PERIODIC INSPECTION OF STATIC CRYOGENIC VESSELS

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1 Introduction

The current European regulation (PED) only covers design, manufacturing and placing on the market. The Pressure Equipment Directive (PED) applies to placing on the marked and putting into service of pressure equipment and accessories for the first time. It does not specify the requirements for the in service examination of pressure equipment. The national legislation's and practices for periodic in service inspection and testing of pressure equipment varies considerably between European Countries, for similar vessels, on similar service. A similar situation exists in the countries in Asia.

The commonly accepted codes for design and manufacturing of pressure equipment and accessories in Asia include the European PED, the U.S. ASME Boiler and Pressure Vessel code, and the national codes of specific countries e.g. GB (Guo Biao) in China and JIS in Japan.

This document is based on the practices in Europe and provides good guidance for operations in Asia.

2 Definitions

Static Vacuum Insulated Cryogenic Pressure Vessels. - As detailed in EN 13458.[1]

3 Scope and Purpose

3.1 Scope

This document considers the periodic inspection and testing of static vacuum insulated cryogenic pressure vessels used in the storage of refrigerated liquefied gases, excluding toxic gases. Considering the design and materials of construction of these vessels, this also includes carbon dioxide and nitrous oxide.
It does not consider the vessels/equipment directly used in the production of these products or those used for transport, which are covered by the Transport Pressure Equipment Directive (TPED) or transport of dangerous goods regulations e.g. ADR in Europe.

3.2 Purpose

This document considers the influence of periodic inspection and testing of static vacuum insulated cryogenic pressure vessels on the continuing safety of these vessels, as the underlying concern of the industrial gases industry is the safe operation of all its equipment.
An extensive review of existing national regulations in Europe is made.

4 Technical Background

4.1 Production

The basic process for producing oxygen, nitrogen and argon requires compression, cooling, purification, liquefaction and distillation of air, which takes place at cryogenic temperatures.
The gases formed in vapour or liquid are non-corrosive, non-toxic and non-flammable. Air contains these gases in the following percentages, oxygen 21%, nitrogen 78%, argon 0.9%. The balance (0.1%) includes water, carbon dioxide, rare gases, and other impurities in very small quantities. Whilst none of the gases is toxic the reduction of oxygen levels below normal can cause asphyxiation. Increased concentrations of oxygen can accelerate, but not initiate, combustion of other materials. The process is directed to the production of gaseous and liquid products. In its simplest form compressed and cooled air is purified and cooled to liquefaction temperatures in the passes of a heat exchanger against waste nitrogen and pure product gases.

[1] EN 13458 Cryogenic Vessels Static Vacuum Insulated. CEN July 2002.

Impurities such as small traces of CO_2 or hydrocarbon contaminants being carried by the air are removed before introduction into the column.
The careful and essential purification of the process streams ensures that the cryogenic fluids produced do not contain elements that could initiate corrosion.
The compressed air at liquefaction temperature is then distilled in a column. The column and associated process vessels separate the air into its major constituents, which are drawn off as gaseous and liquid products. These products are very cold, at high levels of purity, and by the nature of the process are free from water vapour.

Table 1. Typical Physical Properties.

Gas	**Boiling Point at 1.013 bar**	**Critical Temperature**	**Critical Pressure**	**Density at 1.013 bar**
Air	- 194°C	- 141°C	37 bar	0.86 kg/litre
Oxygen	- 183°C	- 118°C	50 bar	1.14 kg/litre
Nitrogen	- 196°C	- 147°C	33 bar	0.81 kg/litre
Argon	- 186°C	- 122°C	48 bar	1.40 kg/litre

4.2 Pressure Vessel

For the purposes of this document pressure equipment is defined, as in the PED, with a maximum, allowable pressure of more than 0.5 bar.
The PED excludes pressure equipment < 0.5 bar.
Vaporisers are categorised as pressure vessels.

