



CRYOGENIC VAPORISATION SYSTEMS – PREVENTION OF BRITTLE FRACTURE OF EQUIPMENT AND PIPING

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PREFACE

As part of a programme of harmonization of industry standards, the Asia Industrial Gases Association (AIGA) has published AIGA 027 “*Cryogenic Vaporisation Systems – prevention of Brittle Fracture of Equipment and Piping*”, jointly produced by members of the International Harmonization Council and originally published by European Industrial Gases Association (EIGA) EIGA Doc 133 “*Cryogenic Vaporisation Systems – prevention of Brittle Fracture of Equipment and Piping*”

This publication is intended as an international harmonized publication for the worldwide use and application by all members of Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), 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. Also, any references to regional regulatory requirements are those that apply to European requirements.

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Amendments to 027/15

Section	Change
All	Significant revision to all sections

NOTE Technical changes from the previous edition are underlined

2 Introduction

Cryogenic (or cold) fluids can be inadvertently admitted to process piping and equipment due to the malfunctioning of cryogenic liquid vaporisation systems, which can result in catastrophic failure due to brittle fracture. When certain metals, typically carbon steels, become cold they undergo changes in their structure, which makes them less ductile, i.e., they become brittle. Other metals such as stainless steels, aluminium, brass, and copper do not exhibit this ductile / brittle transition and remain ductile at low temperatures. This publication has been written to identify the hazards associated with cryogenic liquid vaporization systems and to recommend the safeguards to be taken.

3 Scope and purpose

This publication applies to cryogenic liquid supply systems, located either on a customer site or a production site, where cryogenic liquid is vaporised and is then supplied either as the primary or secondary source of gaseous product. This publication is limited to the prevention of brittle fracture in piping and associated equipment installed downstream of the vaporisation system.

The secondary source of supply can be a back-up supply to a production plant when the production plant trips or is shut down, a supplementary supply to meet customer demand where it exceeds the capacity of the production plant (peak-shaving), or as a back-up supply at a customer site (for example, a healthcare facility).

The safeguard principles presented in this publication apply to any process fluid supply system where the temperature of the cryogenic liquid source is less than the minimum temperature rating of the piping and / or associated equipment downstream of the vaporiser.

Examples include:

- nitrogen;
- oxygen;
- argon;
- helium;
- hydrogen;
- natural gas;
- carbon monoxide;
- methane; and
- ethylene.

Carbon dioxide and nitrous oxide are excluded from the scope of this publication; however, the principles of this publication may be applied.

The supply systems work by vaporising cryogenic liquid, typically in response to decreasing pipeline pressure.

Supply systems are made up of the following:

- liquid supply from either a low pressure tank and pump arrangement or directly from a high pressure tank;

- vaporisation system that could be a natural draft ambient air-heated type or one that uses an external energy source for example, steam, hot water, electricity, direct fired;
- interconnecting liquid and outlet gas piping, valves, and fittings up to the battery limit; and
- low temperature protection system (LTPS) as detailed in this publication.

Although this publication does not cover the following situations, the techniques listed may be considered for cold embrittlement prevention:

- Air separation and other cryogenic processes with columns, separators, or tanks in which a gas stream from a sump is normally supplied through downstream heat exchange equipment, or liquefaction units where a cryogenic fluid can exit through warm-end process piping during a shutdown or upset scenario. Cryogenic processes are assumed to have their own LTPS;
- Piping systems within which a fluid is expanded across a valve or restriction with the resultant temperature being less than the ductile-to-brittle-transition-temperature (DBTT) for the piping system; and
- Vessels that are depressurised rapidly: as work is done in a vessel by a gas expanding as it is discharged out of the valve, the temperature inside the vessel and the vessel wall can be lowered.

This publication recommends safe practice for the design of new cryogenic vaporiser systems. For existing systems, a risk assessment shall be undertaken to establish if any modifications are required. The principles developed in this publication can be used for this purpose.

4 Definitions

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

4.1 Publication terminology

4.1.1 Shall

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

4.1.2 Should

Indicates that a procedure is recommended.

4.1.3 May

Indicates that the procedure is optional.

4.1.4 Will

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

4.1.5 Can

Indicates a possibility or ability.

4.2 Technical definitions

4.2.1 Battery limit

Physical point where the rights and responsibilities of custody of the gaseous product transfers from the supplier to the customer.

4.2.2 **Brittle fracture**

Failure caused by a crack that propagates rapidly through the material. A brittle material has little resistance to failure once the elastic limit has been reached.

NOTE Pressurised equipment subject to such a failure leads to a sudden and violent energy release, the projection of fragments, and the release of a fluid that can be oxidising, flammable, toxic, etc.

4.2.3 **Ductile**

Property of a metal that allows it to elongate, with a rapid increase in local stresses, prior to failing.

4.2.4 End use point

Physical location where gaseous product is consumed by the customer.

4.2.5 **Fail safe systems**

System is considered to be fail safe if, under all reasonable expectations of in-service malfunctions or component or wiring failures, the aggregate response of the system is such that it maintains the intended prevention of a hazardous condition.

4.2.6 **Flow reduction systems**

Systems employing vaporisers where it is accepted by the customer or the process that the flow can be reduced. See 8.5.

4.2.7 **Flow restriction systems**

Properly designed restrictive orifice or other fixed device installed immediately downstream of the vaporiser to limit the flow to a maximum value.

4.2.8 Logic solver

System of relays and pneumatic controls or a digital system that can perform one or more control or safety function(s).

4.2.9 **Pressure**

Bar shall indicate gauge pressure unless otherwise noted i.e., (bar, abs) for absolute pressure and (bar, dif) for differential pressure.

4.2.10 **Resilient material**

Material that is able to maintain its mechanical integrity at cryogenic temperatures.

4.2.11 **On-site unit**

Process plant or equipment that generates gas as the primary source of supply to the user.

NOTE Examples are cryogenic air separation, pressure swing adsorption, membrane system, etc.

4.2.12 **Shutoff device**

Component that reliably interrupts the process flow.

4.2.13 **Uninterruptible supply systems**

System designed so that the flow to the process or end user cannot be immediately interrupted. See 9.1.

NOTE For example: inert gas blanketing for a hazardous atmosphere or process; or oxygen supply to a health care facility.

4.2.14 **Utility and utilities**

Means to supply heat to a vaporiser designed to vaporise cryogenic liquids and include all of the following applications:

- electrical power to drive hot air or ambient air fans, blowers, water or fuel pumps, and immersion or radiant heaters or electrically heated metal block vaporisers;
- supply of fossil fuels, including natural gas or fuel oil, which is combusted to generate heat or steam;
- steam supplied from a customer or other source; and
- other sources of pumped or circulating heating fluids such as water baths, hot water streams, glycol-water streams, heat transfer fluids, or similar forms of process or waste heat supply.

Utilities do not include natural draft ambient air-heated vaporisers. Utilities do include forced draft ambient air-heated vaporisers.

4.2.15 **Vaporisers**

Heat exchanger that changes the state of a cryogenic liquid to a vapour, by transferring thermal energy from an external source to the fluid.

5 **Types of vaporiser**

Typical types of vaporiser systems include:

- Natural draft ambient air-heated vaporisers are vaporisers where convection currents in the atmospheric air close to the surface of finned tubes use the sensible heat of the surrounding air to provide heat for vaporisation and to raise the vaporiser outlet gas temperature to a value close to that of the ambient air;
- Natural draft ambient air-heated vaporiser with switchover system: two vaporisers or groups of vaporisers in parallel where the flow is switched between the vaporisers or groups to allow defrosting of one vaporiser or group;
- Water bath vaporiser: a water bath is maintained at a desired temperature by means of hot water circulation, steam injection, electrical heater elements, or hydrocarbon fuel fired heaters. A vaporisation coil or tube bundle in the water bath uses the heat from the water to vaporise the cryogenic liquid and to provide superheating to raise the vaporiser outlet gas temperature. The thermal mass of the water helps to reduce the variation in the process outlet temperature;
- Ambient air-heated vaporisers with trim heaters: electrical heaters are installed downstream of ambient air vaporisers, to provide superheating to raise the vaporiser outlet gas temperature to greater than the minimum allowed temperature for the downstream system;

- Forced draft ambient air-heated vaporisers: a fan is used to blow air across the surface of finned tubes, and so use the sensible heat of the surrounding air to provide heat for vaporisation and to raise the vaporiser outlet gas temperature to a value close to that of the ambient air. The vaporiser has reduced vaporisation capacity when the fan is not operating;
- Electrically heated metal block vaporisers: electrical power is used in electrical heater elements embedded in a metal block to heat the block. The vaporisation coil is also embedded in the block; so heat is transferred from the block to the cryogenic fluid for vaporisation and superheating.
- Vaporisers with heating fluid pumped through without ballast, for example, ambient temperature, warm or hot water: the sensible heat in the water being used to provide heat for vaporisation and to raise the vaporiser outlet gas temperature; and
- Direct steam jacketed vaporisers: steam is injected into a heat exchanger at a controlled rate to condense on the product tubes and the latent heat from the steam is used to vaporise the cryogenic liquid and to provide superheating to raise the vaporiser outlet gas temperature to a value at or greater than that of the ambient air. There is no significant thermal mass to help to reduce the variation in the process outlet temperature, if the steam flow varies.

