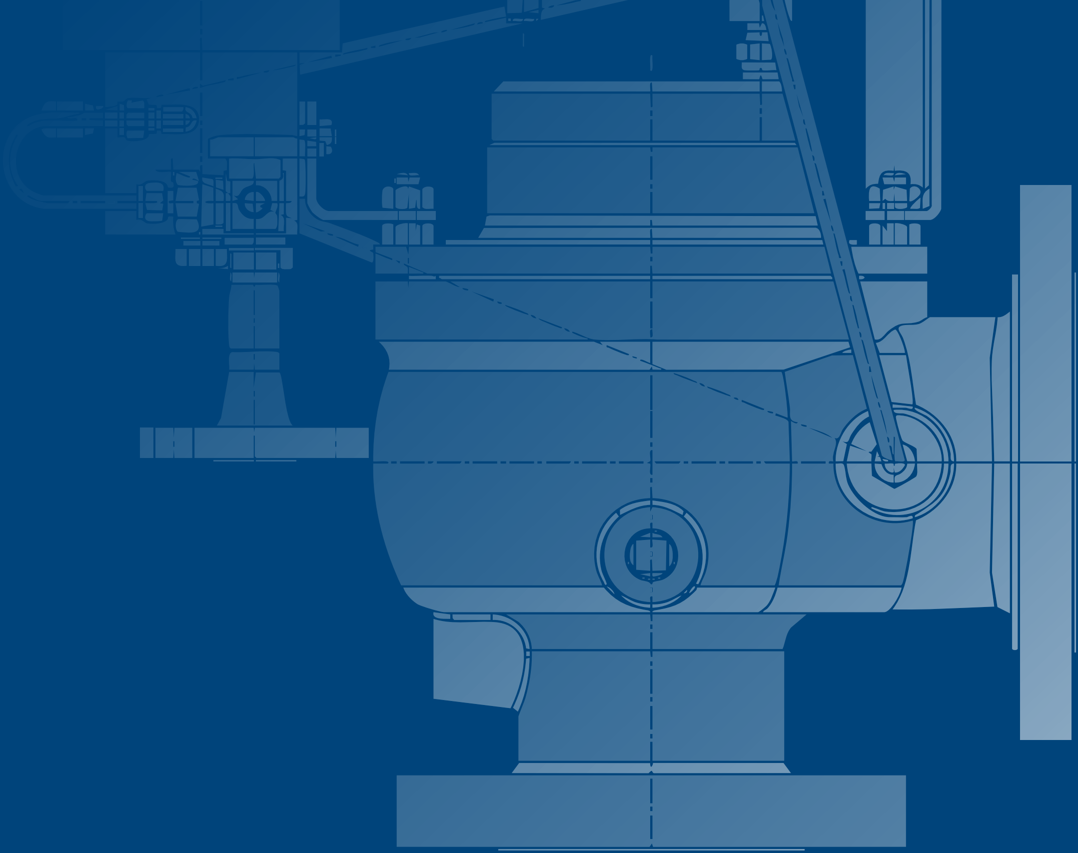

SIGTTO Society of International Gas Tanker & Terminal Operators Ltd

Carbon Dioxide Pressure Relief System

First Edition

Carbon Dioxide Pressure Relief System

SIGTTO

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The Society of International Gas Tanker and Terminal Operators (SIGTTO) is a non-profit making organisation dedicated to protecting and promoting the mutual interests of its members in matters related to the safe and reliable operation of gas tankers and terminals within a sound environment. The Society was founded in 1979 and was granted consultative status at the International Maritime Organization in November 1983.

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Introduction and Scope

1 Introduction and Scope

1.1 Introduction

This document assesses the suitability of, and current practice related to, pressure relief valve (PRV) systems for gas carriers designed to transport liquefied carbon dioxide (LCO_2). This safety-focused review considers current liquefied gas regulations, such as the IGC Code[1] and industry best practice, along with the unique properties of carbon dioxide (CO_2).

In 2024, SIGTTO published the first edition of *Carbon Dioxide Cargo on Gas Carriers*,[2] a review of current practice for the transportation of LCO_2 on board gas carriers. In addition, updates about CO_2 carriers have been included in the IGC Code by the International Maritime Organization (IMO). This document provides more detail on current knowledge of PRV systems for LCO_2.

The review is limited by the lack of information currently available for the emerging trade of CO_2 shipping. Once the liquefied gas industry has greater experience, additional information will become available.

