2.6 Overfill

When the maximum liquid level of the tank is exceeded.

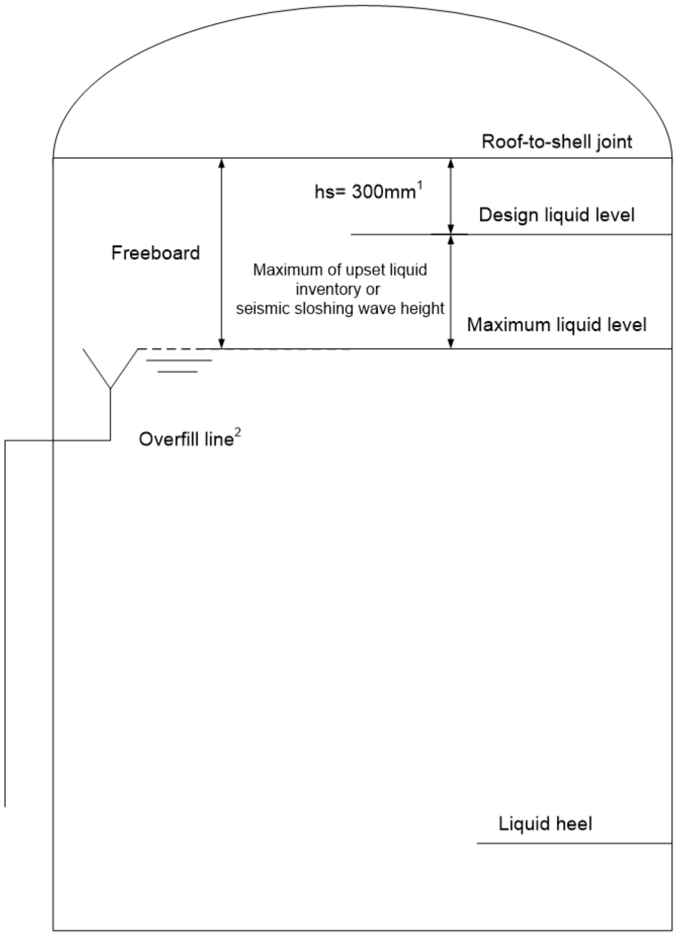
3.2.7 Overflow

Intentional disposal of excess liquid entering the tank.

3.2.8 Pressure relief device (PRD)

Device designed to protect a vessel or piping from achieving pressures higher or lower (vacuum) than its design to avoid the failure of the pipe or vessel.

NOTE—Because these devices can have significant flow when activated, the discharge should be directed to a safe area.



1) API 620, Annex L, seismic design calculates sloshing height and add hs = 300 mm [4].

2) The maximum elevation for the overfill line position is shown in this figure. For the dedicated overflow line, the elevation may be at a higher level up to the design liquid level.

Figure 1—Example of liquid level definitions for flat-bottom storage tanks

4 General properties and hazards

Properties	Oxygen	Nitrogen	Argon
Gas density at 15 °C, 1.013 bara (59 °F, 14.7 psia)[1]	1.36 kg/m^3 (0.085 lb/ft^3)	1.19 kg/m^3 (0.074 lb/ft^3)	1.69 kg/m^3 (0.106 lb/ft^3)
Boiling point at 1.013 bara (14.7 psia)[1]	–183 °C (–297 °F)	–196 °C (–320 °F)	–186 °C (–303 °F)
Liquid density at boiling point and 1.013 bara (14.7 psia)[1]	1142 kg/m³ (74.23 lb/ft^3)	809 kg/m³ (50.47 lb/ft^3)	1396 kg/m³ (87.02 lb/ft^3)
[1)] psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure.			

At ambient conditions 1 m³ of liquid oxygen gives approximately 850 m³ of gas, 1 m³ of liquid nitrogen gives approximately 690 m³ of gas, and 1 m³ of liquid argon gives approximately 830 m³ of gas.

4.1 Oxygen

4.1.1 Properties

Oxygen, which is essential to life, is colourless, odourless, and tasteless. The normal concentration in air is approximately 21% by volume.

The presence of an oxygen-enriched atmosphere cannot be detected by human senses. Oxygen also does not produce any physiological effects that could alert personnel to the presence of oxygen enrichment. Increasing the oxygen concentration of the air at atmospheric pressure does not constitute a significant health hazard.

At atmospheric pressure, liquid oxygen boils at –183 °C (–297 °F) and has a slight blue colour.

Oxygen is heavier than air. It can accumulate in low lying areas such as pits, trenches, and underground cavities or rooms. This is particularly relevant when there is a cold oxygen spill. In that case, the generated cold gaseous oxygen is three times heavier than air.

4.1.2 Hazards

Oxygen is not flammable but supports and accelerates combustion. Oxygen concentrations greater than 23.5% create fire hazards but not asphyxiation hazards. Flammable materials, including some materials that are normally relatively non-flammable in air, burn very rapidly in high oxygen concentrations. As concentrations increase above 23.5% oxygen, ease of ignition of clothing increases dramatically. Once ignited by even a relatively weak ignition source such as a spark or cigarette, clothing can burst into flames and burn rapidly. At greater than 40% oxygen, the fibres on clothing and body hair and oil are subject to flash fire when ignited, which spreads rapidly over the entire exposed surface.

Personnel should not be exposed to oxygen-enriched atmospheres because of the increased risk of fire. Areas where it is possible to have high oxygen content shall be well ventilated. Vents shall be piped outside of buildings or to a safe area. Where an oxygen-enriched atmosphere is possible, precautions shall be taken such as installation of oxygen analysers with alarms, ensuring a minimum number of air changes per hour, implementing special entry procedures, or a combination of these procedures. Warning signs shall be posted at all entrances to alert personnel to the potential hazard of an oxygen-enriched atmosphere. For additional information on oxygen hazards, see EIGA Doc 04, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres* [5].

4.2 Argon

4.2.1 Properties

Argon is a colourless, odourless, and tasteless, monatomic gas that comprises approximately 1% of the atmosphere (0.934% by volume).

Argon is non-toxic, chemically inert, and only slightly soluble in water. It is non-flammable and inhibits combustion. It can act as an asphyxiant by displacing the amount of oxygen necessary to support life.

Argon gas is approximately 38% more dense than air. It can be liquefied to a colourless liquid that boils at
–186 °C (–303 °F) at atmospheric pressure. Liquid argon at its normal boiling point is 39% heavier than water. Above its critical temperature of –122.3 °C (–188.1 °F), argon can exist only as a gas regardless of pressure.

4.2.2 Hazards

Breathing argon or nitrogen-enriched air can cause asphyxiation due to the lack of oxygen essential to maintain life. A person can become unconscious without sensing the lack of oxygen and without any warning. In severe cases of oxygen deficiency, unconsciousness comes quickly with possible fatal consequences. Remove the victim to fresh air. When necessary, perform artificial respiration and get medical assistance.

Oxygen deficiency can arise when purging a confined space or vessel such as a storage tank with nitrogen or other inert gases or by combustion processes without adequate ventilation. Confined areas where process equipment use inert gases can also become oxygen deficient if some mechanical malfunction occurs or there is insufficient ventilation. Personnel should not enter such an area or confined space if there is any possibility of oxygen deficiency. Because of the hazards stated previously, precautions shall be taken before attempting to enter a confined space where there can be an oxygen-deficient atmosphere. Personnel should not enter areas where the oxygen concentration is less than 19.5% unless a self-contained breathing apparatus (SCBA) or air line respirator is used. For personnel protection, the air quality of confined areas can be monitored with either portable or permanently installed, commercially available analytical/alarm systems.

Because of its relatively high density compared with air, argon gas can accumulate in pits thereby creating a hazardous oxygen-deficient atmosphere. Cold nitrogen gas can also accumulate in pits.

Precautions shall be taken when handling liquefied inert gases due to their potential for creating asphyxiation hazards and their extremely cold temperatures. See Title 29 of the U.S. *Code of Federal Regulations*
(29 CFR) Part 1910.146 and CGA P-12, *Safe Handling of Cryogenic Liquids* [6, 7].

For more specific data on symptoms and effects on personnel exposed to oxygen-deficient atmospheres, see EIGA Doc 44, *Hazards of Oxygen-Deficient Atmospheres* [8].

4.3 Nitrogen

4.3.1 Properties

Nitrogen is an element that at atmospheric temperatures and pressures exists as a colourless, odourless, tasteless diatomic gas. Approximately four-fifths of the atmosphere is nitrogen (78.03% by volume). Nitrogen is non-toxic and chemically inert at ordinary pressure and temperature conditions. It is non-flammable and inhibits combustion. It can act as an asphyxiant by displacing the amount of oxygen necessary to support life.

As a gas at ambient temperature, nitrogen is approximately 3% less dense than air. It can be cooled and compressed to a colourless liquid that under atmospheric pressure boils at –196 °C (–320 °F). As a liquid (at normal boiling point), nitrogen is approximately 81% as heavy as water. When heated above its critical temperature of –146.9 °C (–232.4 °F), nitrogen can exist only as a gas regardless of pressure.

4.3.2 Hazards

See 4.2.2.

4.4 Ice build-up

Pressure relief devices (PRDs), vacuum breakers, and vent valves connected to the inner tank can be adversely affected by the formation of water ice deposits and build-up either internally or externally on these devices and their associated piping. Typical sources of ice build-up formation are:

- improper purging and drying of the storage tank and nozzles after hydrotesting;
- rainwater leakage into the equipment;
- atmospheric air and moisture aspiration during a shutdown or during vacuum episodes;
- moisture aspiration into pressure building gas from water or steam vaporiser leaks; and
- backflow of gas from vapour recovery systems that could contain moisture.

Such ice build-up can lead to restriction or plugging of the PRDs, vacuum breakers, and vents nozzles and outlets. This is critical due to the nature of the low pressure setting of these devices.

If the tank vent valve is undersized or the PRD is not seated properly, continuous venting can occur through the vent valve and PRD, which can lead to external ice build-up and reduce their relieving capacity. External ice build-up should be monitored as it can accumulate over time and engulf the vent valve and PRD, inhibiting their function or reducing their capacity.

For other icing concerns, see 5.4.2 and 7.3.6.1.

4.5 Oil, grease, combustible materials, cleaning, and other foreign matter

Most oils, greases, and organic materials constitute a fire or explosion hazard in oxygen-enriched atmospheres and shall not be used for equipment that is intended for oxygen service. Only materials acceptable for oxygen service applications shall be used.

It is important that all traces of degreasing agents are removed from the system prior to commissioning with oxygen. Some agents such as halogenated solvents can be non-flammable in air, but can explode in oxygen-enriched atmosphere or in liquid oxygen. Refer to EIGA Doc 33, *Cleaning of Equipment for Oxygen Service* on cleaning for oxygen service [9].

Although neither liquid nitrogen nor argon react with oil or grease, it is good practice to apply a reasonable standard of cleanliness, although not as stringent as that required for an oxygen installation. Particular consideration should be given to cleaning nitrogen or argon systems as for oxygen service if it is possible that they could be put into oxygen service in the future.

Good housekeeping practices are necessary to prevent contamination by loose debris or combustibles.

4.6 Embrittlement of materials

Many materials such as some carbon steels and plastics are brittle at very low temperatures and the use of appropriate materials for the prevailing service conditions is essential.

Metals suitable for cryogenic temperatures includes stainless steel and other austenitic steels (such as AISI 304 and 316), 9% nickel steel, copper and its alloys, and aluminium.

Polytetrafluoroethylene (PTFE) is the most widely used plastic material for sealing purposes in cryogenic liquid service but other reinforced plastics and copper are also used in certain cases.

4.7 Cryogenic temperatures

The products of a cryogenic air separation plant have associated hazards such as:

- Cryogenic injuries or burns resulting from skin contact with very cold vapour, liquid, or surfaces. Effects are similar to those of a heat burn. Severity varies with the temperature and time of exposure. Exposed or insufficiently protected parts of the body can stick to cold surfaces due to the rapid freezing of available moisture. Skin and flesh can be torn on removal;

- Risk of frostbite or hypothermia (general body and brain cooling) in a cold environment. In the case of frostbite, there can be a warning as the body sections freeze. As the body temperature drops, the first indications of hypothermia are bizarre or unusual behaviour followed, often rapidly, by loss of consciousness;
- Respiratory problems caused by the inhalation of cold gas. Short-term exposure generally causes discomfort; however, prolonged inhalation can result in effects leading to serious illness such as pulmonary oedema or pneumonia; and
- Cold gases that are heavier than air tend to settle and flow to low levels and can create a dense water vapour fog. Depending on topography and weather conditions, hazardous concentrations, reduced visibility, or both can occur at considerable distances from the point of discharge.

For further details, see CGA P-12 [7].

