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Addendum A

Safety Standard for Closed-Circuit Carbon Dioxide Refrigeration Systems

Public Review #1 Draft

International Institute of Ammonia Refrigeration
1001 North Fairfax Street, Suite 503
Alexandria, VA 22314
Phone: (703) 312-4200
Fax: (703) 312-0065
www.iiar.org

Chapter 11. Overpressure Protection Devices

11.1 General. Pressure relief devices provided for the purpose of relieving excess pressure due to fire or other abnormal conditions shall comply with this chapter.

~~11.1.1 Fusible plugs shall not be used.~~

11.2 Pressure Relief Devices.

11.2.1 Refrigeration systems shall be protected by not less than one pressure relief device.

11.2.2 Fusible plugs shall not be used.

11.2.3 Pressure relief devices provided for vessels constructed in accordance with ASME B&PVC, Section VIII, Division 1, shall comply with that code and other applicable requirements of this standard.

11.2.4 Relief device arrangements shall be configured to allow access for inspection, maintenance, and repair.

11.2.5 Pressure relief devices intended for vapor service shall be connected above the highest anticipated liquid carbon dioxide level.

11.2.6 Where relief devices are located in refrigerated spaces, precautions shall be taken to prevent moisture migration into the valve body or relief vent line.

11.2.7 **Setting of Pressure Relief Devices**

11.2.7.1 The set pressure for a pressure relief device shall not exceed the design pressure of equipment protected by the device.

11.2.7.2 The set pressure of a rupture member if used in series with a relief device shall not exceed the design pressure of the equipment protected by the rupture member.

11.2.7.3 Provision shall be made to detect pressure build-up between the rupture member and the relief device, with which it is installed in series, due to leakage through the upstream relief device.

11.2.8 **Marking of Relief Devices**

11.2.8.1 Pressure relief devices for carbon dioxide-containing equipment shall be set and sealed by the manufacturer. Pressure relief devices shall be marked by the manufacturer with the data required in ASME B&PVC, Section VIII,

Division 1.

11.2.8.1.1 Resetting of a pressure relief device shall be performed by the manufacturer or a company holding a valid testing certificate for this work.

11.2.8.2 The capacity in SCFM (m3/s) or in lb air/min (kg air/min) at 60°F shall be stamped on devices or available on request.

11.2.8.3 Rupture members for carbon dioxide-containing pressure vessels shall be marked with the data required in ASME B&PVC, Section VIII, Division 1.

11.3 Overpressure ~~Relief~~ Protection.

11.3.1 Pressure vessels and other types of equipment built and stamped in accordance with ASME B&PVC, Section VIII, Division 1, shall be provided with certified pressure relief protection.

11.3.2 Pressure vessels intended to operate completely filled with liquid carbon dioxide and capable of being isolated by stop valves from other portions of a refrigeration system shall be protected with a certified hydrostatic service relief device as required by ASME B&PVC Section VIII, Division 1. Hydrostatic overpressure relief shall comply with Section 11.8.

11.3.3 Pressure relief devices shall be sized in accordance with Section 11.3.7.

11.3.4 Pressure vessels less than 10 ft^3 (0.3 m^3) internal gross volume shall be protected by one or more pressure relief devices.

11.3.5 Pressure vessels of 10 ft^3 (0.3 m^3) or more internal gross volume shall be protected by one or more of the following:

1. One or more dual pressure relief devices installed with a three-way valve to allow testing or repair, provided that

   a. Where dual relief devices are used, each device shall comply with Section 11.3.7.

   b. Three-way valves used for dual relief devices shall be set to a fully seated position (i.e., with one side open and one side closed).

   c. Where multiple dual relief device assemblies are used, the sum of the capacities of the pressure relief devices actively protecting the vessel equals or exceeds the requirements set forth in Section 11.3.7.

2. A single pressure relief device, provided that

a. The vessel can be isolated and pumped out.

b. The relief device is located on the lowside of the system.

c. Other pressure vessels in the system are separately protected in accordance with Section 11.3.7.