1.2 Scope

The information provided in this document is intended for organisations that are involved in the design and operation of CO_2 pressure relief systems on gas carriers. For multi-gas carriers, only the CO_2 relief system has been considered.

Cargo equipment and onboard carbon capture are not covered by this document, but the information provided may be helpful.

The level of technical detail assumes that the reader is familiar with the design and operation of PRV systems on liquefied gas carriers. Not all concepts are simplified or explained at an introductory level.

[1] IMO – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)

[2] SIGTTO – Carbon Dioxide Cargo on Gas Carriers

2

Relief Valve Types

2 Relief Valve Types

CO_2 pressure relief systems may use different types of relief valves, including spring loaded or pilot operated relief valves (PORV). PORVs are discussed in more detail in the following sections as there are key points to consider for CO_2 pressure relief systems.

2.1 Pop and Modulating Type

For this discussion, PORVs can be classified into two categories: *pop-action* and *modulating-action*. The pop-action PORV (Figure 1) opens fully when the set pressure is reached. This results in maximum flow out of the relief valve, which may reduce the likelihood of dry ice plugging in the discharge line.

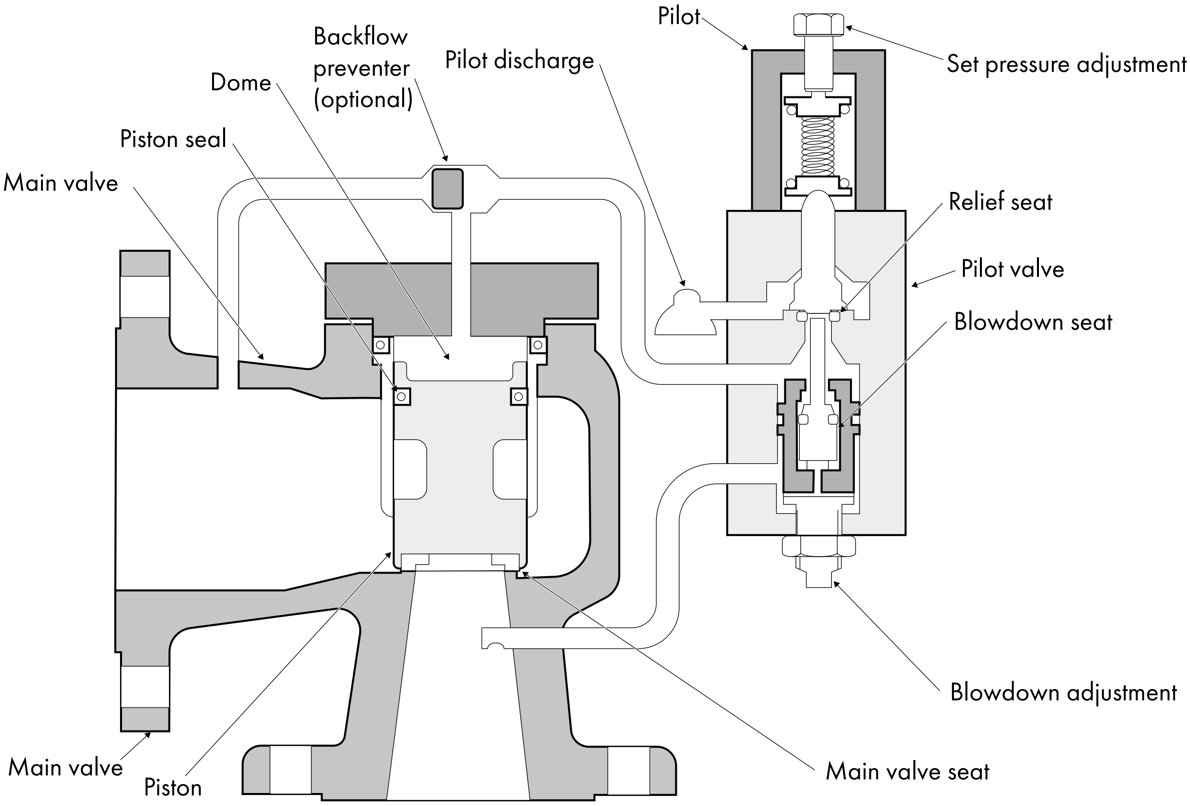

Figure 1: Pop-action pilot operated valve (non-flowing type)

The modulating-action PORV (Figure 2) opens in proportion to the pressure detected. This results in varying flow rates that depend on the pressure detected. This typically results in less product loss compared with a pop-action PORV. A key feature of the modulating-action PORV is less pressure drop in the pilot valve and dome chamber, which could reduce the probability of dry ice plugging.