4.2.1 Cryogenic Vessel

Static vacuum insulated cryogenic vessels are usually of a capacity less than 400,000 litres. The inner vessel contains the liquefied gas under pressure and represents the actual pressure vessel, and is designed to withstand internal pressure, external vacuum, and cryogenic temperatures. The inner vessel is surrounded by an enclosure in the form of a jacket within which a vacuum is maintained to achieve the necessary degree of insulation between the surface of the jacket and the enclosed vessel. The inner vessel is of simple cylindrical shape with dished or spherical heads. The vacuum interspace is filled with an insulating material. The vacuum jacket acts as insulation containment and the support structure for the inner vessel. It is manufactured from carbon steel and is not usually classified as a pressure vessel. In the event that the inner vessel leaks the vacuum jacket pressure relief device operates to avoid damage. These vessels are installed at customer premises and together with other equipment are known as cold converters, or customer stations. For the purposes of this document they are referred to as vacuum insulated cryogenic vessels.
Vacuum insulated storage vessels operate at reasonably constant working pressures with only very occasional total de-pressurisation and re-pressurisation.
The liquid space temperature remains almost constant. Only small external loads are applied to the inner vessel from pipework as it is designed to avoid stresses occurring due to contraction or expansion on cool-down or warm-up. Supports and anchor bars from the inner vessel to the outer jacket are designed to provide minimum heat transfer.
The loss of vacuum in the interspace is normally not a safety problem if it occurs during tank operation, the additional insulation material used is sufficient to keep the vessel contents evaporation rate within the inner vessel relief valves normal rating. Any loss of vacuum should be investigated as this could affect the integrity of the vessel and support system.

4.2.2 Cryogenic Vaporisers

All cryogenic vaporisers are of tubular construction and transfer heat to obtain vaporisation of the cryogenic liquid using ambient air, water, steam or other hot liquids or gases.

Some vaporisers are normal heat exchangers of shell and tube type well known and proven over many years in the chemical industry, designed, fabricated and tested in accordance with recognised pressure vessel codes.

In water immersed vaporisers the tubes are manufactured in corrosion resistant materials such as copper or austenitic stainless steel, but depending on the quality of the water, corrosion attack from the water side is possible. External visual inspection is possible by emptying the water bath, but internal inspection is limited due to the small tubular construction.

Ambient air heated vaporisers are tube bundles or tube assemblies of aluminium alloy, copper or stainless steel tubes, equipped with fins for improved heat transfer. External visual inspections are possible at accessible parts of the assembly.

All vaporisers consist of reasonably simple designs with little fabrication complexity. Temperature changes from ambient temperature to cryogenic, and pressure cycling can sometimes occur several times per hour. The operating pressure can be up to 350 bar, but are usually much less. There are no external loads to be taken into consideration, but tubes are sometimes exposed to vibrations.

Some mechanical problems due to vibrations have occurred in service but these have only involved operational inconvenience, not safety, and can be detected by carrying out visual external examinations.

Table 2. Cryogenic Equipment – Design and Operating Conditions Summary.

Object (Vessel)	**Design Complexity**	**Operating Temperature Range**	**Operating Stability**	**Temperature Cycling**	**Pressure Cycling**	**External Loads**
Vacuum Insulated Storage Tanks	Low	Cryogenic	Good	No	No	No
Cryogenic Vaporisers Shell & Tube Type	Low	Partial Cryogenic	Good	Yes	Low	No
Object (Vessel)	**Corrosion Potential**		**Energy Potential**	**Effects of Containment / Insulation**	**Accessibility for Inspection**	**Damage Potential**
	Internal Environment	**External Environment**				
Vacuum Insulated Storage Tanks	No	No	Low to [1] Medium	Good	None	Low
Cryogenic Vaporisers Shell & Tube Type	No	Low to Medium	Low	None	Good	Low

Note.

[1] Depends on size and pressure

4.3 Legislation

An extensive review of current legislation and practice for periodic inspection and pressure testing of cryogenic pressure vessels revealed that there is a very wide difference of regulations existing between the European countries.

A summary of the regulations at the time of publication is shown in Table 3.

Due to the complexity of the regulations and the various qualifications and addenda, the summary tables can only indicate the general situation. The regulating bodies may have introduced changes during the review period. Therefore users of this document should refer to the latest legislation of the country in question.

As an example, the periodical inspection and pressure test requirements for cryogenic pressure vessels for Finland, the Netherlands and the United Kingdom are:

Inspection **Pressure Test**

Finland	Every 16 years	Every 16 years
The Netherlands	Every 6 years	None
United Kingdom	5 years	None

Investigations of current practices were carried out by the Working Group. It was revealed that some authorities give exemptions from the regulations by taking into consideration the operating conditions in the air separation process and the safety record. Some authorities require additional particular requirements at the design, manufacture or initial pressure test stage before giving exemptions.
For static vacuum insulated cryogenic vessels, EN 13458-3 covers periodic inspections and all the other operational requirements. This part 3 is referred to in EN 13458-2 (design) which is a harmonised standard for the PED. EIGA recommend that the requirement stated in this part 3 be used at a European level to harmonise the periodic inspection and maintenance of cryogenic vessels.

