FLARE NETWORK

by: Ali Kiashemshaki

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Session Overview

- Basic Principles
- Relief Scenarios
- Relief Load Calculation
- Pressure Relief Devices
- PSV Sizing

Basic Principles

Codes & Practices

- Each engineering or production company has developed its own rules on specific problems related to safety of process plants.

- Design of safety facilities is regulated by national and local codes which vary from country to country. These codes generally do not cover all aspects of safety but dictate specific rules on the most critical areas, such as requirements for safety valves on pressure vessels.

- To develop a satisfactory design of safety facilities it is, therefore, necessary to integrate the rules given by the National, local, and Client codes with recommended practices, which are not mandatory but have been broadly accepted by the industry and proven by experience.

Basic Principles

Codes & Practices – API Standard

- This collection is the result of several years' work by engineers of the petroleum industry and was originally intended to supplement the information set forth in Pressure Vessel Section VIII of ASME Boiler and Pressure Vessel Code.

- API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

Basic Principles

Codes & Practices – API Standard

- The API Standard related to relief systems are condensed in the two following reports :

  - API STD 520 : Sizing, Selection, and Installation of Pressure Relieving Devices:

    Part I, Tenth Ed, June 2020

    This practice is intended for use for relief valves to be installed on vessels with design pressures of 15 psig (1.03 barg, 1.05 kg/cm2 G) or greater.

    Part II, Seventh Ed, June 2020

  - API STD 521 : Pressure Relieving and Depressuring Systems, Seventh Ed, June 2020.

Basic Principles

Codes & Practices

ASME Boiler and Pressure Vessel Code

- Section I Power Boiler
- Section VIII Pressure Vessels

- These codes identify where pressure relieving devices are required, allowable set pressures and accumulation, etc. These requirements are mandatory.

- The primary sections of interest in Section VIII are UG-15 to UG-136 and Appendices M and 11.

Basic Principles

<u>***Codes & Practices***</u>

NFPA Standard

- NFPA 30 : Flammable and Combustible Liquids Code, Use this standard for non-refinery low pressure storage, less than 15 psig (1.03 barg, 1.05 kg/cm2 G).

- NFPA 58 : Standard for Storage and Handling of Liquefied Petroleum Gases, Use for non-refinery gas plant LPG storage

API Standard

- STD 526 : Flanged Steel Safety-Relief Valves

  This standard specifies dimensions of carbon and alloy steel safety-relief valves.

  Seventh Ed, Apr 2017

- STD 2000 : Venting Atmospheric and Low-Pressure Storage Tanks (Non-refrigerated and Refrigerated)

  This standard covers the specification of relief valves for vessels and tanks with design pressures less than 15 psig (1.03 barg, 1.05 kg/cm2 G). Seventh Ed, Mar 2014

Basic Principles

<u>Codes & Practices</u>

ANSI Standard

- B31.1 Power Piping
- B31.2 Industrial Gas and Air Piping
- B31.3 Petroleum Refinery Piping
- B31.4 Liquid Petroleum Transportation Piping
- B31.5 Refrigeration Piping
- B31.6 Chemical Process Piping
- B31.8 Gas Transmission and Distribution Piping

Basic Principles

Codes & Practices

Books :

- Pressure Relief and Effluent Handling Systems (CCPS)
- Pressure Safety Design Practices For Refinery And Chemical Operation

DIERS Methodology:

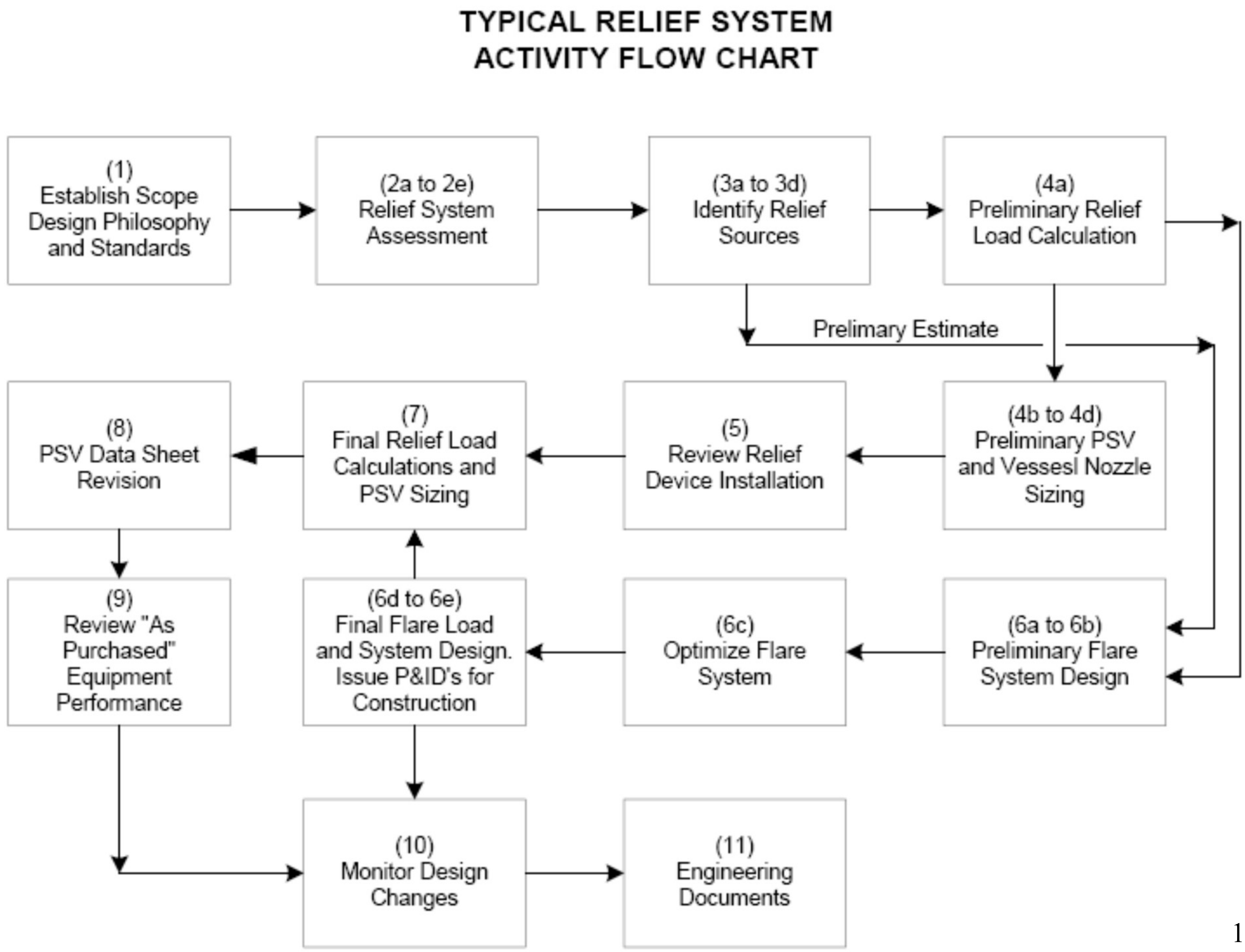
The Design Institute for Emergency Relief Systems (DIERS) was formed in 1979 under the auspices of the American Institute of Chemical Engineers (AICHE) to develop methods for the design of emergency relief systems to handle runaway reactions.

The DIERS research results are available as :

- Technical Publications.

- SAFIRE Emergency Relief System Design Computer Program

Basic Principles



Basic Principles

1) Establish scope, design philosophy and standards

- Primary Responsibility : Lead process engineer
- Secondary Responsibility : Unit process engineer, Flare system process engineer

Review Scope, Standards and Guides, and applicable Laws and Codes for application to the design. Add client involvement.

2) System Assessment

- Primary Responsibility : Unit Process Engineer, Reviewed by Lead Process Engineer
- Consultant Responsibility : Control System Engineer, Mechanical & Piping Engineer

System assessment consists of a review of the process design to identify where relief system requirements may affect design pressures, plot plans or other basic design specifications. Key information required: Process H & M Balances and PFD.

