



PREVENTION OF EXCESSIVE PRESSURE DURING FILLING OF CRYOGENIC VESSELS

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1 Introduction

This document details the methods that can be used to prevent the overpressurization of both transportable and static cryogenic pressure vessels during filling. It replaces guidance given in two separate and earlier EIGA documents, IGC 59/98 *Prevention of Excessive pressure in Cryogenic Tanks During Filling* and IGC 77/01 *Protection of Cryogenic Transportable Tanks Against Excessive Pressure During Filling*. This document replaces the CGA publications PS-8, *CGA Position Statement on the Protection of Cryogenic Storage Tanks from Overpressure During Operator-Attended Refill* and PS-14, *CGA Position Statement on the Protection of Cryogenic Transport Vessels from Overpressurization During Operator-Attended Refill*.

2 Scope and purpose

2.1 Scope

This document 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 overpressurized, during filling e.g., 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.

It is intended to address the issue of receiving vessels greater than 1000 litres water capacity for liquid argon, nitrogen, oxygen, natural gas, helium, hydrogen, or ethylene. This document should also be used for receiving vessels under 1000 litres that are not designed for transport when full. This document 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.

Protective measures that prevent the overpressurization of receiving vessels in service e.g., 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 accident focused the attention of the gas industry on the fact that a cryogenic storage tank can be pressurized above 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 recent technical developments in pumping equipment (increasing delivery pressures and flow rates), the safety margin the tanks have against failure may 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) e.g., road tankers, railroad tank cars transferring product from the production facility to the customers site and those on the customer site itself (static pressure vessels) that provide on site storage for the cryogenic fluids.

Overpressurization avoidance has been effected through operator procedures and training. This training includes for example:

- an initial and practical training verified by a qualification test,

- a re-examination and requalification verified by a selected driver inspector.

The safety record of filling operations today indicates that the training of the 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 document and by introducing an additional safety protection system when required.

3 Definitions

3.1 Definitions

MAWP

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

MAPFP

Maximum Allowable Pump Feed Pressure. The maximum pressure that a receiver tank's fill coupling, fill valves and pipe work and any connected circuit are designed for. It is typically between 15 bar and 45 bar. It is normally higher than the MAWP of the tank, to allow for pressure drop in the inlet system during the filling.

UPL

Upper Pressure Limit. The highest pressure it is acceptable to allow a tank to reach under abnormal conditions (e.g., test pressure).

WP

Working Pressure. The 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).

Fly wire system

A standardized wire connection between the receiving tank and the pump control system used to transfer signal during the filling.

MDP

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

Transport tank

Transport tank includes fixed tanks (of tank vehicles or tank wagons), demountable tanks, tank containers and swap bodies for cryogenic fluids.

Cryogenic storage tank

Typically a static (stationary) vacuum-insulated vessel also known as the receiver tank.

Cryogenic fluid

A refrigerated liquefied gas that is partly liquid because of its low temperature.

Pressurized loading systems

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

Receiving vessel

Covers both cryogenic storage tank and transport tank.

3.2 Background

3.2.1 Transport tanks

Transport tanks for cryogenic fluids are normally low pressure tanks (typically with a design pressure of less than 3 bar) that are designed manufactured and used in accordance with the applicable transport regulations.

In many cases these tanks are filled from a pressure source (at the production facility) with a pressure that exceeds the MAWP of the transport tanker.

Typically the applicable transport regulations do not cover methods for filling and withdrawal. To discharge the cryogenic fluid in to the receiver tank, the road tanker is fitted with a centrifugal pump.

3.2.2 Static tanks

Static cryogenic tanks provide gas or liquid for customer use and have a WP ranging from a few bars up to in excess of 35 bar. During filling this WP must be kept constant in order not to disturb the user's process. The pressurized loading systems (e.g., transport tank pump) used to fill the static cryogenic vessel must 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 cryogenic fluid flowing into the tank.

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

4 Transport tanks

4.1 Filling operation

Transport tanks are normally filled with closed vents to reduce losses. In order to make the transfer of product into the transport tank possible without depressurization, the pressure source of the filling station may 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 e.g., by observing when liquid flows from a try-cock, by weight, or by measurement of flow.