As can be seen from Table 3 the periodicity of inspections and the type of inspection required vary greatly within Europe for similar vessels, on similar service.

Table 3. Periodical Inspection and Test (Status as of January 2003.)

Summary of re-testing practice – Cryogenic pressure vessels

Country	**External Examination**	**Internal Examination**	**Pressure Test**
Austria	Every 4 years	NONE	Leak test every 12 years
Belgium	N_2, A_2: every 5 years O_2: every 6 years	NONE	Lift test of the relief valves: every 3 years
Denmark	Every 3 years	NONE	NONE
Finland	Every 4 years	Every 8 years	Pneumatic test at 1.1 PS every 8 years
France	Every 40 months	NONE	NONE
Germany	NONE [1]	NONE [1]	NONE [1]
Eire	NONE	NONE	NONE
Italy	Every year (safety valve check)	NONE	Every 10 years (Pneumatic At 110% of PS) Safety valve lift + vacuum check (3 hours)
Luxembourg	NONE	NONE	NONE
Netherlands	Every 6 years	NONE	Lift of the safety valves every 4 years
Norway	NONE	NONE	NONE
Portugal	Every 2.5 years	NONE	Every 5 years at 1.1 PS
Spain	NONE	NONE	Leak test at PS and check of the safety valves every 5 years. Pneumatic test at 1.1 PS every 15 years
Sweden	NONE	NONE	NONE
Switzerland	Every 2 years (only accessible parts, e.g. external of vacuum jacket)	NONE	NONE
United Kingdom	NONE [2]	NONE [2]	NONE [2]

Note.
[1] Tests are requested if a repair is necessary
[2] Written scheme of examination, prepared by the competent person, that specifies the examination frequency and procedure.

5 General considerations

5.1 Background

Static vacuum insulated cryogenic vessels used for cryogenic fluids are different from those used for other gases and liquids, as outlined below.

5.2 Materials

The materials of construction used for vessels in cryogenic service are aluminium and its alloys, copper and its alloys, austenitic stainless steel, and other suitable steels containing nickel. These materials are resistant to brittle fracture at low operating temperatures and quick extension of cracking, and have been proven over many years of service (Note : for Carbon Dioxide and Nitrous Oxide, with their higher operating temperatures, carbon steels are sometimes used and their resistance to brittle fracture shall be considered (see EN 1252). These materials are also more resistant to corrosion than other materials used for vessels in general service.
Mechanical tensile strength properties of the above materials are enhanced at cryogenic operating conditions. The enhanced strength is not always taken into account for the stress calculation of wall thickness according to the pressure vessels codes. This provides an additional safety margin at the operating condition, e.g. 4.5% Mg Aluminium Allow increases in strength by 9% (0.2% proof) or 49% (UTS), 9% nickel steel increases in strength by 38% (0.2% proof) or 60% (UTS), and austenitic stainless steel increases in strength by 10% to 70% (0.2% proof) or 120% to 150% (UTS) from values at +20°C to –196°C.

5.3 Construction

Cryogenic vessels are operated at pressures at or above atmospheric pressure and are therefore designed, manufactured, tested and inspected to the high standards of recognised pressure vessels codes.
Vacuum insulated vessels are manufactured and tested to ensure and maintain a vacuum of less than 0.01 millibar in the interspace between the outer shell and the inner vessel.
Vessel parts, piping and fittings, are connected by welding or brazing. Flanged and screwed connections are eliminated as far as possible to avoid leaks of gas or liquid which if they occurred at any connection could damage the vessel foundations or insulation containment. In the case of vacuum insulated vessels, such leaks would badly affect the properties of the insulation. This is one reason why cryogenic vessels normally have no manholes as access into the inner vessel, and, have the final seams welded from the outside. This practice is in accordance with the codes and is approved by the major pressure vessel approval authorities.

5.4 Corrosion

The wall of the inner vessel in contact with the cryogenic fluid is not subject to corrosion, as the cryogenic fluids are dry, clean and corrosion is non-existent at such low temperatures. Furthermore, the outside wall of the inner vessel is protected from corrosion by the vacuum in the space between the jacket and the inner vessel.

