

CGA S-1.3 — 2024

10TH EDITION

**PRESSURE RELIEF
DEVICE STANDARDS -
PART 3 -
STATIONARY
STORAGE
CONTAINERS FOR
COMPRESSED GASES**

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NOTE—Technical changes from the previous edition are underlined.

NOTE—Appendices A and B (Informative) are for information only.

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1 Introduction

This part of the Pressure Relief Device Standards presents the minimum requirements recommended by the Compressed Gas Association, Inc. (CGA) for pressure relief devices (PRDs) being used on compressed gas storage containers constructed in accordance with the *ASME Boiler & Pressure Vessel Code* (ASME Code) or the equivalent [1].¹ While these standards are written specifically to cover compressed gases as defined in 3.2.3, the procedures are applicable to storage containers with a maximum allowable working pressure (MAWP) exceeding 15 psi (103 kPa).²

2 Scope and purpose

2.1 Scope

It is recommended that containers use PRDs that meet the applicable requirements of the edition of the ASME Code or other applicable regulations, codes, standards, or specifications in effect at the time of manufacture. The container PRDs shall also meet the requirements of this standard, except containers for liquefied petroleum gas and anhydrous ammonia shall use PRDs meeting the applicable requirements of the following two standards:

- NFPA 58, *Liquefied Petroleum Gas Code* [3]; and
- CGA G-2.1, *Requirements for the Storage and Handling of Anhydrous Ammonia (an American National Standard)* [4].

A number of states and cities have pressure vessel laws and regulations that include requirements for PRDs. Manufacturers and users are cautioned that in some instances the relief devices recommended in this standard might not be acceptable unless special permission is obtained from the authority having jurisdiction (AHJ).

2.2 Purpose

The purpose of this standard is to complement the requirements of various regulations, codes, standards, or specifications applicable to storage containers for compressed gases. In case of conflict, the requirements of the regulations, codes, standards, or specifications of the AHJ over such containers shall apply. It is recommended that containers fabricated after December 31, 1995, use PRDs that meet the requirements of this edition of CGA S-1.3.

3 Definitions

For the purpose of this standard, 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.

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

² psi, bar, and kPa shall indicate gauge pressure unless otherwise noted as (psia; bar, abs; and kPa, abs) for absolute pressure or (psid; bar, dif; and kPa, dif) for differential pressure. All kPa values are rounded off per CGA P-11, *Guideline on Metric Practice in the Compressed Gas Industry* [2].

3.1.5 Can

Indicates a possibility or ability.

3.2 Technical definitions

3.2.1 ASME Code

Paragraph U-68, U-69, U-200, or U-201 of Section VIII of the *ASME Boiler & Pressure Vessel Code*, 1949 Edition; or Section VIII of the *ASME Code*, 1950 edition through the current edition, including addenda [1].

3.2.2 Combination pressure relief device (PRD)

- Breaking pin device in combination with a pressure relief valve in which the breaking pin device is located between the container and the pressure relief valve;
- Rupture disk in combination with a pressure relief valve in which the rupture disk is located between the container and the pressure relief valve; or
- Buckling pin device in combination with a pressure relief valve in which the buckling pin device is located between the container and the relief valve.

3.2.3 Compressed gas

Any material or mixture in the container having either an absolute pressure exceeding 40 psi at 68 °F (276 kPa at 20 °C), or an absolute pressure exceeding 104 psi at 130 °F (717 kPa at 54 °C) or both, or any liquid flammable material having Reid absolute vapor pressure exceeding 40 psi at 100 °F (276 kPa at 38 °C).

NOTE—See ASTM D323, *Standard Test Method for Vapor Pressure of Petroleum Products (Reid Method)* [5].

3.2.4 Flow capacity

Capacity of a PRD in cubic foot per minute (cubic meter per hour) of free air discharged at the required flow rating pressure.

3.2.5 Flow rating pressure

Inlet static pressure at which the relieving capacity of a PRD is determined for rating purposes.

3.2.6 Fluidhead

Pressure developed from a height of liquid column above a reference point.

3.2.7 Fluids

Liquid, critical, supercritical, and gaseous states of a substance.

3.2.8 Free air/free gas

Air or gas measured at a pressure of 14.696 psia at 60 °F (101.325 kPa, abs at 15 °C).

3.2.9 Liquefied compressed gas

Gas under the charged pressure is partially liquid at 68 °F (20 °C).

NOTE—A flammable compressed gas meeting the definition given in Title 49 of the U.S. *Code of Federal Regulations* (49 CFR), 173.115(a) that is nonliquefied under the charged pressure and 68 °F (20 °C), but is partially liquid under the charged pressure and a temperature higher than –40 °F (–40 °C), shall follow the requirements for liquefied compressed gases [6].

3.2.10 Maximum allowable working pressure (MAWP)

Identical to MAWP as used in the ASME Code for the original design and construction of the container, except for containers constructed in accordance with U-68 and U-69 of Section VIII of the ASME Code, 1949 edition. For those containers, the MAWP is 125% of the original ASME value, provided the AHJ approves such increased MAWP and a nameplate marked with the new MAWP is attached to the container [1].

NOTE—MAWP, as used in this standard, applies to design pressure as used in Section VIII, Division 2 of the ASME Code [1]. For vacuum-insulated containers, the MAWP shall be established by subtracting the sum of 14.7 psi (101 kPa) and fluid-head from the maximum pressure difference between the inside and outside of the wall of the container for which the wall of the container is designed in accordance with applicable regulations, codes, standards, or specifications.

3.2.11 Nonliquefied compressed gas

Gas other than a gas in solution and under the charged pressure that is entirely gaseous at 68 °F (20 °C).

3.2.12 Nonreclosing pressure relief device

PRD designed to remain open after operation.

NOTE—A manual resetting means may be provided.

3.2.12.1 Breaking pin device

Nonreclosing PRD actuated by inlet static pressure and designed to function by the breakage of a load-carrying section of a pin that supports a pressure-containing member. Such devices are used in combination between a pressure relief valve and the container.

3.2.12.2 Buckling pin device

Nonreclosing PRD actuated by inlet static pressure and designed to function by buckling of a poppet restraining pin.

NOTE—It can be balanced (responsive only to inlet pressure) or unbalanced (responsive to the difference between inlet and discharge pressure).

3.2.12.3 Rupture disk device

Nonreclosing PRD actuated by inlet static pressure and designed to function by the rupturing of a disk.

3.2.13 Overall length (OAL)

Length of the shell of a pressure vessel between the two heads. This includes the straight length and the straight flanges on the heads, but not the length of the curved portion of the head.