4.8 Perlite

Perlite is commonly used for the insulation of storage tanks. Perlite is a natural volcanic mineral that can be expanded by heating to form very lightweight, porous, odourless, non-flammable, non-toxic silicate powder. It is a highly effective insulating material used to reduce refrigeration losses or heat leak into the tank. The nature of the material and the large quantities involved require the use of specific operating, handling, and safety procedures.

Perlite is lightweight and becomes airborne very easily. If perlite enters the eyes or respiratory tract, it can cause serious irritation. A perlite product can contain crystalline silica, which is considered to be a nuisance dust.

For further details see EIGA Doc 146, *Perlite Management* [10].

5 Storage tank system design considerations

5.1 General

Installations shall be designed, manufactured, and installed in accordance with recognised storage tank, piping, and building codes and, where appropriate, in accordance with statutory requirements (including the computation of wind loads and seismic loads, if required) and shall comply with the equipment manufacturers and the production site operator’s specifications. The selection, design, and arrangement of the protection systems shall also be based on an assessment of the risk and consequences of exposure to operating personnel and the general public as a result of a spillage due to a failure.

All equipment and materials for oxygen service including the insulation shall be oxygen compatible.

5.2 Flat-bottom tanks

5.2.1 Description

The typical tank configuration for the storage of liquid oxygen, liquid nitrogen, and liquid argon in flat-bottom tanks is a double wall, single containment type, where the liquid is contained in an inner tank and an outer tank serves to contain the insulation.

Single containment is the type of containment comprising an inner tank and an outer tank that is designed so that only the inner tank is required to meet the low temperature ductility requirements for storage of the liquid. The annular space between the inner and outer tanks is insulated with perlite and is purged/pressurised with a dry, inert gas (usually nitrogen). It is not designed to contain the cryogenic liquid in the event of leakage from the inner tank.

Liquid oxygen, liquid nitrogen, and liquid argon flat-bottom cryogenic storage tanks are not designed with systems to comply with either double containment or full containment as defined by API 625, *Tank Systems for Refrigerated Liquefied Gas Storage* or other international codes and standards [11]. The reasons include:

- Service history of liquid oxygen, liquid nitrogen, and liquid argon flat-bottom tanks, the construction material, the contained liquids (dry, clean, and non-corrosive), the design and construction carried out to well established and internationally approved design codes, the operating mode without significant pressure and temperature cycles, and the prevention measures addressed in this publication make the probability of a catastrophic failure of the tank very low;
- Liquid oxygen, liquid nitrogen, and liquid argon are neither toxic nor flammable;
- Volume of contained liquid is typically small compared to other storage such as liquefied natural gas (LNG), ammonia, and petroleum products;
- Bund wall or dyke for cryogenic liquids introduces a number of hazards to personnel for the potential creation of an oxygen-deficient or oxygen-enriched atmosphere. Where a bund wall or dyke is required by risk assessment or regulation to contain cryogenic liquid spillage, hazards identified in 4.1.2 and 4.2.2 shall be mitigated;
- Avoidance of deep pools of cryogenic liquid by using the site area to promote rapid vaporisation;
- Prevention—There are multiple layers of protection in place such as redundant PRDs, overfilling protection, emergency shutoff protection on major liquid lines, external integrity checks, 100% x-ray of liquid lines circumferential welds, prohibition of transition joints, flanged or threaded joints, bellows, or flexible metal hoses, and prohibition of piping branch connections being located within the annular space of the tank; and
- Mitigation—Offsite risks from liquid releases are mitigated by directing the spill to a safe location and preventing the liquid from exceeding the site boundary. Examples include tank positioning, surface grading for liquid diversion, and freeze traps in the rainwater drainage system.

5.2.2 Applicable codes and standards

The design, fabrication, and testing of flat-bottom storage tanks and connected piping shall conform to all applicable national and local regulations.

The industrial gas industry has successfully designed, fabricated and tested flat-bottom storage tanks to the requirements of the code API 620 including Annex Q [4].

Seismic design for storage tanks located at grade is addressed by Annex L of API 620 [4]. However, Annex L of API 620 states “Application to tanks supported on a framework elevated above grade is beyond the scope of this Annex” [4]. As such, the seismic design of tanks located on elevated concrete structures needs to establish the accelerations for the combined tank, foundation, and ground configuration using site specific response spectrum for the site conditions.

To take account for sloshing movement of liquid, the selected design code shall be applied. If there is no requirement for sloshing movement, the minimum freeboard is as specified in Annex L of API 620 [4].

Piping is usually designed, fabricated, and tested in accordance with ASME B31.3, *Process Piping* [12].

Alternative codes or standards to API 620 or ASME B31.3 may be used provided that a detailed review has been carried out to demonstrate that an equivalent level of safety exists [4, 12].

Alternative codes or standards that have been used for the design of the tank include:

- BS 7777, *Flat-bottomed, vertical, cylindrical storage tanks for low temperature service* [13];
- EN 14620, *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C* [14]; or
- DIN 4119, *Above-ground cylindrical flat-bottom tank structures of metallic materials* [15].

None of these codes or standards include any reference for the verification of inner vessel to external pressure but a design method can be found in AD 2000 Merkblatt B6, *Cylindrical shells subjected to external overpressure* or DIN 18800, *Steel structures – Part 1, Design and construction* [16, 17].

5.2.3 Inner tank

Aluminium shall not be used for the field fabrication of the inner tank due to the difficulties of their welding procedure. The inner tank shall be fabricated of materials capable of withstanding the cryogenic temperature and the internal pressure of the stored liquid. In addition, any materials used shall be compatible with oxygen when in liquid oxygen service. The preferred material is austenitic stainless steel for its larger margin between tensile stress and yield stress and the consequent better resistance to fatigue compared to 9% nickel steel.

The design of the inner tank shall consider the most critical combination of:

- minimum and maximum design internal pressure;
- maximum liquid hydrostatic load;
- insulation load due to its compaction;
- external pressure;
- thermal stresses, in particular due to the inner tank cooldown;
- foundation settlement loads;
- pipe and concentrated loads;
- seismic loads; and
- any other load required by the applicable code, national, or local regulation.

Cryogenic spillage due to the major failure of a flat-bottom storage tank is one of the worst case scenarios of air separation plant risks. In case of extreme overpressure, it shall be ensured that the weakest point of the inner tank is not at the bottom cylindrical seam.

The need to prevent a rupture by overpressure at the bottom of the inner tank is identified in the various available codes. API 650, *Welded Tanks for Oil Storage,* mentions a frangible joint between the roof and the shell as a possible user requirement [18]. API 620 establishes a link between the sizing of the anchorage straps and the design of the roof-to-shell junction [4]. BS 7777 explicitly states that the weakest point of the structure shall not be at the bottom and presents it as a further increase in safety [13]. None of these three codes describe how to design and manufacture a frangible joint so that it can break as intended. Design codes give requirements for minimum cross-sectional area of the roof-to-shell joint but do not specify an upper limitation. Owing to the greater internal design pressures and smaller diameters for liquid oxygen, liquid nitrogen, and liquid argon flat-bottom tanks compared to API 650 tanks, a strengthened roof-to-shell junction is required [18]. The combination of these two factors make it difficult to achieve a frangible joint. The tank designs shall ensure the roof-to-shell junction is not over strengthened, undermining the intention that this joint be weaker than the anchor strap capacity. Therefore, limits on the cross-sectional area need to be considered.

If the design code allows, an alternative to having a frangible roof could be the installation of a limited size frangible piece such as a rupture disk with a large flow capacity protecting the tank at a predictable value. This value shall be defined so that the rupture disk can burst before inducing stresses greater than the maximum allowable stresses of the vessel parts in contact with the liquid at exceptional loading cases that can lead to tank rupture.

Any manway installed under the liquid level shall be full penetration welded after completion of fabrication. Weld shall undergo 100% examination by volumetric testing methods.

Self-supporting roof designs shall be in accordance with API 620 or an approved alternative design code [4]. Tank roof designs using a reinforced membrane design that is not covered by API 620 are acceptable [4]. However, an inner tank reinforced membrane roof design shall not strengthen the roof-to-shell joint (compression ring). It is intended for the compression ring to fail in preference to the anchors.

5.2.4 Outer tank

The outer tank shall be designed to support the annular space insulation material and the gas purge pressure but it is not required to be fabricated with materials capable of withstanding the cryogenic temperatures of the stored liquid. The outer tank is usually made of carbon steel.

As a minimum, the outer tank shall be designed to resist the minimum wind and seismic loads required by national codes for the installation site. External loads such as snow, ice, and mechanical loads such as stairs, platforms, and ladders shall be considered in the design of the system.

Provision for tightness should be considered to prevent corrosion by excluding moisture between the bottom of the outer tank and the foundation.

5.2.5 Annular space purge/pressurising gas

Main safety concerns about the annular space are the following:

- If air is present in the annular space of liquid nitrogen or liquid argon storage tanks, components of the air with a dew point temperature greater than that of the stored liquids can condense;
- Accumulation of condensed liquids in the annular space can lead to cooling of the outer tank to a point where the outer tank could fail;
- The condensed liquids can become oxygen enriched and can include atmospheric contaminants such as hydrocarbons. A rapid reaction between the accumulated hydrocarbon contaminants and the condensed oxygen-enriched liquid can occur and result in an energy release within the annular space. A rapid reaction can also occur with the insulation or other materials in the annular space that are not compatible with the oxygen-enriched liquid;
- If there is cryogenic liquid trapped in the annular space, a pressure increase can occur due to rapidly expanding liquid to gas by vaporisation during warming of the tank; and
- A failure of the annular space piping components and insulation system can occur if an annular space purge or pressurising gas is not maintained because atmospheric moisture and carbon dioxide in the air could freeze on cold surfaces causing, for example, a restriction in free movement of piping.

Therefore, annular spaces of flat-bottom storage tanks should be purged immediately after perlite filling has been completed. Before cooling down the inner tank, the annular space shall be continuously pressurised or purged with a dry, inert gas that cannot condense or freeze at the operating conditions of the inner tank. Care shall be taken to prevent damage (buckling) of the inner tank bottom when the purge is activated before cooldown and liquid filling. See 8.3. Sufficient purge/pressurising gas shall be supplied to ensure a positive pressure is maintained throughout the annular space. Sufficient annular space purge/pressurising gas maintains the insulation in a dry state, which provides the best insulation qualities. Wet or frozen insulation can increase heat losses and can increase the boiloff rates of the stored liquid.

A purge/pressurising gas distribution system shall be provided around the complete circumference of the base of the tank in the annular space. This purge/pressurising system shall be designed to prevent insulation from plugging the purge system piping and ensure uniform distribution of gas throughout the annular space. Operation of the system shall ensure that there is positive pressure throughout the annular space.

A pressure or flow-indicating device shall be provided on the purge gas supply line downstream of the regulator to indicate the presence of pressurising gas to the annular space. If a pressure transmitter is provided, it shall have low and high alarms.

The tank annular space shall have a pressure indicating device with alarms to alert the operator in case the pressure is too low or too high.

Past incidents have shown that an annular space pressure that is greater than the inner tank pressure can damage the roof and/or the bottom of the inner storage. The relative movement between inner tank and pipes can lead to rupture of pipe. This can occur:

- after the hydraulic test, if the vessel is emptied without a vent valve being opened;
- if the pressure building system is out of order and liquid is withdrawn;
- as a result of gas (vapour) condensation when filling the tank through top fill nozzles; and
- before cooldown, if the annular space is pressurised with the empty tank at atmospheric pressure.

5.3 Piping and nozzles

Failure of a liquid nozzle or piping connected to the inner tank can lead to hazardous on-site as well as off-site effects.

Within the annular space, all piping joints connected to the inner tank, including instrument and sample lines, shall be welded. All lines penetrating below the maximum liquid level shall be butt welded and the wall thickness shall be selected for the anticipated service conditions. Common practice is to use Schedule 40 or equivalent thickness for these lines, though a different wall thickness may be used following a design review.

No transition joints, flanged or threaded joints, bellows, or flexible metal hoses shall be used in the annular space piping connected to the inner tank.

No piping branch connections shall be located within the annular space of the tank, upstream of the tank's isolation valve (see 5.5). Each branch piping connection made outside of the tank's annular space and upstream of the remotely operated emergency shutoff valve (ESV) shall be provided with its own manual and/or ESV as required by 5.5.1 and be of all-welded construction up to the ESV.

The risk of liquid nozzle failures is minimised by an inspection of the installation after construction has been completed.

All butt welds in liquid outlet nozzles and related piping up to the isolation valve shall be 100% radiographed. Piping connected to the vapour space shall be tested according to the requirements of ASME B31.3 [12].

Piping and nozzles connected to the inner tank shall comply with the material requirements adopted for inner tank.

5.3.1 Piping stress calculation

The piping design shall take into account thermal expansion and stresses. Perlite loading should be considered. All lines connected to the inner tank shall be subject to a piping stress calculation.

