



CGA P-8.9—2023 BULK LIQUID OXYGEN, NITROGEN, AND ARGON STORAGE SYSTEMS AT PRODUCTION SITES

THIRD EDITION

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PREFACE:

As part of a program of harmonization of industry standards, the Compressed Gas Association (CGA) has issued CGA P-8.9, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites*, jointly produced by members of the International Harmonization Council and originally published by the European Industrial Gases Association (EIGA) as EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen, and Argon Storage Systems at Production Sites*.

This publication is intended as an international harmonized standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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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 liters.

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

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 CGA P-31, *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 recognize 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 emphasize 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 vaporizers, 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.

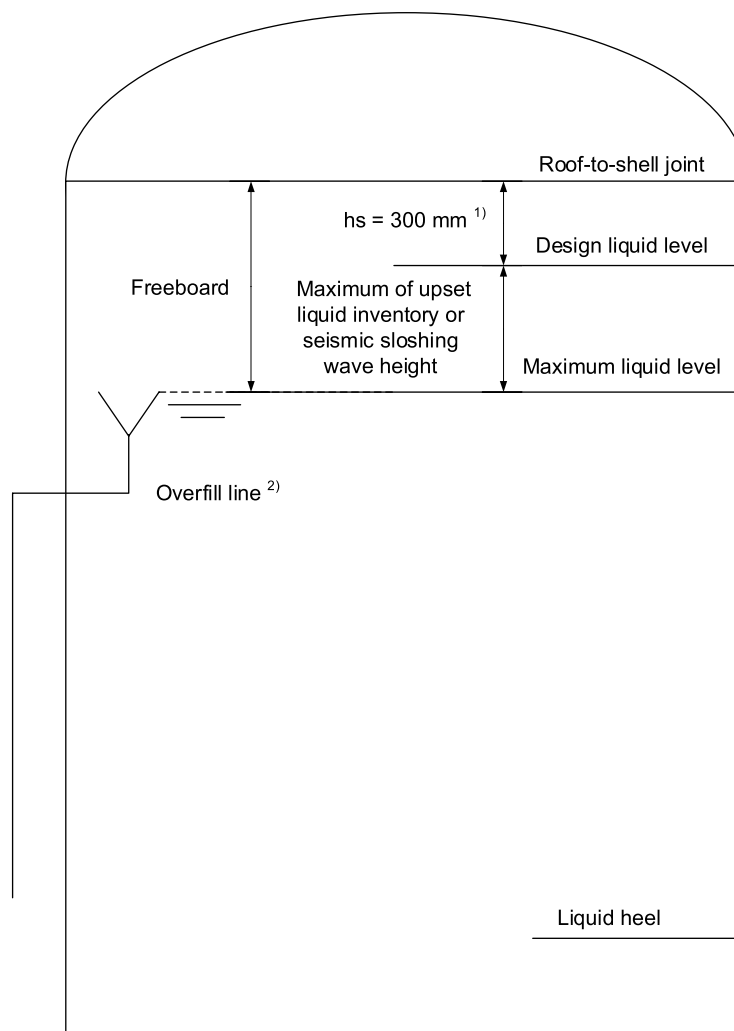
3.2.7 Overflow

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 $h_s = 300 \text{ mm}$ [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 59 °F, 14.7 psia (15 °C, 1.013 bara) ¹⁾	0.085 lb/ft ³ (1.36 kg/m ³)	0.074 lb/ft ³ (1.19 kg/m ³)	0.106 lb/ft ³ (1.69 kg/m ³)
Boiling point at 14.7 psia (1.013 bara) ¹⁾	−297 °F (−183 °C)	−320 °F (−196 °C)	−303 °F (−186 °C)
Liquid density at boiling point and 14.7 psia (1.013 bara) ¹⁾	74.23 lb/ft ³ (1142 kg/m ³)	50.47 lb/ft ³ (809 kg/m ³)	87.02 lb/ft ³ (1396 kg/m 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. All kPa values are rounded off per CGA P-11, <i>Guideline for Metric Practice in the Compressed Gas Industry</i> [5].			

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 colorless, odorless, 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 –297 °F (–183 °C) and has a slight blue color.

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 greater than 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 fibers 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 analyzers 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 CGA P-45, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres* [6].

4.2 Argon

4.2.1 Properties

Argon is a colorless, odorless, 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 colorless liquid that boils at –303 °F (–186 °C) at atmospheric pressure. Liquid argon at its normal boiling point is 39% heavier than water. Above its critical temperature of –188.1 °F (–122.3 °C), 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 airline 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, *Guideline for Safe Handling of Cryogenic and Refrigerated Liquids* [7, 8].

For more specific data on symptoms and effects on personnel exposed to oxygen-deficient atmospheres, see CGA P-76, *Hazards of Oxygen-Deficient Atmospheres* [9].

4.3 Nitrogen

4.3.1 Properties

Nitrogen is an element that at atmospheric temperatures and pressures exists as a colorless, odorless, 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 colorless liquid that under atmospheric pressure boils at -320°F (-196°C). As a liquid (at normal boiling point), nitrogen is approximately 81% as heavy as water. When heated above its critical temperature of -232.4°F (-146.9°C), 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 vaporizer leaks; and
- backflow of gas from vapor 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 CGA G-4.1, *Cleaning of Equipment for Oxygen Service* on cleaning for oxygen service [10].

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 aluminum.

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 vapor, 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 behavior 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 vapor 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 [8].

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, odorless, 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 CGA P-8.3, *Perlite Management* [11].

5 Storage tank system design considerations

5.1 General

Installations shall be designed, manufactured, and installed in accordance with recognized 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/pressurized 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 [12]. 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 vaporization;
- 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* [13].

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, 13].

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* [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* [15]; or
- DIN 4119, *Above-ground cylindrical flat-bottom tank structures of metallic materials* [16].

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* [17, 18].

5.2.3 Inner tank

Aluminum 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 [19]. 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 [14]. 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 [19]. 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/pressurizing 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 vaporization 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 pressurizing 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 pressurized 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/pressurizing gas shall be supplied to ensure a positive pressure is maintained throughout the annular space. Sufficient annular space purge/pressurizing 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/pressurizing gas distribution system shall be provided around the complete circumference of the base of the tank in the annular space. This purge/pressurizing 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 pressurizing 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 (vapor) condensation when filling the tank through top fill nozzles; and
- before cooldown, if the annular space is pressurized 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 minimized 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 vapor space shall be tested according to the requirements of ASME B31.3 [13].

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 analyzed in accordance with ASME B31.3 or equivalent local codes or standards, including the stress limitation required by that code [13].

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.