4.1.1 Filling by pump

It is common to fill a transport tank using a pumping system, via a single filling hose. To obtain sufficient flow rates, the pump has a possible maximum discharge pressure in excess of the receiving vessel's MAWP.

The standard filling procedure requires the operator to continuously monitor and control the receiving tank pressure below MAWP by adjustment of the top and bottom fill balance.

Automatic systems using flow meters or weight 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 may 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 may rise to the pump MDP.

4.1.2 Filling with pressure balance

This method of filling involves hose connections between the gas phase and the liquid phase of the receiver and 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 overpressurization of the storage tank will be reduced when using this two hose transfer method as the pressure can 'balance'.

4.1.3 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 may be produced by increasing the pressure in the gas phase of the storage tank by operating a pressure build up system. Other methods may be used e.g., 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 may be pressurized up to the MAWP of the static storage tank, plus the liquid head.

4.2 Preventive measures

In reviewing the possible methods and devices to protect transport tanks against overpressurization during filling, the following principles shall be considered:

- methods that are independent of the filling station or transport tank are preferred.
- methods with a link between the transport tank and the filling station are acceptable but require management control systems to ensure that only compatible transport tanks are used to fill.
- the set pressure of any device should not exceed the UPL of the lowest pressure transport tank to be filled.

The integrity of the method used shall be appropriate for the assessed risk.

4.2.1 Pressure relief system

This method involves confirming (or increasing) the main pressure relief capacity on the transport tank such that 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.

4.2.2 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

- the UPL set pressure is reached, or
- if a low pressure value is not met it can be detected that the hose is not connected to the transport tank.

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

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

4.2.4 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.

4.3 Recommendations

Equipment and procedures for filling transport tanks vary between companies and locations. Therefore each company should carry out a risk assessment for the equipment and the filling procedure in use, for its own tankers 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 may be the test pressure of the tank increased by the enhancement of the material properties at the operating temperature, where sufficient design characteristics of the inner vessel are known, or a higher pressure, provided this is supported by a suitable and sufficient 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 above 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.

5 Static tanks

5.1 Equipment and procedures

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

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

The standard filling procedure requires the operator to continuously monitor the receiver tank 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 try-cock 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 receiver tank 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 tank's relief system.

When prioritizing preventative measures for the small number of low pressure vessels, there can be a risk of exceeding the vessel material yield stress using the most common type of pumps.

With an extreme combination of a low pressure tank and a high pressure pump, it is possible to exceed the receiver vessel's material ultimate tensile strength.

Very few standard or low pressure customer vessels manufactured before 1996 have relief systems (and lines to these relief systems) able to cope with the flow rates generated by a typical centrifugal delivery pumping systems.

5.2 Principles for overpressure protection

In reviewing the possible methods and devices to protect receiver tanks against overpressurization during filling, a large number of options can be considered.

1. Overpressurization protection means that the pressure in the receiving tank under accidental conditions should not exceed its UPL even if the operator is unable to follow the correct procedure.
2. Receiver tank's fill point piping should be designed to the MAPFP.
3. The MDP used to fill a receiver tank should not exceed the receiver tank's MAPFP. The pump systems outlet end should be fitted with a coupling rated for at least the MDP.
4. When an overpressurization protection system is tripped it should remain in that state until reset by a special procedure. If the operator is permitted to reset the system alone, there should be a procedure forcing him to account for the incident. The above requirements do not apply to the main relief devices of the receiver tank.
5. The design of the overpressurization 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 receiver tanks are located at the same site, 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.
8. Owners of cryogenic tankers and/or receiver tanks should have a management system in place to ensure that the tankers engaged to fill receiver tanks will be compatible with the receiver tank's MAPFP and overpressure protection system.

5.3 Examples of overpressure protection

Examples of overpressure protection methods in use are given in the following.

5.3.1 Receiver tank with relief device capacity matching the inlet flow

This method involves confirming or increasing the tank's relief capacity, so that when the receiver tank 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 design pressure of the receiver's tank MAPFP.

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

For receiver tanks operating under ASME jurisdiction, CGA P-40, *Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Storage Tanks*, shall be used to perform the calculations. 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 pipe work to match the relief capacity available is an option. This can be done using orifice plate type devices.

A disadvantage with this method is that for many existing low pressure tanks, the fill rate can become very low, even when a high pressure pressurized loading system is used. If a tank adapted to be filled with a high pressure pressurized loading system also needs to be served by pumps with lower delivery pressure, the achievable flow rate may become unacceptably low.