3.2.14 Pressure control valve

Direct-acting automated valve (such as a back pressure regulator) that vents gas to maintain container pressure within a desired range.

3.2.15 Pressure relief device (PRD)

Device designed to open at a specified value of pressure to prevent the internal pressure from rising above a specified value.

NOTE—It can be a pressure relief valve, a nonreclosing PRD, or a nonreclosing PRD in combination with a pressure relief valve. The term pressure relief is synonymous with the expression “safety relief” as used in various applicable regulations, codes, standards, or specifications.

3.2.16 Pressure relief valve

Type of PRD designed to relieve excess pressure and to reclose and reseal to prevent further flow of fluid from the container after resealing pressure is achieved.

NOTE—It is characterized by rapid-opening pop action or by opening generally proportional to the increase in pressure over the opening pressure.

3.2.17 Refrigerated (cryogenic) liquid

Liquid with a normal boiling point lower than −130 °F (−90 °C) at a pressure of one atmosphere absolute.

3.2.18 Refrigerated liquid

Liquid that shall be maintained at temperatures lower than the ambient for storage and transportation in the liquid state less than the MAWP of the container.

3.2.19 Resealing pressure

Value of decreasing inlet static pressure at which the leakage detected is within the specified limits.

NOTE—The method of detection can be a specified water seal on the outlet or other means appropriate for the application.

3.2.20 Set pressure

Pressure at which a pressure relief valve is set to start-to-discharge.

3.2.21 Start-to-discharge pressure

Pressure measured at the valve inlet of a pressure relief valve at which there is a measurable lift or at which discharge becomes continuous as determined by seeing, feeling, or hearing.

3.2.22 Storage container

Any container designed to be mounted on a stationary foundation and in which any compressed gas, refrigerated liquid, or refrigerated (cryogenic) liquid is to be stored.

3.2.23 Test pressure

Highest pressure difference the container wall withstands between the inside and outside during testing to meet the requirements of applicable regulations, codes, standards, or specifications.

4 Types of pressure relief devices

Types of PRDs covered by this standard include:

- pressure relief valve;
- rupture disk device;
- rupture disk device in combination with pressure relief valve;
- breaking pin device in combination with pressure relief valve;
- buckling pin device; and
- buckling pin device in combination with pressure relief valve.

5 Application requirements for pressure relief devices

5.1 General

At a minimum, containers in all services shall be provided with a primary PRD either in direct communication with the vessel or in the piping leading to the vessel or group of vessels. Containers in refrigerated (cryogenic) liquid service have additional demands that require a primary system of one or more PRDs and a secondary system of one or more pressure relief valves, rupture disks, or breaking/buckling pin devices.

Primary PRDs should be reclosing. Secondary PRDs may be reclosing or nonreclosing. The use of nonreclosing secondary PRDs should be restricted to protection against fire or liquid overfill, where such emergency events are credible.

Pilot-operated pressure relief valves may be used, provided that the pilot is self-actuated and the main valve opens automatically at not over the set pressure and discharges its full rated capacity if some essential part of the pilot fails. When considering failure of a pilot system, blockages of the pilot system from solidification of gases or liquids in the pilot system due to ambient temperatures or cooling of the valve due to flow of cryogenic fluids through piping or other devices/components should be evaluated.

5.1.1 Applicable standards

PRDs shall meet the applicable requirements for design, materials, installation, set pressure including tolerance, resealing pressure, marking, and certification of flow capacity of the current edition of the following applicable standards:

- ASME Code, Section VIII, Division 1, UG-125 through UG-136; and Division 2, part AR [1];
- UL 132, *Safety Relief Valves for Anhydrous Ammonia and LP-Gas* [7];
- CGA S-1.1, *Pressure Relief Device Standards—Part 1—Cylinders for Compressed Gases* [8]; and
- NFPA 58 [3].

Requirements for flow capacities are specified in Section 6.

5.1.2 Marked set pressure

PRDs shall have marked set pressures as follows.

5.1.2.1 Refrigerated (cryogenic) liquid carbon monoxide

For refrigerated (cryogenic) liquid carbon monoxide, the minimum marked set pressure shall be the maximum allowable working pressure (MAWP) of the container.

5.1.2.2 Primary pressure relief devices

The marked set pressure of one of the primary PRDs shall not exceed the MAWP of the container and the marked set pressure of all other primary PRDs shall not exceed 105% of the MAWP of the container.

5.1.2.3 Secondary relief system

Each pressure relief valve or breaking/buckling pin device in the secondary pressure relief system shall be designed to begin functioning at a pressure no greater than 110% of the MAWP of the container. When installed for fire emergencies, rupture disks in the secondary pressure relief system shall have a marked estimated rupture pressure not to exceed 110% of the MAWP at a coincident disk temperature not to exceed 800 °F (427 °C), and stamped with an ambient temperature, nominally 72 °F (22 °C), rupture pressure, not exceeding the test pressure of the container (also see 5.1.12). When installed for runaway liquid fill emergencies, rupture disks in the secondary pressure relief system shall have a stamped rupture pressure in accordance with CGA P-59, *Prevention of Excessive Pressure During Filling of Cryogenic Vessels* [9].

The ambient temperature rupture pressure may be increased to a maximum of 150% of the MAWP, provided one of the following conditions is satisfied:

- Seams of the container are nondestructively examined and found acceptable in accordance with the ASME Code [1]; or
- Owner assures that the primary PRDs on the container are pressure relief valves having the total capacity as specified in 6.3 and are retested at least every 5 years.

NOTE—While ambient temperature is nominally 72 °F (22 °C), the ambient temperature used for rating rupture disks varies by manufacturer. This range is typically between 32 °F (0 °C) and 100 °F (38 °C).

5.1.2.4 Rated working pressure

For containers constructed in accordance with paragraph U-68 or U-69 of the ASME Code, 1949 Edition, the PRD set pressure may be based on the rated working pressure marked on the metal certification plate attached to the container (see 3.2.10), with the concurrence of the AHJ [1].

5.1.2.5 Overdesigned container

If an overdesigned container is used, the marked set pressure of the PRD shall be based on a pressure between the minimum required working pressure for the lading and the marked set pressure as specified in 5.1.2.2 and 5.1.2.3.

5.1.3 Design, material, and location

The design, material, and location of PRDs shall be suitable for the intended service. Each PRD shall be designed and constructed for a pressure equal to or exceeding the MAWP of the container at the coldest temperature reasonably expected to be encountered.