Basic Principles

3) Relief Source Identification

- Primary Responsibility : Unit Process Engineer
- Secondary/Consultant Responsibility : Lead Process Engineer, Flare system process engineer

Identify sources of process stream relief loads during P&ID development, identify services which require relief devices.

Basic Principles

4) Preliminary PSV Sizing

- Primary Responsibility : Unit Process Engineer
- Consultant Responsibility : Control Systems Engineer, Mechanical Engineer

This step assists in identifying early needs for adequately sized PSVs and vessel nozzles.

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5) Relief Device Installation Review

- Primary Responsibility : Unit Process Engineer
- Consultant Responsibility : Control Systems Engineer, Mechanical Engineer

Unit Process Engineer performs a review of inlet & outlet piping losses. Markup process P&ID's to reflect installation.

Basic Principles

6) Flare System Design

- Primary Responsibility : Flare System/Process Engineer
- Consultant Responsibility : Mechanical/Piping Engineer

Collect unit flare load summary with relief device calculation sheets. Check consistency.

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7) Final Relief Load Computation and sizing

- Primary Responsibility : Unit Process Engineer
- Consultant Responsibility : Control Systems Engineer, Flare System Engineer

performs final check of relief load case evaluations and relief valve sizing based on finalized flare system design.

Basic Principles

8) Final PSV Data Sheet Revision

- Primary Responsibility : Process Engineer
- Consultant Responsibility : Control Systems Engineer

Issue final revision for Control Systems Engineer to prepare instrument data sheets and purchase specifications.

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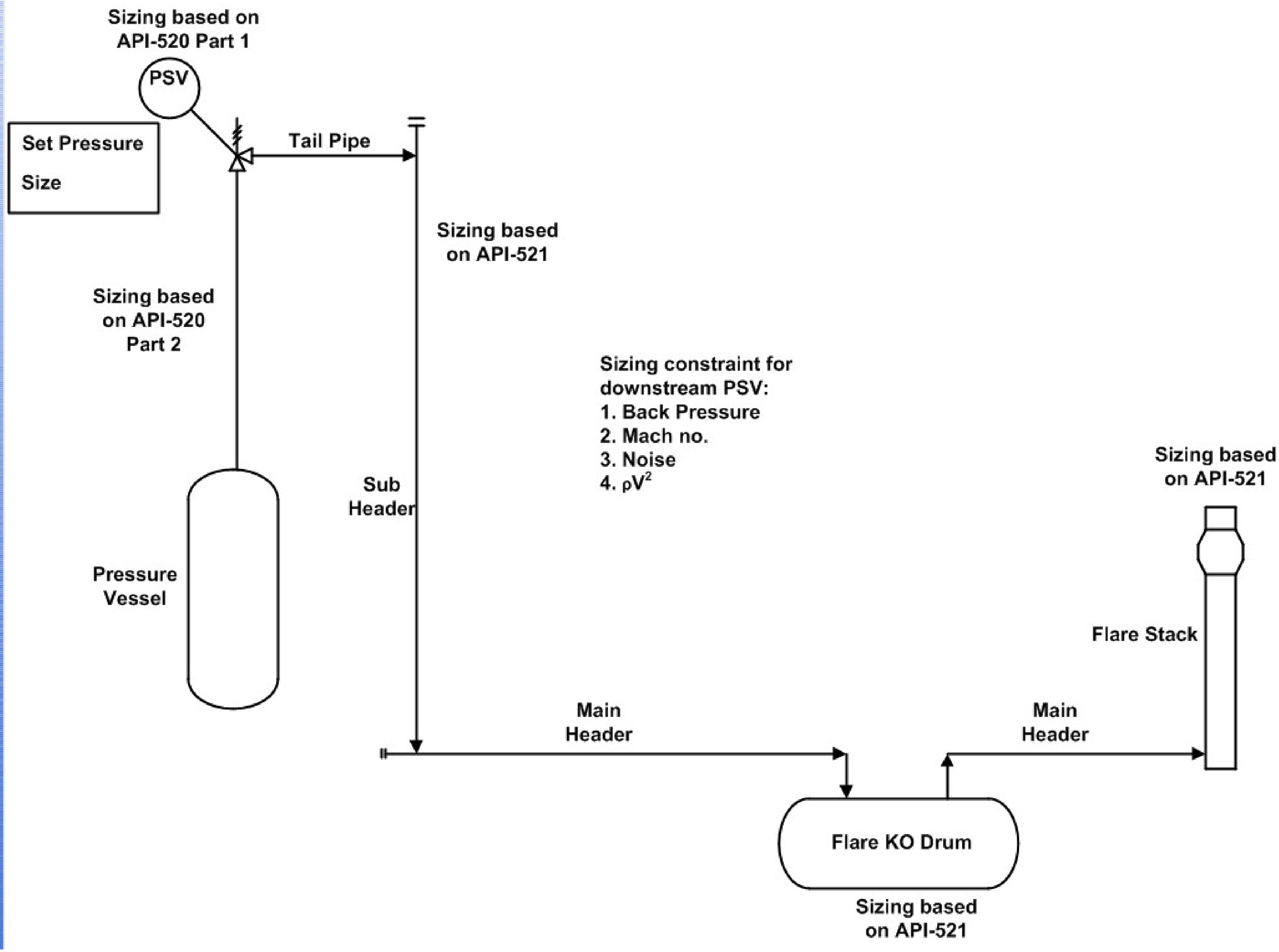
Basic Principles