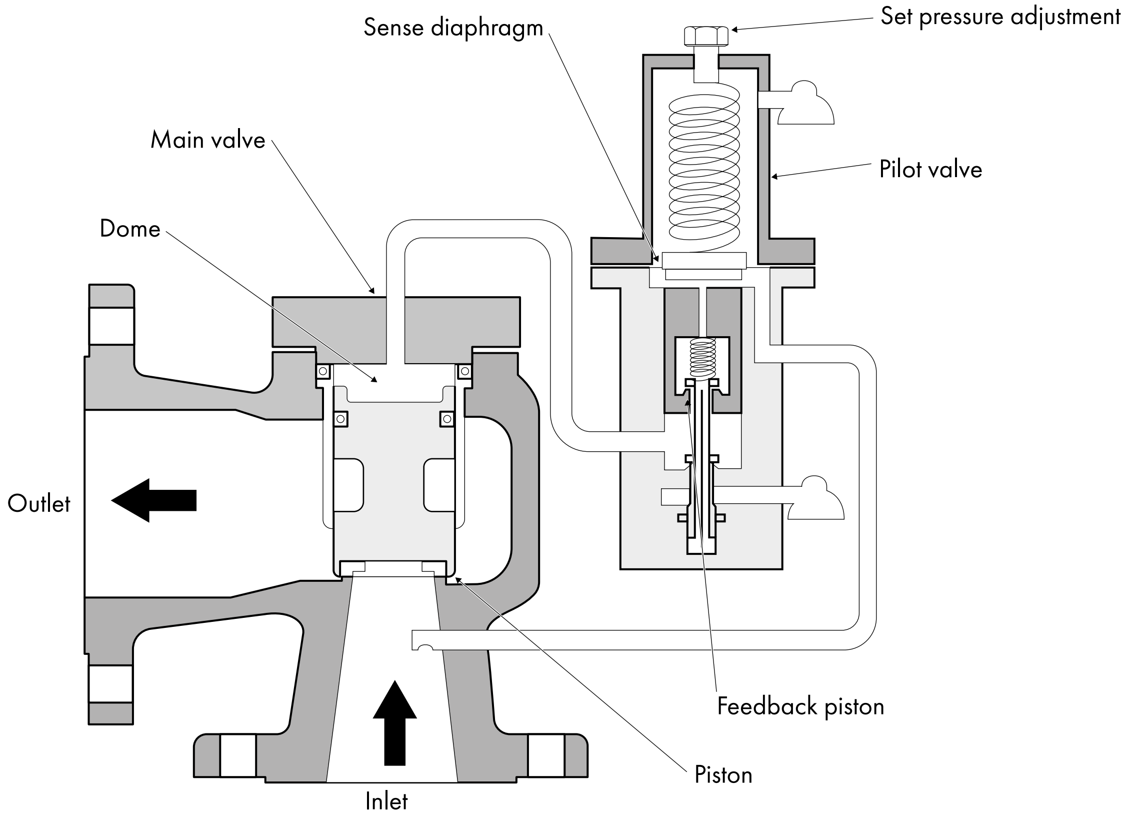

Figure 2: Modulating-action pilot operated valve (non-flowing type)

The different characteristics of the pop and modulating PORVs may be suitable for specific LCO_2 cargo systems. These characteristics should be evaluated in the design stage of the cargo system.

2.2 Flowing and Non-Flowing Type

Another categorisation for PORVs is *flowing* and *non-flowing pilot*. In a flowing type (Figure 3), a certain amount of fluid continuously flows through the pilot valve when the relief valve opens. This may create a pressure drop at the pilot exhaust and possibly in the dome chamber. This type of design may have the potential for dry ice plugging in the pilot and dome chamber.