5.1.4 Communication with the vapor space

The piping to PRDs shall be in direct communication with the vapor space of the container. Intervening stop valves are acceptable in noncryogenic service when allowed by the ASME Code [1].

5.1.5 Pressure relief for piping and hoses

Any portion of cold or cryogenic piping or hose that can be closed at each end, making it possible for the contents to develop pressures in excess of the design pressure of that portion of piping at 130 °F (54 °C), shall be provided with a means for pressure relief set to operate at a pressure not exceeding the lesser of piping system test pressure or 120% of the design pressure of that portion of the piping or hose according to ASME B31.3, *Process Piping* [10].

NOTE—PRDs used to protect piping and hose are not required to carry the marking of a UV or UD stamp. ASME B31.3, paragraph 322.6.3 (a) states “Pressure relieving devices required by paragraph 301.2.2 (a) shall be in accordance with the BPV code Section VIII, Division 1, UG-125(c), UG-126 through UG-128, and UG-132 through UG-136, excluding UG-135(e) and UG-136(c)” [10]. Based on the exclusions of the noted paragraphs, ASME B31.3 does not require pressure relieving devices on piping systems to carry the marking of a UV or UD stamp [10]. In addition, the exclusion also negates the ASME requirement for capacity certification. In Canada, piping PRDs are registered as Category G fittings per Canadian Standards Association (CSA) B51, *Boiler, Pressure Vessel, and Pressure Piping Code*, Part 1, Table 1, Categories of Fittings [11].

5.1.6 Pressures in excess of maximum allowable working pressure

When scenarios such as operation of pressure buildup coils, failure of a regulator or control valve, or operation of gaseous filling equipment can produce pressures in excess of the MAWP of the container, pressure relief valve(s) shall be provided that are capable of preventing the development of container pressure in excess of 110% of MAWP for a single relief valve or 116% of MAWP for multiple relief valves.

5.1.6.1 Overpressure of refrigerated (cryogenic) liquid containers during operator-attended refill

Refrigerated (cryogenic) liquid containers shall be protected from overpressure during operator-attended refill according to CGA P-59 and CGA P-40, *Calculation Method for the Analysis and Prevention of Overpressure During Refilling of Cryogenic Storage Tanks with Rupture Disk(s)* [9, 12].

5.1.6.2 Overpressure of refrigerated (cryogenic) storage containers during unattended refill

In addition to the requirements of 5.1.6.1, when the operation of filling equipment can produce pressures in excess of the MAWP of the container, the owner shall evaluate the capability of the filling equipment and ensure that the capacity of the container pressure relief system is sufficient as the following details.

For all containers at the capacity of the filling equipment, the differential pressure of the pressure relief system from the container to the atmosphere, including all PRDs with a set pressure not greater than 105% of the MAWP of the container, shall not exceed 116% of the MAWP of the container. For filling equipment that transfers the lading in liquefied state, the differential pressure of the pressure relief system shall be evaluated for discharge of the liquid. This evaluation shall be performed in accordance with conventional hydraulic analysis or by using the following equations:

$$\Delta P_{\text{system}} = \left(Q^2 \left(G \left(\frac{\left(\frac{12 \times F \times L}{D} \right) + N}{(890.6 \times D^4)} \right) \right) + \left(\frac{Q^2 \times G}{(1444 \times K_{d^2} \times A^2)} \right) \right)$$

and

$$\Delta P_{\text{piping}} = \left(Q^2 \left(G \left(\frac{\left(\frac{12 \times F \times L}{D} \right) + N}{(890.6 \times D^4)} \right) \right) \right) \leq 0.15 \times \Delta P_{\text{system}}$$

Where:

ΔP = Differential pressure from inner vessel to relief discharge (psi)

Q = Capacity of filling equipment (U.S. gallon per minute [GPM])

G = Specific gravity (G for water = 1.0)

F = Piping friction factor (0.02 is reasonable)

L = Piping length (ft)

D = Piping inside diameter [ID] (in)

N = Number of velocity head losses for all fittings and valves

K_d = Coefficient of discharge (0.62 for disks)

A = Relief device orifice area (in²)

5.1.7 Rated discharge capacity

The rated discharge capacity of each PRD shall be determined at a pressure not exceeding the applicable flow rating pressures specified in 6.3.4.

5.1.8 Proper functioning

All PRDs shall be installed and located so their proper functioning is not hindered by the nature of the vessel's contents including cooling effects.

5.1.9 Containers for refrigerated fluids

In addition to the required PRDs, containers for refrigerated (cryogenic) fluids (except carbon monoxide) and refrigerated liquid service may be equipped with one or more pressure relief valves set at a pressure less than the MAWP of the container. Capacity of the pressure relief valves can be calculated using the formula in 6.2.2 for a flow rating pressure not to exceed 110% of the set pressure of the pressure relief valve.

Many containers are also equipped with pressure control relief valves that vent gas, or take gas from the vapor space of the container and direct it into the use lines (economizer system), to maintain tank pressure below MAWP. See 5.3.3 for details on the use of pressure control relief valves on liquid carbon dioxide containers.

5.1.10 Rupture disks

One or more rupture disk devices or breaking/buckling pin devices with marked rupture pressures at ambient temperature which is between 150% and 200% of the MAWP of the container may be used in parallel on containers in refrigerated (cryogenic) liquid (except carbon monoxide) or refrigerated liquid service in addition to the required PRDs.

5.1.11 Minimum required working pressures

The minimum required working pressures for containers for various compressed gases are shown in Table 1.

5.1.12 Set pressures and flow rating pressures (fluidhead)

When set pressures and flow rating pressures for relief devices are specified as the container test pressure or as a percent of the container test pressure, the set pressures determined shall be reduced by the maximum fluidhead (see example in 5.1.14).

Table 1—Minimum required working pressures

Gas	Minimum required working pressure	
	psi	kPa
Air, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Anhydrous ammonia	265	1830
Anhydrous dimethylamine	150	1035
Anhydrous monomethylamine	150	1035
Anhydrous trimethylamine	150	1035
Argon, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Butadiene, inhibited	100	690
Carbon dioxide, refrigerated liquid	1) ¹⁾	1) ¹⁾
Carbon monoxide, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Chlorine	225	1550
Chlorodifluoroethane (R-142 b)	100	690
Chlorodifluoromethane (R-22)	250	1725
Dichlorodifluoromethane (R-12)	150	1035
Dichlorodifluoromethane-difluoroethane mixture (R-500)	250	1725
Dichlorodifluoromethane-dichlorotetrafluoroethane mixture (R-12/R-114 mixture)	150	1035
Dichlorodifluoromethane-trichlorofluoromethane mixture (R-12/R-11 mixture)	150	1035
Difluoroethane (R-152a)	150	1035
Ethylene, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Helium, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Hydrogen, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Liquefied petroleum gas	1) ¹⁾	1) ¹⁾
Methyl chloride	150	1035
Methyl mercaptan	100	690
Neon, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Nitrogen, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Nitrous oxide, refrigerated liquid	1) ¹⁾	1) ¹⁾
Oxygen, refrigerated (cryogenic) liquid	1) ¹⁾	1) ¹⁾
Sulfur dioxide	150	1035
Vinyl chloride	150	1035
1) ¹⁾ No minimum MAWP specified.		