Basic Principles

<u>Design Pressure</u>

- Design pressure is the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) that results in the greatest required component thickness and the highest component rating (e.g., highest ASME B16.5 flange class).

<u>Maximum allowable working pressure (MAWP)</u>

- The maximum gauge pressure permissible at the top of a completed vessel in its normal operating position at the designated coincident temperature specified for that pressure. The pressure is the least of the values for the internal or external pressure as determined by the vessel design rules for each element of the vessel using actual nominal thickness, exclusive of additional metal thickness allowed for corrosion and loadings other than pressure.

Basic Principles

Maximum allowable working pressure (MAWP)

- Theoretically, the M.A.W.P. should be the basis for the pressure setting of the pressure relieving device protecting the vessel.

- In most of the cases, however, the pressure relieving device is set at the design pressure and not at the M.A.W.P. because the latter is only known late in the design, when the detailed mechanical design of the vessel is completed.

- The MAWP is the pressure which will be stamped on any ASME VIII vessel.

$$MAWP >= DP$$

Terminology

- *Pressure Relief Valve :* is an automatic pressure-relieving device actuated by the static pressure upstream of the valve, and which opens in proportion to the increase in pressure over the opening pressure. It is used primarily for liquid service.

- *Pressure Safety Valve :* is an automatic pressure-relieving device actuated by the static pressure upstream of the valve and characterized by rapid full opening or pop action. It is used for gas or vapor service. (In the petroleum industry it is used normally for steam or air.)

- *Contingency :* An abnormal event which is the cause of an emergency condition.

- *Remote Contingency :* An abnormal condition which could result in exceeding **design pressure** at the coincident temperature, but whose probability of occurrence **is** so low it is not considered as a **design contingency.**

Terminology

- *(Max.) Operating Pressure:* It is the (max.) pressure expected during system operation.

- *Max. Allowable Working Pressure (MAWP):* As defined in the construction codes for pressure vessels , the maximum allowable working pressure depends on the type of material, its thickness, and the service conditions set as the basis for design. The vessel or equipment may not be operated above this pressure, or its equivalent stress at any other metal. Temperature

- *Design Pressure:* is the pressure used as a basis for determining the minimum metal thickness of a vessel or equipment. The design pressure is never greater than the maximum allowable working pressure. In the case where the actual metal thickness available for strength is not known, the design pressure is assumed to be equal to the maximum allowable working pressure.