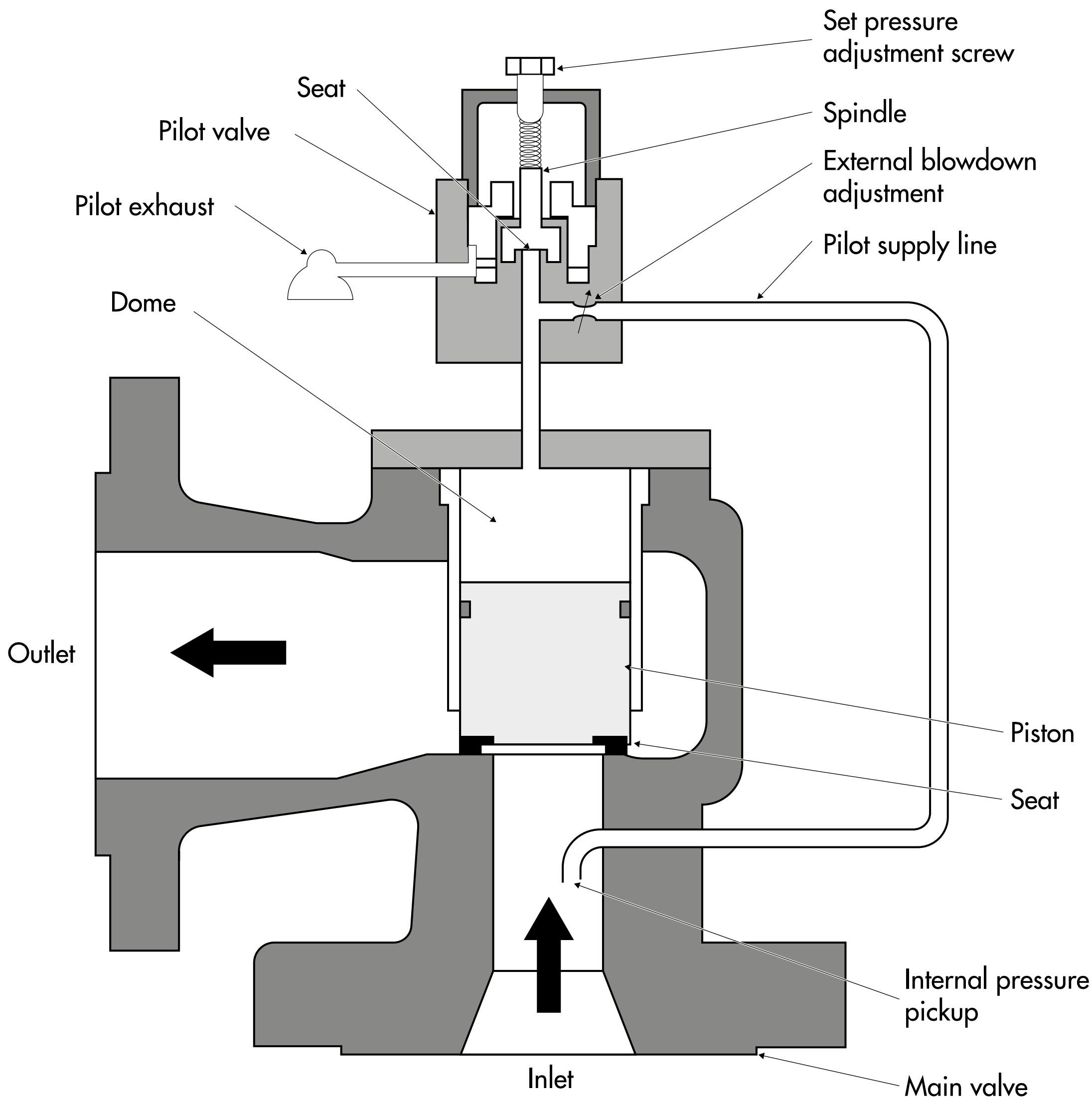

Figure 3: Flowing type pilot operated valve

In a non-flowing type there is no continuous flow through the pilot, which may avoid dry ice accumulation. Figures 1 and 2 show non-flowing type PORVs and Figure 3 shows a flowing type. Non-flowing pilot may be more suitable for applications where there is a potential for dry ice formation. The exhaust of the pilot is typically directed to the open atmosphere, not to a vent pipe, to reduce the potential of dry ice blocking the pilot exhaust.

3

Carbon Dioxide Hazards and Properties in Pressure Relief Valve System

3 Carbon Dioxide Hazards and Properties in Pressure Relief Valve System

The unique hazards of CO_2 and ways to mitigate them in the design of CO_2 cargo relief systems are discussed in the following sections. The hazards of CO_2 relate to its solidification, potential impurities, and toxicity.