5.5 Insulation

Due to the extremely low temperatures special insulation is necessary. This consists of either a wound fibre/aluminium foil or expanded powder in the interspace between the vessel and the jacket, as well as the vacuum. The insulation thickness may be in excess of 0.5 metres and this makes access for external and internal visual inspection of the inner vessel difficult.

5.6 Cleanliness

The need for very high standards of cleanliness for equipment used in oxygen service requires particular attention during manufacture and construction. This includes special care during pressure testing by using clean gases. Experience shows that the service conditions, during normal operation, ensure that the equipment retains its required standard of cleanliness. Opening cryogenic vessels under site conditions may introduce contaminants, foreign matter and moisture, which may result in a greater potential risk than if no such action was taken.

5.7 Pneumatic Pressure Testing

Pneumatic pressure testing instead of hydraulic is normally essential for cryogenic vessels since any residual water or humidity that remained in the equipment after a hydraulic test will block up lines or create damage due to freezing on small lines, valves, instrumentation and equipment. This practice is in accordance with the pressure vessel codes and is approved by the major pressure vessel approval authorities.

6 In Service

6.1 Inspections

An external inspection of the inner vessel (of a cryogenic pressure vessel) is not usually practical due to the presence of the insulation and vacuum in the interspace. Any interference could adversely affect the thermal properties of the insulation by destroying the vacuum, which could prove difficult to reinstate on site. Visual internal inspection of the vessels is also not practical due to the elimination of bolted manholes and connections, and the difficulty of ensuring a gas tight seal at the low temperatures involved.

6.2 Failure Mechanisms

Normal failure mechanisms are: -

Corrosion - This does not occur in service due to the materials of construction and the inert properties of the cryogenic fluids that they are in contact with.

Fatigue - These vessels are subjected to a very low number and rate of pressure cycles due to the method of filling and operation. The design of the vessel itself is based on a simple balloon type inner vessel with a limited number of nozzles and attachments.

Erosion - There is no known erosion mechanism present in this type of vessel.

In most countries, these features and the particular operating conditions have been recognised and the required periodic testing and inspection have been adjusted accordingly.
Numerous internal inspections of cryogenic vessels have been carried out by the companies represented by the working group members and in all cases no defects or evidence of deterioration compared to the new conditions have been revealed.
There are also few problems relating to these types of vessels in service. The inspection reports and incident reports support the view that the current design features are satisfactory. If design changes were introduced to enable periodic inspection to be carried out it is considered that it would adversely affect the pressure integrity and the internal cleanliness of the vessels, moreover the introduction of design changes may in the future affect the established good safety record.

7 Pressure relief devices

7.1 Background

The process vessels and storage equipment used on cryogenic systems are protected against overpressure above design conditions by use of pressure relief valves and or bursting discs. Further guidance is given in EN 13458 part 3.

7.1.1 Types of Periodical Inspection and Test

Pressure relief valves are periodically examined by different methods :

- Visual inspection, in situ
- Lift test, in situ
  - By use of lift lever, if provided
  - By use of pressure
- Bench test

7.1.2 Visual inspection, in situ

Includes :

- Examination for seat tightness
- Freedom from blockage of vent by ice formation or other foreign matter
- Corrosion
- Freedom from external damage
- Confirm by checking valve data that the correct valve is installed and that the valve has not been tampered with, i.e. that the locking wire and seal are intact

When a relief valve protecting cryogenic equipment is leaking, it is easily seen as the valve outlet will be covered by ice due to the condensation and freezing of water vapour from the surrounding air. The presence of ice can impair the safe functioning of the valve, and any defect must be remedied.

7.1.3 Lift test, in situ

Includes :
Visual inspection and a check that the relief valve functions correctly by lifting the valve disc from its seat, either by using the lift lever, when provided, or alternatively by means of raising pressure.

7.1.4 Bench test

Means the removal of the valve from the equipment being protected, carrying out a full examination and a final check that the valve lifts at its correct pressure setting.
It is normal for two safety devices to be on line at any one time. Either two safety valves or a safety valve and a bursting disc. When bursting discs are used, it is essential that correct design, selection, and supervision of fitting are provided. As bursting discs do not fail at a higher pressure than the original pressure rating after a period of service, they are not considered to be a safety problem.
Bursting discs are not normally fitted to carbon dioxide vessels.