5.1.13 Set pressure and flow rating pressures for vacuum-insulated containers

When relief device set pressures and flow rating pressures are specified as the product of a percent factor and MAWP of a vacuum-insulated container, the set pressures and flow rating pressures determined can be increased by an amount obtained by subtracting 14.7 psi (101 kPa) from the product of the percent factor and 14.7 psi (101 kPa).

In U.S. customary units:

Set or flow rating pressure in psi where MAWP shall be in psi =

$$\frac{(\% \text{ Factor}) (\text{MAWP})}{100} + \frac{(\% \text{ Factor}) (14.7)}{100} - 14.7$$

In metric units:

Set or flow rating pressure in kPa where MAWP shall be in kPa =

$$\frac{(\% \text{ Factor}) (\text{MAWP})}{100} + \frac{(\% \text{ Factor}) (101)}{100} - 101$$

Example: Let MAWP = 200 psi (1379 kPa); set pressure = 110% of MAWP; and flow rating pressure = 121% of MAWP for a PRD on a vacuum-insulated container.

In U.S. customary units:

$$\begin{aligned}\text{Set pressure, psi} &= \frac{110}{100} (\text{MAWP}) + \frac{110}{100} (14.7) - 14.7 \\ &= \frac{110}{100} (200) + 16.17 - 14.7 \\ &= 221.47\end{aligned}$$

$$\begin{aligned}\text{Flow rating pressure, psi} &= \frac{121}{100} (\text{MAWP}) + \frac{121}{100} (14.7) - 14.7 \\ &= \frac{121}{100} (200) + 17.79 - 14.7 \\ &= 245.09\end{aligned}$$

In metric units:

$$\begin{aligned}\text{Set pressure, kPa} &= \frac{110}{100} (\text{MAWP}) + \frac{110}{100} (101) - 101 \\ &= \frac{110}{100} (1379) + 111.01 - 101 \\ &= 1527.00\end{aligned}$$

$$\begin{aligned}\text{Flow rating pressure, kPa} &= \frac{121}{100} (\text{MAWP}) + \frac{121}{100} (101) - 101 \\ &= \frac{121}{100} (1379) + \frac{121(101)}{100} - 101 \\ &= 1690.00\end{aligned}$$

5.1.14 Reduction of set pressure and flow rating pressure for vacuum-insulated containers

When set pressures and flow rating pressures for relief devices are specified as the container test pressure or as a percent of the test pressure of a vacuum-insulated container, the set pressures and flow rating pressures determined shall be reduced by 14.7 psi (101 kPa).

Example: Let the test pressure of a vacuum-jacketed container be 150 psi (1035 kPa) and fluidhead be 5 psi (35 kPa). If the set pressure of a PRD on this container is specified as 90% of the test pressure of the container, then the set pressure shall be specified as:

- In U.S. customary units:
Set pressure = (0.90) (150 psi) - 14.7 psi - 5 psi = 115.3 psi; and
- In metric units:
Set pressure = (0.90) (1035 kPa) - 101 kPa - 35 kPa = 796 kPa.

5.1.15 Minimum flow capacity

In accordance with the ASME Code, when a container is protected by a single PRD, minimum flow capacity of the PRD shall be sufficient to maintain the container pressure less than 110% of the MAWP during operational emergencies excluding exposure to fire. When multiple PRDs are installed, then the total minimum flow capacity of the pressure relief system shall be sufficient to maintain the container pressure less than 116% of the MAWP during operational emergencies excluding exposure to fire. When considering exposure to a fire, then the total minimum flow capacity of the pressure relief system shall be sufficient to maintain the container pressure less than 121% of the MAWP (also see 5.1.13 and 5.1.14 for vacuum-insulated containers).

5.1.16 Combination pressure relief devices

Combination PRDs may be used in lieu of pressure relief valves on containers where a loss of valuable material by leakage should be avoided or contamination of the atmosphere by leakage of noxious gases shall be minimized. Nonreclosing PRDs shall be used on containers holding substances that can render a pressure relief valve inoperative.

5.2 Piping of pressure relief systems

When fittings and piping are used on the upstream and/or downstream sides of a pressure relief system, the passages shall be designed so the flow capacity of the pressure relief system is not reduced below the required flow rate for the container on which the pressure relief system is installed. When spring-loaded relief valves are used, inlet pressure drop shall be limited to 3% of set pressure, and discharge pressure drop or backpressure shall be limited to 10% of set pressure. More detailed engineering analysis may allow for higher pressure drops as long as the flow rate for the system is demonstrated to meet or exceed the requirements of the container. It should also demonstrate performance is not compromised by valve chatter. The opening through all piping and fittings shall have at least the same flow area as the inlet of the PRD to which it is connected. The nominal size of the discharge piping shall be at least as large as that of the relief device outlet. Oversized relief devices may be used without requiring all openings in its line to have the same flow area provided the required flow capacity is ensured through the system. When oversized spring-loaded relief valves are used, consider the potential for chattering of the valves due to inlet piping restrictions.

Pressure relief systems shall be arranged to prevent any impingement of escaping gas or liquid upon the container, jacket, control devices, structural parts, or operating personnel. Each pressure relief system shall be arranged, or protected, to prevent the accumulation of foreign material between the relief device and the atmospheric discharge opening. The arrangement shall not impede flow through the system. Pressure relief systems on containers for flammable gases shall be arranged to discharge upward to the open air. The design and construction of upward facing vent terminations shall prevent the intrusion of water into the piping.

Breaking/buckling pin devices shall be installed in a direction to prevent accumulation of rainwater within the device or the pin guide adjacent to the piston.