3.1 Solidification Potential

The potential for solidification of relief flows from CO_2 cargoes varies with the transportation pressure. Table 1 provides the terms used based on the approximate tank transportation pressure as defined in ISO 27929.[3]

Type	Tank pressure (MPa)
Low-pressure	0.7
Medium-pressure	1.7
High-pressure	7.0

Table 1: Approximate tank transportation pressure categories for LCO_2

Figure 4 shows the different states of CO_2 when relieved from a PRV. Under low- and medium-pressure conditions (A), the expected state is gas for a PRV release. For all other conditions, dry ice is expected to be produced. PRV manufacturers and system designers should always consider the potential for dry ice formation in any design.

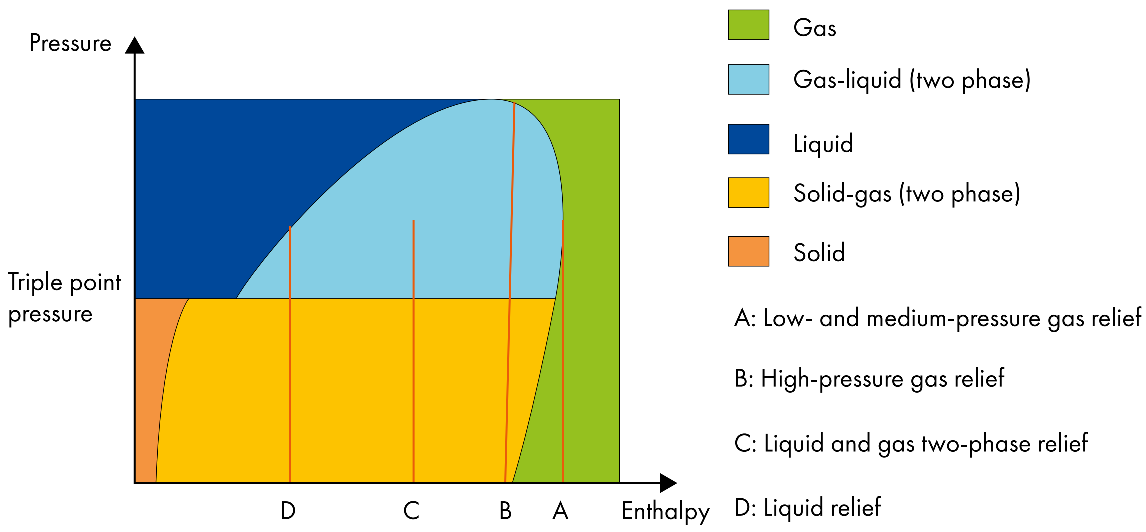

Figure 4: Pressure relief under various scenarios

[3] ISO – 27929 – Transportation of CO_2 by ship

3.1.1 Pipeline pressure relief

The IGC Code (paragraphs 5.2.2.4, 5.5.6 and 5.5.7) requires certain cargo liquid lines to be fitted with a PRV. LCO_2 relieved to atmospheric pressure is expected to generate dry ice. Back pressure in the outlet of a PRV can help prevent the formation of dry ice in a PRV piping system. If PRV piping leads to a cargo tank, care should be taken to ensure that sufficient back pressure is maintained in the line to prevent dry ice plugging.

If a PRV is fitted to a pipeline or equipment for vapour release, the potential for dry ice plugging should also be assessed in the design. Under certain conditions, such as high pressure, vapour pressure relief may generate dry ice.

3.1.2 Pressure relief valve outlet protection

The IGC Code (paragraph 8.2.15) requires a 13 × 13 mm mesh to protect the outlet of a PRV vent. This may not be suitable for a CO_2 PRV because of the potential for blockage by dry ice and such a mesh should not be fitted, as stated in the IGC Code paragraph 17.21.3. The design of a CO_2 PRV should prevent water, snow, debris and animal entry into the relief piping.

When designing the PRV outlet, care should be taken to ensure that the function and capacity of the PRV is not adversely affected. The reliability of any design should be suitable for the PRV, which is safety-critical equipment. The design should not require human intervention to ensure the operation of the PRV.

3.1.3 Cargo tank pressure loss

Uncontrolled pressure loss in a tank containing LCO_2 can result in the liquid turning to solid. This event may exceed the design limits of the tank.

The isolation valve specified in the IGC Code (paragraph 8.2.9) can help to reduce the risk of cargo tank pressure loss caused by a malfunction of the PRV. The isolation valve should be operable when the PRV is open, so the design should consider the provision of remote and local operation of the isolation valve.

