



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

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

Prepared by AHG-3.29 of WG-3 Atmospheric Gases Process & Equipment

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA), publication, "Cryogenic Vaporisation Systems – Prevention of Brittle Fracture of Equipment and Piping", has been used as the basis of an internationally harmonised gas association's publication on this subject.

This publication is intended as an international harmonised 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 133/14

Section	Change
All	Significant revision to all sections

NOTE Technical changes from the previous edition are underlined

1 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.

2 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.

3 Definitions

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

3.1 Publication terminology

3.1.1 Shall

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

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Will

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

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Battery limit

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

3.2.2 **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.

3.2.3 **Ductile**

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

3.2.4 End use point

Physical location where gaseous product is consumed by the customer.

3.2.5 **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.

3.2.6 **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.

3.2.7 **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.

3.2.8 Logic solver

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

3.2.9 **Pressure**

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

3.2.10 **Resilient material**

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

3.2.11 **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.

3.2.12 **Shutoff device**

Component that reliably interrupts the process flow.

3.2.13 **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.

3.2.14 **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.

3.2.15 **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.

4 **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.

4.1 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.

4.2 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.

5 Causes and consequences of low temperature

5.1 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.
Natural draft 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.
Natural 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.
Natural 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).
Forced draft ambient air-heated vaporisers	<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>
Natural draft ambient air-heated vaporisers with trim heaters	<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>
Natural draft ambient air-heated vaporisers with switchover	<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.
Fired heater water bath vaporisers	<u>Fuel gas failure.</u>	<u>Burner management systems malfunction.</u> <u>Loss of fuel supply.</u>
Vaporisers with heating fluid pumped through	<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.

5.2 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