Vaporiser systems are typically categorised as either high thermal ballast (HTB) or low thermal ballast (LTB). The maximum design flow rate for the vaporiser system shall be used to determine the ballast time. The performance of ambient air-heated vaporisers shall be evaluated at the minimum ambient design temperature.

5.1 High thermal ballast vaporisers

A HTB vaporiser is one that has a significant amount of stored energy ballast remaining at a time of power outage, energy-input malfunction, or overdraw condition. On failure of utility, the time taken for the outlet temperature to fall to the embrittlement temperature will be 15 minutes or more. An energy-input malfunction can occur by loss of steam or burner fuel or electrical heating to a water bath vaporiser or by ice and frost build-up on an ambient air-heated vaporiser.

A water bath vaporiser having a large quantity of water can be considered as a HTB vaporiser but could become a low thermal ballast (LTB) vaporiser in the case of lack of water, for example, caused by a water leak or low water bath temperature.

5.2 Low thermal ballast vaporisers

An LTB vaporiser is one that has little or no stored energy ballast remaining at a time of power outage, energy- input malfunction, or overdraw condition. On failure of utility, the outlet temperature can fall to the embrittlement temperature in less than 15 minutes. The vaporiser materials of construction and the retained mass of the heat transfer media (for example, water) define the thermal ballast.

6 Causes and consequences of low temperature

6.1 Causes of low temperature

Some of the causes of low temperature at the outlet of a vaporiser are listed in Table 1.

Table 1 – Causes of low temperature

Type of vaporiser	Cause of low temperature	Example(s) of cause of low temperature
All types	Customer overdraw exceeds design capacity, particularly for an extended period.	Customer adds extra equipment that requires additional flow capacity without notifying the gas company.
All types	Flow exceeds rated capacity of the vaporiser.	Relief valve on pipeline opens and sticks open. Prolonged venting downstream of vaporiser.
All types	Pipeline pressure or flow control valve goes fully open.	Control valve actuator failure. Control valve positioner malfunction.
All types	Control system fails in a way that creates a low temperature at the vaporiser.	Failure of basic pressure control or flow control system.
<u>Natural draft</u> or forced draft ambient air-heated vaporisers	Vaporiser heavily iced due to high demand, peak shaving, main gas supply plant trips out, etc.	Vaporisers are rated for a given flow rate and time. If this is exceeded, gas outlet temperature can drop.
<u>Natural</u> or forced draft ambient air-heated vaporisers	Vaporiser heavily iced.	With a vaporiser changeover system, a changeover valve failing to move to the correct position will lead to this situation.
<u>Natural</u> or forced draft, ambient air-heated vaporisers	Low ambient temperature for prolonged period does not allow opportunity for defrosting the vaporiser.	Failure of timed changeover if fitted. Poor siting of vaporiser where it cannot defrost. Changes to layout around the vaporiser that affect its efficiency (walls built close by).
<u>Forced draft ambient air-heated vaporisers</u>	<u>Fan stops.</u> <u>Defrost heaters, where fitted, do not operate.</u>	<u>Electrical power failure.</u> <u>Switchgear fault.</u> <u>Fan mechanical failure.</u>
<u>Natural draft ambient air-heated vaporisers with trim heaters</u>	<u>Trim heater unable to maintain gas temperature greater than the required minimum temperature.</u>	<u>Electrical power failure.</u> <u>Switchgear fault.</u> <u>Heater element burns out.</u> <u>Excessive flow.</u>
<u>Natural draft ambient air-heated vaporisers with switchover</u>	<u>Flow exceeds rated capacity of vaporiser bank.</u>	<u>Electrical power failure.</u> <u>Switchover time set incorrectly.</u>
All water bath vaporisers	Low or no water level in water bath.	Drain valve left open. Leaks in water bath. Water/Steam supply system failure.
<u>Fired heater water bath vaporisers</u>	<u>Fuel gas failure.</u>	<u>Burner management systems malfunction.</u> <u>Loss of fuel supply.</u>
<u>Vaporisers with heating fluid pumped through</u>	<u>Heat source fails, low or no flow of thermal fluid.</u>	<u>Electrical power failure.</u> <u>Switchgear fault.</u> <u>Pump mechanical failure.</u>
Steam vaporisers	Steam control valve fails to open. Steam supply from boiler fails.	Valve actuator failure. Positioner malfunction. Controller malfunction. Superheated steam boils off contents of water bath.
Electrically heated vaporisers	Failure of electrical heating.	Electrical power supply failure. Switchgear fault. Heater elements burn out.
Water bath, steam, and electrical vaporisers	Servicing of a vaporiser on which the heat source has been decommissioned.	Liquid supply to the vaporiser not isolated when the heat source is removed.

6.2 Consequences of low temperature

Every material that is susceptible to brittle fracture has an associated DBTT. This ductile-to-brittle transition can cause an existing defect in a material to propagate to a crack, or even start a crack with no additional increase in stress. A brittle failure of an item is more destructive, as the crack propagates

rapidly, and sections of material can become detached, whereas with a ductile failure the material “tears” and the pressure is vented in a more controlled fashion. The DBTT is that temperature below which the Charpy impact value shows a very rapid decrease and failure occurs without plastic deformation, for example, without the occurrence of a significant amount of stretching or yielding. The relationship between ductility and temperature for typical low carbon steel is illustrated in Figure 1. Low carbon steel shows a decrease in the fracture energy with decreasing temperature. Common structural materials such as carbon and low alloy steels are not suitable for low temperature equipment and are susceptible to brittle fracture at these lower temperatures.

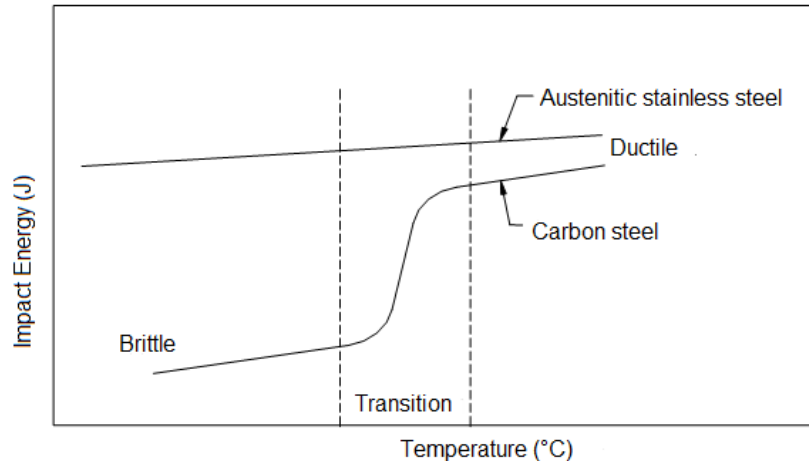


Figure 1 – Relationship between impact energy and temperature for carbon and austenitic stainless steels

Austenitic stainless steels are tough and remain ductile at low temperatures.

Materials such as stainless steels, aluminium, brass, and copper do not exhibit any ductile/brittle transition and may be used down to cryogenic temperatures.

Any piece of equipment (pipe, vessels, valves, etc.) that could be subjected to low temperatures shall be assessed to ensure it is suitable to withstand the temperature.

When considering the use of non-metallic materials downstream of vaporisers, the low temperature properties of the material shall be evaluated before a decision to use it is made.