Damage to the cargo tank can lead to uncontrolled pressure loss. The probability of damage to the tank dome fittings should be considered. Information on assessment and mitigation measures in the design should be provided in the Cargo Operation Manual required by the IGC Code.

3.2 Static Electricity

LCO_2 has the potential to generate electric charge during pressure relief. The movement of dry ice particles can generate high levels of static electricity in the pipe walls. The design should consider the potential hazard of static electricity caused by LCO_2 especially where the presence of flammable vapour is expected. More information can be found in publications such as NFPA 12[4] and CGA SB-33.[5]

[4] NFPA – 12 – Standard on carbon dioxide extinguishing systems

[5] CGA – SB-33 – Static electricity hazards of liquid or solid carbon dioxide

3.3 Impurities in Liquefied Carbon Dioxide

The source of LCO_2 cargo is from the capture of CO_2 from industrial processes. The different sources and capture and processing methods may lead to the presence of other compounds in the LCO_2. Impurities can affect the physical properties of CO_2, such as the triple point, bubble point, and phase behaviour. Impurities can also adversely react with materials that may be suitable for pure CO_2. Impurities should be carefully considered when designing PRV systems.

3.4 Pressure Relief Valve Release Hazard

PRV discharge piping on a CO_2 carrier is expected to be of short length and will release at a lower level compared with a flammable gas cargo. CO_2 vapour and dry ice can cause concern for personnel safety and certain equipment operation nearby.

A dispersion study alone may not be enough because of the complex geometry of, and impurities in the CO_2, so it may be necessary to undertake computational fluid dynamics (CFD) or other suitable methods or other equivalent methods to predict the gas dispersion and exposure to personnel.

Release of CO_2 from the vent piping may also result in dry ice accumulation on the deck. This should be mitigated or the deck area protected from the effects of the cold temperature.

4

Key Recommendations

4 Key Recommendations

The goals of the CO_2 cargo pressure relief system design should aim to prevent overpressure, uncontrolled loss of pressure, and human injury. The pressure relief system functional requirements may be summarised as follows:

1. Provide sufficient capacity and design to prevent overpressure.
2. Minimise dry ice formation in the PRV system.
3. Prevent uncontrolled loss of pressure.
4. Minimise the adverse impact of a CO_2 release.

The IGC Code provides requirements in Chapter 5 for process and piping, Chapter 8 for vent systems, and Chapter 15 for cargo tank filling limits. These requirements provide the main framework for PRV design for gas carriers. Chapter 17 provides specific requirements for CO_2 cargoes.

Related documents include IMO Resolution A.829(19),[6] which considers two-phase flow from the PRV on a Type C tank, and typical industry standards, including API 520[7,8] and API 521,[9] where additional information may be found. However, the concern related to dry ice is not sufficiently addressed by these IMO or American Petroleum Institute (API) standards.

The following quote from Section 5.21.2 *Liquid-vapor mixture and solids formation* in API 520 Part I provides a helpful summary of the current situation:

> "Some fluids (egg carbon dioxide and wet propane) can form solids when they are discharged through the relieving device. No uniformly accepted method has been established for reducing the possibility of plugging."

Recognising the current knowledge level in the industry, including the lack of design standards and design and operational experience, it is considered sensible to take a conservative approach to the design of PRV systems.

The following recommendations are considered appropriate for LCO_2 at this stage:

1. Cargo Tank Filling Limit

1.1 The cargo tank PRV should remain in the vapour phase when the tank reaches the PRV set pressure.

1.2 The reference temperature (IGC Code paragraph 15.1.3) should be the temperature corresponding to the vapour pressure of the cargo at the set pressure of the PRV. This should be the case even if the cargo vapour pressure or temperature control referred to in IGC Code Chapter 7 is provided.

1.3 A filling limit (IGC Code paragraph 15.4) greater than 98% should not be specified for Type C tanks.

2. Isolation Valve (IGC Code Paragraph 8.2.9)

2.1 The isolation valve should be fitted and capable of remote operation in addition to local operation.

2.2 A positive indication of valve position (open or closed) should be provided locally and at all remote-control stations.