WARNING: *Users are warned that water can freeze within the guide or piston and prevent actuation of the device. This could lead to container rupture, resulting in equipment damage, serious injury or death.*

On refrigerated (cryogenic) containers and on other containers where fire exposure is a credible emergency event, the following applies:

- No shutoff valves shall be installed between the PRD and the container;
- In cases where two or more PRDs are installed on the same container, a shutoff valve may be used where the arrangement of the shutoff valve or valves always ensures full required flow capacity through at least one PRD. A preferred approach is to use diverter valves installed before two PRDs so at least one PRD is on line all the time (The diverter valve shall not be left in the middle position during normal operation); and
- Pressure relief valves may have upstream shutoff valves if the container is provided with PRDs, including at least one PRD in direct communication with the vapor space as specified.

For containers in other services, the following applies:

- Where all emergency overpressure events originate external to the container, a shutoff valve may be installed between the PRD and the container in accordance with the ASME Code [1]. This is allowed because closing the shutoff valve isolates the container from the source of overpressure; and
- Where shutoff valves are installed between the PRDs and the container, the installation and operation of the shutoff valves shall comply with section M-5 (a) of the ASME Code [1]. This section requires that the shutoff valve be locked open and be operated by a qualified person who remains at the valve location during maintenance operations.

5.3 Commodity-based requirements

5.3.1 Specific requirements

All PRDs on storage containers for anhydrous ammonia shall meet the applicable requirements of CGA G-2.1 [4]. All PRDs on storage containers for liquefied petroleum gas shall meet the applicable requirements of NFPA 58 [3].

Rupture disk devices and breaking/buckling pin devices are not permitted on containers that contain such hazardous materials as carbon monoxide, except in combination with pressure relief valves as specified in 3.2.2.

For requirements for PRDs on chlorine containers, see 49 CFR Part 179.300-15 and CGSB 43.147, *Construction, Modification, Qualification, Maintenance, and Selection and Use of Means of Containment for the Handling, Offering for Transport, or Transporting of Dangerous Goods by Rail* as appropriate [6, 13].

5.3.2 Nonliquefied compressed gases

When a fire is not a credible emergency condition, the minimum total flow capacity of the primary PRD(s) shall be calculated using engineering methods applicable to the operational emergency conditions. For example, the capacity of the PRD(s) shall exceed the capacity of a compressor or pump used to fill the container, or shall be capable of relieving the overpressure caused by a failed-open regulator or control valve. The flow rating pressure shall not exceed 110% and 116% MAWP of the container respectively for single and multiple primary PRDs.

The minimum required total combined flow capacity of the system of PRDs for fire emergency conditions shall be calculated using the formula in 6.3.1. The system of PRDs shall limit the container pressure less than 121% of the MAWP of the container.

5.3.3 Liquefied compressed gases, refrigerated fluids, and refrigerated (cryogenic) fluids

Each container shall be provided with a primary system of one or more PRDs and a secondary system of one or more pressure relief valves, rupture disks, or breaking/buckling pin devices.

Also see 5.1.13 and 5.1.14 for vacuum-insulated containers.

Carbon dioxide and nitrous oxide containers are exempted from the requirement for a secondary relief system if all of the following conditions are met:

- The container shall have a pressure control valve set at no greater than 97% of the set point of the primary relief device, which meets the minimum flow rate requirement for operational emergency conditions (except fire) specified in 6.2. Minimum flow for this pressure control valve shall be sized to handle operational emergencies, except fire exposure. The flow rating pressure shall not exceed the lowest set point of the primary relief system; and
- The primary relief system meets the minimum flow capacity requirements for operational emergencies (including fire) specified in 6.3.

Alternatively, carbon dioxide and nitrous oxide containers with a capacity of less than 132 gal (500 L) may be equipped with safety relief devices as follows:

- A primary pressure relief valve with a set pressure equal to the MAWP of the container that meets the minimum flow capacity requirements for operational emergencies (including fire) specified in 6.3;
- A secondary pressure relief valve with a set pressure no greater than 150% of the MAWP of the container that also meets the minimum flow capacity requirements for operational emergencies (including fire) specified in 6.3; and
- Pressure relief valve or "bleeder valve" set below MAWP is not required in this configuration.

5.3.3.1 Calculation of minimum total flow rate requirement

The minimum total flow rate requirement of the primary system of pressure relief valves for operational emergency conditions, except fire, shall be calculated using the applicable formula in 6.2.2. A flow rating pressure shall not to exceed 110% and 116% of the MAWP of the container for single and multiple primary pressure relief valves, respectively.

5.3.3.2 Calculation of minimum total combined flow rate requirement

The minimum total combined flow rate requirement of the primary and secondary systems of PRDs for operational emergency conditions, including fire, shall be calculated using the applicable formula in 6.3.2 or 6.3.3. A flow rating pressure shall not to exceed 121% of the MAWP of the container.

5.3.3.3 Rupture disks in containers in flammable service

If a container in flammable product service with piping locations more than 10 ft (3 m) apart (for example, manifolds at opposite ends of tanks) uses rupture disks with marked rupture pressures at ambient temperature greater than 110% of the MAWP of the container (see 5.1.13) to satisfy the minimum total combined flow rate required to maintain the container pressure below the limits specified in 5.3, then each such piping location shall be provided with rupture disks with total minimum flow rate required of the rupture disks. A piping location is defined as a location where probable sources for fire from flammable product leaks or spills (such as nonwelded pipe or tube joints, valves and instruments, fill and withdrawal connections, vents, etc.) are present.

Rupture disks in flammable product service with marked rupture pressures at ambient temperature greater than 110% of the MAWP of the container (also see 5.1.13) shall be installed within 5 ft (1.5 m) of the container wall, above the level of the container fill, and withdrawal connections and other possible sources of leaks mentioned in this section.

Materials with the highest rate of decrease in strength with temperature from ambient to 800 °F (427 °C) should be considered for rupture disks while avoiding hazards due to premature or frequent rupture of the disks from fatigue or corrosion.

5.4 Jacket relief device

The jackets of containers shall be protected by a suitable PRD to release internal pressure. This relief device shall function at a pressure not exceeding the internal design pressure of the jacket calculated in accordance with the ASME Code based on maximum external collapse pressure on the inner vessel calculated with a safety factor of two or 25 psi (172 kPa), whichever is less [1].

The total discharge area of vacuum jacket relief devices shall be at least 0.00024 in²/lb (0.3414 mm²/kg) of water capacity of the inner vessel.

6 Design and construction requirements for pressure relief devices

6.1 General

The design, materials of construction, and assembly of a PRD shall prevent significant changes in the functioning of the device and serious deterioration of the materials due to service conditions within the period between

replacements. The chemical and physical properties of the materials shall be uniform and suitable for the requirements of the part manufactured. Parts and components shall be suitably cleaned for the intended service.

