



PREVENTION OF EXCESSIVE PRESSURE DURING FILLING OF CRYOGENIC VESSELS

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PREVENTION OF EXCESSIVE PRESSURE DURING FILLING OF CRYOGENIC VESSELS

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA), publication, *Prevention of Excessive Pressure during Filling of Cryogenic Vessels*, 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 standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Amendments to 151/15

Section	Change
2.1	Clarifications added to the Scope
4	Minor changes added
5	Minor changes added
6.3.7	Added
6.4	Clarification on 'Limiting pressure'
7	Minor changes added
8	Adapted as per the core text
Appendix A	Deleted

Note: Technical changes from the previous edition are underlined

1 Introduction

This publication details the methods that can be used to prevent the over-pressurisation of both transportable and static pressure vessels during filling.

2 Scope and purpose

2.1 Scope

This publication is intended to provide guidance to the filler/owner of either transportable or static cryogenic tanks, detailing the systems and procedures that can be used to prevent them being over-pressurized during filling (i.e., causing a catastrophic failure by excessive pressure). Vessels for which the upper pressure limit (UPL) cannot be exceeded by the maximum allowable pump feed pressure (MAPFP) do not require any additional protection.

This publication is intended to address the issue of transportable or static cryogenic tanks greater than 1000 L (264 gal) water capacity for liquefied cryogenic gases and refrigerated liquids such as nitrous oxide and carbon dioxide. This publication should also be used for receiving vessels under 1000 L (264 gal) that are not designed for transport when full. This publication can also be used as guidance for other products and other transfer systems. It does not consider the hazardous nature of any product release, only the prevention of a failure of the tank due to pressure. This does not apply to cryogenic tanks with flat bottoms. For flat bottomed cryogenic tanks, refer to EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites* [1].¹

Protective measures that prevent the over-pressurisation of receiving vessels in service (for example, by failure of the vacuum, pressure raising, flame engulfment, etc.) are detailed in other codes and standards, and are not considered further here.

2.2 Purpose

In 1996, a serious incident focused the attention of the gas industry on the fact that a cryogenic storage tank can be pressurized greater than its bursting pressure during filling. If a high pressure or high flow pump is used to fill a low pressure tank and if the safety measures are not appropriate or do not work, then an unsafe situation can arise.

This was the first significant incident of this type in an industry that has operated safely and reliably with an estimated several million filling operations carried out per year. However, due to technical developments in pumping equipment (increasing delivery pressures and flow rates), the safety margin the tanks have against failure can be reduced unless the protective measures against such an event occurring have not been upgraded simultaneously.

It is an essential management task to systematically control any changes to product transfer systems to ensure that the integrity of the tanks being filled is not jeopardized.

Pressure vessels are used in the distribution and site storage of cryogenic liquids on customer sites. This includes those involved in the transport of cryogenic fluids (transportable pressure vessels) such as road tankers, rail tank cars transferring product from the production facility to the customer's site, and those on the customer site itself (static pressure vessels) that provide on-site storage for the cryogenic fluids.

The primary means of controlling vessel pressure during an operator attended fill is by a trained and qualified operator, making it a manually controlled process. The case for the over-pressurization scenario during operator attended filling is often outside the pressure vessel design code for sizing of pressure relief devices.

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

Over-pressurisation avoidance has been achieved through operator procedures and training. This training includes, for example:

- initial and practical training verified by a qualification test; and
- re-examination and requalification verified by a driver trainer or supervisor.

The safety record of filling operations indicates that the training of personnel has been exemplary based on historical performance. In order to accommodate the continuously improving capability of pumping systems, the objective is now to further improve overall safety by applying the principles of this publication and by introducing an additional safety protection system when required.

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 Will

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

3.1.4 May

Indicates that the procedure is optional.

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 Cryogenic fluid

Refrigerated liquefied gas that is partly liquid because of its low temperature

3.2.2 Cryogenic storage tank

Typically a static (stationary) vacuum-insulated vessel also known as the receiving vessel

3.2.3 Fly wire system

A wired connection between the receiving vessel and the pump control system used to transfer signal during the filling.

3.2.4 Maximum allowable working pressure (MAWP)

Maximum pressure a tank is designed for during normal operation. A vessel's pressure relief devices are normally set to open at the MAWP.

