



# SAFE DESIGN AND OPERATION OF CRYOGENIC ENCLOSURES

**Doc 170/21**

Revision of Doc 170/17

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# SAFE DESIGN AND OPERATION OF CRYOGENIC ENCLOSURES

Prepared by AHG-3.31 of Industrial Gases Council

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has published EIGA Doc 170, *Safe Design and Operation of Cryogenic Enclosures*. 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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#### Amendments from 170/17

| Section | Change                                         |
|---------|------------------------------------------------|
|         | Editorial to align style with IHC associations |
|         |                                                |
|         |                                                |
|         |                                                |

Note     Technical changes from the previous edition are underlined

## 1 Introduction

Cryogenic processes often operate inside enclosures that insulate the process equipment and interconnecting piping from ambient air and temperature. This prevents many problems, including excessive heat leak into the process and water freezing around the equipment. In many cases, the enclosure is purged with a dry gas to prevent ambient air from entering the enclosure and creating hazardous mixtures.

## 2 Scope and purpose

Cryogenic enclosures can create potential process safety hazards. This publication identifies general hazards and provides guidance to reduce their frequency and consequences. It provides safety guidance and addresses design and operating practices only as they affect safety.

This publication addresses both cryogenic air separation unit (ASU) and hydrogen / carbon monoxide (HYCO) processes. A number of existing publications cover special requirements of these processes and their equipment [1, 2, 3, 4].<sup>1</sup>

This publication is primarily to document current practices and is intended to apply to new facilities. It is recognised that some existing plants may not meet all recommendations or requirements from this publication. This publication is not intended to be applied retroactively, including where this publication uses the word “shall”.

This publication does not cover the following:

- generally accepted engineering practices for structures and process equipment. Only those issues that are specific to cryogenic enclosures are included;
- enclosures for processes producing liquid hydrogen or helium. The extreme cold temperatures of these processes require specialised knowledge and practices that are beyond the scope of this publication; and
- external structures on / attached to the cryogenic enclosure for example, platforms, ladders, vents, lightning arrestors, etc. For more information on the safe location of oxygen and nitrogen vents relative to the location of platforms and ladders, see EIGA Doc 154, *Safe Location of Oxygen and Inert Gas Vents* [5].

## 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.

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<sup>1</sup> References are shown by bracketed numbers and are listed in order of appearance in the reference section.

### 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 Air separation unit

Separates air into its components. An ASU is assumed to operate at cryogenic temperatures.

### 3.2.2 Coldbox and cylindrical enclosure

Enclosure containing insulation that separates a cryogenic process from the surrounding environment. The terms coldbox or box are often used to refer to an enclosure with a rectangular cross section, and the term cylindrical enclosure to refer to an enclosure with a cylindrical cross section. However, the term coldbox is sometimes used to refer to all enclosures, regardless of cross section shape.

### 3.2.3 Cryogenic

Temperatures less than approximately  $-90\text{ }^{\circ}\text{C}$  ( $-130\text{ }^{\circ}\text{F}$ ) [6].

NOTE Cryogenic processes require insulation to reduce heat transfer from the surrounding environment.

### 3.2.4 Derime

Periodic preventive maintenance procedure where the process equipment is warmed up while simultaneously being swept with clean dry gas to remove any accumulated moisture, carbon dioxide, and atmospheric impurities.

NOTE Also known as defrosting, de-icing, and thawing.

### 3.2.5 Enclosure

Structure that retains the insulation and surrounds the equipment.

NOTE Cryogenic processes are often insulated by placing the cryogenic equipment and piping in one or more enclosures that are filled with insulation.

### 3.2.6 HYCO

Processes that cryogenically process gaseous mixtures containing hydrogen ( $\text{H}_2$ ) and / or carbon monoxide ( $\text{CO}$ ).

### 3.2.7 Perlite eruption

Rapid, uncontrolled displacement of perlite within the insulation space that can result in a violent perlite release. It is commonly caused by the rapid vaporisation of pooled cryogenic liquid in the perlite that has suddenly been warmed, moved, or physically disturbed.