Brittle failure can result in the following hazardous consequences:

- Pressure volume (PV) energy release: release of the pressure energy contained in the equipment. The pressure energy can cause damage or injury from blast wave pressure forces on structures and personnel. Buffer vessels and large diameter piping associated with vaporisers and constructed of materials that are susceptible to brittle fracture present a particular hazard to personnel because of the increased PV energy available on failure and the consequent increased area in which injury or fatality could occur;
- Fragmentation of equipment: propelling of fragments and whole pieces of the failed equipment at high velocity away from its point of origin is capable of causing injury to personnel or further damage to equipment adjacent to the fragmented equipment;
- Loss of containment: the uncontrolled release of the contained process fluid has potential for increasing the hazardous consequences beyond the zone affected by equipment fragmentation and overpressure. Process fluids that are released can introduce hazards to personnel and equipment, depending upon the physical and chemical properties of the fluid;

- Cryogenic liquids escaping from the equipment can result in a large liquid spill and vapour cloud. Cryogenic burns, obscured vision, and injury to personnel as well as collateral damage to adjacent equipment are all possible;
- Toxic fluids can cause adverse health effects in personnel or possible death if sufficient exposure occurs. This risk exists in case of a brittle fracture downstream of a vaporisation system handling either a toxic fluid or nitrogen when used to purge toxic fluid applications. When the vaporised fluid is toxic, a loss of containment releases the toxic directly to the atmosphere. For a nitrogen vaporisation system that is connected to a toxic system, a nitrogen release can result in an oxygen-deficient atmosphere and depending on the location of the fracture in relationship to the backflow prevention devices and / or automatic isolation valves, the toxic fluid can backflow to the fracture and release directly to the atmosphere. Similarly, where nitrogen is used to purge flammable gases in the downstream process, a comparable hazard can exist.
- Flammable fluids such as hydrogen, ethylene, and methane can form a combustible vapour cloud or jet. Ignition of the cloud can cause an overpressure that will add to the effects of the release of pressure energy. Jet fires, flash fires, or pool fires can continue after the release of product and can result in burn injuries to personnel and/or equipment damage;
- Oxygen release can cause the formation of an oxygen-enriched atmosphere that can support rapid combustion of many materials;
- Asphyxiant release (for example, nitrogen, argon) can cause the formation of an oxygen-deficient atmosphere, with risk of fatality or injury to persons within the oxygen-deficient atmosphere;
- Cold burns: a secondary hazard is the risk of cold burns from skin contact with cold piping and vessels following the product release; and
- Availability of gas supply: embrittlement and failure of the system will also result in a failure to supply the customer, which in some cases can create an additional hazard for the customer. Activation of a LTPS will also reduce or interrupt customer supply, but full supply can be re-established more quickly than in the case of a brittle failure.

7 Design philosophy

7.1 Inherent safety

For low temperature embrittlement, an inherently safe vaporisation system is one where the outlet gas temperature has no possibility of falling to less than the minimum temperature rating of the piping material or associated equipment. In such a situation, no special measures for low temperature protection are required, and so this is the preferred option for the system.

For example, a vaporisation system with all downstream components and piping up to and including the end use points that is constructed from materials suitable for cryogenic temperatures (for example, stainless steel, copper, brass) is inherently safe from a low temperature embrittlement perspective. However, it can pose other downstream risks to the end user due to supplying cryogenic gas or liquid to the end use point(s) of the system.

7.2 Risk assessment

In all other situations, the entire system (including all process measurement systems, temperature and flow rate monitoring, and control systems) shall be evaluated by hazard review and be subject to a risk assessment. This evaluation may be carried out on a generic basis. Consequences need to be evaluated when failure of the pressurised system is possible and these consequences should be reduced wherever possible (for example, by elimination of buffer vessels where not required).

The risk assessment should consider:

- likelihood of the low temperature event, taking into account type of vaporiser and the existing or predicted usage pattern;
- consequences of low temperature, taking into account the nature of the fluid, the stored energy, the location of the equipment, and the likelihood of presence of people in the vicinity;
- presence of any layers of protection existing in such areas as general process design and the basic process control system;
- presence of alarms that can be responded to in a timely manner and an effective way; and
- any other mitigation measures or factors that reduce the likelihood or consequence of the event, for example, frequency of inspection visits to monitor ice build-up, frosting of pipework, etc.

These factors should be considered in determining the required probability of failure on demand of any required LTPS.

For information on a methodology to determine the required probability of failure on demand of a LTPS in relation to a defined hazard rate target, see IEC 61511—All Parts, Functional safety - Safety instrumented systems for the process industry sector [1].¹

The hazard review and risk assessment should include the customer's system. Where this is not possible, due to lack of information about the customer system, then a clear battery limit shall be defined with normal and abnormal process parameters.

The specification of the LTPS may use any combination of the safeguards listed in the following paragraphs. Not all of the safeguards listed need to be provided, but the design of the system shall incorporate sufficient safeguards so that the assessment of the protection system results in an acceptably low risk.

Typically, safeguards consist of systems and components designed to accomplish the following:

- Minimise the probability for process demands or excursions that could cause entrainment or carryover of cold vapours or liquids from vaporisers into downstream systems, for example, by throttling the flow to a maximum limit or by using a fixed flow restriction device;
- Monitor and detect low temperature, high flow rates of cold liquid or gas, or loss of heat supply to exchangers;
- Shut off devices to stop the process flows; and
- Provide an alternative vaporiser or gas supply system.

Typically, monitoring equipment, with associated alarms and shutdowns as required by the risk assessment, includes the following:

- low temperature detection in the process streams exiting vaporisers;
- detection of loss of utilities to heating units on vaporisers;
- low temperature detection or low pressure detection in the utility supply to a heating unit in a vaporiser system; and
- detection of low or no water level in water bath.

The shutoff device(s) is (are) the final components of the LTPS.

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

The function of a shutoff device on a gas process system is to:

- shut off the gas flow;
- reduce the gas flow before shutoff; or
- reduce the gas flow to return to normal operating conditions.

Acceptable shutoff devices include:

- throttling valve if it is accepted by the customer or the process that the flow can be reduced;
- control valve;
- on/off valve (shutoff valve);
- dome-loaded pressure regulator with a pneumatic temperature controller;
- self-operated low temperature shutoff valve;
- solenoid valve; and
- pump command stop or power supply stop.

A shutoff device can be located either upstream or downstream of the vaporiser.

When available, the probability of failure on demand of safeguards shall be considered in the risk assessment. This data may be available from the equipment manufacturer, gas company data, or from recognised published sources.

Any subsequent design or operational changes shall be subject to a revision of the hazard review and risk assessment. The gas supplier should notify the customer that any changes to their equipment can impact the safe operation of the system.

7.3 Reliability of customer supply

As part of the risk assessment, the impact of the proposed safeguards on the reliability of supply to the customer shall be considered. This is particularly important for uninterruptible supply systems where the gas supply is used to avoid catastrophic events at the user site. For example, the assessment may weigh the impact of a short interruption of supply versus a long-term supply failure in the event that the product system is damaged and out of service.

Where required, increased system on-stream reliability may be enhanced, for example, by component (or system) redundancy (for example, two out of three voting on temperature sensors, twin parallel shutoff valves, or twin vaporiser trains) or upgrading material selection to an inherently safe system.

8 Ranking of hazards

As part of the risk assessment process, the likelihood and consequence of low temperature events shall be considered. The relative severity of consequences and relative likelihood of initiating events can be ranked. The following sections provide guidance on the overall risk ranking.

8.1 Pressure volume energy

Release of the pressure energy contained in the equipment can cause damage or injury from localised pressure forces on structures and personnel. The propelling of fragments and whole pieces of the failed equipment at high velocity away from its point of origin is also capable of causing injury to personnel in the site or further damage to equipment adjacent to the fragmented equipment. Buffer vessels and large diameter piping associated with vaporisers and constructed of materials that are susceptible to brittle

fracture present a particular hazard to personnel because of the increased PV energy available on failure and the consequent increased area where injury or fatality could occur from the blast overpressure wave. The severity of the hazard can be ranked in a decreasing scale as follows, where P is the maximum operating pressure in bar gauge and V is the volume of the vessel in litres. See Table 2.

For pipelines, volume (V) shall be based on the internal pipe diameter (D) and is calculated as the internal volume of the length equivalent to 5 internal pipe diameters (5D).

$$V = S \times 5D = (\pi \times D^2 / 4) \times 5D = 1.25 \times \pi \times D^3$$

Table 2 – Pressure volume energy classification

<u>PV severity level</u>	<u>Value</u>
<u>P0</u>	<u>$P \leq 0.140 \text{ bar}$ or $PV \leq 1 \text{ bar.L}$ ($P \leq 2 \text{ psi}$ or $PV \leq 0.5 \text{ psi.ft}^3$)</u>
<u>P1</u>	<u>$1 < PV \leq 16 \text{ bar.L}$ ($0.5 < PV \leq 8 \text{ psi.ft}^3$)</u>
<u>P2</u>	<u>$16 < PV \leq 180 \text{ bar.L}$ ($8 < PV \leq 90 \text{ psi.ft}^3$)</u>
<u>P3</u>	<u>$180 < PV \leq 500\,000 \text{ bar.L}$ ($90 < PV \leq 250\,000 \text{ psi.ft}^3$)</u>
<u>P4 ¹⁾</u>	<u>$PV > 500\,000 \text{ bar.L}$ ($PV > 250\,000 \text{ psi.ft}^3$)</u>
<p>¹⁾ <u>The required protection against the cold embrittlement risk shall be determined by a risk assessment, taking into account the impact on highly populated areas and places of public assembly. The risk assessment shall be done according to local regulations, if any, and company rules, and consider the effects related to:</u></p> <ul style="list-style-type: none"> • <u>hazard of the released gas; and</u> • <u>blast pressure, including the possible domino effects (for example, collapsing of a nearby hazardous product storage.</u> 	

8.2 Hazard of fluid

Cryogenic liquid escaping from the equipment can result in a large liquid spill and vapour cloud. Cryogenic burns, obscured vision, and injury to personnel as well as collateral damage to adjacent equipment are all possible. The severity of the hazard can be ranked in a decreasing scale as shown in Table 3