3.2.5 Maximum allowable pump feed pressure (MAPFP)

Maximum pressure that a receiver vessel's fill coupling, fill valves and pipe work and any connected circuit are designed for. It is typically between 15 bar and 45 bar (220 psi and 650 psi). It is normally higher than the MAWP of the tank, to allow for pressure drop in the inlet system during the filling.

3.2.6 Maximum delivery pressure (MDP)

Maximum pressure that can be produced by a given pump or pressure transfer system used to fill a receiver tank.

3.2.7 Pressurized loading systems

Any system used to transfer product via gravity, pressure differential, or mechanical means (i.e., ground pump, transfer pump).

3.2.8 Receiving vessel

Vessel that is being filled; it includes both cryogenic storage tank and transport tank.

3.2.9 Transport tank

Includes fixed tanks (of tank vehicles, trailers, or tank wagons), demountable tanks, tank containers and swap bodies for liquefied cryogenic gases and refrigerated liquids

3.2.10 Upper pressure limit (UPL)

Highest pressure it is acceptable to allow a vessel to reach under abnormal filling conditions (e.g., test pressure).

3.2.11 Working pressure (WP)

Pressure at which the vessel is set to operate. It is the set pressure of the pressure control devices (the pressure build-up and the economizer regulators).

4. Background

4.1 Background transport tanks

Transport tanks are designed, manufactured and used in accordance with the applicable transport regulations.

The transport tank can be filled from a pressure source (at the production facility) with a pressure that exceeds the maximum allowable working pressure (MAWP) of the transport tank.

Typically the applicable transport regulations do not cover methods for filling and withdrawal. To discharge the fluid into the receiving vessel, the transport tank may be fitted with a centrifugal pump.

4.2 Background static vessels

Static vessels provide gas or liquid for customer use and have a working pressure (WP) ranging from just above atmospheric pressure up to in excess of 35 bar (510 psi). During filling this WP should be kept constant in order not to disturb the user's process. The pressurized loading systems used to fill the static cryogenic vessel should:

- have an output pressure that at least matches the highest WP in the range of tanks to be filled (at various customer sites); and
- produce additional pressure to overcome the frictional pressure drop of the fluid flowing into the tank.

This means that pressurized loading systems could produce a maximum pressure that exceeds the MAWP of the receiver tank.

Pressurised loading systems typically include a storage tank and a pump, however some pressurized delivery systems rely only on the pressure of the storage tank to deliver the fluid without a pump.

5 Transport tanks

5.1 Filling operation

Transport tanks are normally filled with minimal required venting to reduce losses. In order to make the transfer of product into the transport tank possible without depressurization, the pressure source can exceed the MAWP of the transport tank.

Detecting when the maximum level of liquid is reached in the tank is done by various methods throughout the gas industry (for example, by observing when liquid flows from a try-cock, by weight, or by measurement of flow).

5.1.1 Single hose filling by pump

It is common to fill a transport tank using a pumping system via a single filling hose except for carbon dioxide and nitrous oxide which are commonly filled with a dual hose (liquid feed and vapor return). To obtain sufficient flow rates, the pump has a possible maximum discharge pressure in excess of the receiving vessel's MAWP.

The standard single hose filling procedure requires the operator to continuously monitor and control the receiving vessel pressure by adjustment of the top and bottom fill valves. In any case, keeping the pressure below the MAWP is critical to safety.

Automatic systems using flow meters or weigh scales may be used.

Filling is complete when the intended amount of liquid is transferred or the maximum fill level is reached. In situations where the operator either fails to end the fill process when the maximum filling level is reached, or fails to control the tank pressure during fill, the pressure in the transport tank will increase and can reach the MAWP, causing the relief devices to open. If the flow of the pump is greater than the capacity of the relief system, the pressure in the transport tank can rise to the pump maximum delivery pressure (MDP) which can be much greater than the MAWP of the transport tank.

5.1.2 Filling with pressure balance

This method of filling involves an additional hose connection between the gas phase of the receiving vessel (transport tank) and the storage tank.

The differential pressure requirement of the transfer system will be reduced as the pressure of the transport tank and the storage tank will be equalized before/during filling. This method may also be used to reduce loss of gaseous product from the gas phase of the transport tank.

The product may be transferred by a pump or by the liquid head of the storage tank. The filling procedure is normally controlled by an operator who may be supported by automatic systems.

Any potential over-pressurisation of the receiving vessel can be reduced when using this two hose transfer method as the pressure can balance.