11.3.6 Where pressure relief devices discharge into other portions of the refrigeration system, the portion of the system receiving the internal discharge shall be equipped with pressure relief devices capable of discharging the increased capacity in accordance with Section 11.3.7, and the pressure relief devices discharging into the system shall be with one of the following types:

1. A pressure relief device not appreciably affected by backpressure.

2. A pressure relief device affected by backpressure, in which case the valve's set pressure added to the set pressure of the relief device protecting the downstream portion of the system shall not exceed the maximum allowable working pressure of any equipment being protected and shall comply with the following:

   a. The pressure relief device that protects the higher pressure vessel shall be selected to deliver capacity in accordance with Section 11.3.7 without exceeding the minimum design pressure of the higher pressure vessel accounting for the change in mass flow capacity due to the elevated backpressure.

   b. The capacity of the pressure relief device protecting the part of the system receiving a discharge from a pressure relief device protecting a higher pressure vessel shall be at least the sum of the capacity required in Section 11.3.7 plus the mass flow capacity of the pressure relief device discharging into that part of the system.

   c. The design pressure of the body of the relief device used on the higher pressure vessel shall be rated for operation at the design pressure of the higher pressure vessel in both pressure-containing areas of the valve.

      EXCEPTION: Where hydrostatic overpressure protection relief devices are discharged into other portions of a refrigeration system that are protected by pressure relief devices designed to relieve vapor in accordance with Section 11.3, the capacity of the hydrostatic overpressure protection relief devices shall not be required to be summed with the vapor capacity required in Section 11.3.7

11.3.7 **Pressure Relief Device Capacity Determination**

11.3.7.1 Pressure relief devices shall have sufficient mass flow carrying capacity to limit the pressure rise in protected equipment to prevent catastrophic failure. The minimum required relief capacity shall depend on the equipment being protected, the effects of inlet pressure losses, and the scenarios under which overpressure is being created. This relief capacity protection includes heat loads from cleaning operations and process loads.

11.3.7.2 The following sources of heat loads that can lead to overpressure shall be considered when determining the pressure relief device capacity for refrigerant-containing equipment. It is permissible to use manufacturer's data when determining relief requirements. All applicable heat loads capable of causing overpressure shall be considered, and the capacity of the pressure relief device shall be based on the scenario with the largest capacity requirements:

11.3.7.2.1 **Overpressure Due to External Fire**

i. **Pressure Vessels**

The required discharge capacity of a pressure relief device for each pressure vessel shall be determined by the following equation:

$C = f \cdot D \cdot L$ (lb/min)

[$C = f \cdot D \cdot L$ (kg/s)]

Where

C = required discharge capacity of the relief device, lb air/min (kg/s)

f = capacity factor of the relief device, lbm/ft2-min (kg/m2-s) std air: For Carbon Dioxide *f* shall be as noted in Table 11.3.7–1 (IP) or Table 11.3.7-2 (SI):

~~For Carbon Dioxide *f* = 1.0 (0.082)~~

~~[1.0 is in inch-pounds (IP), 0.082 is in International System of Units (SI)]~~

D = outside diameter of vessel, ft (m)

L = length of vessel, ft (m).

When one pressure relief device is used to protect more than one

pressure vessel, the required capacity shall be the sum of the capacities required for each pressure vessel.

ii. **Oil Separators**

The required discharge capacity of a pressure relief device for each oil separator shall be determined by the following equation:

$C = f \cdot D \cdot L$ (lb/min)

[$C = f \cdot D \cdot L$ (kg/s)]

Where

C = required discharge capacity of the relief device, lb air/min (kg/s)

f = capacity factor of the relief device, lbm/ft2-min (kg/m2-s) std air: For Carbon Dioxide *f* shall be as noted in Table 11.3.7–1 (IP) or Table 11.3.7-2 (SI):

~~For Carbon Dioxide *f* = 1.0 (0.082)~~

~~[1.0 is in inch-pounds (IP), 0.082 is in International System of Units (SI)]~~

D = outside diameter of vessel, ft (m)

L = length of vessel, ft (m).

iii. **Plate Heat Exchangers**

The capacity of the pressure relief device for plate heat exchangers shall be based on the largest projected area of the exchanger using the following equation:

$C_{r,plate\ HX} = f \cdot \sqrt{L^2 + W^2} \cdot H$ (lb/min)

[$C_{r,plate\ HX} = f \cdot \sqrt{L^2 + W^2} \cdot H$ (kg/s)]

Where

$C_{r,plate\ HX}$ = minimum required relief device capacity for plate heat exchanger (lb/min of air) [kg/s].

f = capacity factor of the relief device, lbm/ft2-min (kg/m2-s) std air: For Carbon Dioxide *f* shall be as noted in Table 11.3.7–1 (IP) or Table 11.3.7-2 (SI):

~~For Carbon Dioxide f = 1.0 (0.082)~~

~~[1.0 is in inch-pounds (IP), 0.082 is in International System of Units (SI)]~~

L = length of the plate pack (ft) [m]. W = width of the plate pack (ft) [m].