All lines shall be analysed in accordance with ASME B31.3 or equivalent local codes or standards, including the stress limitation required by that code [12].

In the definition of pipe end constraint conditions, lines shall be considered fixed in the translational and torsional directions at the inner tank. The piping connections at the outer tank are not rigid; however, the pipe shall be considered fixed in the translational and torsional directions. The pipe stress analysis shall address the effect of connected external piping. Limiting interface loads and/or reducing allowable stresses for the internal piping may be adopted to make allowance for the effects of the external piping.

A flexible connection between the pipe and the outer tank may be used. In this case, the stress analysis shall consider both the annular space piping and the external piping as one system.

Piping stress analysis shall take into account the following loading combinations:

- cold line and warm tank;
- warm line and cold tank; and
- cold line and cold tank.

The design and installation of the piping system shall ensure that piping is not prestressed prior to tank cooldown.

Pipe stress analysis shall consider sustained stresses that are due to loadings such as pressure and weight (gravity) and maximum displacement stress ranges between loading combinations.

5.3.2 Accumulation of hydrocarbons

For liquid oxygen storage tanks, the design shall take into account methods to prevent the slow accumulation of hydrocarbons by boiling in dead-end connections. Where hydrocarbons can accumulate, safeguards such as periodical purging, liquid traps, and thermosyphon pipes shall be used. Particular care shall be paid to spare lines, to dead ends caused by taking equipment such as pumps out of service, and to intermittent use lines.

This requirement is recommended for storage tanks where a change of product service could occur in the lifetime of the storage tank.

5.3.3 Piping penetration in the outer tank

Provision shall be made for free movement of connected piping to minimise thrusts and moments applied to the sidewall connection. Allowance shall be made for the rotation of the sidewall connection caused by the restraint of the tank bottom to the sidewall expansion from stress and temperature as well as for thermal and elastic movement of the piping (see section 5.27.8 of API 620) [4].

Where liquid lines exit the outer tank, the design of these lines and wall penetrations shall consider the following requirements:

- Flexibility of the line within the annular space shall be ensured either with an expansion loop in the annular space between the inner tank and the outer tank or with an expansion bellows on the outer tank penetration for differential contractions;
- The wall penetrations shall be designed so that they avoid the risk of liquid withdrawal line rupture upstream of the automatic shutoff valve. This can occur due to:
  - Differential movement between the outer tank and the inner tank caused by an accidental overpressure of the tank annular space leading to the outer tank shell rising; and
  - Overpressure or overfill (resulting in a liquid level above the roof-to-shell joint) of the inner tank, which results in lifting of the inner tank.

An anchor point should be included downstream of the automatic shutoff valve to guard against a rupture caused by excessive stress on piping downstream of the shutoff valve. The flexibility of the line between outer shell connection and fixed point (downstream of the automatic shutoff valve) shall be ensured.

5.3.4 Top filling arrangement

Liquid lines entering into the inner tank above the maximum liquid level and having an air gap or siphon break above any extension below the maximum liquid level towards the bottom of the tank are not treated as lines connected to the liquid space. If no air gap or siphon break is provided, those lines shall be treated as connected to the liquid space.

5.4 Tank control and protection

High pressure or vacuum condition in the inner tank, overfill of the inner tank, or overpressure in the annular space can cause inner tank failure and release of the stored cryogenic liquid.

5.4.1 Inner tank pressure/vacuum monitoring and control

Overpressure and overfill in the inner vessel mainly affect the shell anchorage system, the junction between roof and shell, or between bottom and shell depending upon the inner tank design.

The inner tank pressure control system shall include the following:

- Automatic positive pressure control venting system to maintain the pressure at the operating pressure of the inner tank. For determining the design capacity for this positive pressure control system, refer to the normal operating condition cases *Qv* listed at 5.4.2.7. Additional requirements for valve sizing shall include the pressure building gas flow and should include the tank cooldown rate; and
- Automatic positive pressure control building system to maintain the pressure at the operating pressure of the inner tank, if there is the possibility to pull a vacuum beyond the design conditions (for example, by high speed withdrawal pumps, subcooled feeding). A pressure building vaporiser or other equivalent system shall be provided to automatically maintain pressure higher than the required minimum. For determining the design capacity for this pressure control system, see 5.4.3 for operating conditions to consider.

The inner tank pressure measurement shall have at least two independent pressure sensing lines, root valves, and pressure transmitters.

The control system(s) shall process the transmitter signals such that a single component failure does not result in tank over/under pressure via the control system. A single component failure shall not result in the pressure vent controller closing and the pressure build-up controller opening at the same time.

See Figure 2 for an example of redundant control systems.

The pressure in the inner tank shall:

- be monitored by pressure indicators; and
- have high and low pressure alarms to provide warnings to operating personnel.

Consideration should be given to the installation of:

- additional pressure alarms to provide further indication to operating personnel; and
- a trip action triggered by a pressure signal that automatically places the tank in a safe condition.

Examples of a trip action include isolation of:

- all liquid withdrawal lines on low-low pressure; and
- all sources of pressure into the tank on high-high pressure.

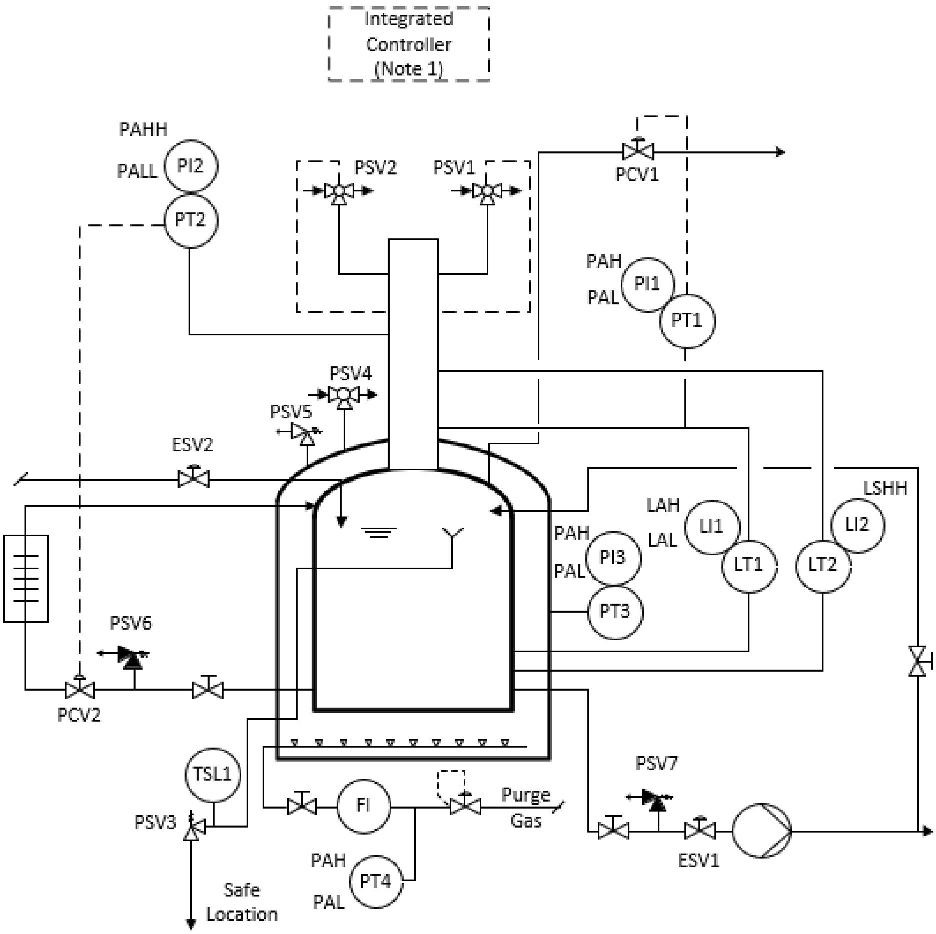
5.4.2 Inner tank overpressure protection devices

Inner tank overpressure relief devices shall include a minimum of two independent in-service PRDs set at a pressure no greater than the maximum allowable working pressure (MAWP). The capacity of each device shall be such that if one malfunctions or is removed temporarily for maintenance, the tank is still protected from all overpressure cases considered in the sizing of the PRDs. The system design shall not impede periodic testing, maintenance, and replacement of the PRDs. The devices and their installations shall be suitable for the prevailing environmental conditions such as rain ingress, freezing rain, ambient temperature extremes, etc.

The minimum of two independent PRDs can be achieved by any combination of pressure relief valves and bursting disks. The inner tank PRDs shall have individual piping connecting directly to the inner tank or individual piping connecting to a single large nozzle.

Inlet line pressure drop shall be calculated in accordance with applicable codes such as API 520, *Sizing, Selection, and Installation of Pressure-relieving Devices—Part 1—Sizing and Selection*, and API 521, *Pressure-relieving and Depressuring Systems* [19, 20]. Chattering of the pressure relief valves can make the pressure relief valves leak with resulting ice formation and consequent plugging of the pressure relief valves.

Consideration may be given to the installation of a third PRD set at a pressure greater than the MAWP.



Legend			
PSV1, PSV2	Inner tank overpressure-vacuum protection devices (5.4.2 and 5.4.3)	LAL	Level alarm low
PSV4, PSV5	Outer tank overpressure-under pressure protection device (5.4.4 and 5.4.5)	LI1, LI2	Level indicator
PSV3	Overflow protection (5.4.6)	LT1, LT2	Inner tank level measurement device (5.4.6)
PSV6, PSV7	Thermal relief valve	TSL1	Switch, overfill line low temperature
PCV1, PCV2	Inner tank pressure control valve (5.4.1)	PAH	Pressure alarm high
PI1, PI2, PI3	Pressure indicator	PAHH	Pressure alarm high high
PT1, PT2, PT3, PT4	Pressure transmitter	PAL	Pressure alarm low
ESV1, ESV2	ESVs (5.5.1)	PALL	Pressure alarm low low
LAH	Level alarm high	FI	Flow indicator
[1] Alternative to separate pressure controllers, an integrated pressure controller with PT1 and PT2 can be used.			

Figure 2—Example of a flat-bottom tank storage system

5.4.2.1 Multiple overpressure protection devices on a common nozzle

Multiple PRDs connected to a single large nozzle configuration shall have a large nozzle with a minimum nominal diameter of 300 mm (12 in) directly from the inner tank. If the size of the largest PRD is greater than 300 mm (12 in), the large connection to the inner tank shall have a diameter greater than or equal to that PRD. Branch lines from the large nozzle to the PRD shall transition as close as possible to the PRD inlet and shall be external to the outer tank.

If flowing lines are routed to the single large nozzle, additional analysis is required to determine if the size of the common nozzle needs to be increased to greater than 300 mm (12 in) to allow for separation to mitigate cold migration to the PRDs. The configuration shall ensure that the PRDs remain ice-free when the flowing lines are in operation.

5.4.2.2 Individual overpressure protection devices not on a common nozzle

Multiple individual lines shall be used when the inner tank connection is less than 300 mm (12 in) to minimize the overpressure risk from plugging of a single inlet nozzle. For individually piped PRD lines, at least one line shall be dedicated to only overpressure relief service (does not include vacuum) and be connected directly to the inner tanks with a nozzle diameter greater than or equal to that of the PRD. The remaining individual PRD line(s) may have non-flowing branch lines or infrequent flowing lines that are operated only under administrative controls. The transition from the minimum line size to any PRD inlet shall be external to the outer tank and close to the individual device

5.4.2.3 Combined overpressure and vacuum relief devices

5.4.2.4 Combined overpressure and vacuum relief devices may be used. The minimum line size shall be the PRD inlet size or a minimum nominal diameter of 150 mm (6 in), whichever is greater. This minimum line size reduces the impact of internal ice blockage.

5.4.2.5 Ice build-up

5.4.2.5.1 Internal ice

Combined overpressure and vacuum relief valves have a risk of moisture entering the inlet nozzle from the ambient air and freezing. A large connection minimizes the risk of ice plugging.

Other mitigations for internal ice blockage may include:

- Monitoring programs that track and trend low pressure conditions (see 9.3.3); and
- Higher inner tank design pressures such as 34.5 kPa (5 psi) allow the inner tank to operate with increased pressure margins between the operating pressure and vacuum conditions. This minimizes the opportunity of ambient air entering and the risk of ice plugging.

5.4.2.5.2 External ice

External ice build-up shall be monitored as it can accumulate over time and engulf the PRDs inhibiting their function.

5.4.2.6 Pilot operated pressure relief valves

Pilot operated pressure relief valves sensing lines shall be independently connected to a location where the tank pressure measurement is not affected by flow. Examples of undesirable locations of pressure relief valve sensing line connections include those where PRD flow, vent valve flow, and in-service process line flow occurs.