For examples of PRD sizing calculations, see Appendix A and B.

6.1.1 Applicable standards

PRDs shall meet the applicable requirements listed in 5.1.1.

6.1.2 Surface area formulas

When the surface area is not stamped on the container nameplate or when the marking is not legible, the area can be calculated by using the following formulas:

1. Cylindrical container with hemispherical heads:

$$\text{Area} = 3.1416 \times (\text{overall length} \times \text{outside diameter} + \text{outside diameter}^2)$$

2. Cylindrical container with 2:1 semi ellipsoidal heads:

$$\text{Area} = 3.1416 \times \text{overall length} \times \text{outside diameter} + 2 \times 1.084 \times \text{outside diameter}^2$$

3. Spherical container:

$$\text{Area} = 3.1416 \times \text{outside diameter}^2.$$

6.1.3 Temperature for flow capacity calculation

The temperature for flow capacity calculation shall be determined as follows.

The temperature to use in flow capacity calculations for subcritical fluids shall be the saturation temperature at the flow rating pressure.

When calculating flow capacities of PRDs for critical and supercritical fluids, the temperature to use in these calculations shall be the temperature at which

$$\frac{\sqrt{v}}{v \left(\frac{\partial h}{\partial v} \right)_p}$$

is a maximum for the specified flow rating pressure. For the specified flow rating pressure, both v (the specific volume) and

$$v \left(\frac{\partial h}{\partial v} \right)_p$$

(the specific heat input) varies with temperature. The specific heat input is listed in National Institute of Standards and Technology (NIST) *Thermophysical Properties of Fluid Systems* [14].³

6.1.4 Determining the relief capacities for containers of liquefied compressed gases, refrigerated fluids, and refrigerated (cryogenic) fluids

System piping and heat transfer can influence the overall capacity of the pressure relief system. In such cases, a complete thermodynamic and fluid flow analysis is required. A complete analysis includes: consideration for pressure drop, heat input, potential flow reduction due to unintended choked flows, and potential for subsonic

³ It is recommended that the thermophysical properties of gases required for calculations be taken from technical notes published by the National Institute of Standards and Technology. www.nist.gov

flow at the relief device. Alternatively, the relief device capacities can be modified as described below. The system capacities are compared to the relief requirements in 5.3.3.1 and 5.3.3.2. The following methodologies assume the pressure relief system ultimately discharges to atmosphere and is independently flowing (not manifolded). See Figure 1.

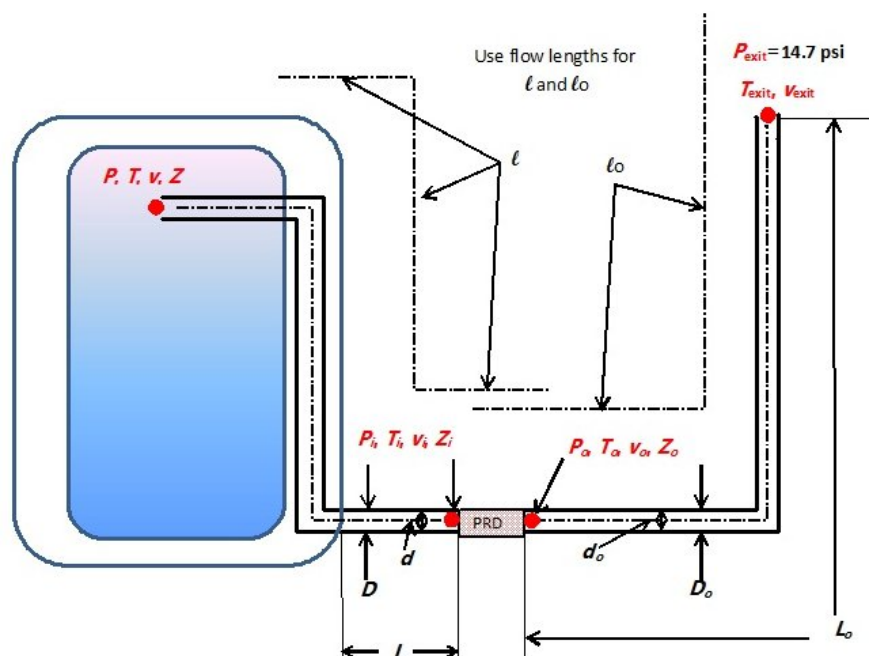


Figure 1—Nomenclature

6.1.4.1 Determining pressure relief system capacity when using a spring-loaded reclosing pressure relief valve

6.1.4.1.1 Determining the effect of inlet piping

- Establish the total $Q_{a_v/v}$ by adding all of the capacities of all of the individual relief valves located on the same manifold.

$Q_{a_v/v}$ = Rated flow capacity of the selected relief valve(s) in scfm of air at 60 °F 14.696 psia (m^3/hr of free air at 288.15 Kelvin 101.325 kPa, abs). The selected relief valve(s) shall have a rated capacity that exceeds the required flow rate calculated using the applicable formula from 6.2, 6.3.2, or 6.3.3

- Set an initial value for $W_{sys,0}$ based on the flow capacity of the valve being considered for the system. Establish the mass flow capacity using the following formulas:

U.S. customary units:

$$W_{sys,0} = \frac{Q_{a_v/v} \times C}{18.35} \sqrt{\frac{M}{Z \times T}}$$

Metric units:

$$W_{sys,0} = \frac{Q_{a_v/v} \times C}{92.34} \sqrt{\frac{M}{Z \times T}}$$

Where:

$W_{sys,0}$ = Initial estimate of the mass flow capacity of the pressure relief system in lbm/hr (kg/hr), of the lading

C = Constant for gas or fluid related to ratio of specific heats ($k = C_p/C_v$) at standard conditions from Table 2

M = Molecular weight of fluid

T = Temperature as specified in 6.1.3 in degrees Rankine (Kelvin)

Z = Compressibility factor at the temperature specified in 6.1.3 and flow rating pressure

$Q_{a_v/v}$ = Rated flow capacity of the selected relief valve(s) in scfm of air at 60 °F 14.696 psia (m³/hr of free air at 288.15 degrees Kelvin, 101.325 kPa, abs) as defined in 6.1.4.1.1 a).

Alternatively, if the rated (i.e., tabulated or stamped) values for air at the set point are unavailable, $Q_{a_v/v}$ can be determined by the following formulas.