5.1.3 Pressure transfer

Transport tanks may be filled without pumps by pressure transfer if the pressure of the storage tank exceeds the pressure of the transport tank.

The necessary pressure difference for the liquid product transfer can be produced by increasing the pressure in the gas phase of the storage tank by operating a pressure build up system or reducing the

pressure in the receiving vessel. Other methods may be used (for example, using the liquid head of the storage tank).

The filling procedure is normally controlled by an operator who may be supported by automatic systems.

If the operator fails to stop the filling procedure at the maximum fill level the transport tank can be pressurized up to the MAWP of the storage tank, plus the liquid head.

5.1.4 Preventive measures

In reviewing the possible methods and devices to protect against over pressurization during filling, the following principles shall be considered:

- Methods that do not rely on the filling source or the relief capacity of the transport tank are preferred;
- Methods with a link between the transport tank and the filling source are acceptable, but require management control systems to ensure that only compatible transport tanks are used to fill; and
- The set pressure of any device should not exceed the UPL of the lowest pressure transport tank to be filled.

The method used shall be appropriate for the assessed risk.

5.1.5 Pressure relief system

This method involves confirming or increasing the main pressure relief capacity on the transport tank so the maximum fill flow rate can be safely relieved without the transport tank exceeding its UPL.

Should the fill flow be found to exceed the main relief capacity of the transport tank, restrictions to the inlet flow line (e.g., orifice plates) may be considered as a solution.

5.1.6 Fly hose system

This system transfers the pressure in the transport tank via a small bore flexible hose to the control box of the filling station.

The system logic shall be such that product transfer is stopped if:

- UPL set pressure is reached; or
- Low pressure value is not met, indicating that the fly hose is not connected to the transport tank.

5.1.7 Transport tank pressure controlled shutoff device

The filling line of the transport tank is fitted with an automatic shutoff valve, which is controlled by the pressure of the transport tank. The valve will be closed if:

- transport tank pressure equals or exceeds its UPL; or
- power supply to open the valve is closed or not available.

This protection method is independent of the filling station and is fail safe.

5.1.8 Fill plant shutoff system

This system consists of a pressure sensing device fitted to the transfer line. The device will isolate and/or stop the transfer pump if the UPL set pressure is exceeded. This protection method is independent of the transport tank.

5.2 Recommendations

Equipment and procedures for filling transport tanks vary between companies and locations. Each company should carry out a risk assessment for the equipment and the filling procedure in use, for its own transport tanks at every location where they are filled, including those at other gas company sites.

For this assessment the maximum filling pressure at the filling station and the UPL of the transport tanks should be considered. The UPL of the transport tank should, as a general rule, not exceed the test pressure of the transport tank. The effect of the vacuum on the test pressure shall be considered if required.

Alternatively, by agreement with the regulatory authority having jurisdiction, the UPL can be the test pressure of the transport tank increased by the enhancement of the material properties at the operating temperature, where design characteristics of the inner vessel are known; or a higher pressure, provided this is supported by a suitable documented risk assessment of the combined system (transfer pump-transport tank), for each type of transport tank.

This risk assessment shall be reviewed if any of the previously described circumstances should change. An effective management of change system needs to be in place.

If the result of the risk assessment identifies the possibility that the UPL or the pressure agreed by the regulatory authority having jurisdiction can be exceeded, then one of the detailed systems or an equivalent alternative shall be used to reduce the risk to an acceptable level.

6 Static tanks

6.1 Equipment and procedures

Equipment and procedures for filling static tanks from transport tanks vary between gas companies.

What is common throughout the industry is that most static tanks are filled using centrifugal pumping systems, which have possible maximum discharge pressures in excess of the receiving vessel's MAWP.

The standard filling procedure for cryogenic liquids requires the operator to continuously monitor the receiving vessel pressure and adjust the flow of liquid into the vessel by controlling the top and bottom fill valves to keep the pressure at the WP. The filling is finished when the intended amount of liquid is transferred or the maximum fill level is reached. The normal method of detecting when the maximum level is reached is to observe when liquid issues from the trycock line valve.

Only in situations where the operator is unable to follow this procedure and fails to regulate the fill valves correctly or to finish the fill when the maximum filling level is reached, will the pressure in the receiving vessel increase and finally exceed the MAWP, thus activating the relief devices. Should the operator still fail to intervene and stop the fluid transfer, the final pressure in the tank will depend on the balance between the pressure/flow characteristics of the pump and pipework, and the pressure/flow characteristics of the receiving vessel's relief system.