[6] IMO – Resolution A.829(19) – Guidelines for the Evaluation of the Adequacy of Type C Tank Vent Systems

[7] API – 520 Part I – Sizing, selection, and installation of pressure-relieving devices in refineries – Sizing and selection

[8] API – 520 Part II – Sizing, selection, and installation of pressure-relieving devices in refineries – Installation

[9] API – 521 – Pressure-relieving and depressurizing systems

2.3 Failure of the remote-control system should not cause a change in the isolation valve position (fail locked or fail-as-is).

2.4 The control system is safety-critical and should not be operable from within the basic process control system.

2.5 The status should be clearly visible in the navigation bridge and cargo control room and may be integrated with a critical alarm and action panel.

2.6 Each isolation valve should be operable by a dedicated manual control.

2.7 Each isolation valve should be controlled independently.

2.8 The system should be guarded against accidental operation and should require two separate and independent actions to actuate the valve.

2.9 Permanent labelling at the operating station(s) should be provided to advise that the isolation valve should not be operated without the permission of the Master.

3. Cargo Tank Pressure Relief Valve Discharge Pipe

3.1 The IGC Code (paragraphs 8.2.10.3 and 8.2.10.4) does not apply to the LCO_2 pressure relief system and instead a short discharge pipe on the outlet of the PRV should be used. The short pipe should be kept as simple as possible, avoiding branches, tees and sudden increases in cross section.

3.2 A dispersion study combined with CFD or other suitable methods should be carried out to understand the behaviour of a typical release.

3.3 Air intake design of the accommodation and machinery space should consider the dispersion and CFD or other suitable or equivalent study.

3.4 Each PRV should have an independent outlet piping directly to the atmosphere to prevent plugging or partial blockage caused by the formation of dry ice from other PRVs on the same tank.

3.5 A short pipe should relieve to a safe protected location in the cargo area.

3.6 The protected area should be permanently labelled to warn personnel of the danger.

3.7 The protected area may need to be designed for the accumulation of dry ice by, for example, using proper materials for low temperature and suitable coaming.

4. Piping System Pressure Relief Valve Discharge Pipe

4.1 For liquid piping system PRV, it should relieve to the cargo tank or closed pressurized system as practicable as possible.

4.2 For vapour piping system PRV, it may need to consider back pressure to avoid possibility of solidification.

5. Material Selection

5.1 A structured assessment should be conducted as per Section 4.3 of *Carbon Dioxide Cargo on Gas Carriers*[10].

5.2 Materials used for the pressure relief system should have a design temperature of –78.5°C or lower as identified.

5.3 The impact of impurities should be considered in the selection of materials, and the inspection regimes should be conservative because of uncertainty.

6. Pressure Relief Valve Testing

6.1 CO_2 should be used for prototype testing of relief valves.

6.2 A PRV capacity test may be carried out by using air and the PRV capacity calculated according to a recognised standard, such as API 520 or ISO 4126[11].

6.3 For in-service testing and maintenance, CO_2 is not required as the test fluid.

6.4 More frequent inspections may be considered because of the uncertainties about cargo impurities.

7. Additional Recommendations

7.1 A dropped object study should be carried out to ensure that threats to the integrity of the tank dome are identified and mitigated.

7.2 A respiratory protective equipment assessment should be carried out to determine whether additional protection is required for personnel in the event of a PRV release. Note that filter-type respirators do not offer protection.

7.3 Information on the assessment and mitigation of the unique hazards of CO_2 should be provided in the Cargo Operation Manual (IGC Code paragraph 18.2).

7.4 Hazards of static electricity should be assessed and mitigated to protect personnel and prevent ignition of flammable vapour where present.

7.5 Potential PRV leakage may be identified by a detector at the discharge pipe outlet, indicating that further investigation is warranted. Portable equipment can be used for the detection of CO_2 as an alternative to a permanently installed system.

[10] SIGTTO – Carbon Dioxide Cargo on Gas Carriers

[11] ISO – 4126 – Safety devices for protection against excessive pressure

Annexes

Annex 1 – Glossary of Terms and Abbreviations

API American Petroleum Institute

CFD Computational Fluid Dynamics

CGA Compressed Gas Association

CO_2 Carbon Dioxide

IMO International Maritime Organization

ISO International Organization for Standardization

LCO_2 Liquefied Carbon Dioxide

NFPA National Fire Protection Association

PORV Pilot Operated Relief Valve

PRV Pressure Relief Valve

Annex 2 – Reference List

IMO – International Code for the Construction and Equipment for Ships Carrying Liquefied Gases in Bulk (IGC Code)