U.S. customary units:

Metric units:

$$Q_{a_v/v} = 18.35 \times K_d \times A \times P$$

$$Q_{a_v/v} = 0.00699 \times K_d \times A \times P$$

Where:

A = Relief valve orifice area in in² (mm²)

P = Flow rating pressure as defined in 5.1.13 in psia (kPa, abs)

K_d = Discharge coefficient for the relief valve

The initial assumed pressure, $P_{i,0}$, at the inlet to the PRD and is set to P .

The following sections (c – i) are iterated from $n = 1, 2, 3$, etc. until a mass flow capacity, W_{sys} , is converged.

- c) For operational emergency conditions (excluding fire), calculate the temperature at the inlet to the PRD(s) using the following formula:

U.S. customary units:

Metric units:

$$T_{i,n} = 590 - \frac{590 - T}{e^{\left(\frac{0.55 \times D \times L}{W_{sys,n-1} \times C_p} \right)}}$$

$$T_{i,n} = 328 - \frac{328 - T}{e^{\left(\frac{134.8 \times D \times L}{W_{sys,n-1} \times C_p} \right)}}$$

Where:

$T_{i,n}$ = Temperature at the inlet to the PRD(s) during full flow conditions in degrees Rankine (Kelvin)

T = Temperature specified in 6.1.3 in degrees Rankine (Kelvin); alternately, value of T_{sat} given in Table 3 may be used

D = Outside diameter in inches (m) of the piping between outer jacket (or container if there is no outer jacket) and PRD subject to heat transfer

L = Length of piping between outer jacket (or container if there is no outer jacket) and PRD(s) in ft (m) subject to heat transfer.

e = 2.71828, the base of natural logarithms

$W_{sys, n-1}$ = Estimated mass flow capacity from the previous iteration of the lading flowing through the pressure relief system, in lbm/hr (kg/hr)

C_p = Specific heat at constant pressure (P) of the lading and at an average temperature between:

- T and 590 degrees Rankine (328 degrees Kelvin), Btu/lbm °F (kJ/kg °C) for operational emergency conditions without fire

P = Flow rating pressure in psia (kPa, abs)

- d) For operational emergency conditions (including fire), calculate the temperature at the inlet to the PRD(s) using the following formula:

U.S. customary units:

$$T_{i,n} = 1660 - \frac{1660 - T}{e^{\left(\frac{8.44 \times D \times L}{W_{sys,n-1} \times C_p} \right)}}$$

Metric units:

$$T_{i,n} = 992 - \frac{992 - T}{e^{\left(\frac{2070 \times D \times L}{W_{sys,n-1} \times C_p} \right)}}$$

Where:

- $T_{i,n}$ = Temperature at the inlet to the PRD(s) during full flow conditions in degrees Rankine (Kelvin)
- T = Temperature specified in 6.1.3 in degrees Rankine (Kelvin); alternately, value of T_{sat} given in Table 3 may be used
- D = Outside diameter in inches (m) of the piping between outer jacket (or container if there is no outer jacket) and PRD subject to heat transfer
- L = Length of piping between outer jacket (or container if there is no outer jacket) and PRD(s) in ft (m) subject to heat transfer.
- e = 2.71828, the base of natural logarithms
- $W_{sys, n-1}$ = Estimated mass flow capacity from the previous iteration of the lading flowing through the pressure relief system, in lbm/hr (kg/hr)
- C_p = Specific heat at constant pressure (P) of the lading and at an average temperature between:
- T and 1660 degrees Rankine (922 degrees Kelvin), Btu/lbm degrees Rankine (kJ/kg degrees Kelvin) for operational emergency conditions with fire (see Table 3)
- P = Flow rating pressure in psia (kPa, abs)

- e) Calculate the average specific volume at the flow rating condition:

$$v_{ai,n} = \frac{v + v_{i,n}}{2}$$

Where:

- $v_{ai,n}$ = Average specific volume of the lading being relieved through the inlet piping in ft³/lbm (m³/kg)
- v = Specific volume in ft³/lbm (m³/kg) of the lading in the container at flow rating pressure (P) and saturation temperature (T) as defined in 6.1.3
- $v_{i,n}$ = Specific volume in ft³/lbm (m³/kg) of the lading being relieved at $P_{i,n-1}$ and $T_{i,n}$. $v_{i,n}$ can be initially estimated as the specific volume at the flow rating pressure (P) and T_i calculated in step a)

- f) Calculate the pressure at the inlet of the pressure relief valves using the Darcy formula given below:

U.S. customary units:

$$P_{i,n} = P - \frac{3.36 \times 10^{-6} \times f \times \ell \times (W_{sys,n-1})^2 \times v_{ai,n}}{d^5}$$

Metric units:

$$P_{i,n} = P - \frac{6.253 \times 10^{-11} \times f \times \ell \times (W_{sys,n-1})^2 \times v_{ai,n}}{d^5}$$

Where:

- $P_{i,n}$ = Pressure at the inlet of the pressure relief valve(s) in psia (kPa, abs)
- P = Flow rating pressure in psia (kPa, abs)

- f = Friction factor. See Crane TP-410, *Flow of Fluids Through Valves, Fittings, and Pipes* [15]. A reasonable value to use if no other information is available for pipes with 1 in to 4 in (2.5 cm to 10 cm) internal diameter is 0.02
- ℓ = Equivalent length of pipe in ft (m). See Crane TP-410 for the method of calculating equivalent pipe lengths for elbows, reducers, valves, etc. [15]
- $W_{sys,n-1}$ = Estimated mass flow capacity from the previous iteration of the lading flowing through the pressure relief system in lbm/hr (kg/hr)
- $v_{ai,n}$ = Average specific volume of the lading being relieved through the inlet piping in ft³/lbm (m³/kg)
- d = Internal diameter of the pipe upstream of the pressure relief valve(s) in inches (m). This would be the reference diameter if there are multiple diameters (for example, pipe size changes) upstream of the pressure relief valve(s)

g) Calculate the correction factor:

$$F_n = \sqrt{\frac{P \times v_{i,n}}{P_{i,n} \times v}}$$

Where:

- F_n = The correction factor
- $P_{i,n}$ = Pressure at the inlet of the pressure relief valve(s) in psia (kPa, abs)
- $v_{i,n}$ = Specific volume in ft³/lbm (m³/kg) of the lading being relieved at $P_{i,n-1}$ and $T_{i,n}$. $v_{i,n}$ can be initially estimated as the specific volume at the flow rating pressure, P , and T_i calculated in 6.1.3
- P = Flow rating pressure in psia (kPa, abs)
- v = Specific volume in ft³/lbm (m³/kg) of the lading in the container, at flow rating pressure (P) and saturation temperature (T) as defined in 6.1.3

h) Calculate $W_{sys,n}$ by dividing $W_{sys,0}$ by F_n :

$$W_{sys,n} = \frac{W_{sys,0}}{F_n}$$

Where:

- $W_{sys,n}$ = Estimated mass flow capacity for the current iteration of the lading flowing through the pressure relief system in lbm/hr (kg/hr)
- $W_{sys,0}$ = Initial estimate of the mass flow capacity of the pressure relief system in lbm/hr (kg/hr) of the lading from 6.1.4.1.1
- F_n = The correction factor calculated in 6.1.4.1.1 g)

i) Calculate the error in the current estimated mass flow relative to the previous iteration:

$$E_{i,n} = \left| \left(\frac{W_{sys,n-1} - W_{sys,n}}{W_{sys,n-1}} \right) \right|$$

Where:

- $E_{i,n}$ = The error calculated for the current iteration
- $W_{sys,n}$ = Estimated mass flow capacity for the current iteration of the lading flowing through the pressure relief system in lbm/hr (kg/hr)
- $W_{sys,n-1}$ = Estimated mass flow capacity from the previous iteration of the lading flowing through the pressure relief system in lbm/hr (kg/hr)

j) If $E_{i,n}$ is greater than 0.01, increase n by 1 then return to 6.1.4.1.1 c). If $E_{i,n}$ is less than or equal to 0.01, then:

- $P_i = P_{i,n}$
- $W_{sys} = W_{sys,n}$
- $V_i = V_{i,n}$
- $T_i = T_{i,n}$

Proceed to 6.1.4.1.2.

6.1.4.1.2 Determining the effect of outlet piping

Calculate the exit temperature of the lading flowing through the pressure relief system.

For operational emergency conditions (except fire):

U.S. customary units:

Metric units:

$$T_{exit} = 590 - \frac{590 - T_o}{e^{\left(\frac{0.55 \times D_o \times L_o}{W_{sys} \times C_p} \right)}}$$

$$T_{exit} = 328 - \frac{328 - T_o}{e^{\left(\frac{134.8 \times D_o \times L_o}{W_{sys} \times C_p} \right)}}$$

For operational emergency conditions (including fire):

U.S. customary units:

Metric units:

$$T_{exit} = 1660 - \frac{1660 - T_o}{e^{\left(\frac{8.44 \times D_o \times L_o}{W_{sys} \times C_p} \right)}}$$

$$T_{exit} = 992 - \frac{992 - T_o}{e^{\left(\frac{2070 \times D_o \times L_o}{W_{sys} \times C_p} \right)}}$$

Where:

- T_{exit} = Temperature at the exit of the relief system during full flow conditions in degrees Rankine (Kelvin)
- T_o = Temperature of the lading at the outlet of the pressure relief valve(s) = $T_i \left(\frac{2}{k+1} \right)$ in degrees Rankine (Kelvin)
- T_i = Calculated temperature from the final iteration in 6.1.4.1.1 of the lading at the inlet of the pressure relief valve(s) in degrees Rankine (Kelvin)
- k = The ratio of specific heats ($k = C_p/C_v$) at 60 °F and 14.696 psia (15 °C and 101.325 kPa, abs)
- D_o = Outside diameter in inches (m) of the relief system outlet piping subject to heat transfer
- L_o = Length of piping between pressure relieve valve outlet and exit to atmosphere subject to heat transfer
- e = 2.71828, the base of natural logarithms
- W_{sys} = Calculated mass flow capacity from the final iteration in 6.1.4.1.1 of the lading flowing through the pressure relief system, in lbm/hr (kg/hr)
- C_p = Specific heat at constant pressure, P , of lading and at an average temperature between:
 - T and 590 degrees Rankine (328 Kelvin), Btu/lbm °F (kJ/kg °C) for operational emergency conditions without fire; or
 - T and 1660 degrees Rankine (922 Kelvin), Btu/lbm degrees Rankine (kJ/kg Kelvin) for operational emergency conditions with fire (see Table 3)

T = Temperature specified in 6.1.3 in degrees Rankine (Kelvin). Alternately, value of T_{sat} given in Table 3 may be used

P = Flow rating pressure in psia (kPa, abs)

Set the initial back pressure for the relief valve, $P_{o,0}$.

$$P_{o,0} = P_i$$

Where:

$P_{o,0}$ = Set initial value for the outlet piping back pressure in psia (kPa, abs)

P_i = Calculated pressure from the final iteration in 6.1.4.1.1 of the lading at the inlet of the pressure relief valve(s) in psia (kPa, abs)

The following sections (a - c) are iterated from $m = 1, 2, 3$, etc. until a back pressure (P_o) is converged.

a) Calculate the average specific volume at the flow rating condition:

$$v_{ao,m} = \frac{v_{exit} + v_{o,m}}{2}$$

Where:

$v_{o,m}$ = Specific volume in ft³/lbm (m³/kg) of the lading being relieved at $P_{o,m-1}$ and T_o

v_{exit} = Specific volume in ft³/lbm (m³/kg) of the lading in the container at atmospheric pressure and T_{exit}

$v_{ao,m}$ = Average specific volume of the lading being relieved through the outlet piping in ft³/lbm (m³/kg)

b) Determine the backpressure point, P_o , from the following equation:

U.S. Customary units:

Metric units:

$$P_{o,m} = \frac{3.36 \times 10^{-6} \times f_o \times \ell_o \times W_{sys}^2 \times v_{ao,m}}{d_o^5} + 14.7 \quad P_{o,m} = \frac{6.253 \times 10^{-11} \times f_o \times \ell_o \times W_{sys}^2 \times v_{ao,m}}{d_o^5} + 101.325$$

Where:

$v_{ao,m}$ = Average specific volume of the lading being relieved through the outlet piping in ft³/lbm (m³/kg)

f_o = Friction factor (see Crane TP-410) [15]. A reasonable value to use if no other information is available for pipes with 1 in to 4 in (2.5 cm to 10 cm) internal diameter is 0.02

ℓ_o = Equivalent length of pipe in ft (m). For the method of calculating equivalent pipe lengths for elbows, reducers, valves, etc. See Crane TP-410 [15]

d_o = Internal diameter of the pipe downstream of the pressure relief valve(s) in inches (m). This would be the reference diameter if there are multiple diameters (for example, pipe size changes) downstream of the pressure relief valve(s)

W_{sys} = Calculated mass flow capacity from the final iteration in 6.1.4.1.1 of the lading flowing through the pressure relief system in lbm/hr (kg/hr)

$P_{o,m}$ = Estimated back pressure of the lading flowing through the pressure relief system in psia (kPa, abs)