Table 3 – Fluid hazard classification

<u>Hazard severity level</u>	<u>Hazard type</u>	<u>Example</u>
H3	Flammable <u>or toxic</u>	Rupture of piping downstream of the vaporiser could result in: <ul style="list-style-type: none"> • <u>toxic gas release flowing back from the user system or from a liquid carbon monoxide vaporiser; or</u> • <u>flammable gas release from the user system or from a liquid hydrogen, liquid methane, or liquid ethylene vaporiser.</u>
H2	Oxygen <u>or other oxidisers</u>	Oxygen release will cause the formation of an oxygen-enriched atmosphere that can support rapid combustion of many materials. Person(s) in the vicinity who are smoking, driving vehicles, or engaged in hot work are particularly at risk.
H1	Inert (i.e. <u>not oxidising, not flammable, not toxic</u>)	Asphyxiant release (for example, nitrogen, argon) will cause the formation of an oxygen-deficient atmosphere, which <u>results in a risk of fatality or injury to persons within the oxygen-deficient atmosphere.</u>
<p>NOTE <u>In case of vaporisation of inert gas as safety gas, backflow and release of flammable / toxic gases from customer can be prevented with nonreturn valve(s) placed downstream of a non-resilient portion of piping.</u></p>		

8.3 Likelihood of low temperature

The likelihood of a low temperature event occurring is affected by the process design and degree of ballast of the vaporiser. The likelihood of the hazard can be ranked in a decreasing scale as shown in Table 4.

Table 4 – Classification of likelihood of low temperature occurrence

Low temperature likelihood level	Type
L3	<u>Water bath or any other non-natural draft ambient air-heated vaporiser</u>
L2	<u>Natural draft ambient air-heated vaporiser with trim, or manual switchover</u>
L1	<u>One or more natural draft ambient air-heated vaporiser with fail safe automatic switchover.</u>
NOTES	
1 LTB vaporisers are specifically excluded from Table 4. <u>See 8.8.</u>	
2 <u>Natural draft ambient air-heated vaporisers fitted with fail safe switchover valves have proven to be highly reliable in service. In the event of a fault, switchover valves fail to the open position to allow product flow through all vaporisers.</u>	

8.4 Operating pattern

The likelihood of a low temperature event occurring is affected by the operating pattern of the vaporiser. The likelihood of the hazard can be ranked in a decreasing scale as shown in Table 5.

Table 5 – Classification of service type

Operating pattern	Type
S2	Continuous supply or backup used for peak shaving.
S1	Only back-up supply.

9 Safe design criteria

9.1 Vaporiser outlet materials

When the piping downstream of a cryogenic vaporiser, including the customer's supply piping and associated process equipment, is fabricated entirely of materials suitable for cryogenic temperature, a low temperature shutoff system is not required. While this design is inherently safe from a low temperature embrittlement perspective, it can pose other downstream risks to the end user due to supplying cryogenic gas or liquid to the end use point(s) of the system.

Any vaporisation system requires a length of piping in resilient material at the exit of the vaporiser. This piping shall be of sufficient length such that the gas temperature during upset conditions, possibly leading to a shutdown of the system, does not bring the equipment temperature to less than the DBTT at the end of this piping length, before appropriate corrective action is taken. The temperature element shall be installed to ensure that the element measurement is not impacted by ambient temperatures.

The parameters to consider for the required length of piping in resilient material downstream of the vaporiser include, but are not limited to:

- reaction time to activate the LTPS (from the cooling of the temperature element to the activation of the shutoff device);

- margin between temperature trip threshold and DBTT;
- gas velocity; and
- temperature drop rate due to vaporiser failure.

Where a LTPS is installed, its components (low temperature detection instrumentation and shutoff device(s)) shall be made of resilient material and:

- low temperature detection instrumentation shall be installed;
- at the outlet of the vaporiser to allow the instrumentation adequate time to react to a change in the outlet conditions;
- in such a way that the temperature measurement is not impacted by ambient temperatures; and
- If installed downstream of the vaporiser, the shutoff device(s) shall be installed within the run of resilient piping.

All piping and equipment (for example, regulators and manual valves) installed in the resilient length of pipe shall be constructed of material suitable for cryogenic service.

For pressure relief devices (PRDs) located at the outlet of a cryogenic liquid vaporiser, the inlet piping of the PRDs and the outlet piping where appropriate, shall be capable of withstanding cryogenic conditions in the event that the relief device is required to function, for example, in the event of vaporiser overload or blocked in condition.

Adequate piping flexibility shall be maintained for the entire system downstream of the vaporiser, up to and including the customer's battery limit.

9.2 Natural draft ambient air-heated vaporisers

Natural draft ambient air-heated vaporisers are safer than designs requiring an external heat supply. The sizing of the unit takes into account the expected ambient conditions, the expected continuous service time of the vaporiser, and the declared flow rate and consumption pattern of the customer. Natural draft ambient air-heated vaporisers that have been correctly sized are more likely to prevent a hazardous low temperature from occurring at the expected conditions than utility vaporisers. However, there is still some risk of a hazardous low temperature condition occurring (for example, continuous service, with considerable ice build-up and no defrost, or low ambient air temperature).

High reliability gas supply systems use natural draft ambient air-heated vaporisers whenever possible.

9.3 Independent layers of protection

The LTPS shall be designed to throttle flow to correspond with the energy available to the vaporiser.

LTPS are typically comprised of three components:

- temperature detection device(s);
- logic solver; and
- shutoff device(s).

A logic solver may be a system of relays and pneumatic controls, a programmable logic controller (PLC), or other electronic control system.

A failure of a basic process control system (BPCS) can be a cause of low temperature (as noted in Table 1), so this shall be taken into account when defining the solution.

Where two or more LTPS are provided, the components in each LTPS should be independent of each other, to reduce the potential for common mode failure, i.e., the LTPS are independent layers of protection.

9.4 Shutoff devices and valves

Any of the following are acceptable means of shutoff for a shutoff device:

- vaporiser outlet valve shutoff;
- vaporiser inlet valve shutoff; or
- pump motor shutdown on pump(s) feeding liquid to the vaporiser.

Where shutoff valve(s) are used, they shall be designed to fail closed on loss of power or instrument fluid. Fail-open shutoff valves shall not be used on vaporiser systems, unless a detailed risk assessment indicates that this is acceptable.

It may be acceptable for the emergency shutoff function to be incorporated into an existing control valve (for example, by fitting a solenoid onto the air supply to a fail close control valve). Such a system shall be adequately designed for the purpose and configured to allow periodic testing of the shutoff function.

Control valves that are fitted with a manual handwheel that can prevent it from fully closing should not be used as shutoff valves. This manual override can limit the normal operation of the valve and prevent it from fully closing, which would prevent the LTPS from operating as designed.

Liquefied gas shall not be trapped between automatically or manually operated shutoff valves or check valves without that part of the system having a pressure relief valve.

Where an inlet valve shutoff is used, there is potential that after the valve is closed, cold gas may continue to flow for a short period of time. The system shall be designed to address this issue.

The design of the shutoff valve should prevent excessive ice formation that can compromise the valve operation.

9.5 Throttling valves

A throttling valve may be used to limit the flow of the fluid so as to never overdraw the capacity of the vaporisers.

A temperature control function is often used to act on the pipeline control valve. This will reduce the flow of product as the temperature starts to fall thus preventing a low temperature condition and a potential subsequent trip.

Should the throttling response fail to adequately control the vaporiser exit gas temperature, a shutdown of flow shall take place, unless a detailed risk assessment indicates that this is not acceptable or not necessary.

9.6 Temperature sensing devices

Single sensing devices or one out of two voting systems may be required depending on the required probability of failure on demand. A two out of three voting system may be needed to activate a shutdown system for reliability reasons. The impact of ambient temperatures on the operation of the device shall be considered. A faulty signal (for example, due to a sensing device fault) should count as a vote to put the installation in safe mode.

When selecting a device and designing the system, maintenance and testing requirements as well as response time should be considered. For devices such as switches, proof test interval has a direct

relationship to probability of failure on demand. For example, it is a well-known problem that capillary type devices that are fitted without a thermowell can only be tested during a shutdown.

9.7 Vaporisation system flow capacity

In order to avoid cold ingress downstream of the vaporisation system, vaporisation system capacity shall not be exceeded. Protections to limit the liquid flow may be installed (for example, flow controller).

9.8 Low thermal ballast vaporisers

Due to the rapid discharge gas temperature decay rate, LTB vaporisers (for example, pumped fluid shell and tube vaporisers without ballast on utility failure, direct steam jacket vaporisers) require a detailed risk assessment to ensure the risks are identified and mitigated. Direct steam jacket vaporiser use is not recommended for new installations.