H = height of the plate pack (ft) [m].

iv. **Shell and Tube Heat Exchangers**

The capacity of the pressure relief device for shell and tube heat exchangers shall be based on the sum of the capacities required for the heat exchanger and the surge drum, if provided, as follows:

$C = f \cdot (D_v \cdot L_v + D_s \cdot L_s)$ (lb/min)

[$C = f \cdot (D_v \cdot L_v + D_s \cdot L_s)$ (kg/s)]

Where

C = required discharge capacity of the relief device, lb air/min (kg/s).

f = capacity factor of the relief device, lbm/ft2-min (kg/m2-s) std air: For Carbon Dioxide f shall be as noted in Table 11.3.7–1 (IP) or Table 11.3.7-2 (SI):

~~For Carbon Dioxide f = 1.0 (0.082)~~

~~[1.0 is in inch-pounds (IP), 0.082 is in International System of Units (SI)]~~

D_v = outside diameter of the main vessel portion of the shell and tube heat exchanger, ft (m).

L_v = length of main vessel portion of the shell and tube heat exchanger, ft (m).

D_s = outside diameter of the surge drum, ft (m).

L_s = length of the surge drum, ft (m).

v. **Product Storage**

Tanks For product storage tanks with cooling jackets, the capacity of the pressure relief device shall be based on the diameter of the

storage tank and the height of the cooling jacket as follows:

$C_{r,tank} = f \cdot D \cdot H$ (lb/min)

[$C_{r,tank} = f \cdot D \cdot H$ (kg/s)]

Where

$C_{r,tank}$ = required discharge capacity of the relief device, lb air/min (kg/s).

f = capacity factor of the relief device, lbm/ft2-min (kg/m2-s) std air: For Carbon Dioxide *f* shall be as noted in Table 11.3.7–1 (IP) or Table 11.3.7-2 (SI):

~~For Carbon Dioxide *f* = 1.0 (0.082)~~

~~[1.0 is in inch-pounds (IP), 0.082 is in International System of Units (SI)]~~

D = outside diameter of the tank, ft (m).

H = height of the active portion of the heat exchanger (distance between the refrigerant supply and return) ft (m).

~~11.3.8~~ 11.3.7.2.1.1 Where combustible material is stored within 20 ft (6.1 m) of a pressure vessel that is outside of a machinery room, the relief device capacity factor, *f,* in the formulas shall be ~~increased~~ multiplied by a factor of 2.5~~, for Carbon Dioxide *f* = 2.5 (0.205)~~.

11.3.7.3 **Scenarios for Potential Overpressure Conditions During Isolation**

i. **Positive Displacement Compressor Protection**. Pressure relief protection for positive displacement compressors shall comply with Chapter 8, Section 8.1.3.

ii. **Oil Cooling Heat Exchangers.** The designer shall evaluate potential overpressure scenarios.

iii. **Hydrostatic Overpressure Relief Protection.** Hydrostatic overpressure relief shall comply with Section 11.8.

~~11.3.7.2.3~~ 11.3.7.4 **Potential for Overpressure Due to Internal Heat Load**. The designer shall evaluate potential overpressure scenarios due to internal heat loads.

~~11.2.7.2.4~~ 11.3.7.5 **Other Potential Overpressure Scenarios.** The designer shall evaluate

other potential overpressure scenarios as applicable to the specific equipment being protected.

Table 11.3.7-1 (IP): Std Air Capacity Factor vs CO2 Design Pressure

CO2 Design Pressure, psig	Capacity Factor f, lbm/ft2-min std air
250	1.71
300	1.73
350	1.76
400	1.79
450	1.82
500	1.84
550	1.87
600	1.90
650	1.92
700	1.94
750	1.95
800	1.96
850	1.96
900	1.94
950	1.92
1000	1.89
1050	1.84
1100	1.79
1150	1.73
1200	1.67
1250	1.62
1300	1.57
1350	1.52
1400	1.49
1450	1.46
1500	1.44
1550	1.42
1600	1.40
1650	1.38
1700	1.37
1750	1.35
1800	1.34
1850	1.32
1900	1.30
1950	1.29
2000	1.27
2050	1.26