5.3.2 Receiver tank inlet flow stop or limiting service

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

The device is controlled via a signal line from the top of the tank. Any isolation valve (s) on this signal line should be designed and 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.

5.3.3 Fly wire systems

The system is a high-integrity electrical pump trip circuit connecting the transport tank and the receiver tank via a simple two-wire plug in flying lead. The circuit is powered from the tanker end and broken, in the event of vessel overpressurization by the operation of some device on the tank.

The device can 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 should be such that the pump is stopped before the UPL is exceeded.

NOTE—The fly wire system may not be acceptable as the sole remedy for overpressure protection in some locations.

5.3.4 Dedicated coupling

These are couplings that have configurations that are pressure specific, allowing transport tanks to only fill storage tanks with a matching dedicated coupling. The coupling 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.

5.4 Recommendations

5.4.1 Minimum requirements

The basic minimum requirement is that any receiver tank should have effective overpressurization protection, for filling by pumps with MDPs up to the MAPFP specified for the tank.

5.4.2 Limiting pressure

The limiting pressure within the tank should be the UPL and, as a general rule, this should not exceed the test pressure of the receiver 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 may be the test pressure of the tank increased by the enhancement of the material properties at the operating temperature, where sufficient design characteristics of the inner vessel are known, or a higher pressure, provided this is supported by a suitable and sufficient documented risk assessment of the combined system (transfer pump -transport tank), for each type of receiver tank.

This risk assessment shall be reviewed if any of the above 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.

6 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 cryogenic storage tank during operator-attended fill should be identified and, if necessary, communicated to the supplier.

In addition, the filler shall ensure he has authorization from the owner to fill the receiver and has confirmation that this receiver can be safely filled.

6.1 Existing installations

Existing installations should be reviewed and if it is found necessary, retrofitted to conform to the recommendations of this document in accordance with a firm plan, giving priority to installations with the highest risk situation, i.e. low pressure receiver tanks filled by high pressure pumping systems.

6.2 Applicable principles and techniques

When implementing an overpressurization protection system, it shall conform with all the principles given in 5.1. The overpressure protection system may be one of the examples given in 5.2 or be of any other design with equivalent reliability and integrity.

6.3 The role of driver-monitored procedures

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

6.3.1 Training of personnel

Training of personnel involved in filling should be reviewed with emphasis on the importance of observing the receiver tank pressure continuously and the correct use of the means to avoid overfilling (e.g., the try-cock).

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

Appendix A: Example of Fly Wire System (Informative)

It is proposed that a current instead of a simple voltage circuit be used to allow the pump to be tripped if the circuit is shorted as well as broken. It will be possible to run the pump only if the current in the loop is within defined limits.

If the circuit is interrupted or not connected, the current is zero and the pump will not run. If the circuit has a short by damage or attempted tampering, the current becomes too great and the pump will not run. If a system with breaking wire membranes is used and the tank is fitted with dual rupture discs, the membranes should be wired in series. If a pressure switch is used and an isolation valve is fitted in the signal line for service or replacement, a method is required to ensure that the pressure switch is active when the fly wire circuit is in use.

This can be achieved using a three-way valve on the line to the pressure switch together with a pressure switch equipped with both a high and a low trip level.

The low trip will create an open circuit if the connection to the tank is not live.

To ensure that the socket on a neighbouring tank is not used in place of an inoperable circuit on the tank to be filled, tanks with sockets within 5 meters should be wired in series.

In order to qualify as a safety system, the system of management control should ensure that only compatible vehicles are used to fill tanks with fly wire protection.

A recommended standard for electrical fly wires is detailed below. By adhering to this standard, compatibility can be ensured between the equipment of different operators.

Plug and socket to comply with CEE DIN 49465 2 Pole 16 amp – 24v.

Static tank connector : Female Fly Wire : Male.

Pin number	Function	Electrical characteristics
1	Current loop for pump control	loop resistance 1.5 kohm \pm 10 %, max; 30 V supply, min 10 kohm to Ground resistance.
2	Current loop for pump control	loop resistance 1.5 kohm \pm 10 %, max; 30 V supply, min 10 kohm to Ground resistance.