9.9 Buffer vessels and location

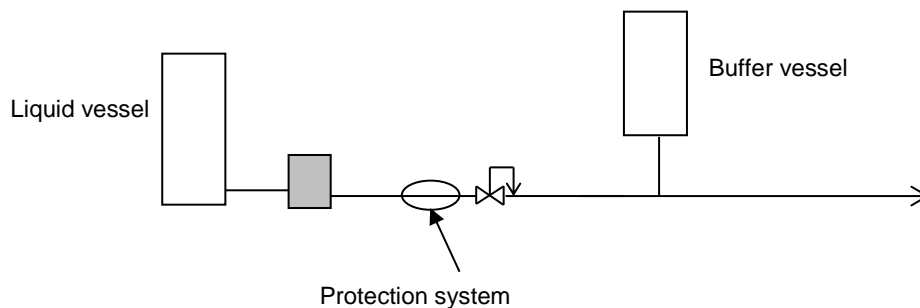
9.9.1 Location of buffer vessels made of carbon steel material

Buffer vessels fabricated from carbon steel installed downstream of vaporiser systems present a particular hazard to personnel due to the increased energy from the volume of gas available on low temperature failure and the consequent increased area where injury or fatality could occur from the blast overpressure wave.

Where used, the location of buffer vessels shall minimise the risk of having cold fluid being introduced into them. Depending on the installation type, different locations in the supply system are possible as shown in 8.9.1.1 and 8.9.1.2.

9.9.1.1 Installation type 1 – Continuous supply

Installations with a liquid vessel, vaporisation system, and buffer vessel: When possible, the buffer should be installed on a branched line not on the main line as shown in Figure 2. In this configuration, the buffer vessel is less subject to low temperature exposure in the event of an LTPS failure.



NOTE This figure as well as the following ones, only represent arrangement and protection systems related to the cold embrittlement risk.

Figure 2 – Buffer installation for continuous service

If the buffer vessel is installed on the main line as shown in Figure 3, cold gas can flow through the buffer vessel in the event of an LTPS failure, resulting in an increased likelihood of cold embrittlement risk. Figure 3 shall not be used for new installations.

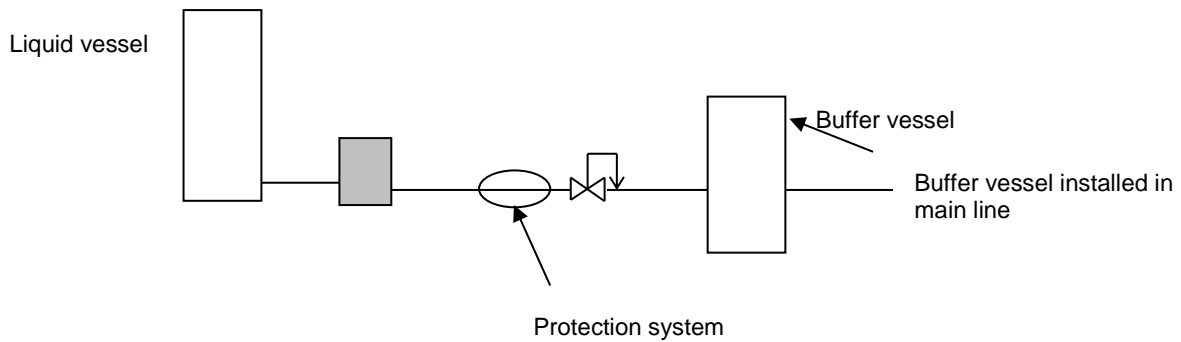


Figure 3 – Other buffer installation possible for continuous service

In both cases (buffer installed on a branched line or buffer installed on the main line), a protection system adapted to the cold embrittlement risk of this buffer vessel shall be installed upstream of this buffer vessel.

9.9.1.2 Installation type 2 – Back-up supply only or backup with peak shaving

Installations with a liquid vessel, a vaporisation system, an on-site unit, and a buffer vessel:

There are two possible locations for the position of the buffer vessel:

- Install the buffer vessel on the on-site unit line, upstream of the vaporisation system tie-in, in the product line or in a branched line, protected by a non-return valve. See Figure 4. In this configuration, with the buffer vessel placed on the on-site unit outlet line, it is protected due to its position and by the non-return valve; or
- The buffer may be installed downstream of the vaporisation system (in a branched line), but in that case, a protection system adapted to the cold embrittlement risk of this buffer vessel shall be installed upstream of this buffer vessel. See Figure 5.

9.9.2 Location of buffer vessels made of low temperature resistant materials

When the buffer vessel is fabricated entirely of materials suitable for cryogenic temperature, no special considerations are required for location of the vessel in the piping.

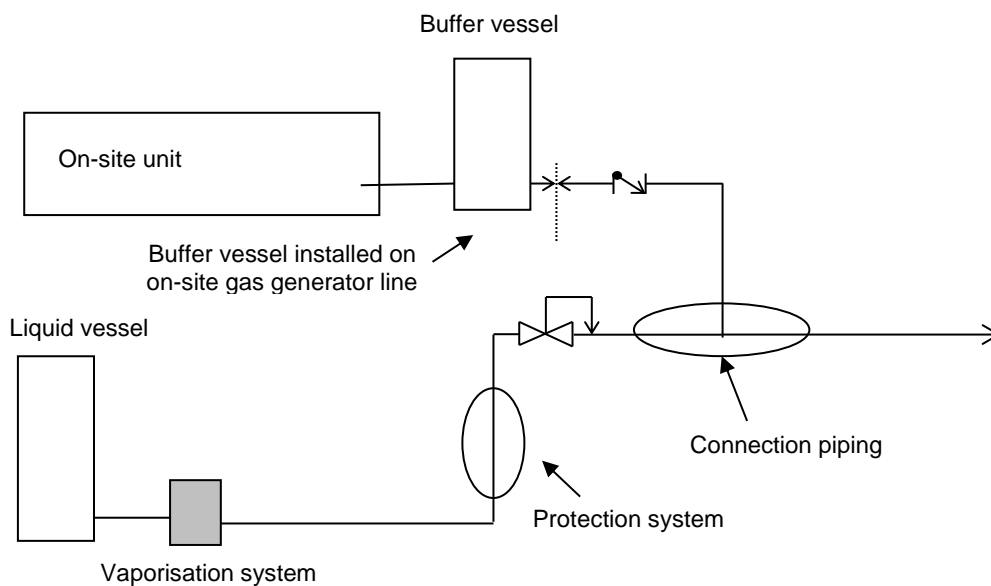


Figure 4 – Buffer installation preferred for back-up service

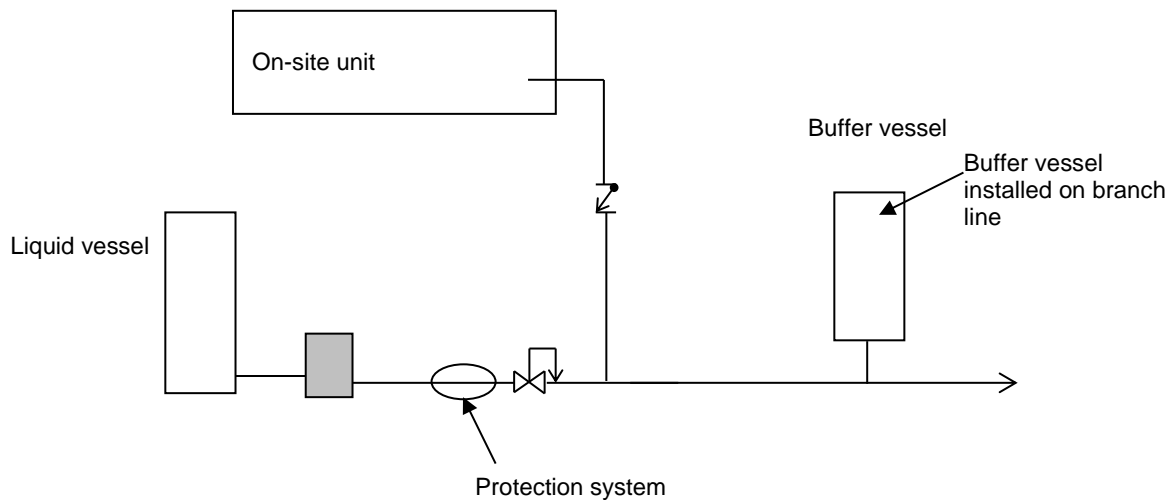


Figure 5 – Other buffer installation possible for back-up service

9.10 Different vaporisers in parallel

Different vaporisers connected in parallel can create situations leading to a hazard for example, natural draft ambient air-heated vaporiser(s) as peak shaving to a steam heated water bath vaporiser; or the addition of a second vaporiser of a different manufacturer with a different performance.

If the hydraulic and thermal parameters of the two vaporiser systems are not identical, the cryogenic liquid flows preferentially into the smaller vaporiser that usually has a smaller pressure drop.

As this smaller vaporiser starts to become colder and the vaporisation capacity is reduced, the pressure drop further decreases (due to more liquid being present in the vaporiser tubes).

If this continues, all the liquid will flow only into the smaller vaporiser system and the other one is completely unused.