6.2 Principles for overpressure protection

In reviewing the possible methods and devices to protect receiving vessel against over-pressurisation during filling, a number of options can be considered.

1. Over-pressurisation protection means that the pressure in the receiving vessel under accidental conditions should not exceed its UPL even if the operator is unable to follow the correct procedure.
2. vessel's fill point piping should be designed to the MAPFP.
3. The MDP used to fill a receiving vessel should not exceed the receiving vessel's MAPFP.

4. When an over-pressurisation protection system is tripped, it should remain in that state until reset by a specific procedure. If the operator is permitted to reset the system, there should be either a procedure requiring them to record the incident or an automatic event record. The operator shall be trained to record the event or have knowledge of the automatic event recording system.
5. The design of the over-pressurisation protection system should be fail-safe.
6. The protection system should offer no incentive for overriding or non-compliance with correct procedures (e.g., when multiple receiving vessels are located at the same site, and/or the design of the protection system should not allow one tank to be filled while the protection system is connected to another).
7. The protection system should have all necessary characteristics for compliance with applicable codes and acceptance by authorities.

Where the operator has been trained and qualified in the filling process and the provisions of 6.3.1 are in place, the manual loading operation is not considered as a component of the maximum quantity that can be supplied to the attached equipment. As such, the operator is considered to be the primary means of overpressure protection; thus, allowing secondary pressure relief devices to be set so the UPL is not exceeded.

8. Owners of transport tanks and/or receiving vessels should have a management system in place to ensure that the transport tanks engaged to fill static tanks will be compatible with the receiving vessel's MAPFP and overpressure protection system.

6.3 Examples of overpressure protection systems

Examples of overpressure protection methods in use are as follows.

6.3.1 vessel with relief device capacity matching the inlet flow

This method involves confirming or increasing the receiving vessel's relief capacity. When the pressure reaches the UPL, the flow through the pressure relief device(s) at least matches the flow from a pressurized loading system capable of producing a pressure (MDP) up to the receiving vessel's MAPFP.

The relief device should vent to a safe location, i.e., away from building entrances, operators and zones where customer personnel or public could reasonably be anticipated.

For receiving vessels operating under ASME jurisdictions, EIGA Doc 168, *Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Storage Tanks with Rupture Disks*, shall be used to perform the calculations [2]. If the relief capacity cannot be increased (due to restricted relief line size within the tank etc.), then increasing the flow restrictions on the inlet pipework to match the relief capacity available is an option. This may be achieved using orifice plate type devices.

A disadvantage with this method is that for many low pressure tanks, the fill rate can become very low, even when a high pressure pressurized loading system is used.

6.3.2 Receiving vessel inlet flow stop or limiting device

This device may be an actuated valve or regulator inserted between the receiving vessel fill connection and the first shutoff valves. The device is open during normal filling and closes or restricts the flow if the receiving vessel pressure becomes too high.

The device is controlled via a signal line from the tank. Any isolation valve(s) on this signal line shall be designed and/or managed so that it is not possible to fill the tank when the signal line valve is closed. When the device has tripped due to high tank pressure, reopening should only be possible when the tank pressure is in the permissible range and should require a prescribed action or tool.

6.3.3 Linked over pressurization protection system

The system links a source and a receiving vessel together through a process control connection. The system shall include a pump trip to interrupt the flow in the event of vessel over pressurization.

6.3.4 Fly wire system

The system is a trip circuit connecting the transport tank and the receiving vessel via a two-wire plug-in flying lead.

The device may be a pressure switch or a rupture disc with a built in electrical wire, or a separate membrane with built in electrical wire in series with the normal rupture disc.

The pressure switch or rupture disc setting shall be such that the pump is stopped before the UPL is exceeded.

6.3.5 Transport based system

If there is no device on the tank, the pump trip circuit may alternatively be broken based on the pressure measured on the connection pipe or flexible hose between the transport tank and the receiving vessel. The pressure threshold shall be such that the pump is stopped before the receiving vessel UPL is exceeded. Tests shall be performed to validate the system can calculate the pressure of the receiving vessel.

NOTE With a pump stop system, a management system shall be in place to ensure the correct pressure selection on the transport tank.

6.3.6 Dedicated fill connections

These are fill connections that have configurations that are pressure specific, allowing transport tanks to only fill storage tanks with a matching dedicated connection. The connection shall ensure that the UPL is not exceeded. Adaptors shall not be used between the pressure-specific couplings of the filling vessel and receiving vessel.