Terminology

- *Set Pressure:* is the inlet pressure at which the pressure relief valve is adjusted to open under service conditions.
- *Accumulation :* The pressure increase over the *maximum allowable working pressure* of the vessel, expressed in pressure units or as a percentage of maximum allowable working pressure (MAWP) or design pressure. Maximum allowable accumulations are established by applicable codes for emergency operating and fire contingencies.
- *Overpressure :* is the pressure increase over the *set pressure* of the primary relieving device during discharge. Overpressure is the same as accumulation only when the relieving device is set to open at the maximum allowable working pressure of the vessel.
- *Relieving Pressure :* is equal to the valve set pressure (or rupture disk burst pressure) plus the *overpressure.*

Terminology

- *According to UG-125 of ASME Section VIII, Division 1:*

… .All pressure vessels other than unfired steam boilers shall be protected by a pressure relief device that shall prevent the pressure from rising more than 10% or 3 psi, whichever is greater, above the maximum allowable working pressure except as permitted in (1) and (2) below...

- *Sub -paragraphs (1) and (2) mention cases where the pressure rise may be higher.*
- *However , when ASME talks about certifying the capacity of a relief device, MAWP is never mentioned. ASME Section VIII, Division 1, clearly states in paragraph UG-131 (c)(1) that:*

...Capacity certification tests shall be conducted at a pressure which does not exceed the pressure for which the pressure relief valve is set to operate by more than 10% or 3 psi, whichever is greater, except as provided in (c)(2)...

Terminology

- *Sub -paragraph (c) (2) covers a fire case.*
- *Relieving Temperature :* The temperature of the flowing fluid at relieving conditions may be higher or lower than the operating temperature.
- *Slowdown (BlowDown):* is the difference between the set pressure and the reseating pressure of a pressure relief valve, expressed as percent of set pressure.
- *Superimposed Back Pressure :* is the pressure at the outlet of the pressure relief valve while the valve is in a closed position. This type of back pressure comes from other sources in the discharge system; it may be constant or variable; and it may govern whether a conventional or balanced bellows valve should be used in specific applications.

Terminology

- *Built-up BackPressure :* The increase in pressure at the outlet of a pressure relief device that develops as a result of flow after the pressure relief device opens.

- *Rupture Disk Device :* A non-reclosing pressure relief device actuated by static differential pressure between the inlet and outlet of the device and designed to function by the bursting of a rupture disk. A rupture disk device includes a rupture disk and a rupture disk holder.

Terminology

Set Pressure and Accumulation Limits for Pressure Relief Devices

Contingency	Single Device Installations		Multiple Device Installations	
	Maximum Set Pressure %	Maximum Accumulated Pressure %	Maximum Set Pressure %	Maximum Accumulated Pressure %
Non-fire Case				
First relief device	100	110	100	116
Additional device(s)	—	—	105	116
Fire Case				
First relief device	100	121	100	121
Additional device(s)	—	—	105	121
Supplemental device	—	—	110	121
NOTE All values are percentages of the maximum allowable working pressure.				

Terminology

Example Determination of Relieving Pressure for Operating Contingencies for a Single Relief Device Installation

Characteristic	Value
Relief Device Set Pressure Equal to MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	110.0 (758)
Relief device set pressure, psig (kPag)	100.0 (689)
Allowable overpressure, psi (kPa)	10.0 (69)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	124.7 (860)
Relief Device Set Pressure Less Than MAWP	
Protected vessel MAWP, psig (kPag)	100.0 (689)
Maximum accumulated pressure, psig (kPag)	110.0 (758)
Relief device set pressure, psig (kPag)	90.0 (621)
Allowable overpressure, psi (kPa)	20.0 (138)
Barometric pressure, psia (kPa)	14.7 (101)
Relieving pressure, P_1, psia (kPa)	124.7 (860)
NOTE The above examples assume a barometric pressure of 14.7 psia (101.3 kPa). The barometric pressure corresponding to site elevation should be used.	

Philosophy

Philosophy

- *Double Jeopardy :* The causes of overpressure are considered to be unrelated if no process or mechanical or electrical linkages exist among them, or if the length of time that elapses between possible successive occurrences of these causes is sufficient to make their classification unrelated.

  The simultaneous occurrence of two or more unrelated causes of overpressure (also known as double or multiple jeopardy) is not a basis for design.