5.4.2.7 Isolation of overpressure protection devices

Isolation valves, diverter valves, or spectacle blinds may be provided upstream of the PRD for maintenance purposes.

Isolation or diverter valves should be of the full port design. In addition to pressure drop concerns, internal valve paths with low points and turns have locations where moisture can collect and freeze, reducing the gas flow up to full blockage.

5.4.2.7.1 Isolation valves

When isolation valves are used, a captive key interlock system or control through management procedures shall be provided so that no more than one PRD can be taken out of service at a time.

5.4.2.7.2 Diverter valves

When used, diverter valve design shall be such that one PRD is always in service at its full capacity.

5.4.2.8 Sizing of inner tank pressure relief devices

To define the capacity of PRDs, all expected operational and upset condition combinations shall be considered. The design relieving flow capacity Q_s for each inner tank PRD shall consider the following formula:

$Q_s > \Sigma Q_v + Q_a$

Where:

ΣQ_v = the sum of all the flows in normal operating conditions Q_v that are expected to be simultaneous

Q_a = the highest flow generated by upset conditions

Normal operating scenarios Q_v to be considered include:

- normal boiloff rate from ambient heat leak; and
- liquid flash and gas displacement from:
  - plant production
  - cooldown of connected equipment such as pumps
  - pump recycles
  - loading of road trailers and rail tank cars (vapour recovery) and
  - unloading road trailers or rail tank cars into the tank.

Upset conditions Q_a should include the largest of the following independent upset conditions:

- malfunction of control valves in the pressure control circuit;
- malfunction of control valve in the tank fill line resulting in excess flash and vapour displacement;
- substantial decrease in barometric pressure;
- loss of liquid subcooling in the feed;
- backflow from high pressure downstream piping;
- maximum flow from any high pressure gas or liquid cross tie, transfer, or connection including cooldown gases;
- other circumstances resulting from equipment failures that could be unique to the particular installation; and
- external fire (for example, as stipulated in standard API 2000, *Venting Atmospheric and Low-pressure Storage Tanks* [21]).

A warm tank cooldown and fill is a rare event that is addressed in 8.3.

PRDs to prevent the inner tank from overpressurization are designed for vapour flow only and are not meant to protect the tank from overfilling. Protection of the tank from overfilling is performed by following the mandatory requirements of 5.4.6.

The system designer should consider the gas temperature at which the relief gas can relieve. Pressure relief valves and burst disks should be sized for relieving cold gas.The pressure at which the burst disk ruptures is a function of temperature. This is typically ambient temperature.

Installation and sizing criteria for flat-bottom storage tank PRDs can be found in API 620 and API 2000 [4, 21].

***WARNING**: Experience has shown that during the lifetime of a plant the operating conditions of storage can change from those that had been the original basis of sizing the overpressure relief devices. In a few exceptional cases, the result was that the design pressure of the inner vessel or the design capacity of vent valve and PRD was exceeded. A mandatory management of change (MOC) protocol such as the one described in* EIGA Doc 51, Management of Change *is therefore required [22].*

The pipes and valves connecting to PRDs and the vent piping shall be sized for the flow conditions in accordance with a relevant code such as API 521 [20]. The vent pipes shall be supported and designed to prevent blockage by ice and other foreign matter. The vents shall be piped to safe locations.

5.4.3 Inner tank vacuum protection

Flat-bottom liquid storage tanks are typically not designed for full vacuum. Consequently, at least two vacuum relief devices shall be installed to protect against vacuum. The capacity of each device shall be such that if one malfunctions or is removed temporarily for maintenance, the tank is still protected from all under pressure cases considered in the sizing of the vacuum relief devices. The devices shall be set no greater than the allowable vacuum design rating of the inner tank. For example, if the inner tank vacuum design rating is 10.0 mbar (4 inches) of water, the device can be set between 0 mbar and –10.0mbar (0 inches and –4 inches) of water column.

A combination overpressure/vacuum relief device is typically used for this application given that the installation meets the requirement of 5.4.2.3.

The calculation of vacuum relieving capacity for the inner tank should consider the worst foreseeable combination of operational and upset conditions such as:

- withdrawal of liquid at the maximum rate;
- maximum vapour withdrawal rate;
- increase in barometric pressure;
- sudden cooling of tank vapour when filling or recirculating liquid through a top fill nozzle; and
- other circumstances resulting from equipment failures and operating errors that can be unique to the particular installation.

Installation and sizing criteria for flat-bottom storage tank pressure devices can be found in standards such as API 620 and API 2000 [4, 21].

5.4.4 Outer tank overpressure protection

Overpressure of the annular space can lead to failure of the inner tank. The annular space can be over-pressurised from a number of sources including:

- leak from the internal tank or annular space piping;
- failure of the annular space pressurising system; and
- sudden changes in atmospheric pressure.

It is the responsibility of the system designer to evaluate the maximum flow capacity and the gas temperature to be considered for the sizing of the PRDs, taking into consideration the volume of the annular space, all the normal operating conditions, and the maximum upset condition that can occur for the specific installation.

A minimum of two PRDs shall be provided for overpressure protection:

- A breather PRD shall be provided and be set no greater than the MAWP. This device may also incorporate the vacuum protection as detailed in 5.4.5; and
- The annular space shall also be protected against overpressurisation (as stated in the previous list items) by an additional device such as a spring-loaded pressure relief valve or an emergency pressure vent weighted cover set at a pressure greater than the operating pressure of the annular

space, but no greater than a pressure that would overstress the inner or outer tank. In the case a weighted cover is used, it shall be provided with a retaining device that shall not restrict the capacity of the relief device to prevent the cover from being lost in the case of overpressure or high wind.

These devices shall be installed after the end of the perlite filling operation and should be periodically inspected and cleaned to avoid any choking of the device due to perlite accumulation. If a filter is placed upstream of the pressure relief device to avoid perlite escaping from the annular space, consideration shall be given to avoiding plugging and excess pressure drop in the system.

5.4.5 Outer tank vacuum protection

A vacuum condition can be created in the annular space by rapid cooldown of the inner tank or sudden changes in atmospheric conditions.

Outer tank vacuum protection shall be accomplished by installing at least one vacuum relief device on the outer tank. The device(s) shall be set no greater than the allowable vacuum design rating of the outer tank. For example, if the outer tank vacuum design rating is 10.0 mbar (4 inches) of water, the device can be set between 0 mbar and –10.0 mbar (0 inches and –4 inches) of water column.

A combination overpressure/vacuum relief device can be used for this application given that the installation meets the requirements in 5.4.4.

Installation and sizing criteria for flat-bottom storage tank pressure devices can be found in standards such as API 620 and API 2000 [4, 21].

5.4.6 Inner tank overfill and low level protection

If overfilled, flat-bottom tanks can be subject to serious damage or failure resulting in spillage of the tank contents or overflowing liquid.

Filling a flat-bottom tank to levels greater than the roof-to-shell joint results in an uplifting hydrostatic force on the inner tank dome that can cause the failure of a number of components including the inner tank anchor/hold down straps or the inner tank roof-to-shell joint. Therefore, the PRDs do not protect the tank against the overfilling hazard.

Liquid level measurement not only provides normal operating inventory status, but also inputs to safety systems to prevent overfilling.

Therefore, as a minimum, two independent liquid level measurement devices shall be installed on flat-bottom cryogenic storage tanks.

Liquid level measurement devices typically include differential pressure devices, liquid float devices, and radar and sonic devices.

Overfill protection shall be either a high level trip to close the tank filling valves or an overflow line capable of passing the maximum liquid filling rate at the maximum liquid level.

A temperature detection device in an overflow line may be used to detect the tank overfill condition to provide a diverse method of monitoring. The overflow line should be designed to prevent the possibility of a warm gas vapor lock.

Freeboard is required above maximum liquid level to satisfy seismic design codes.

Additional freeboard may be required for upset liquid inventory flowing into the tank. Overflow relief devices may be designed to eliminate the need for this additional freeboard. Upset liquid inventory sources may include an upstream process, backflow from downstream high pressure liquid tanks, or trailer offloading. See Figure 1 for an illustration of tank liquid heights.

5.4.6.1 Primary liquid level measurement device

The primary liquid level measurement device shall be used for normal operating indication and shall be a differential pressure type. The read out shall be accessible to the operator and provide a continuous indication of the tank inventory. This device shall alarm on both low and high levels indicating possible abnormal tank operation. Typical set points are 5% of full tank contents and falling and 95% of full tank contents and rising. Operator response to the high alarm should be to take appropriate corrective action. The setting of the high alarm shall allow sufficient time for a response following its activation that can prevent the level rising and the high-high level activation. The primary measurement device may initiate an action to automatically isolate the tank to prevent further filling.

Minimum level alarm setting shall not be less than the static head required to avoid the floor from bulging up in the middle caused by annular space pressure and by partial vacuum of the inner vessel. If required to prevent the floor from bulging, a low-low level shutdown shall isolate all of the liquid withdrawal lines.

5.4.6.2 Secondary liquid level measurement device

The secondary liquid level measurement device, independent of the primary device, shall be installed to indicate an operating range, to detect the maximum liquid level, and to initiate action to automatically isolate the tank to prevent further filling. If the secondary liquid level measurement device is a differential pressure type, it shall have individual tank penetrations, root valves, and sensing lines. Temperature detection in an overfill/overflow line can only be used as an additional protection device.

The primary and secondary instrumentation loops may be combined in programmable logic controller (PLC) logic to provide normal operating indication and trip protection using diagnostic functions to improve reliability while maintaining high safety integrity. However, this shall only be done after a hazard analysis (such as HAZOP, safety integrity level [SIL]) to ensure that independence and redundancy are maintained.

The secondary measurement device shall have a visible/audible alarm to inform the operator that trip has been activated. The operator actions shall be clearly specified and documented including instructions for the operator to verify if liquid flows into the tank have been terminated.

Risk assessments shall be carried out to identify all sources of liquid into the tank including production, liquid from road trailers or rail tank cars, transfer of liquid from other tanks, etc.

Isolation of all liquid filling sources shall be done by closing automatic isolation valves on all lines that can deliver liquid to the tank and by de-energising any pumps used for transferring liquid into the tank. In the event that a transfer pump is also used for other process purposes that could prevent their de-energisation, a risk assessment shall be performed and consideration should be given to installing double automatic isolation on the inlet line to the tank. If only one automatic isolating device is provided, the possibility of failure shall be considered.

5.4.6.3 Other considerations

In conjunction with 5.4.6, a protection system based on tank overflow shall direct the liquid to a safe location or direct the overflow to a cryogenic vaporiser.

The overflow disposal area or the size and duty of the vaporiser shall be adequate to allow for expected response time.

5.5 Isolation valves

Each liquid line that connects to the inner tank below the maximum liquid level shall be provided with at least two independent means of isolation. This may be any combination of manual isolation valves and ESVs. Spare nozzles not connected to a process line may only have one isolation valve but they should be provided with a blind flange or a welded cap. Suitable means shall be provided for preventing the build-up of pressure due to trapped liquid or cold vapour between any two isolation valves or between the valve and the cap.

These isolation valves shall be located as close as practical to the outer tank penetration in an easily accessible location. The protection of isolation valves from external damage shall be considered.

Instrument lines or sample lines smaller than 50 mm (2 in) nominal bore emanating from below the maximum liquid level may have only one isolation valve.

The first external isolation valve on all process lines connected below the maximum liquid level of the tank shall have sufficient sealing capability to prevent excessive leakage.

Without adequate sealing, an uncontrollable release of liquid can occur during intrusive maintenance of downstream piping components. For example, if the thermal relief valve is being replaced and there is inadequate isolation upstream of the thermal relief valve, an uncontrollable cryogenic liquid leak can occur when the thermal relief valve is removed or in rare cases, does not reseat. In this example, the entire tank may have to be drained to address this situation.

WARNING: *The isolation valve allows for maintenance on downstream components. However, maintenance work on the isolation valve itself should be avoided without draining the tank contents due to safety concerns.*

5.5.1 Emergency shutoff valves

All liquid lines of 50 mm (2 in) nominal bore or greater connected to the inner tank below the maximum liquid level shall have an ESV.

The ESV shall be capable of being remotely operated in emergency situations to isolate spills from failed piping. This ESV is in addition to any normal isolating valve required for process operation (for example, to isolate a transfer pump). A manual isolation valve shall be installed immediately upstream of an externally mounted ESV for maintenance of the ESV.

The remote operated ESVs may be located externally or internally in the inner tank.

The ESVs shall restrict the flow of liquid from the tank in the event of a line failure downstream. Each emergency valve shall be reliable and quick acting and be capable of operation under conditions of heavy liquid spillage. The valve shall fail safe in a closed position on failure of operating power or operating liquid supply. The tank pressure or the liquid head shall act to assist the closing of the valve.