6.3.7 Pressure transfer

Static tanks may be filled without pumps by pressure transfer if the pressure of the transport tank exceeds the pressure of the static tank.

The necessary pressure difference for the liquid product transfer can be produced by increasing the pressure in the gas phase of the transport tank by operating a pressure build-up system or reducing the pressure in the receiving vessel. Other methods may be used (for example, using the liquid head of the transport tank).

The filling procedure is normally controlled by an operator who may be assisted by automatic systems.

If the operator fails to stop the filling procedure at the maximum fill level the receiving vessel can be pressurized up to the MAWP of the transport tank, plus the liquid head.

6.4 Limiting pressure

The limiting pressure within the static tank should be the UPL and, as a general rule, this should not exceed the test pressure of the receiving vessel. The effect of the vacuum on the test pressure shall be considered if required.

Alternatively, by agreement with the regulatory authority having jurisdiction, the UPL may be the test pressure of the tank increased by the enhancement of the material properties at the operating temperature, where design characteristics of the inner vessel are known; or a higher pressure, provided this is supported by a suitable and documented risk assessment of the combined system (transfer pump - transport tank), for each type of receiving vessel.

This risk assessment shall be reviewed if any of the previously described circumstances should change. An effective management of change system needs to be in place.

If the result of the risk assessment identifies the possibility that the (UPL or the pressure agreed by the regulatory authority having jurisdiction) may be exceeded, then one of the detailed systems or an equivalent alternative should be used to reduce the risk to an acceptable level.

7 General recommendations

A receiving vessel may be filled by a gas supplier or a gas supplier's agent that is not the owner of the vessel. However, it is the tank owner's responsibility to ensure the receiving vessel is adequately protected against overpressure and the gas supplier can safely make deliveries. The receiving vessel owner should confirm that the tank pressure cannot exceed the tank's UPL. Upon request from the tank owner, the gas supplier shall provide the delivery vehicle flow and pressure characteristics to the tank owner. These are typically provided as a curve describing the pressure rise across the pump as a function of flow for the pump operating at maximum speed. For pressure transfer systems this is typically provided as the maximum flow rate and pressure of the delivery system. It is the storage tank owner's responsibility to provide a system for identifying changes that affect tank relief device sizing, available tank relief device capacity, and MDP and flow rate for its supplier. Changes that impact the protection of the tank during operator-attended fill should be identified and, if necessary, communicated to the supplier.

In addition, the filler shall ensure that authorization has been issued by the owner to fill the tank and has confirmation that this tank can be safely filled.

7.1 Existing installations

Existing installations shall be reviewed and if it is found necessary, retrofitted to conform to the recommendations of this publication in accordance with a firm plan, giving priority to installations with the highest risk situation (e.g., low pressure receiving vessels filled by high pressure pumping systems).

7.2 Applicable principles and techniques

When implementing an over-pressurisation protection system, it shall conform to all the principles given in this publication. The overpressure protection system may be one of the examples given in this publication or be of any other design with equivalent reliability and integrity.

7.3 Role of driver-monitored procedures

The additional equipment recommended is not intended to replace the driver-monitored procedure, but to offer additional safety.

7.3.1 Training of personnel

Training of personnel involved in filling should be reviewed with emphasis on the importance of observing the pressures continuously and the correct use of the means to avoid overfilling (for example, the trycock).

Operators loading systems shall receive periodic training and qualification. Furthermore, their skills to operate the system and to control the tank pressure within the specified operating range, as well as within acceptable limits, shall be recertified periodically. The training shall contain information that the operator shall be the primary means of overpressure control, and that the safety relief systems on the vessel may not be able to control the vessel pressure within design code limits. It shall be made clear to the operator that they are the primary means of overpressure control, and shall remain in control of the transfer process to the receiving vessel as the safety relief systems are not designed to keep the receiving vessel pressure within design code limits.

The risks associated with overfilling shall be fully understood by all relevant personnel. All relevant training shall be documented.

8. References

Unless otherwise specified, the latest edition shall apply.

[1] EIGA Doc 127, *Bulk Liquid Oxygen, Nitrogen and Argon Storage Systems at Production Sites*, European Industrial Gases Association. www.eiga.eu

[2] EIGA Doc 168, *Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Storage Tanks with Rupture Disks*, European Industrial Gases Association. www.eiga.eu