### 3.2.8 Perlite release

Uncontrolled spillage of perlite to the environment.

## 4 Design considerations

The cryogenic enclosure shall be designed and constructed in accordance with the applicable national and local building code including seismic and wind loads for the installation location. If there is no national or local building code, an internationally accepted building code shall be applied by the manufacturer.

### 4.1 Types of insulation

The enclosure has one or more types of insulation to reduce heat leak into the process piping and equipment. The most common insulation methods used are perlite, mineral wool, and vacuum.

#### 4.1.1 Perlite

Perlite is an inert volcanic glass that forms an odourless, non-flammable, non-toxic lightweight powder aggregate when expanded by heat. It is a highly effective insulating material used to reduce refrigeration losses or heat leak into the cryogenic enclosure.

**CAUTION:** *Since it is a lightweight powder, it can become an asphyxiation hazard if inhaled or if a person becomes submerged in perlite, which can result in death or serious injury.*

#### 4.1.2 Mineral wool

Mineral wool is a wool-like inorganic material produced by blowing steam or air through molten slag or rock. Mineral wool shall be non-combustible and contain less than 0.5% by weight of organic material [7]. Industry experience has shown that this level of organic material is operationally acceptable. One test for combustibility of materials is addressed in ISO 1182, *Reaction to fire tests for products-Non-combustibility test*, which may be used to test for organic materials [8].

Mineral wool should have a pH between 6 and 9.5. If the pH is outside of this range and the mineral wool becomes wet, it becomes corrosive to piping and equipment.

#### 4.1.3 Vacuum

With vacuum insulation, the item to be insulated is placed within some type of enclosure. A vacuum is pulled on the annular space between the item and the enclosure, which reduces heat transfer by convection. The heat leak can be further reduced by placing insulation (typically perlite, metal foils, or other super insulation) within the space to further reduce heat leak through conduction or radiation.

Vacuum insulation provides more resistance to heat leak than mineral wool or perlite. Vacuum insulation may be considered, particularly for small coldboxes or piping. Such insulation leads to a better insulation and more compact enclosures, which are convenient for transport and on-site erection.

With vacuum insulation, no nitrogen purge is needed. For enclosures with vacuum insulation, the vessel walls shall be designed to withstand full vacuum conditions. Helium leak tests are generally required during assembly to detect small leaks.

If the filling of insulating material (for example, perlite) is performed by vacuum suction, precautions shall be taken to avoid damaging piping lines or connections in the annular space, for example, controlling the rate of filling, reinforcing the supports of small lines or connections.

Vacuum gauge or fittings should be installed to verify the vacuum level within the annular space, which will allow the insulating properties to be confirmed during operation.

Relief devices (rupture disks and / or lift plates that can be maintained by vacuum suction) shall be installed to protect the annular space against overpressure. When an insulation barrier is placed upstream of the relieving device, it shall be designed not to restrict the relieving capacity.

Getters or adsorbents may be used in the annular space to trap various gases, which can be released in the annular space. Because oxygen can enter the annular space inadvertently (for example, leaks

from ambient air), the compatibility of these getters or adsorbents with oxygen shall be considered [9, 6].

Superinsulation typically consists of thin metal foils to reduce radiant heat transfer. The thin metals can be combustible in oxygen. A risk assessment shall be performed when using super insulation.

## **4.2 Enclosure casing**

The enclosure casing is typically made from carbon steel plates. The plates can be bolted or welded together to enclose the insulation. The plates can then be attached to a frame or support structure, or the plates can be self-supporting. Damage to the enclosure beam structure could damage equipment or reduce the support to process equipment and piping.

The enclosure cross section can be rectangular or cylindrical. The enclosure can be over-pressurised in case of leaks or higher purge gas pressure (see 7.2).

### **4.2.1 Cylindrical enclosures**

Cylindrical enclosures surround the cryogenic equipment and piping. Equipment is typically not supported from the enclosure structure; rather it is supported with a separate support system.