The location and design of external, remote-operable shutoff valves shall be located as close as practical to the outer tank penetration. It shall be protected against possible damage from external hazards like vehicle impact, fire or projection of parts, or molten materials from failure of pumps or other equipment. Hazards associated with the presence of liquid oxygen pumps are addressed in EIGA Doc 148, *Stationary, Electric-Motor-Driven Centrifugal Liquid Oxygen Pumps* [23].

On inlet piping entering below maximum liquid levels, check valves designed with the capability for testing can be used in place of external remote operated ESVs. See Figure 3. Liquid spills from storage tank inlet line failures can be eliminated by designing the liquid inlet nozzle to be in the vapour space of the tank with a siphon break provided in the design. Inlet line failures using this design can result in a release of cold gas rather than a cryogenic liquid. Releases of cold gas from a failed inlet line can allow operators to safely initiate closure of manual valves to limit the amount released. The line should be provided with a manual valve located in an easily accessible location as close to the outer tank wall penetration as the line routing permits.

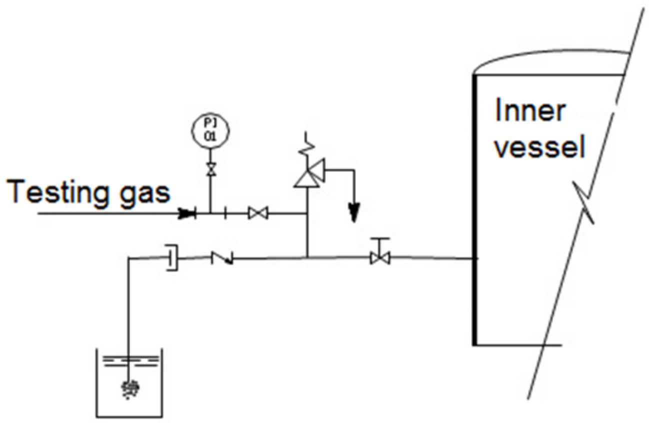


Figure 3—Emergency shutoff valves

Provision shall be made for operation of the emergency isolation shutoff valves at ground level from a safe point remote from the potential area of flow of leaking liquid. To improve personnel capabilities to actuate closure in emergencies, consideration should be given to provide multiple locations for ESVs actuation (for example, trailer loading area, egress routes, control room, site exit/entrance, etc.). Actuation shall close all ESVs associated with that tank. This decision should be based on plant staffing and the possibility of locating one actuation station in an area with a low probability of being influenced by a vapour cloud such as a normally manned control room. The locations of the operating points, their purpose, and mode of operation shall be indicated by suitable notices. Additional requirements for unmanned plants are included in EIGA Doc 132, *Unmanned Air Gas Plants: Design and Operation* [24]. For uninterruptible supply systems, a risk assessment shall be performed taking into consideration the safety impact to the user processes. See 3.2.9 of EIGA Doc 133, *Cryogenic Vaporisation Systems—Prevention of Brittle Fracture of Equipment and Piping* [25].

5.6 Foundations

5.6.1 General

The tank foundation shall be designed to withstand the weight of the tank and insulation, maximum design tank contents that could be experienced during operation of the tank, internal pressure, and other possible loads resulting from wind, snow, ice, earthquake, and/or water content during testing. Subsidence conditions should be considered where required by local conditions.

Suggested practices regarding foundations are included in Annex C of API 620 [4].

The flat bottom of the inner tank shall be thermally insulated from the foundation to ensure the mechanical integrity of the foundations. The cellular glass insulation shall extend beyond the diameter of the inner tank annular plate sufficiently to allow for the distribution of the loads from the inner tank wall to the cellular glass. Usually, this insulation is constructed from cellular glass blocks (foam glass). The thickness of the cellular glass insulation between the inner and outer tank bases affects the temperature of the foundation pile cap. Consideration shall be given to the allowable temperature of the foundation pile cap and the acceptability of ice formation on the underside of the foundation pile cap when accepting a minimum thickness of cellular glass. If insufficient thickness is used, the foundation pile cap reinforcing bar could need to be stainless steel because of the low temperature.

Anchor bolts or straps shall be provided for the inner and outer tank and shall be cast in or pass through and be clamped to the underside of the foundation.

For tank bottoms and foundations in contact with the soil, foundation heating should be provided to prevent ground freezing and frost heave. For tanks supported aboveground on a pile cap, a minimum air gap of 1 m (3.3 ft) is required to ensure adequate air circulation under the pile cap.

Where liquid storage tanks are required to be installed at an elevated level, they shall be supported by structures engineered for the purpose. Consideration should be given to protect such structures from damage by cryogenic liquid spillage.

The design of anchor/hold down straps for the inner and outer vessel and their attachment to the concrete foundation shall take into account the anticipated pull-out loads to guarantee the mechanical integrity of the tank.

5.6.2 Base insulation

Cellular glass insulation shall be subjected to compressive load batch testing as specified in ASTM C240, *Standard Test Methods for Testing Cellular Glass Insulation Block*, EN 826, *Thermal insulating products for building applications – Determination of compression behaviour*, or equivalent method [26, 27]. These standard tests employ bitumen capping on the compression faces of single test blocks. The bitumen capping ensures even load distribution and minimises cell crushing. The use of bitumen is prohibited in the insulation system for liquid oxygen, liquid nitrogen, and liquid argon tanks.

The standard batch tests do not address the mode of failure, failure displacements, and post-failure behaviour that are of critical importance to the intended use of the product.

The exclusion of the bitumen adversely affects the load bearing capacity and amount of cell crushing, therefore alternative interleaving materials such as glass fibre cloth and/or inorganic powder can be employed to aid even load distribution and minimise the amount of cell crushing.

The compressive load carrying characteristics of the selected cellular glass insulation system, including any interleaving materials, shall be established by carrying out compressive load tests (type approval test) that are representative of the actual system to be used. This shall include block-on-block testing with the selected interleaving on the load faces. The tests establish the effectiveness of the materials and the bearing capacity shall be reduced by that effectiveness.

A minimum safety factor of 2.5 against compressive collapse under normal design conditions and a safety factor of 2.0 against compressive collapse under seismic loading shall be applied against the reduced allowable compressive strength.

The amount of crushing is a function of the cellular glass and the selected interleaving material. The amount of crush shall be established during the type approval testing, allowing for this crushing shall be included in the tank interspace piping design.

5.6.3 Installation of cellular glass base insulation

The inner tank base insulation shall be installed on a level surface, which could require a levelling layer on the base of the outer tank. Installation shall be carried out under dry conditions. One possible method of construction is to substantially complete the outer tank, including the roof, but allowing for access to the inner tank and then complete the inner tank base insulation system. See Figure 4. Although cellular glass does not absorb water, the presence of water in the base insulation could result in ice damage to the cellular glass with the potential for settlement and anchor loosening in the event that the tank is warmed up in service. Also, any ice in the base insulation can cause additional heat leak.

Any channels made in the cellular glass base insulation for anchor straps shall be filled with insulation (for example, perlite, mineral wool [ceramic fibre]). Such channels shall be sized and positioned to accommodate thermal movement of the inner tank that occurs upon cooldown.

Horizontal channels in the cellular glass for pipework shall run inside stainless steel bridging or box sections designed to fully support the inner tank floor loading. The pipe shall be centralised in the channel to permit thermal movement.

The inner tank bottom and sidewall shall not rest directly on the cellular glass, but shall have a concrete footing/levelling layer on top of the cellular glass blocks to spread the load and protect the cellular glass during floor construction. There shall be a metallic barrier (such as aluminium) between the concrete levelling layer and the top of the base insulation to act as a membrane to prevent moisture from the concrete entering the base insulation. Organic membranes such as polyethylene are not acceptable. In some cases, a concrete ring beam could be required under the sidewall. Any reinforcing bars in the concrete ring beam shall be stainless steel. During construction, the outer perimeter of the base insulation shall be protected from damage. The cellular glass blocks in each layer shall be laid side-by-side in rows, but successive layers shall be staggered in two directions or layers shall be rotated by not less than 30 degrees. See Figure 4. The use of pieces with plan dimensions less than half a block shall be avoided. This is particularly important at the edge of the cellular glass layer, which is the region with the highest loads.

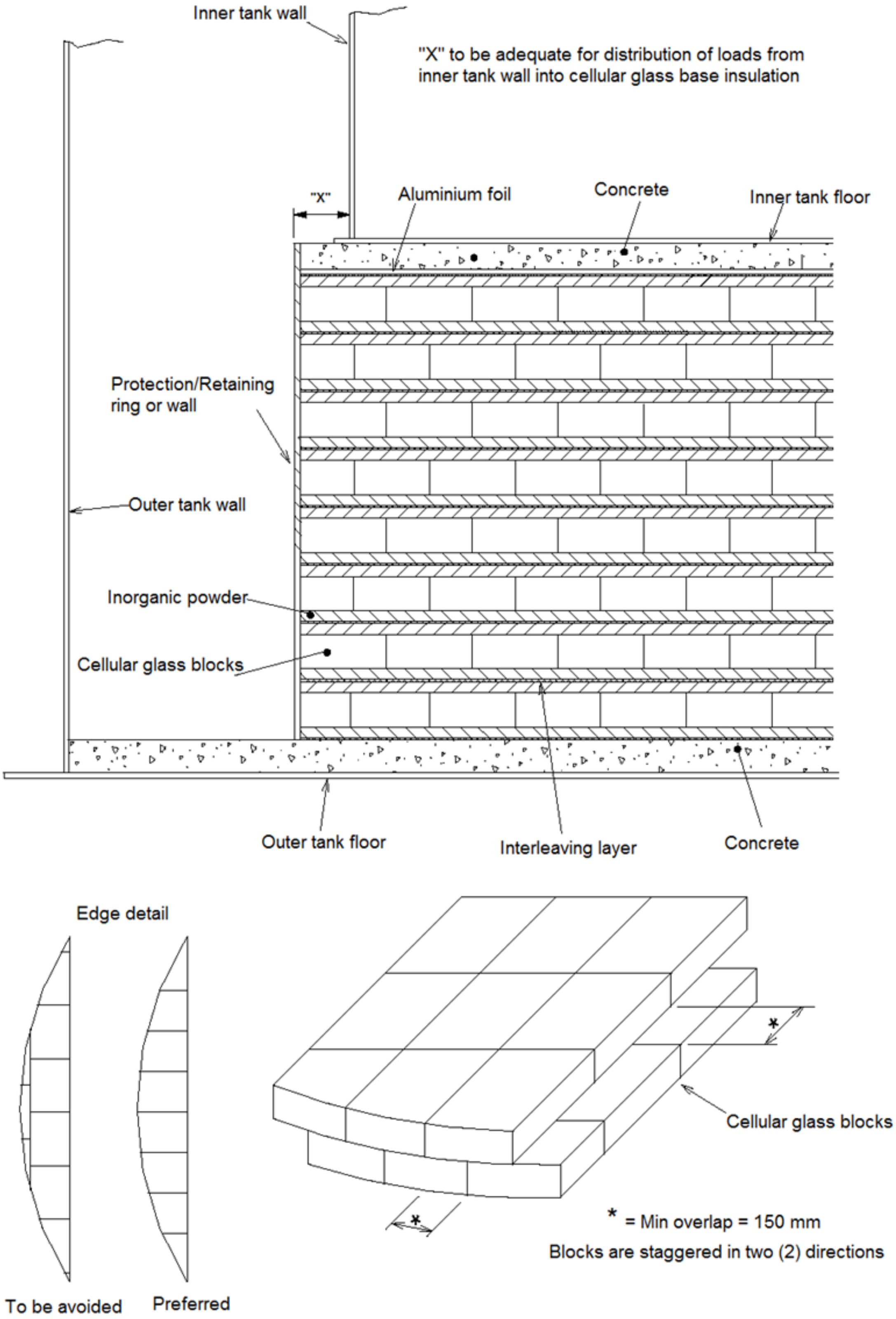


Figure 4—Typical arrangement of base insulation system

6 Storage tank fabrication

6.1 General

The fabrication at the site of storage tanks and associated piping shall be in accordance with the requirements of the code and standards used for the design.

However, requirements beyond those stated in the selected design code are required for the specific storage of liquid oxygen, liquid nitrogen, and liquid argon at production sites. Such requirements are stated in other sections of this publication, for example the requirement for non-destructive testing of liquid lines penetrating the inner tank below the maximum liquid level are stated in 5.3.

NOTE—There can be additional requirements imposed by the user, local, and/or national regulations.

As a minimum the following shall be addressed during construction:

- workmanship;
- plate cutting and edge preparation;
- plate forming/pressing;
- welding procedure;
- welding procedure qualification;
- production weld tests including impact testing;
- repairs of weld defects; and
- non-destructive testing in accordance with the design requirements.