8 Incident statistics

EIGA member companies collate their own incident data and send it to EIGA for circulation. There are approximately 60 000 cryogenic vessels in service within Europe, some of which have been in service since the 1960's. They have amassed a large number of safe operating hours during this time.
Individual member groups of EIGA e.g. the BCGA[2] in the UK compile their own data at the request of the enforcing authority to ensure the continued safe operation of these vessels in service. This includes the demolition and internal examination of a number of vessels every year to ensure that there are no unsuspected failure mechanisms at work. None have ever been found.
Inspections of cryogenic vessel shells that have been carried out by member companies over a large number of years are also available.
The inspections were generally carried out during equipment modification or maintenance when the opportunity was taken to examine the vessel shells either fully, internal of external only, or locally (where the amount of shell able to be examined was limited by the access available).
On a number of occasions thorough examinations have been made, in conjunction with Inspecting Authorities, on particular vessels to confirm the industry's view that vessels in cryogenic service do not deteriorate. These examinations have resulted in the Inspecting Authorities giving exemptions from periodic inspection or test.

[2] Code of Practice CP25 Revalidation of Bulk Liquid Oxygen, Nitrogen, Argon and Hydrogen Cryogenic Storage Tanks. 1998. British Compressed Gases Association.

It is considered that the large amount of evidence produced, the safe operation of the vessels, and that no cases have been observed of cryogenic vessels exhibiting defects reducing the integrity and strength of the vessel shells, provides considerable support for not requiring their periodic inspection and test during service.

9 Conclusions

It is concluded that it is not a necessity for a periodic inspection or test of static vacuum insulated cryogenic vessels for the following reasons.

- No recorded incidents affecting safety from a large vessel population with a large number of in service hours.
- No corrosion, fatigue or erosion
- Insulation protection
- Enhanced material properties at low temperature
- Cleanliness conditions
- The stored cryogenic fluid does not effect the vessel material
- The internal examination of a vessel could prove more harmful than the benefits gained from the examination
- Sample vessels are being demolished and internally examined on a routine basis and no defects effecting safety have been found
- Most competent authorities recognise the special nature of these vessels and exemptions are granted from more onerous inspection regimes.

Taking into account the design and operating factors of these vessels the conclusion is that periodic inspection and testing is generally unnecessary.
However, attention is drawn to the importance of pressure relieving devices.

10 Recommendations

Exemption from periodic inspection and testing still requires regular observation and maintenance of the equipment and the following recommendations are made:

- When a cryogenic vessel is taken out of service for modification or maintenance, then accessible areas should be examined by a competent engineer and a record made of the results of the inspection.

10.1 Vacuum Insulated Storage Vessels.

An annual visual check of the condition of the outer jacket, support structure, exposed pipework and controls should be carried out. Vessel lifting lugs should be inspected prior to use, e.g. for absence of corrosion.
The vacuum jacket pressure relief device should be visually inspected whenever the tank is installed or after painting. In addition, other checks may be appropriate e.g. the level of vacuum in the interspace, the evaporation rate of cryogenic liquid or the rate of pressure rise of the inner tank, should be checked periodically to confirm the soundness of the insulation. These checks should be in accordance with EN 13458-3.

10.2 Cryogenic Vaporisers

For shell and tube vaporisers, a periodical examination of shell and external tubular side and a leak test pneumatically of tube side at design pressure is recommended.
Ambient air vaporisers consisting of a bank of tubes manifolded together do not justify a regular periodical examination or test.

10.3 Pressure Relief Devices`

The importance of pressure relieving devices and their influence on safety is recognised and the following recommendations are made:

Pressure relief devices shall be visually inspected regularly. If any defects are observed, e.g. seat leakage, corrosion, ice or other blockage, the relief devices shall be bench tested or replaced.

When storage tanks are used on customer premises the user and the supplier of the liquid gases should carry out frequent visual examinations of the relief devices. If any defects are observed the relief devices shall be replaced.
It is good operating practice that inspections and test of relief devices are recorded in a logbook. After any lift or bench test is carried out a report should be issued giving the status of the device.
The above recommendations are summarised in the table below.

Table 4. Cryogenic Equipment – Recommended Examinations.

Object (Vessel)	**Periodic Inspection**	**Periodic Testing**	**Relieving Devices**
Vacuum Insulated Storage Tanks	No [1] Monitor jacket insulation space for leaks.	No [1]	Inspect regularly (All). Test every 5 years (only for primary tank relief valves).
Cryogenic Vaporisers Shell & Tube Type	Yes	Yes	

Note.
[1] Only at time of modification or repair.