If a cylindrical enclosure is pressurised to the point of failure, the pressure-volume (PV) energy will likely be significantly larger than a similarly sized rectangular enclosure. This is particularly true if the enclosure is designed for vacuum insulation. The possibility of higher stored PV energy shall be considered in the design of cylindrical enclosures (see 7.2).

### **4.2.2 Rectangular enclosures**

Rectangular enclosures have a structural skeleton of beams, and some or all equipment and piping are supported from these beams. Metal plates are attached to structural frame. The plates can be attached to the frame on either the inside (towards the insulation) or the outside (towards the ambient).

Rectangular enclosures can contain less pressure before failure. Damage to the enclosure beam structure could damage equipment or reduce the support to process equipment and piping.

### **4.2.3 Perlite filling / removal nozzles**

Perlite filling / removal nozzles should be located to allow safe access for adding and removing perlite. Nozzles may be added to the coldbox at multiple levels including the roof. It is recommended to locate removal nozzle(s) at the platform levels for access. The distance between nozzles is typically 10 m to 12 m (32 ft to 39 ft). Details of perlite filling and removal procedures are given in EIGA Doc 146, *Perlite Management* [10].

### **4.2.4 Enclosures with multiple sections**

Enclosures may have multiple sections depending on process and equipment layout. Design consideration should be given to installation of isolation barriers between enclosure sections that would prevent perlite from flowing from one section to another. Isolation barriers reduce the possibility of perlite bridging that can lead to collapse when removing perlite from adjacent sections. Isolation barriers should allow for purge gas flow. See 6.1.3.

### **4.2.5 Overpressure protection**

The cryogenic enclosure shall be equipped with overpressure protection device(s). The number, size, and location of the overpressure protection device(s) shall take into account, at a minimum, the dimensions of the cryogenic enclosure, the presence of internal partitions, and / or potential leak points such as flange connections (see 7.2). When an insulation barrier is placed upstream of the relieving device, it shall be designed not to restrict the relieving capacity.

### 4.3 Piping design

Piping shall be designed and manufactured to a recognised piping code such as American Society of Mechanical Engineers (ASME) B31.3, *Process Piping* that takes into account temperature, pressure, fluid, and service conditions to which the piping will be operated [11].

Piping and vessels shall be protected by overpressure relief devices in accordance with the applicable code.

Leaks from process equipment and piping, whether large or small, can overpressure the enclosure and / or create hazardous atmospheres. Therefore, design and construction methods shall be used to reduce the probability of leaks.

Piping within the perlite insulation space should have welded joints because these joints significantly reduce the possibility of leaks. Butt welds are preferred as these joints can have improved non-destructive testing (NDT) such as full radiographic examination. Mechanical joints (such as bolted flanges or threaded connections) shall be avoided, where feasible. Where mechanical joints are used, a blanket or stuffing box of mineral wool shall be used to isolate a potential mechanical joint leak. Cryogenic pump and turbine boxes that are segregated from the main cryogenic enclosure may be insulated with perlite without blankets or stuffing boxes on mechanical joints, if the consequences from a leak are assessed to be low. The mineral wool stuffing box prevents a leak from causing perlite erosion of the equipment (see 7.5) and also allows for easier maintenance. These isolated small enclosures should have their base or floor sloped above perlite's angle of repose. This ensures that perlite will naturally fill underneath and around these enclosures and insulate the enclosures [10].

All process pipes and utility lines, shall be designed so that the thermal and mechanical stresses are less than the maximum allowable for the design life of the plant, which minimises the risk of line failure. Taking into account the piping support system including pipe penetrations, stresses shall be considered for the following:

- nozzles;
- transition joints;
- process bellows, flexible joints, or braided hose;
- valve or other piping equipment weaker than connected pipes, and
- flanges.

All instrument tubing shall be installed so that the thermal and mechanical stresses are acceptable for the design life of the plant.