2100	1.24
2150	1.23
2200	1.21
2250	1.20
2300	1.19
2350	1.18
2400	1.17
2450	1.15
2500	1.14
2550	1.14
2600	1.13
2650	1.12
2700	1.11
2750	1.10
2800	1.10
2850	1.09
2900	1.08
2950	1.08
3000	1.07

Notes:

1. Capacity Factor f, based on heat input of 150 Btu/ft2-min and Standard Air definition of 0.0765 lbm/ft3 density (60°F, 29.921 in Hg) at a relieving pressure 10% above design pressure.
2. Reference: W. Greulich, C. Kruger (2023) "Carbon-Dioxide System Relief Sizing" 2023 IIAR Annual Meeting Proceedings (Long Beach), International Institute of All-Natural Refrigeration, Alexandria VA

Table 11.3.7-2 (SI): Std Air Capacity Factor vs CO2 Design Pressure

CO2 Design Pressure, barg	Capacity Factor f, kg/m2-s std air
15	0.138
20	0.141
25	0.144
30	0.147
35	0.150
40	0.153
45	0.156
50	0.158
55	0.159
60	0.159
65	0.157
70	0.152
75	0.147

80	0.140
85	0.133
90	0.127
95	0.122
100	0.119
105	0.116
110	0.114
115	0.112
120	0.110
125	0.108
130	0.106
135	0.105
140	0.103
145	0.101
150	0.099
155	0.098
160	0.096
165	0.095
170	0.094
175	0.093
180	0.092
185	0.091
190	0.090
195	0.089
200	0.088

Notes:

1. Capacity Factor f, based on heat input of 28.4 kW/m2 and Standard Air definition of 1.225 kg/m3 density (15°C, 1 atm) at a relieving pressure 10% above design pressure.
2. Reference: W. Greulich, C. Kruger (2023) "Carbon-Dioxide System Relief Sizing" 2023 IIAR Annual Meeting Proceedings (Long Beach), International Institute of All-Natural Refrigeration, Alexandria VA

~~11.3.8 Where combustible material is stored within 20 ft (6.1 m) of a pressure vessel that is outside of a machinery room, the relief device capacity factor, ƒ, in the formulas shall be increased by a factor of 2.5, for Carbon Dioxide *ƒ* = 2.5 (0.205).~~

Note Only: Content moved to 11.3.7.2.1.1.

11.3.8 The rated discharge capacity of a pressure relief device shall be determined in accordance with ASME B&PVC, Section VIII, Division 1. The marking of relief devices shall be in accordance with Section 11.2.8.

~~11.3.9 The rated discharge capacity of a pressure relief device shall be determined in accordance with ASME B&PVC, Section VIII, Division 1. The marking of relief devices~~

~~shall be in accordance with Section 11.2.7.~~

11.3.9 The rated discharge capacity of a rupture member discharging under critical flow conditions shall be determined by the following equations:

$$C = 0.64 \cdot P_1 \cdot d^2$$

$$d = 1.25 \cdot \sqrt{\frac{C}{P_1}}$$

$$(C = 1.1x10^{-6} \cdot P_1 \cdot d^2)$$

$$\left(d = 959 \cdot \sqrt{\frac{C}{P_1}}\right)$$

Where
C = rated discharge capacity in lbm/min (kg/s) of standard air.
d = smallest of the internal diameter of the inlet pipe, retaining flanges or rupture member in inches (mm).
P_1 = rated pressure (psig) · 1.1 + 14.7 psia. [P_1 = rated pressure (kPa gauge) · 1.1 + 101.3 kPa].

Provisions shall prevent plugging the piping in the event the rupture member relieves.

~~11.3.10 The rated discharge capacity of a rupture member discharging under critical flow conditions shall be determined by the following equations:~~

~~$C = 0.64 P_1 d^2$ (lb/min)~~

~~$d = 1.25 (C/P_1)^{0.5}$ (in.)~~

~~[$C = 1.1 \cdot 10^{-6} P_1 d^2$ (kg/s)]~~

~~[$d = 959 (C/P_1)^{0.5}$ (mm)]~~

~~Where~~

~~*C* = rated discharge capacity in lb/min (kg/s) of air.~~

~~*d* = smallest of the internal diameter of the inlet pipe, retaining flanges or rupture member in in. (mm).~~

~~P_1 = rated pressure (psig) · 1.1 + 14.7 psi. [P_1 = rated pressure (kPa gauge) · 1.1 + 101.3 kPa].~~

~~Provisions shall prevent plugging the piping in the event the rupture member relieves.~~