- Fail-safe devices, automatic start-up equipment, emergency shutdown system, voting system, and other conventional control instrumentation should not replace pressure relieving devices as protection for individual process equipment.

Philosophy

Philosophy

- The design shall comply with the local regulations and the user's risk tolerance criteria, whichever is more restrictive. If these risk tolerance criteria are not available a minimum, the overall system performance including instrumented safeguards should provide safety integrity level 3 (SIL-3).
- Although favorable response of conventional instrumentation should not be assumed when sizing individual process equipment pressure relief, in the design of some components of a relieving system, such as the collection header, flare, and flare tip, favorable response of some instrument systems can be assumed. The decision to base the design of such systems on excluded or reduced specific loads due to the favorable response of instrument systems should consider the number and reliability of applicable instrument systems.

Philosophy

<u>Philosophy</u>

- In evaluating relieving requirements by control valve failure, any control valves that are not under consideration as a failure should be assumed to remain in the position required for normal processing flow.

  In other words, no credit should be taken for any favorable instrument response.

- Pressure relieving devices protect a vessel or item of equipment against overpressure and not against failure due to high temperature when exposed to fire, nor failure due to corrosion.

Philosophy

- In general, restrictions, either a specially designed spool piece or a restriction orifice, should not be used as a means of limiting the capacity of a pressurization path.
- In special cases, where large incentives (such as reducing the size of the flare system) apply, a restriction may be used, provided that all the following conditions are satisfied:

1. A warning against unauthorized removal is provided by means of the following:

    a. A warning sign plate welded to the restriction, and

    b. A note in the relevant documentation (specification, flow diagrams, operating manuals, etc.) is provided.

2. Concentric reducers are installed upstream and downstream of any restriction spool piece used. These reducers minimize turbulence, erosion, and noise.

Philosophy

Philosophy

3. Physical means of preventing inadvertent removal of the restriction orifice, if used, (for example welding to the adjacent piping flange), must be provided.

4. The installation of the restriction is reviewed by the appropriate safety group.

5. The restriction orifice must be inspected at turnaround to define if enlargement has occurred.

6. The restriction orifice is mechanically designed for a differential pressure equal to the upstream design pressure.

Philosophy

Philosophy

- In case of evaluating the effects of operator response for the study to decide the maximum relieving load, it should be considered that the response time between 10 and 30 minutes for operator to take appropriate action ,depending on the complexity of the plants, is required.

- ASME VIII : The vessel or equipment may not be operated above MAWP, or its equivalent stress at any other metal temperature.

- ANSI B31.3, Petroleum Refinery Piping Code, permits variations above the maximum allowable working pressure

Philosophy

<u>Philosophy</u>

- ANSI B31.3 : When the increased operating condition will not exceed 10 hours at any one time or 100 hours per year, it is permissible to increase the pressure rating at the temperature existing during the increased operating condition, by a maximum of 33 %.

- ANSI B31.3 : When the increased operating condition will not exceed 50 hours at any one time or 500 hours per year, it is permissible to increase the pressure rating at the temperature existing during the increased operating condition, by a maximum of 20 %.

- All unfired pressure vessels designed to the ASME Code Section VIII **must** be protected by pressure relieving devices.

Philosophy

<u>Philosophy</u>

- The 1.5 Times Design Pressure Rule :

  Equipment may be considered to be adequately protected against overpressure from certain low-probability situations If the pressure does not exceed 1.3 times design pressure.

- In applying this rule, the capacity of the pressure relief system must also be sized to handle the quantity of fluid released at this pressure.

Philosophy

Philosophy

The 1.5 Times Design Pressure Rule :

- Examples :

  - Inadvertent closure of a CSO valve except for CSO valves used to isolate pressure relief devices for maintenance or to isolate individual branches in flare systems for which accidental closure is considered non-credible.
  - Inadvertent opening of a CSC valve.
  - Plugging of a fixed bed reactor catalyst bed (some local codes consider catalyst bed plugging as a contingency that requires normal pressure relief valve protection).
  - Collapse of reactor outlet collector causing total obstruction of flow.
  - Installation of a rupture disc upside down.
  - A control valve failing open with its bypass fully open.