All operating modes shall be considered in the design, including:

- expected number of cooldown and warm-up cycles, such as start-up with or without liquid injection, shutdown and deriming for the design life of the enclosure;
- relative movement of small bore lines attached to larger bore lines during cooldown, warm up, and thaw cycles, which can cause high stresses leading to failure; and
- piping that cycles as part of normal operation such as piping for cryogenic adsorbers.

Dead-ended, non-flowing piping requires seal loops to prevent cryogenic liquids from flowing by gravity towards the enclosure surface. Seal loops should be routed to provide adequate vaporisation of cryogenic liquid to form a vapour lock. Omitting the seal loops will result in excessive process heat leak, boiling of the cryogenic liquid, and potential accumulation of unsafe mixtures. This excessive heat leak can result in ice forming on the enclosure surface (see 8.2). Some examples of this piping are drains from cryogenic equipment and the high pressure side of liquid level taps [2].

Other piping design items that shall be considered are:

- protection of small bore lines (see 4.10);
- free movement of tubing within pipe supports;
- piping loads from perlite insulation;
- supporting process piping that operates with two phase flow during any mode of operation to prevent excessive vibration from causing cyclic fatigue cracking;
- design and selection of specialised joints used to join dissimilar metals such as those utilising explosion-bonded material; and
- if the piping can be exposed to oxygen-enriched fluids, it shall be designed for oxygen service [4, 5, 12].

#### 4.4 Enclosure materials of construction

Structural elements shall be manufactured from materials compatible with the temperature that they are exposed to during normal operations. See 4.6. Due to low temperature embrittlement, the temperature rating of the specific carbon steel grade used shall be confirmed for the normal operating temperature.

Bolted panels on the cryogenic enclosure shall be sealed using a gasket, mastic, or other sealant to prevent water from entering the enclosure.

When constructing the enclosure, materials such as valve boots, wiring insulation, and sealants that are not oxygen compatible may be used in small amounts.

Enclosures surfaces shall be protected from corrosion due to atmospheric conditions. Areas that are particularly susceptible to atmospheric corrosion are:

- flat horizontal sections such as roofs or the top of horizontal ducts; and
- areas where the enclosure surface can have water trapped against it such as the contact zone between plates and external beams.

Corrosion can eventually lead to a breach in the enclosure surface, potentially causing three problems:

- Moisture / rainwater can enter the enclosure, which will reduce insulation effectiveness and create ice. The ice can restrict the movement of piping or equipment as the process cools down or warms up. Restricting the movement can damage the piping or equipment, in turn leading to process leaks;
- Release of purge gas; and
- Release of perlite.

Corrosion protection can be provided by painting, other surface treatment, or material selection. Corrosion protection is usually only provided on the external enclosure surface. Internal corrosion protection is typically not needed because the enclosure is purged with dry nitrogen. Internal corrosion protection is only used if extensive corrosion is anticipated during construction.

Elastomer sealants and metal bolts shall be appropriate for the expected atmospheric corrosion environment to which they will be exposed. This design precaution will avoid a possible breach in the enclosure from a corrosion failure.

Top horizontal plates (such as the roof) shall be designed to provide natural drainage of rainwater. A welded roof provides the maximum protection from rainwater ingress or ice damage. Any penetrations,

access panels, or elastomeric boots can be prone to water leakage. These shall be designed and maintained to prevent water ingress.

The enclosure shall be periodically inspected and maintained. Particular care should be taken in case the coldbox is located in areas with potentially corrosive atmospheres such as a heavy industrial area or in the proximity to the sea.

#### 4.5 Load calculation

The design of the enclosure shall consider the expected loads imposed during the life of the enclosure. These include, but are not limited to, the following:

- Transportation (if any), which can include road, rail, and ship;
- Lifting (if any);
- Erection;
- Fluid pressure from the purge gas or fluidised perlite (see 7.2);
- Different operating modes, both warm and cold. Both shall include the cases with and without process fluid, and also if the system is pressurised or not. Any transient modes shall also be considered (see 4.3);
- Perlite load on piping, equipment, enclosure and foundations, and
- Environmental conditions on-site such as snow, wind, and earthquakes.