The outlet temperature can then fall below the downstream design temperature, creating a hazard.

Therefore, it is important to balance the flows between the vaporisers during commissioning by adjusting vaporiser inlet or outlet valves to avoid this potential hazard. Adequate flow distribution can also be achieved by piping design allowing to feed each vaporiser according to its vaporisation capacity.

10 Considerations for low temperature protection

10.1 Uninterruptible supply system

This type of system is used for a customer or end-use process where a shutdown that fully interrupts process flow to the customer cannot be safely tolerated.

The following standards are relevant to these systems:

- NFPA 55, Compressed Gases and Cryogenic Fluids Code [2];
- NFPA 86, Standard for Ovens and Furnaces [3];
- ISO 7396-1, Medical gas pipeline systems—Part 1: Pipeline systems for compressed medical gases and vacuum [4]; and
- NFPA 99, Health Care Facilities Code [5].

The requirement of uninterrupted flow of product to the use point can be provided for in one of four ways: see 9.1.1, 9.1.2, 9.1.3, and 9.1.4.

Due to the importance of continuity of supply, installation of a high flow and/or low temperature alarm can increase the supply reliability in certain situations. Requirements for response to alarms are described in 10.2.

10.1.1 Materials

Use resilient materials (for example, stainless steel, high nickel alloys, copper, suitable gaskets) throughout the system, up to the customer's battery limit. The customer shall be advised that the system, up to and including the end use point, shall also be cryogenically suitable. Inherent in this approach is the need to provide adequate pipeline flexibility for the full temperature range.

10.1.2 Redundant system

Use a redundant, independent supply system providing flow to the same use points. Each independent cryogenic supply source shall be equipped with an LTPS adapted to its own risk level.

10.1.3 Restrictive orifice

Use a restrictive orifice in the supply system. The orifice shall be sized to limit the flow of the fluid such that the vaporiser is never overdrawn; however, this requires careful calculation.

Parameters that shall be considered include:

- vaporiser capacity and design specifications;
- ambient conditions including seasonal impacts with potential for low air temperature;
- duty cycle;
- end-use application;
- potential pressure fluctuations upstream and downstream of the orifice; and
- capacity of only one bank, for natural draft ambient air-heated vaporisers with fail safe switching.

This solution is applicable only for natural draft ambient air-heated vaporisers or natural draft ambient air-heated vaporisers with fail safe switching (L1) as defined in Table 4, and it is recommended that it be restricted to installations with a PV severity level P0, P1 or P2 (Table 2) and a hazard severity level H1 or H2 (Table 3) only. For this solution, a LTPS does not need to be installed. This solution, which limits the flow, shall be reviewed and accepted by the customer.

The vaporiser should be inspected as a part of prefill checks to determine if corrective action is required. See 12.1 for a list of issues to check for during inspection.

10.1.4 Throttling valve

Use a throttling valve, as described in paragraph 8.5, to limit the flow of the fluid so as to never overdraw the capacity of the vaporisers. The valve shall be designed so that it cannot go to the fully closed position (for example, by use of a mechanical stop device). The requirements for a restrictive orifice per 9.1.3 shall apply to this minimum remaining flow.

10.1.5 Design

Modify the design so that installing a shutoff device is not necessary as per a specific hazard study. For example:

- changing to a natural draft ambient air-heated vaporiser (class L1) in case of an installation having initially the risk combination P1-H1-L2-S2; or
- modifying the location of a pressure vessel as per Figure 4 to reduce the energy class to P1 or P2 in case of an installation initially having the risk combination P3-H1-L1-S1.

10.2 Interruptible supply requirements

If none of the previous low temperature protection methods are applied (see 9.1) and the risk combination requires a LTPS, then instrumented shutdown systems shall be implemented.

10.2.1 Instrumented shutdown systems

For interruptible supply requirements, two response modes are typically encountered:

- immediate shutdown (i.e., no flow reduction prior to shutdown); and
- throttling followed by shutdown.

The specific low temperature shutdown trip point chosen is a function of the pipeline material used and the applied design requirements as described in 9.2.2.

10.2.2 Temperature set points

10.2.2.1 Trip set point

Carbon steel or other materials not rated for cryogenic or cold fluid temperatures shall be protected from cryogenic fluid contact. National pressure vessel and piping standards or codes should be referred to in establishing the suitability of materials to be used in vaporiser systems.

For example, ASME B31.3, Process Piping defines the minimum service temperatures of certain grades of carbon steel to be $-29\text{ }^{\circ}\text{C}$ ($-20\text{ }^{\circ}\text{F}$), when used at the full stress values of the ASME code, without performing a Charpy Impact test [6]. It also allows other grades to be used at lower temperatures if more stringent criteria are met.

Impact testing of carbon steels (specifically those impact tested carbon steels that only meet the minimum requirements of ASTM, ASME, or API) does not guarantee resistance to brittle fracture, but the fine grain size of these low temperature steels does provide some resistance to brittle fracture initiation.

The material selection and therefore the temperature setting at which the low temperature device operates shall be determined by the ambient conditions and any tolerances or lags in the sensing system to ensure that the minimum permissible temperature is not exceeded. This criterion shall, as a minimum, be used for piping up to and including the customer's battery limit. The customer shall be advised of the responsibility in maintaining design adequacy on the customer side of the battery limit.

Where other codes are applicable, LTPS trip set points should follow similar practice.

It is not acceptable to set the trip temperature to less than the downstream design temperature. The trip temperature will normally be set at a greater temperature.

An anti-tamper device should be installed to ensure that the set trip temperature cannot be manually adjusted without adherence to management of change (MOC) requirements and necessary approvals from the system owner.

10.2.2.2 Throttling set point

Flow throttling (when used) is initiated at a defined temperature that is greater than the chosen LTPS trip set point. The throttle set point temperature used is influenced by:

- span limitations of the temperature measuring instrumentation system;
- ambient temperature; and
- rate at which temperature can drop at maximum of flow rate.

10.2.3 Low temperature protection system

Slow responding LTPS controls, appropriately matched to the vaporiser's discharge temperature decay characteristics and considering all foreseeable malfunctions, are acceptable in this case.

The distance between the LTPS sensor and the end of the resilient portion of pipe and equipment shall be defined using the response time of the LTPS instrumentation, the fluid velocity, and the safety margin between the temperature set point and the minimum design temperature.

When sufficient distances cannot be achieved to prevent cold embrittlement, design modification shall be considered to eliminate the risk. For example, fast-acting safety protection loops (SPLs) or high ballast vaporisers.

10.3 IEC 61511

IEC 61511: All Parts, *Functional safety - Safety instrumented systems for the process industry sector* is the process sector implementation of the generic standard IEC 61508: All Parts, *Functional safety of electrical/electronic/programmable electronic safety-related systems* that addresses safety instrumented systems based on the use of electrical/electronic/programmable electronic technology [1, 7]. The standard promotes the concept that the safety instrumented functions are specified, designed, integrated, and validated based on risk assessment. One part of the specification is to establish the needed Safety Integrity Level (SIL) of each function.

The solutions presented in Section 10 are based on a qualitative risk ranking approach, using good industrial design practice and many years of experience in the gas industry, rather than the approach described in IEC 61511 [1]. However, IEC 61511 can be used as a method of supporting the risk assessment and system design process described in this publication [1].

11 Solutions

Low temperature protection requirements for vaporisers are given in Table 6.

11.1 General considerations for low temperature protection systems

When the risk combination requires the installation of a LTPS, the probability of failure on demand of the LTPS, which depends on type/number of detection element(s), type/number of the shutoff device(s) and type of the control system, shall be an appropriate level relative to the likelihood of the low temperature event occurring, the consequences of the embrittlement, and the presence of any other safeguards. As a general rule, the system shall be protected by preventing downstream piping and equipment from becoming too cold by detecting cold temperature exiting the vaporiser and either:

- automatically shutting down the vaporiser system, using one or more shutoff devices and one or more temperature detection devices; or
- providing a low temperature alarm as protection in certain situations as described in the tables, subject to the response requirements noted in 10.2.

One or more sensors on utility supply (for example, low water flow switch, low water level switch, low steam pressure switch, etc.) may also be used to activate an alarm or in certain cases to shut down the vaporiser system.

11.2 Response to alarms

Where Table 6 indicates that LTPS can be provided by alarms, it is essential that the location can be reached by a plant operator, maintenance technician, or trained customer representative in sufficient time to be able to respond to a low temperature alarm condition without placing themselves at risk due to a hazardous situation. The alarm signal shall be transmitted to a location which is staffed 24 hours per day. A contingency plan and administrative procedures shall be in place for when this alarm is activated to prevent brittle fracture. This can include switching between parallel banks of natural draft ambient air-heated vaporisers, limiting the customer flow rate, increasing utility supply, starting up a redundant vaporiser system, etc.

Where the location cannot be reached in sufficient time or adequate response cannot be provided on site, low temperature shutoff is required.