All plates for the inner and outer tanks shall be handled and stored separately to ensure that materials are used in the correct application, for example to avoid carbon steel plates and stainless steel plates being interchanged.

Stainless steel shall be stored and handled to avoid surface contamination. Any contact with other metals such as zinc (galvanised tools) and carbon steel shall be prevented to avoid the risk of weld defects and cosmetic defects.

Heating or hammering is not permissible unless the material is heated to a forging temperature during straightening.

Welding consumables shall be protected and stored in accordance with the conditions stated in the welding consumables standards and/or the supplier’s recommendations.

The workmanship and finish shall be subject to inspection by the manufacturer’s inspector. The purchaser may specify formal inspection activities such as a quality plan.

During site erection, the erector shall ensure that the partially complete tank is secured against possible adverse weather conditions that can occur during construction. This could require the partially constructed tank to be capable of sustaining the design wind speed.

Fabrication tolerances for the inner and outer tank shall be in accordance with the design code and cover the following:

- plumbness of shell walls;
- out of roundness;
- shell radius;
- double curvature roof shape;

- local deviation from theoretical shapes such as flat spots;
- weld discontinuities, alignment of plate joints; and
- bottom plate local distortion.

A criterion for foundation levelness shall be specified by the system designer.

If the design code does not specifically address bottom plate local distortion the following is required:

- Generally, the floors shall be in contact with the support surface below. Floor welding and sequencing of welding shall minimise floor distortion to avoid lifting and reseating of the floor during liquid level fluctuations. This is not specifically addressed by API 620 [4];
- The integrity of the inner tank anchor system is critical. All load-carrying weld joints in the inner tank anchor system shall be 100% non-destructively tested. This shall be accomplished by radiography when possible. Load carrying fillet welds shall be made with a minimum of two passes and shall be subject to dye penetrant examination; and
- Inner tank anchorage (for example, anchor straps, bolts, rods) shall be provided by the tank manufacturer to be set in the concrete foundation. When required to facilitate installation and to provide clear access to the concrete foundation, the anchor straps may be supplied in two pieces requiring a field weld above the concrete foundation. This field weld is critical to the integrity of the tank and shall be full penetration weld and fully radiographed.

6.2 Storage and cleanliness of materials at erection site

Hazards of oil, grease, combustible materials, and other foreign matters in presence of oxygen are addressed in 4.5.

All plates and materials to be used for the construction of the inner vessel and related piping shall be handled and stored in such a way that the possibility of their contamination is minimised.

Equipment and parts (like valves, instrument, pipe spools, etc.) supplied clean for oxygen service shall be handled and stored in their original sealed packing until their installation.

At the end of the fabrication of the tank and related piping, all the parts to come into contact with oxygen shall be verified for cleanliness and accurately recleaned for oxygen service, if necessary.

For practical guidance on how to prepare equipment for oxygen service, see EIGA Doc 33 [9].

6.3 Inspection and testing during the fabrication

Inspection is required to ensure that the tank construction is of the required standard as specified in the applicable design codes and this publication. The party responsible for carrying out the inspection shall have the experience as defined in the selected code.

7 Site selection and layout of installation

7.1 General

The strict adherence to nationally accepted design and construction codes for pressure vessels, storage tanks, and associated equipment, and to the specific operating instructions should ensure safe operation and prevention of accidental releases.

The installation shall be sited to minimise risk to personnel, local population, and property. Consideration shall be given to the location of any potentially hazardous processes in the vicinity that could jeopardise the integrity of the storage installation.

Equipment, associated instrumentation, and manually operated valves shall be located to provide unrestricted access and clear visibility of instruments.

Because of its size or strategic location, an installation may come within the scope of specific legislation for planning control. If so, the siting of any such proposed installation shall be discussed and agreed with the local authority.

When there are considered to be off-site risks, a risk assessment shall be carried out, which may require the addition of mitigating measures such as barriers, curbing, and diking. The risk assessment shall take into account proximity of occupied buildings, areas of public assembly, other vulnerable site equipment (particularly other storage tanks), and prevailing climatic conditions (high humidity, atmospheric corrosion).

Preferably, tanks should be located so that diking or other means of secondary containment are not required. However, local and national codes may require secondary containment.

7.2 Safety distances

Safety distances are intended to protect the storage installation as well as personnel and the environment. They are intended to protect personnel from exposure to an oxygen-enriched or -deficient atmosphere, from cryogenic burns in the event of a release of liquid, to prevent fire enhancement due to a release of liquid oxygen, and to protect the installation from the effect of thermal radiation or jet flame impingement from fire hazards.

Within a number of countries of operation, there are specific requirements for separation distances between cryogenic storage and exposure hazards. Examples of publications that give specific distances include
NFPA 55, *Compressed Gases and Cryogenics Fluids Code*, BCGA CP20, and BCGA CP22 [28, 2, 3].

It is not practicable to define safety distances that alone give adequate protection in the event of a major release of liquid from storage installations. They have to be adopted in conjunction with a package of precautions to control spillage and minimise risk such as:

- taking into account topography, containment, or diversion of spillage;
- siting of storage to allow for likely movement of vapour clouds;
- provision of emergency shutoff valves;
- implementation of emergency procedures (see 10.4); and
- adequate personnel training.

To minimise the off-site risk to the general public and the environment, it is necessary for each of the likely risks and exposures to be considered individually.

7.3 Location of the installation

7.3.1 Outdoor installation

All cryogenic bulk liquid storage installations at production sites shall be located outside in a well-ventilated area.

7.3.2 Location of underground cable ducts, trenches, drains, and open pits

Underground cable ducts, trenches, drains, and open pits should not be located close to bulk storage tanks. This is to avoid confined spaces where oxygen enrichment or deficiency could occur and avoid potential pathways for the leakage from the tank to travel unintentionally to other areas (see 7.3.5). Debris accumulated in cable ducts, trenches, drains, and pits can also pose fire hazards with leaking oxygen.

Equipment requiring regular attention or maintenance should not be installed in pits. Flanged joints and similar sources of potential leakage should also be avoided in pits. Where the installation of equipment and/or the inclusion of potential sources of leakage in pits cannot be avoided, notices shall be posted nearby, warning of the hazards of oxygen enrichment or deficiency. Entry into such locations shall be controlled by a confined space entry procedure.

7.3.3 Protection against electrical hazards

The location shall be chosen so that damage to the installation by electric arcing from overhead or other cables cannot occur. All parts of the installation shall be earthed and protected against lightning according to local regulations. Storage tanks shall be grounded in at least one location. The inner vessel is grounded to the outer vessel by various piping connections. Grounding clips should be austenitic stainless steel or protected against corrosion.

7.3.4 Electrical equipment

Applicable local codes shall be followed. The storage tank area is not considered a hazardous location for electrical equipment. Therefore, suitable weatherproof types of electrical wiring and equipment are acceptable. In areas where high oxygen concentrations could be expected in normal operation, electrical equipment with open or unprotected make-and-break contacts should be avoided.

Lighting shall be provided to allow operations to be carried out safely. Emergency lighting shall be provided.

7.3.5 Management of liquid spillage

The slope of the ground shall be such as to provide normal surface water drainage and direct any cryogenic liquid leaks towards safe areas. Liquid spillage shall be prevented from reaching sensitive areas such as control rooms, offices, workshops, canteens/cafeteria, electrical equipment, machines, natural gas fire heaters, trenches, neighbours, and public areas. This consideration shall be taken into account during the development of the overall plot plan.

Significant liquid spillage can occur due to piping or equipment failure external to the storage tank or tanks. Provisions shall be made to contain or divert it towards a safe area. Hydrants, hoses, spray nozzle, or fans may be used as required to divert liquid and protect vulnerable areas.

Storm water drainage systems shall be provided with water traps or other safeguards to prevent the ingress of cryogenic liquid or gaseous products.

7.3.6 Position of gas vents

Vents, including those from PRDs, shall vent to a safe location so as to avoid hazards to personnel, buildings, structural steelwork, or other equipment.

Vent discharge pipes shall be routed to a location and elevation that minimises fogging and provides for atmospheric dispersion to avoid localised oxygen enrichment or deficiency in areas frequented by operating personnel. Dispersion modelling can be a useful tool in locating vent discharge points.

Vent pipes from pressure relief and vent devices shall be directed away from the outer tank or sufficiently elevated to avoid contact with carbon steel, which could lead to cold temperature embrittlement.

Atmospheric moisture accumulation in potential cold vent lines shall be avoided to prevent <u>internal</u> icing hazards or water accumulation. <u>Moisture accumulation can lead to ice growth, which can result in the plugging of the vent outlet rendering it inoperable</u>. Vent discharges shall be designed to <u>minimize</u> atmospheric moisture ingress and accumulation. Examples include a dry gas purge installed on vent discharge piping, <u>low point</u> drainage holes, and downward sloping piping. If <u>drainage holes are used</u>, <u>they</u> should be inspected periodically to ensure that <u>they are</u> not plugged.

7.3.6.1 Pressure relief devices

PRD operation does not typically provide a constant source of either cold gas or icing. On bulk storage tanks, the PRDs are typically located on the top of the outer tank shell or vented at a high elevation, which minimises fogging at grade.

The PRD inlet piping shall be designed to prevent cold migration to the device body during standby conditions and prevent it from becoming encased in ice.

Design of PRD outlets should consider methods such as installation of screens or blow-off caps to prevent birds or debris from entering the outlets and causing a possible blockage of PRD flow. Screen designs should not restrict the required flow area.

Periodic inspection of the PRD vent piping may be performed as an alternative to screen installation to ensure that the discharge is not blocked.

A visual inspection of the outside of the PRDs should be made on a periodic basis to ensure they are free of ice. Ice build-up can engulf the discharge of the PRDs inhibiting their function.If the PRD body is encased in ice the following actions shall be taken:

- Inspect the internal surfaces of the PRD discharge nozzle (plug and stem, in the case of a relief valve) via the outlet piping. The intent of the inspection is to ensure that the PRD discharge is free of ice. The inspection shall be conducted considering human factors and process risks;
- Visually inspect the PRD discharge via indirect observation such as by camera or inspection mirror; and
- Apply mitigation measures to prevent ice formation, if ice is found on the discharge of the PRD.

7.3.6.2 Automatic vent valves

The automatic vent valve discharge should be located sufficiently above grade to provide adequate atmospheric dispersion to dilute the gas to a safe concentration and to warm the gas to prevent fogging before it settles to operating personnel levels.

Since the exiting vent gas can cool the discharge vent piping tip to near vent gas temperature, the tip shall be insulated, heated, or other means provided to limit ice build-up. The ice could result in blockage of the tank vent nozzles or malfunction of the control valves or creation of a large ice ball that could fall off and injure operating personnel, which can necessitate periodic thawing. Icing of the vent valve and its discharge can inhibit their function and lead to a loss of tank pressure control. Cyclic thawing of the vent valve ice build-up may cause a safety concern for personnel or equipment damage from falling ice. The heating device shall be suitable for cryogenic service and for the vented gas. A catch grating can be placed below the vent or access can be limited to the area beneath the vent to prevent personnel injury from falling ice.

7.3.7 Vapour clouds

When siting the installation, consideration shall be given to the possibility, direction, and velocity of vapour clouds originating from spillage or venting, which could result in an on-site or off-site hazard (decreased visibility, oxygen enrichment, or oxygen deficiency). Dispersion modelling is a useful tool in assisting in the optimal location of storage tank systems.

Installation of temporary or permanent barriers to control the spread of vapour clouds off-site may be considered. Barriers can provide additional time for implementation of site emergency response procedures before the vapour cloud travels off-site.

7.3.8 Firefighting equipment

Local regulations can normally dictate the type and quantity of the firefighting equipment (extinguishers, fire hoses, etc.) required for the installation.

7.4 Liquid transfer area

For details about the requirements for installations used for the loading of oxygen, nitrogen, or argon into trailers, see EIGA Doc 179 [1].

8 Testing and commissioning

8.1 Controls during manufacturing and construction

The manufacturing shall be subject to specification and a quality plan agreed by the manufacturer and user. This shall include all the tests prescribed by the applicable codes and any additional requirements prescribed by the system designer. Guidance on such requirements is given in Section 7 and Annex Q of API 620 [4].

8.2 Testing, pre-commissioning checks, and commissioning of installations

8.2.1 General

Prior to testing and commissioning, a review shall be carried out to ensure that the tank and associated equipment have been designed and constructed in accordance with the design code and specification and that all statutory requirements have been met.

Prior to placing into service, the installation shall be validated as suitable for the intended duty. This validation shall be performed by a competent person that shall have practical and theoretical knowledge and experience of the type of storage tank installation being examined.

Checks shall be made to ensure that the cleanliness requirements of 4.5 have been met.

As a minimum, the following tests shall be carried out by the manufacturer or their representative in accordance with approved procedures.