#### 4.6 Structure beams and process equipment support

The main part of the support structure is usually constructed of carbon steel. However, portions of the support structure can become colder than the embrittlement temperature of carbon steel. These supports shall be made of materials compatible for the anticipated temperatures.

Consideration shall be given to reducing cold conduction between the cryogenic and non-cryogenic portions of the enclosure, particularly through the equipment support structures. This may require placing distance between the process pipes or equipment, coldbox structure members, and / or the enclosures surfaces to prevent cold migration.

Structural members in the cold zone of the enclosure will contract if they become cold. The loads that this contraction imposes on the outer structure and plates shall be considered in the enclosure design.

Combustible material shall be avoided for any supports.

#### 4.7 Foundations

Foundations for cryogenic equipment have the potential for the lower side of the concrete to reach a temperature of 0 °C (32 °F) or less, resulting in the freezing of the subsurface and subsequent frost heaving effects. Frost heaving generally depends on soil conditions, ambient temperatures, and the amount of water available in the soil. The build-up of large layers of ice under cold foundations can take years. To prevent frost heaving at coldbox foundations, the soil under the foundations shall be kept from freezing. A site-specific evaluation should be performed to rate the potential for this effect to occur. Where such a possibility exists, consideration shall be given to one of the following mitigation techniques:

- On small foundations, the heat leak into the area from the atmosphere can cancel the cooling effect through the foundation;

- Provide an air circulation space that is open to atmosphere between the cold equipment or enclosure bottom and the top of the concrete;
- Provide an elevated foundation that has an air circulation space between the top of the soil and the bottom of the concrete foundation slab;
- Provide electric heating cables in the concrete foundation. The heaters and junction boxes should be accessible for periodic checks and maintenance; and
- Install open air conduits in the foundation that rely on convection.

Installation of a temperature sensor(s) on the foundation should be considered to measure the cooling of the soil. If installed, this temperature sensor can also provide information if internal leaks have collected at the bottom of cryogenic enclosure being exposed to low temperatures.

The equipment anchors from within the cryogenic enclosure to the foundation shall be manufactured from material compatible with the anticipated low temperatures such as stainless steel. Cryogenic enclosure casing anchors to the foundation and any rebar within the concrete shall use materials compatible with the foundation's minimum anticipated low temperature at the installation site.

#### 4.8 Enclosure bottom

Typically, industry practice for ASUs is to construct the lower enclosure sections from carbon steel. The floor is either carbon steel or concrete. It is recognised that carbon steel will crack and release small amounts of fluids and (in some cases) perlite, if it comes into contact with cryogenic liquid(s). Industry experience shows that small leaks do not immediately affect the structural integrity of the overall enclosure and do not pose a significant risk to personnel. Cryogenic enclosures that are not directly mounted on a concrete foundation, but elevated by legs, plinths, or other structural columns require a solid enclosure bottom. The enclosure bottom material selection shall be based on the minimum ambient temperature and the minimum expected operating temperature of the insulation material adjacent to the enclosure bottom. This enclosure bottom may be fitted with temperature probes to alarm on temperatures lower than the expected operation conditions, which can indicate there is an internal leak. It should be noted that cold spots can be very localised and the installed temperature elements might not detect all leaks, so they should not be seen as a replacement of regular visual checks for cold spots. The elevated enclosure bottom should not be operated at temperatures less than the materials minimum allowable design temperature.

See 8.1 for the procedures that should be used to determine the risk of such a leak and the time period in which the leak shall be repaired.

For HYCO boxes, see 4.13.

Cryogenic pumps are more susceptible to liquid leaks because:

- they are often installed with bolted flanges for maintenance;
- they have rotating parts that require seals, which can develop leaks; and
- their motion creates vibrations, which can lead to leaks.

Therefore, for pumps installed in enclosures, one or more of the following leak detection methods may be installed:

- temperature detector(s) below the pumps (typically near the enclosure floor);
- seal leak detectors; or
- temperature switch on the pump shaft.