11.3 Recommended solutions for specific situations

Table 6 is a qualitative ranking of LTPS relative to perceived risk of a low temperature event occurring, based on the experience of industry members, taking into account the secondary effects from gas release, which depend on the nature of the gas released as well as stored energy and the relative likelihood of the event occurring, which depends on the operating pattern and type of vaporiser.

A documented risk review should be carried out in all cases. Generic risk reviews may be developed for standard designs and installation locations. The generic risk review should be applicable to the facility being reviewed and any differences identified and addressed. Table 6 lists recommended minimum protection systems for defined situations.

Additional alarms can be recommended by the specific risk review and the number and type of alarms will depend on type of vaporiser. Alarms should be considered for loss of any utility.

Periodic review of consumption through the vaporiser system with the customer can be necessary, and LTPS could need to be modified to reflect changes in consumption, or additional vaporisation capacity could need to be added.

Not all options for LTPS are listed in Table 6.

Other options are listed in Section 9 such as the use of throttling valves, orifices, etc., and these options may also be considered in the risk assessment for the installation.

As consequences can widely impact neighbouring installations, a risk assessment shall be conducted for toxic gases taking into account the impact on highly populated areas and places of public assembly in addition to the LTPS design recommended in Table 6, whatever the vaporiser type, the consumption pattern, and the PV severity level.

Table 6 – Recommended LTPS selection: PV severity levels P0, P1, P2, and P3

<u>Severity level</u>		<u>Low temperature likelihood</u>	<u>Operating pattern</u>	<u>Low temperature protection system solution</u>	<u>Instrumentation/Controls</u>
<u>Pressure volume</u>	<u>Fluid hazard</u>				
P0	H1, H2	L1, L2, L3	S1, S2	If the risk review indicates it is necessary, a temperature sensor with a low alarm or a temperature sensor with a shutoff device should be fitted. Where the risk is deemed to be low, no alarm and/or shutoff device is needed.	None or 1 TE + alarm or 1 TE + 1 SO
	H3	L1	S1, S2	One temperature sensor with a low alarm and a shutoff device should be fitted. Where the risk is deemed to be high, two temperatures sensors with a low alarm and a shutoff device may be fitted.	1 TE + alarm + 1 SO or 2 TE + alarm + 1 SO
		L2, L3	S1, S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors (1oo2) and one shutoff device may be fitted.	2 TE (1oo2) + 2 SO or 2 TE (1oo2) + 1 SO
P1	H1, H2	L1	S1, S2	If the risk review indicates it is necessary, a temperature sensor with a low alarm or a temperature sensor with a shutoff device should be fitted. Where the risk is deemed to be low, no alarm and/or shutoff device is needed.	None or 1 TE + alarm or 1 TE + 1 SO
	H1, H2	L2, L3	S1	A temperature sensor with a shutoff device should be fitted.	1 TE + 1 SO
	H1	L2	S2	A temperature sensor with a shutoff device should be fitted.	1 TE + 1 SO
	H2	L3	S2	Two temperature sensors (1oo2) and one shutoff device should be fitted. If determined acceptable by a risk review, one temperature sensor and one shutoff device may be fitted.	2 TE (1oo2) + 1 SO or 1 TE + 1 SO
	H3	L1	S1, S2	A temperature sensor with a shutoff device should be fitted.	1 TE + 1 SO
		L2, L3	S1, S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted.	2 TE (1oo2) + 2 SO
P2	H1	L1	S1	If the risk review indicates it is necessary, a temperature sensor with a low alarm or a temperature sensor with a shutoff device should be fitted. Where the risk is deemed to be low, no alarm and/or shutoff device is needed.	None or 1 TE + alarm or 1 TE + 1 SO

<u>Severity level</u>		<u>Low temperature likelihood</u>	<u>Operating pattern</u>	<u>Low temperature protection system solution</u>	<u>Instrumentation/Controls</u>
<u>Pressure volume</u>	<u>Fluid hazard</u>				
		L1	S2	<u>A temperature sensor with an alarm and a shutoff device should be fitted. Where the risk is deemed low, no shutoff device is needed.</u>	<u>1 TE + alarm + SO, or 1 TE + alarm</u>
		L2	S1, S2	<u>A temperature sensor with a shutoff device should be fitted.</u>	<u>1 TE + 1 SO</u>
		L3	S1	<u>A temperature sensor with a shutoff device should be fitted. If the risk review indicates it is necessary, an alarm should be fitted on utility.</u>	<u>1 TE + 1 SO, + optional utility alarm</u>
		L3	S2	<u>Two temperature sensors (1oo2) and one shutoff device should be fitted. If determined acceptable by a risk review, one temperature sensor and one shutoff device may be fitted. An alarm should be fitted on utility.</u>	<u>2 TE (1oo2) + 1 SO or 1 TE + 1 SO, and utility alarm</u>
	H2	L1	S1, S2	<u>A temperature sensor with a low alarm or a temperature sensor with a shutoff device should be fitted.</u>	<u>1 TE + Alarm or 1 TE + 1 SO</u>
		L2	S1, S2	<u>Two temperature sensors (1oo2) and one shutoff device should be fitted. If determined acceptable by a risk review, one temperature sensor and one shutoff device may be fitted. An alarm should be fitted on utility.</u>	<u>2 TE (1oo2) + 1 SO or 1 TE + 1 SO, and utility alarm</u>
		L3	S1	<u>Two temperature sensors (1oo2) and one shutoff device should be fitted. If determined acceptable by a risk review, one temperature sensor and one shutoff device may be fitted. An alarm should be fitted on utility.</u>	<u>2 TE (1oo2) + 1 SO or 1 TE + 1 SO, and utility alarm</u>
			S2	<u>Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors and one shutoff device may be fitted. An alarm should be fitted on utility.</u>	<u>2 TE (1oo2) + 2 SO or 2 TE + 1 SO, and utility alarm</u>
	H3	L1	S1	<u>Two temperature sensors (1oo2) and one shutoff device should be fitted. If determined acceptable by a risk review, one temperature sensor and one shutoff device may be fitted.</u>	<u>2 TE (1oo2) + 1 SO or 1TE +1 SO</u>
		L1	S2	<u>Two temperature sensors (1oo2) and one shutoff devices should be fitted.</u>	<u>2 TE (1oo2) + 1 SO</u>
		L2, L3	S1, S2	<u>Two low temperature sensors (1oo2) and two shutoff devices should be fitted. An alarm should be fitted on utility.</u>	<u>2 TE (1oo2) + 2 SO, and utility alarm</u>

<u>Severity level</u>		<u>Low temperature likelihood</u>	<u>Operating pattern</u>	<u>Low temperature protection system solution</u>	<u>Instrumentation/Controls</u>
<u>Pressure volume</u>	<u>Fluid hazard</u>				
P3	H1	L1	S1, S2	A temperature sensor with a shutoff device should be fitted.	1 TE + 1 SO
		L2	S1, S2	Two temperature sensors (1oo2) and one shutoff device should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 1 SO, and utility alarm
		L3	S1	Two temperature sensors (1oo2) and one shutoff device should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 1 SO, and utility alarm
		L3	S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors and one shutoff device may be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 2 SO or 2 TE + 1 SO, and utility alarm
	H2	L1	S1, S2	A temperature sensor with a shutoff device should be fitted.	1 TE + 1 SO
		L2	S1	Two temperature sensors (1oo2) and one shutoff device should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 1 SO, and utility alarm
		L2	S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors and one shutoff device may be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 2 SO or 2 TE + 1 SO, and utility alarm
		L3	S1	Two temperature sensors (1oo2) and one shutoff device should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 1 SO, and utility alarm
	S2		Two temperature sensors (1oo2) and two shutoff devices should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 2 SO, and utility alarm	
	H3	L1	S1, S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors and one shutoff device may be fitted.	2 TE (1oo2) + 2 SO or 2 TE + 1 SO
	H3	L2	S1, S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. If determined acceptable by a risk review, two temperature sensors and one shutoff device may be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 2 SO or 2 TE + 1 SO, and utility alarm
	H3	L3	S1, S2	Two temperature sensors (1oo2) and two shutoff devices should be fitted. An alarm should be fitted on utility.	2 TE (1oo2) + 2 SO, and utility alarm

NOTE—For the applicability of alarms, see 10.2.

12 Operation

12.1 Consumption monitoring

Consumption monitoring can contribute significantly to the safe operation of a vaporisation system. From an original contractual agreement and system design, customer demands often increase as their business grows.

There are two variables that should be monitored:

- Firstly, the flow rate is one of the key design parameters when sizing vaporiser systems. Any increase in customer usage can overload the vaporiser, which could result in a hazardous condition; and
- Secondly, the use pattern also has a significant impact on the capability of a vaporiser, and this should be taken into account at the design stage but also monitored to ensure that any change in use pattern is observed and investigated where necessary.