8.2.2 Tank pressure and leak testing

A hydro-pneumatic test is a test where the tank shell is partially filled with water and gas pressure is applied on top of the water to demonstrate the tightness of the tank. A leak test is performed at a pressure less than the hydro-pneumatic test using a gas for the purpose of detecting leaks that have not been found during the hydro-pneumatic test.

A hydro-pneumatic test of the inner vessel shall be carried out in accordance with the applicable design codes and standards before filling the annular space with insulation. For tanks containing liquids with a specific gravity greater than 1, hydro-pneumatic testing shall be conducted using water according to API 620 or equivalent code [4].

Means of pressure indication suitable for the test pressure shall be installed before the test and precautions shall be taken to prevent overpressure in the system during the test.

Water to be used for the hydro-pneumatic test shall be analysed prior to filling of the tank(s). To prevent the risk of pitting, cracking, or corrosion of the material used in the construction of the tank, the chloride contents (chlorine ion) shall be less than 50 mg/l with a pH between 6 and 8.3 or more stringent, if required by the tank manufacturer. The test water shall only remain in the tank for the shortest time required for the test. In case it is impossible to obtain the requested water quality, alternative test methods that used suitable inhibitors may be agreed between the system designer, manufacturer, and owner of the tank. Water shall be substantially clean and clear.

WARNING: *If the tank is designed for liquid nitrogen only, the maximum level of water filling shall be verified not to exceed the maximum allowable stress in test condition of the foundation and of the bottom cellular glass insulation.*

After the tank is filled with water and before the pneumatic pressure is applied, the foundation straps shall be welded to the inner vessel.

Vents to atmosphere shall be checked to avoid both overpressurisation and the development of a partial vacuum in the tank during the filling and emptying of the tank. Immediately after the test, the tank and any associated equipment shall be drained. The bottom surface of the inner tank shall be rinsed with clean water, thoroughly dried out, and checked for any residual water remaining in pockets.

Upon completion of the hydro-pneumatic test, a thorough visual inspection shall be made of both the inside and outside of the inner vessel and the anchorage.

There shall be a disposal plan for the test water to ensure that the local drainage system can cope with the rate of water disposal and that the water quality does not negatively impact the local environment and complies with any local regulations.

For the hydro-pneumatic test, dry, oil-free air is the preferred test medium. The pressure in the system shall be increased gradually up to the test pressure. Any defects found during the test shall be rectified in accordance with the requirements of the design and fabrication code and the system shall be retested.

WARNING: *If nitrogen is used to perform a pneumatic test or to keep the tank pressurised, a risk of asphyxiation exists inside and around the vessel (see 4.2.2).*

The pressure test shall be witnessed and a test certificate signed and issued. The certificate shall be retained in the plant files.

Upon successful completion of the pressure test of the tank, the tank and associated equipment shall be leak tested. Equipment such as plant instruments and gauges are not normally fitted during the pressure test but shall be fitted prior to pressurising for leak testing.

If the tank is designed for partial vacuum, the test shall be performed in accordance with API 620 or other equivalent design codes [4].

8.2.3 Pre-commissioning checks

A pre-start-up safety review shall be conducted to ensure that all materials and design requirements have been verified. Verify the operational readiness and the integrity of safety systems before putting the tank into service and that personnel are trained before start-up.

At a minimum, the following areas shall be addressed in this review.

8.2.3.1 Pressure relief device installation and set pressure

A check shall be made to ensure that all transport locking devices have been removed from both over and under PRDs for the inner vessel, outer tank, and piping systems and that the devices are undamaged and in working order. If safety valves are provided with locking screws, they shall be removed prior to commissioning.

The PRD set pressure (stamped on or attached to each device) shall be checked to see it is in accordance with the MAWP of the tank. PRDs <u>shall</u> be subjected to a functional test <u>either in the shop or in the field and, for either case, the results shall be documented</u>.

8.2.3.2 Pressure relief device discharge lines

A check shall be made to ensure that all pressure relief valve and bursting disk discharge lines are routed to a safe location and that the valves and discharge lines are supported to take into account reaction forces.

8.2.3.3 Instrumentation and controls and safety systems

Check that instrumentation and controlling devices and safety systems comply with the design specifications. This shall include a functional test and the results documented and maintained in the plant file.

8.2.3.4 Signage

Signage shall be installed before placing the installation into service. Notices shall be clearly displayed at all times on or near the tanks, particularly at access points, to indicate the following:

- LIQUID OXYGEN (or NITROGEN or ARGON);

- NO SMOKING;
- NO HOT WORK;
- NO NAKED LIGHTS;
- NO STORAGE OF OIL, GREASE, OR COMBUSTIBLE MATERIALS; and/or
- AUTHORISED PERSONS ONLY.

Symbols that are in accordance with local regulations may be used instead of written notices.

8.3 Commissioning

After all pre-commissioning checks are completed, commissioning shall be carried out only by authorised personnel and in accordance with a written procedure. Whenever initial cooldown of the tank is performed (either from road tankers or from the production air separation unit), the positive pressure or the negative pressure in the inner vessel and in the annular space shall not exceed the maximum or minimum allowable values indicated in the manufacturer's documents. The pressure in the annular space shall never exceed the actual pressure in the inner tank to avoid lifting of the tank flat bottom.

The cooldown shall be carried out in accordance to an approved procedure, which limits the liquid flow to control the thermal stresses and pressure build-up in the inner vessel due to liquid flashing in the warm tank. Initially, the liquid flow shall be limited to the capacity of one of the tank PRDs assuming that all liquid is vaporised in the warm tank. As cooldown progresses and liquid level begins to build, fill rate may be increased while maintaining a stable tank pressure.

9 Operation and maintenance

9.1 Operation of the installation

Documented operating instructions shall be supplied to operating personnel.

The instructions shall define the safe operating limits of the system and any procedures that are required to operate the system in an emergency situation. The operating instructions shall include any actions required to be taken in response to an excursion outside the design limits of the system (for example, overpressure, rapid temperature change, mechanical damage). Example of an action required is to report the excursion to the company design specialist for any remedial action.

9.2 Hot work

Hot work and open fires shall be prohibited near oxygen installations unless specific precautions are taken (see 10.1).

9.3 Periodic inspection and maintenance

9.3.1 General

The industrial gases industry generally does not carry out periodic internal inspection of cryogenic bulk storage tanks for inner tank and annular space piping.

This policy has been established over many years, based on operating experience, the inherently stable and benign conditions within an operating cryogenic storage tank, and an absence of the traditional failure mechanisms for such equipment namely corrosion, erosion, and fatigue.

However, periodic inspection and maintenance of the storage systems excluding inner tank and annular space shall be carried out to ensure that the installation remains in a safe condition. The scope and time interval for the inspection, maintenance, and repair shall be established by the user in consultation with the manufacturer, applicable regulations, and local authorities, as appropriate. See Appendix C for an example of a typical periodic external inspection checklist of a cryogenic bulk storage tank.

The site should be inspected regularly to ensure that it is maintained in an appropriate condition for the type of installation and that safety distances are respected.

A comprehensive installation dossier shall be available. This dossier shall include:

- process and instrumentation diagrams;
- vessel or tank dossier; and
- operating instructions.

Equipment shall not be taken out of service for repair until all pressure has been released. Any leakage shall be rectified promptly and in a safe manner. Only original spare parts should be used. If this is not possible, the suitability of the spare part shall be approved by a competent person through a MOC process. The MOC process is described in EIGA Doc 51 [22].

The maintenance and assembly of equipment for oxygen shall be carried out in clean, oil-free conditions. All tools and protective clothing (such as overalls, gloves, and footwear) shall be clean and free of grease and oil.

For practical guidance on cleanliness for oxygen service, see EIGA Doc 33 [9].

9.3.2 Tank

Periodic inspection or test of the inner tank is not considered necessary because:

- Cryogenic storage tank inner tanks are constructed from materials that are corrosion resistant. These materials retain their corrosion resistance at temperatures less than ambient and experience shows that corrosion at cryogenic temperatures is negligible;
- Process fluids are dry, clean, and non-corrosive;
- Design and construction are carried out to well-established and internationally recognised codes and standards. Designs take into account pressures, loadings, temperature changes, and movements expected during normal running and during startup and shutdown. The designs also take into account that inner tank and associated piping are largely inaccessible within an outer tank;
- Operating mode of cryogenic storage tanks is generally "steady state" with few pressure and temperature variations;
- Materials used in the construction have high fracture toughness characteristics. The critical defect size, for the initiation of an unstable fracture, would allow a defect to be detected, well before the critical defect size is reached, from an increase in annular space pressure or from the presence of cold patches;
- Materials used in the construction have significantly enhanced yield and ultimate tensile strengths at their working temperature. For example, at cryogenic temperature the ultimate tensile strength of austenitic stainless steel is approximately twice that at ambient temperature; and
- Annular space has a dry, inert purge.

For additional information see BCGA CP39, *In-service requirements of pressure equipment (gas storage and gas distribution systems)* [29].

When a tank is taken out of service for modification or maintenance, the accessible areas of the tank should be examined by a competent person.

An annual external visual examination should also be carried out to confirm that the outer shell, exposed pipework, valves, and controls do not indicate any defects. Where defects are found, they shall be investigated and rectified.

The supply of purge gas to tank annular space should be checked periodically to ensure an effective purge is being maintained. Failure of a purge could lead to moisture accumulation in the annular space of a flat-bottom storage tank and lead to ice formation, which degrades the insulation, limits piping movement, and potentially causes pipe damage.

Tanks located at ground level typically have foundation heaters. If the heaters do not have fault alarms, the heater shall be checked periodically to verify that it is operational.

9.3.3 Pressure indication and pressure relief devices

Inner tank pressure shall be monitored. Low and high pressure alarms and shutdowns, pressure building, and vent and relief device set points shall be verified against the design requirements in accordance with company standard operating procedures (SOPs) and/or local regulations. Corrective actions shall be taken in accordance with the company MOC process. Calibration and testing of the pressure instrumentation devices shall be in accordance with company SOPs.

Prolonged periods of a low pressure alarm status can be an indication that the pressure building system is not functioning or is being overwhelmed by activities that can lower the tank pressure. Corrective action shall be taken to stop the ambient air and moisture from entering the tank through the PRD due to vacuum conditions, which can cause internal plugging (see 4.4).

Prolonged periods of a high pressure alarm status can be an indication that the automatic vent system is not functioning or it is being overwhelmed by the pressure building system or other sources of high pressure. Corrective action shall be taken to lower the pressure to its normal operating pressure by determining the gas source and reducing or eliminating it, or clearing the vent system of ice blockages, closed valves, or failed devices. Operation in a high pressure condition can result in the tank PRDs continuously venting resulting in excessive ice build-up (see 4.4).

When performing maintenance on automatic pressure building and vent systems, ensure that the tank operating pressure is maintained in a safe operating range.

A periodic test of each pressure relief valve shall be carried out to demonstrate its fitness for a further period of service. Pressure relief valves shall be tested in accordance with individual company standards or local regulations. If none exists, a 3 year interval between tests may be considered as a starting point to develop a company specific requirement.

Bursting disk elements can deteriorate with time resulting in their relief pressure rating being reduced. It may, therefore, be necessary to replace disk elements periodically.

Where block valves are installed upstream of PRDs to allow their inspection with the tank in operation, specific locking systems and operational procedures shall exist to ensure that the PRDs are not isolated after the testing. At least one PRD shall be kept in operation during the testing of the second one. The time period with only one operable PRD for inner tank protection should be kept to a minimum. The automatic vent system shall be operable during such time periods and consideration should be given to temporarily lowering the tank operating pressure as well.

All PRDs in cryogenic service should be inspected periodically for external ice accumulation. Accumulated ice should be removed promptly. Failure to do so can prevent the PRD from operating in accordance with the design requirements.

Annular space PRDs shall be inspected to ensure that they are free to operate and not restricted or plugged with perlite. If perlite is found outside of the PRD, it can indicate annular space overpressure events and potential causes should be investigated. The causes of these overpressure events can vary in severity, from an incorrect setting on the annular space purge pressure system to a critical concern such as an internal tank leak.

9.3.4 Level indication and overfill protection

Overfill protection alarms or shutdown systems can be inactive for long periods and can develop undetected faults.

For this reason, the liquid level measurement system and the overfilling protection system shall be tested according to the SIL analysis requirements. If a SIL analysis is not available, the test shall be done at least every 2 years. This test shall confirm operability of the entire system including actuation of the shutdown device at the appropriate design set point and closure of the isolation valves in each tank liquid inlet line.

9.3.5 Emergency shutoff valves

Periodic checks shall be made to ensure that any emergency isolation shutoff valves are operating and any flow from the closed emergency isolation shutoff valve is acceptably small. The ESVs and/or check valves installed to reduce the possibility of continuous liquid releases from the storage system should be tested at an interval no longer than every 2 years, unless a longer interval is determined by a risk assessment. The test for remotely operated ESVs shall confirm valve closure from all actuation points. For check valves, the test shall confirm the valve's capability to prevent significant liquid backflow through a failed line.