SIGTTO – Carbon Dioxide Cargo on Gas Carriers

ISO – 27929 – Transportation of CO_2 by ship

NFPA – 12 – Standard on carbon dioxide extinguishing systems

CGA – SB-33 – Static electricity hazards of liquid or solid carbon dioxide

IMO – Resolution A.829(19) – Guidelines for the Evaluation of the Adequacy of Type C Tank Vent Systems

API – 520 Part I – Sizing, selection, and installation of pressure-relieving devices in refineries – Sizing and selection

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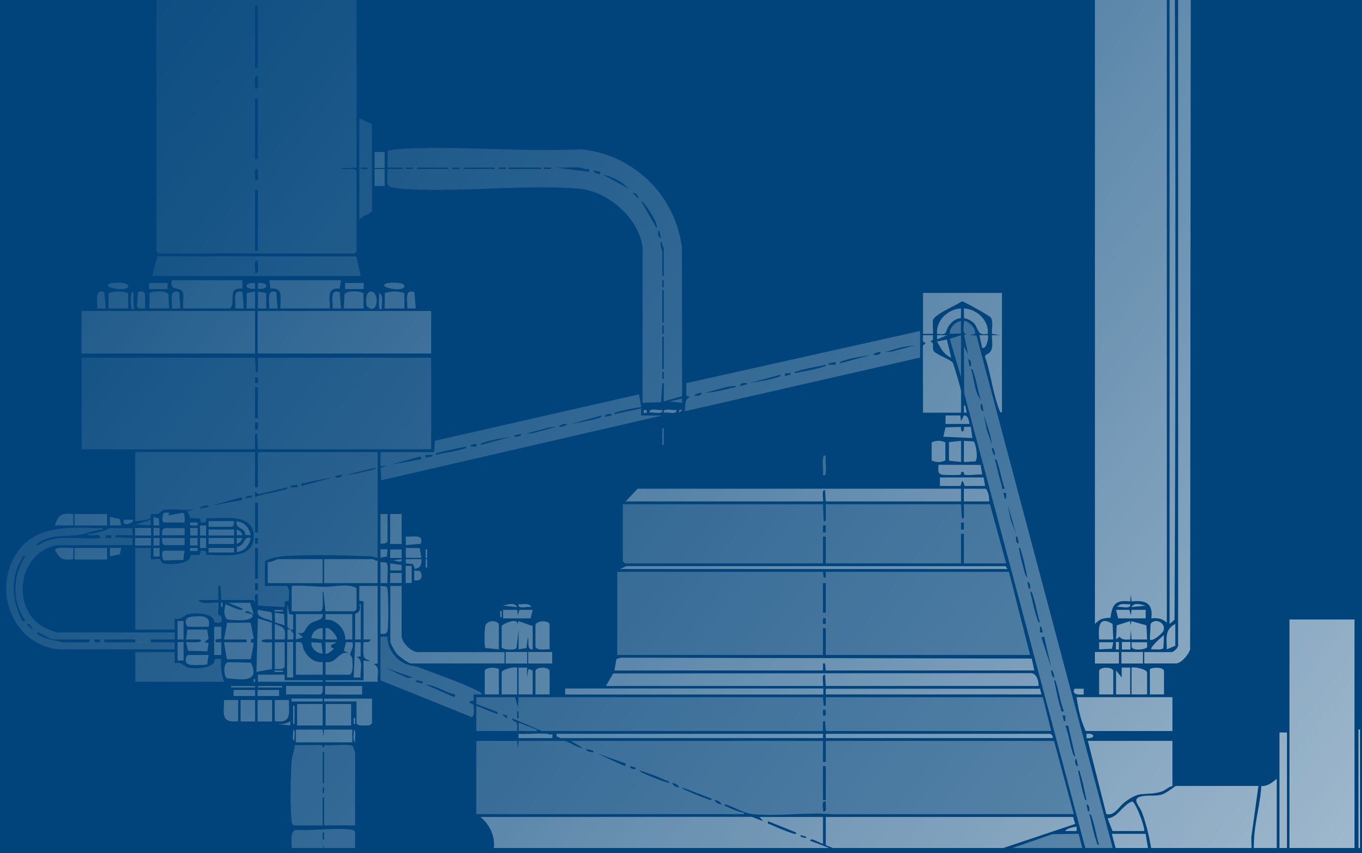
API – 521 – Pressure-relieving and depressurizing systems

ISO – 4126 – Safety devices for protection against excessive pressure



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