The effect of increases in consumption on vaporisation systems can often be masked, particularly on ambient systems where favourable ambient conditions will compensate for increased demands and a problem can only become evident during colder ambient conditions.

Consumption monitoring can be achieved in a number of different ways including local flow metering and flow totalisation or by monitoring the liquid usage rate.

Flow metering will allow for more detailed analysis of liquid consumption. Flow metering can provide instantaneous or time-averaged high flow rate alarms, or provide an input to a flow limiting control function.

The monitoring of liquid usage is commonly carried out as a method of scheduling deliveries of liquid to the customer's storage tank. The remote monitoring of storage can be achieved by telemetry systems that log liquid level and can calculate the rate of change of liquid level. Monitoring can also be achieved by manual logging of liquid level in a storage tank or by checking the frequency of liquid deliveries. Automatic alarms created by monitoring software or periodic review of liquid usage can be undertaken to ensure that the customer demand is not exceeding the design parameters of the system.

When monitoring consumption, the following parameters should be considered:

- capabilities of the vaporisation system;
- appropriate alarm levels for high consumption rate alarms;
- time period over which high consumption rate alarms should be set (instantaneous, hourly, daily, weekly, etc.), which will be dependent on the vaporiser capacity; and
- action to be undertaken if high usage is detected. Whether this is to trigger a design review or more urgent action if the increase is significantly greater than the design values.

In the case of natural draft ambient air-heated vaporisation (L1), a method of consumption monitoring shall be considered if:

- no low temperature shutoff system is installed;
- no low temperature alarm is installed;
- no flow limiting device is fitted; and
- system is not entirely constructed of materials suitable for cryogenic temperatures.

12.2 Manual defrosting

Prolonged periods of operation can result in ice build-up without the opportunity for natural defrosting of natural and / or forced draft ambient air-heated vaporisers. As manual defrosting may be required to return the vaporiser's capacity back to near design rating, using auxiliaries like hot water or steam can enhance the effectiveness of the defrost.

When auxiliaries are not present, physical removal of the ice by manual force (i.e., chipping ice off by hammers, chisels, picks, etc.) requires caution so as to not damage the vaporiser and / or cause a leak.

Whether or not auxiliaries are present, hazards such as falling ice and slippery surfaces shall be considered.

Forced draft ambient air-heated vaporisers can be provided with electric heating elements to warm the air to aid in defrosting.

13 **Periodic inspection, calibration, and testing**

Periodic inspection, calibration, and testing of the vaporisation equipment and protection systems is important for maintaining the reliability of the low temperature protective function. Appropriate inspection, calibration, and test intervals and procedures shall be developed for each system and will be dependent on the design of system, the type of equipment, and the availability of the system for work.

Where the pipeline supply planned shutdown interval is greater than the required LTPS proof test interval, the system should be designed to allow testing of the LTPS without interrupting the customer's supply.

The testing procedure should take into consideration measures to prevent unplanned disruption of the supply to the customer and to remove any overrides on trip devices if the testing is carried out on-line.

Equipment installed for low temperature protection should be included in the maintenance scheduling system. Preventative maintenance (PM) should be scheduled periodically for the LTPS by the maintenance system.

13.1 **Periodic inspection**

Visually check and inspect all temperature control instrumentation and vaporiser regularly for:

- excessive ice build-up;
- frosting of pipework;
- physical damage to the vaporiser system components;
- leakage of process fluid or utilities;
- any apparent change that could affect operation of the vaporiser system;
- change in environment around the vaporiser such as walls or buildings installed around ambient air-heated vaporisers;
- blockages in instrumentation vents (for example, insect or animal nests, debris, etc.);
- settings of the temperature trip set point and/or throttling set point;
- shutoff devices functionality (i.e., vaporiser outlet valve, vaporiser inlet valve, or pump motor shutdown); and

- damage to interconnecting tubing, wiring, etc.

The frequency of inspection is influenced by the following factors:

- type of vaporiser;
- rates of flow and patterns of usage;
- frequency of low temperature alarms or shutdown operation seen in service;
- absence of low temperature alarms or shutoff systems; and
- severity of ambient weather conditions potentially affecting performance (for example, extreme low temperatures, extreme high humidity).

13.2 Periodic calibration and testing

All instrumentation and controls for low temperature protection shall undergo PM calibration and functional testing at a regular interval as determined by the individual company. Each company shall use risk assessment results to determine functional testing intervals (see 6.2). Calibration and testing should include the items noted in 12.2.1 and 12.2.2.

13.2.1 Field inspection, calibration, and testing

Field inspection, calibration, and testing should include:

- verification of all local temperature indicators for vaporiser outlet and pipeline temperature;
- calibration of all temperature transmitters or switches;
- verification of proper operation of logic elements (for example, relays, PLCs);
- verification of operation of temperature control valves and shutoff devices in accordance with design specification;
- functional testing of temperature alarms for proper operation; and
- full loop functional testing of the LTPS to ensure the final control element will close if temperature drops to the trip setting and the process flow is stopped.

13.2.2 Non-field inspection, calibration, and testing

When field calibration of components or proof testing of the LTPS is not practical, the equipment can be sent back to the manufacturer or an appropriate facility for calibration, proof testing, checkout, repair, etc.

Since operating without temperature protection is not an option, it is necessary to have a calibrated device available to change out with the device in service.

To ensure that the LTPS will operate as required, a functional check of the full loop shall be performed at the facility or in the field. Alternatively, individual element testing shall be performed, for example, by separately testing temperature sensors and simulating the signal to verify that the final shutoff device operates as specified and completely stops the process flow.

In all cases, test records should be documented for each installation. Records of proof testing shall be maintained during the life of the vaporiser system.

14 Training for gas company personnel

The following persons shall be given training in the possible causes and consequences of low temperature embrittlement hazards:

- project engineers responsible for the installation of vaporiser systems and LTPS;
- maintenance managers and technicians responsible for the maintenance of vaporiser systems and for the periodic functional testing of LTPS;
- plant operators and supervisors responsible for the operation of plants and associated back-up systems; and
- design engineers responsible for the development of flow sheets and specification of vaporiser systems and LTPS shall also be given training and, in addition, should be knowledgeable in the relevant design standards for LTPS.

Other staff (for example, sales and logistics teams, drivers) should be trained on reporting issues such as excessive ice build-up on vaporisers and excessive consumption.

15 Customer awareness

15.1 Customer agreement

The following information shall be communicated between the customer and the gas company in order to design and operate the vaporising system:

- estimated flowrates and use pattern;
- design performance (particularly the maximum flow and the maximum duration of continuous use for a natural draft ambient air-heated vaporiser) of the vaporising system and the temperature extremes that the customer system can be expected to encounter;
- emergency response when an accidental sudden increase of flow occurs at the customer site;
- procedure to be implemented, including pre-warning time, when the customer's need of gas is increasing or when the duration of use is increasing (ambient air-heated vaporisers);
- contact person and emergency phone number of the gas company; and
- responsibility for maintenance, inspection, etc. of the vaporiser installation.

Furthermore, the agreement should specify the low temperature protection method that is used such as:

- shut off of flow;
- reduction of flow before shut off;
- reduction of flow only; or
- continuously flow without any low temperature protection.

The customer shall be informed of the chosen method and its consequences for the supply reliability and system design on the customer's side of the interface point. The customer should also be made aware of the requirement to periodically test any protective device that is fitted, which can necessitate the interruption of supply if required.

The gas supplier shall always notify the customer in writing when the agreement for a bulk gas supply specifies that low temperature protection is not included in the project scope and that a risk of downstream equipment or piping failure exists if the customer overdraws the vaporiser design capacity. The project records shall maintain copies of documentation indicating the agreed selection of LTPS.

15.2 Customer training and information

The gas supplier shall give the customer appropriate information and information/training material including the relevant safety data sheets (SDS). It is highly recommended that the gas supplier also train all customer personnel involved in the monitoring or maintenance of the vaporiser installation. The training should include:

- information of the gas properties including cryogenic risks;
- risk and precautions with material being exposed to low temperature;
- consequence of accidental releases of gas or liquid;
- proper emergency routines including actions to be taken such as evacuating the immediate area; and
- any contractually defined maintenance and inspection activities.

16 References

Unless otherwise specified, the latest edition shall apply.

[1] IEC 61511: All Parts, *Functional safety - Safety instrumented systems for the process industry sector*, www.iec.ch.

[2] NFPA 55, *Compressed Gases and Cryogenic Fluids Code*, www.nfpa.org.

[3] NFPA 86, *Standard for Ovens and Furnaces*, www.nfpa.org.

[4] ISO 7396-1, *Medical gas pipeline systems—Part 1: Pipeline systems for compressed medical gases and vacuum*, www.iso.org.

[5] NFPA 99, *Health Care Facilities Code*, www.nfpa.org.

[6] ASME B31.3, *Process Piping*, www.asme.org.

[7] IEC 61508: All Parts, *Functional safety of electrical/electronic/programmable electronic safety-related systems*, www.iec.ch.