9.4 Modifications and change of service

Proposed modifications or change of service to a storage tank, its equipment, control systems, process conditions, and operating procedures shall be evaluated for safety, health, and environmental impact and approved prior to any change being made. The approval shall be carried out under a MOC procedure; see EIGA Doc 51 [22].

Any modification shall be carried out in accordance with the applicable design code. Some modifications can require consultation with the manufacturer.

9.4.1 Change of service

Change of service can be a very complex process and it shall only be done after a full engineering review. Key items that shall be addressed during change of service review include, but are not limited to:

- Load on tank design and foundation (liquid density differences);
- Freeboard requirement. See 5.4.6;
- Calibration of the level instruments and alarm and trip set points. Ensuring layers of protections are not lost;
- Impact of gas density and temperature changes;
- Review of process calculations for new PRD and vent valve duties;
- Oxygen compatibility for conversion to liquid oxygen service;
- Tanks and other components cleaned for oxygen service; and
- Piping and components suitability for oxygen service.

10 Training and protection of personnel

10.1 Work permit

Before maintenance or modifications are carried out on the installation, a written work permit for the work (cold work, hot work, entry of vessel, electrical work, etc.) shall be issued by an authorised person to the individual(s) carrying out the work. See EIGA Doc 40, *Work Permit Systems* [30].

10.2 Entry into tanks

Both the inner tank and annular space are confined spaces and formal confined space entry procedures shall be followed. See 29 CFR 1910.146 [6].

Particular hazards of note are:

- perlite;

- cold surfaces; and
- oxygen enrichment and deficiency.

10.3 Training of personnel

All personnel directly involved in the commissioning, operation, and maintenance of storage systems shall receive specific training as required in the operation and maintenance of the equipment. It is recommended that the training be carried out under a formalised system and that records be kept of the training given.

Training shall cover, but not necessarily be limited to, the following subjects for all personnel:

- potential hazards of the cryogenic liquids;
- oxygen enrichment/depletion;
- site safety regulations;
- emergency procedures; and
- use of personal protective equipment.

Recommendations about training of personnel are described in EIGA Doc 23, *Safety Training of Employees* [31].

For additional information about selection of personal protective equipment (PPE), see EIGA Doc 136, *Selection of Personal Protective Equipment* [32].

10.4 Emergency procedures

Emergency procedures shall address cryogenic liquid spills. These procedures shall be developed in coordination with emergency services or firefighters. See also EIGA Safety Info HF06, Site Emergency Response [33].

The procedures shall be readily available to all personnel involved, regularly practised, and checked periodically that they are up to date. Employees likely to be affected shall know the actions required to minimise the adverse effects of such spillage.

The procedure shall consider:

- properties of the cryogenic liquids;
- quantities involved; and
- local topography.

The following are steps that should be addressed in emergency procedures:

- Raise the alarm;
- Summon help and emergency services;
- Notify firefighters immediately (if necessary);
- Evacuate all persons from the immediate danger area and seal it off;
- In case of leakage/spillage:
  - Tighten up leaks, if this can be done without risk
  - Allow liquid to evaporate
  - Prevent liquid entering sewers, pits, trenches
- In case of fire:

  - Keep vessel cool by spraying it with water
  - Do not spray water directly on PRDs or safety equipment; and
- Alert public to possible dangers from vapour clouds and evacuate, when necessary.

11 References

Unless otherwise specified, the latest edition shall apply.

[1] EIGA Doc 179, *Liquid Oxygen, Nitrogen, and Argon Cryogenic Tanker Loading Systems*, European Industrial Gases Association. www.eiga.eu

NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[2] BCGA CP20, *Bulk liquid oxygen storage at productions sites*, British Compressed Gases Association. www.bcga.co.uk

[3] BCGA CP22, *Bulk liquid argon or nitrogen storage at production sites*, British Compressed Gases Association. www.bcga.co.uk

[4] API 620, *Design and Construction of Large, Welded, Low-pressure Storage Tanks*, American Petroleum Institute. www.api.org

[5] EIGA Doc 04, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres*, European Industrial Gases Association. www.eiga.eu

NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[6] *Code of Federal Regulations, Title 29* (Labor), U.S. Government Printing Office. www.gpo.gov

[7] CGA P-12, *Safe Handling of Cryogenic Liquids*, Compressed Gas Association, Inc. www.cganet.com

[8] EIGA Doc 44, *Hazards of Oxygen-Deficient Atmospheres*, European Industrial Gases Association. www.eiga.eu

NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

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NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

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[14] EN 14620, *Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0°C and -165°C*, European Committee for Standardization. www.cen.eu

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[19] API 520, Sizing*, Selection, and Installation of Pressure-relieving Devices—Part 1—Sizing and Selection*, American Petroleum Institute. www.api.org

[20] API *521*, *Pressure-relieving and Depressuring Systems*, American Petroleum Institute. www.api.org

[21] API *2000*, *Venting Atmospheric and Low-pressure Storage Tanks*, American Petroleum Institute. www.api.org

[22] EIGA Doc 51, *Management of Change*, European Industrial Gases Association. www.eiga.eu

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NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

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[27] EN 826, *Thermal insulating products for building applications - Determination of Compression Behaviour*, European Committee for Standardization. www.cen.eu

[28] NFPA 55, *Compressed Gases and Cryogenics Fluids Code*, National Fire Protection Association. www.nfpa.org

[29] BCGA CP39, *In-service requirements of pressure equipment (gas storage and gas distribution systems)*, British Compressed Gases Association. www.bcga.co.uk

[30] EIGA Doc 40, *Work Permit Systems*, European Industrial Gases Association, www.eiga.eu

[31] EIGA Doc 23, *Safety Training of Employees*, European Industrial Gases Association, www.eiga.eu

[32] EIGA Doc 136, *Selection of Personal Protective Equipment*, European Industrial Gases Association. www.eiga.eu

NOTE - This publication is part of an international harmonisation programme for industry standards. The technical content of each regional document is identical, except for regional regulatory requirements. See the referenced document preface for a list of harmonised regional references.

[33] EIGA Safety Info HF06, *Site Emergency Response*, European Industrial Gases Association, www.eiga.eu

[34] CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases*, Compressed Gas Association, Inc. www.cganet.com

[35] EIGA Doc 24, *Vacuum Insulated Cryogenic Storage Tank Systems Pressure Protection Devices*, European Industrial Gases Association, www.eiga.eu

Appendix A—Specific requirements for cluster storage tanks at production sites

A cluster storage tank is a system of multiple inner pressure vessels (or tanks) in a single outer jacket. Usually the inner vessels are workshop manufactured and installed inside the site erected outer jacket. These vessels typically operate at greater than 1 bar (14.50 psi) pressure and are designed as pressure vessels.

The inner vessels are piped together without intermediate manual or automatic isolation valves. All liquid lines of 50 mm (2 in) nominal bore or greater that exit the outer jacket shall have ESVs capable of being remotely operated in emergency situations to isolate spills from failed external piping.

This ESV is additional to any normal isolating valve required for process operation (for example, to isolate a transfer pump). A manual isolation valve should be installed immediately upstream of the ESV for maintenance of the ESV and downstream components.

All liquid piping of 50 mm (2 in) nominal bore or greater shall be fully welded or brazed and protected from external impact up to the ESV inlet.

The vapour spaces are manifolded together without valves and the inner tank over/under pressure protection devices are provided for the common system.

The inner vessels may be designed for full vacuum in which case the cluster may not require under pressure control and protection.

It is the responsibility of the system designer to identify the parts of this publication that are not applicable to the specific installation.

Appendix B—Specific requirements for large capacity vacuum-insulated storage tanks at production sites

Large capacity vacuum-insulated storage vessels are often used for bulk storage at production sites. They are typically shop fabricated and built to pressure vessel design code.

For tanks that are manifolded together, all liquid piping of 50 mm (2 in) nominal bore or greater shall be fully welded or brazed and protected from external impact up to the ESV inlet. The ESV may be located at the end of the manifolded section.

All liquid lines of 50 mm (2 in) nominal bore or greater shall have ESVs capable of being remotely operated in emergency situations to isolate spills from failed external piping.

An ESV(s) may not be required based upon a risk assessment and downstream hazard impact.

This ESV is additional to any normal isolating valve required for process operation (for example, to isolate a transfer pump). A manual isolation valve should be installed immediately upstream of the ESV for maintenance of the ESV and downstream components.

It is the responsibility of the system designer to identify the parts of this publication that are not applicable to the specific installation.

Inner tank and outer jacket pressure and vacuum protection shall be in accordance with the provisions of CGA S-1.3, *Pressure Relief Device Standards—Part 3—Stationary Storage Containers for Compressed Gases* or EIGA Doc 24, *Vacuum Insulated Cryogenic Storage Tank Systems Pressure Protection Devices* [34, 35].

Appendix C—Example of a bulk storage tank annual external inspection checklist

#	Inspection item	Condition found	Remedial actions (if required)
1	Check for ice build-up on or insulation underperformance of the outer tank. NOTE—Pay particular attention to any new ice build-up. Where ice build-up is found: • compare the extent of ice build-up with previous inspections or plant operator reports with consideration of the time of year or ambient temperature. • determine the cause of the ice build-up; • record whether it is indicative of an internal product leak, annular space gas leakage or “cold conduction” due to poor insulation; and • identify any remedial action required.		
2	Check for cracks on the outer tank. NOTE—Pay particular attention to areas where cold pipework penetrates the outer tank such as pressure relief devices and vent pipework. Where cracks are found: • compare size and location with previous inspections or plant operator reports; • determine and record the cause of the cracks; • determine whether there is a risk of loss of perlite or possible loss of support to equipment such as pressure relief devices; and • determine remedial action required.		
3	Check for corrosion on the outer tank and supports. NOTE—Pay particular attention to pressure relief devices or vent pipework supports where the environment could be continually wet and maintenance of paint integrity is harder to ensure.		
4	Check pressure relief devices for: • audible leak tightness; • free from permanent icing; • external icing and icing in tail pipes; • evidence of recent lifting; • adequate support; • unobstructed and safely directed outlets; • identification and marking; and • current “in test” date.		
5	Check annular space purge system for correct functioning: • check and record the purge gas flow meter reading and if available, inlet pressure; • confirm annular space flow has been maintained; and		

#	Inspection item	Condition found	Remedial actions (if required)
	• check external purge pipework is protected against corrosion and that the integrity of the pipework is maintained.		
6	Check annular space pressure and oxygen percent analysis at roof level: • check and record the concentration of oxygen in the annular space gas at the top of the tank from a roof located tapping point if provided to confirm no ingress of atmospheric air; and • check and record the annular space pressure at the top of the tank from a roof located tapping point if provided.		
7	Check any annular space pressure monitoring devices for correct signal, value, tagging, and alarm set point.		
8	Check annular space pressure relief devices for correct marking and signs of recent lifting. Check that they are subject to periodic inspection in accordance with a procedure and within their test date.		
9	Check and record details of level measurement device(s), including set points and functions of low and high alarms and trips. NOTE—Typically at 95% with possible additional secondary set point at 98%.		
10	Check any overflow relief device or overflow control valve for signs of recent function and free from obstruction. Check that they are subject to periodic inspection in accordance with a procedure and within their test date.		
11	Check and record details of any overfill detection device(s) such as low temperature detection in overflow line or high differential pressure level measurement (where no overflow line exists).		
12	Check function of ESVs: • initiate closure of valve actuator; • confirm the actuator strokes fully and smoothly and any limit sensors indicate correctly; and • check that there is minimal liquid flow from the outlets of each of the ESVs following venting of downstream pipework liquid inventory. NOTE—It is recommended that valve closure tests are initiated by different emergency buttons on a rotation basis.		
13	Check and record details of pressure control and pressure raising valves. Record date of last calibration.		
14	Check integrity of outer tank support structure: • check concrete elevated slab and outer tank support structure for ice patches; • check concrete legs and elevated slab for cracks, deterioration, and signs of settlement and compare with previous inspections; and		

#	Inspection item	Condition found	Remedial actions (if required)
	• check the condition of any inner tank hold-down bolts, plates, and nuts that protrude from the underside of the concrete slab.		
15	Check that stairs, ladders, handrails, platforms, and kick plates are in a safe condition.		
16	Check perlite level and top up as required. (If the addition of perlite is more than would be considered due to compaction, further investigation could be required).		
17	Check the tank is clearly labelled with product, any required warning signs and useful information for example volume.		
18	Check tank nameplate is attached and that the tank is being operated within the design limits.		
19	Review plant operator reports since last tank inspection, and any adverse issues raised.		