Philosophy

Administrative Procedures

- Administrative procedures have an important economic role in the safe design and operation of pressure relief systems.
- Application of administrative procedures, however, places a burden on management of the refinery for maintenance of the required procedures. For this reason, these procedures are to be applied only when the benefits exceed the burdens.
- A partial listing of possible administrative procedures follows:

- Lock (or car seal) procedures for block valves associated with pressure relief valves. The procedures should include a list of all block valves which are required to be locked in position, definition of who is authorized to unlock and move block valve positions, procedures for maintaining logs of locked block valve movements and definition of how the procedures will be enforced.

Philosophy

Administrative Procedures

- Requirements that equipment be continuously attended during certain operations, such as when a pressure relief valve is blocked in or when equipment is operated in a mode, such as steam out or pump out, that it is known the pressure relief system is not designed to protect against.

- Limitations on modification of equipment without the proper engineering review of the effect on the pressure relief system. Examples of these types of limitations are restrictions on changes of pump impeller sizes or turbine driver speed settings, operating control valves with their bypass valves partially or fully open, adjustment or removal of control valve minimum or limit stops or revisions to control valve internal trim.

- Operating procedures for shutting down a unit under pre-identified failure conditions.

- Vent and drain procedures for equipment maintenance

Philosophy

Use of Administrative Controls if Corrected Hydrotest Pressure Not Exceeded

- Certain pressure design codes allow the use of administrative controls if the potential overpressure does not exceed the corrected hydrotest pressure, whereas other pressure design codes do not address this subject. Therefore, applying this for equipment built to pressure design codes that do not address the issue could cause the equipment to be overstressed. In these cases, the user should perform mechanical analyses and/or risk analyses. This philosophy is applied to the following scenarios:

a) closed outlets on vessels

b) inadvertent valve opening

c) check valve leakage or failure

d) heat transfer equipment failure

Relief Scenarios

Causes of Overpressure

- The most common are listed below :
  - Closed (Blocked) outlet
  - External fire
  - Inadvertent control valve opening
  - Check-valve malfunction
  - Utility failure
    - Power
    - Cooling water
    - Instrument air
    - Steam
    - Fuel gas (Fuel oil)
  - Thermal expansion
  - Tube rupture of heat exchanger
  - Abnormal process condition : For example, runaway reaction, and so on
  - Equipment failure : Fans, Compressor, Pump, Blower, and so on
  - Column Relief Scenarios (Reflux Failure, Power Failure, etc.)

Relief Scenarios

Closed (Blocked)Outlet

- Can be caused by:
  - Downstream control valve fails closed
  - Isolation valve inadvertently closed by operator
  - Chemical reactions create a flow blockage

- Source pressure exceeds downstream equipment design pressure. Sources are:
  - Pumps
  - Compressors
  - High pressure utilities
  - High pressure upstream fluids

Relief Scenarios

Closed (Blocked)Outlet

- The inadvertent closure of a valve on the outlet of pressure equipment while the equipment is on stream can expose the equipment to a pressure that exceeds the MAWP.
- Every valve (i.e. manual, control, or remotely operated) should be considered as being subject to inadvertent operation.
- If closure of an outlet valve can result in pressure in excess of that allowed by the design code, a PRD is required.
- If the equipment is designed to the maximum source pressure, then closure of an outlet valve will not result in overpressure, so a PRD is not required for the closed outlet scenario.

Relief Scenarios

Closed (Blocked)Outlet

- In the case of a manual valve, administrative controls can be used to prevent the closed outlet scenario unless the resulting pressure exceeds the maximum allowed by the pressure design code [usually the corrected hydrotest pressure is exceeded

- The effect of frictional-pressure drop in the connecting line between the source of overpressure and the system being protected should also be considered in determining the required relieving rate.

- For determining relief loads, it may be assumed that manual or remotely operated valves that are normally open and functioning at the time of failure and that are not affected by the primary cause of failure remain in operation at their normal operating positions.

- This is regardless of the control-valve failure position because failure can be caused by instrument-system failure or misoperation.

Relief Scenarios

Closed (Blocked)Outlet

Liquid Overfill

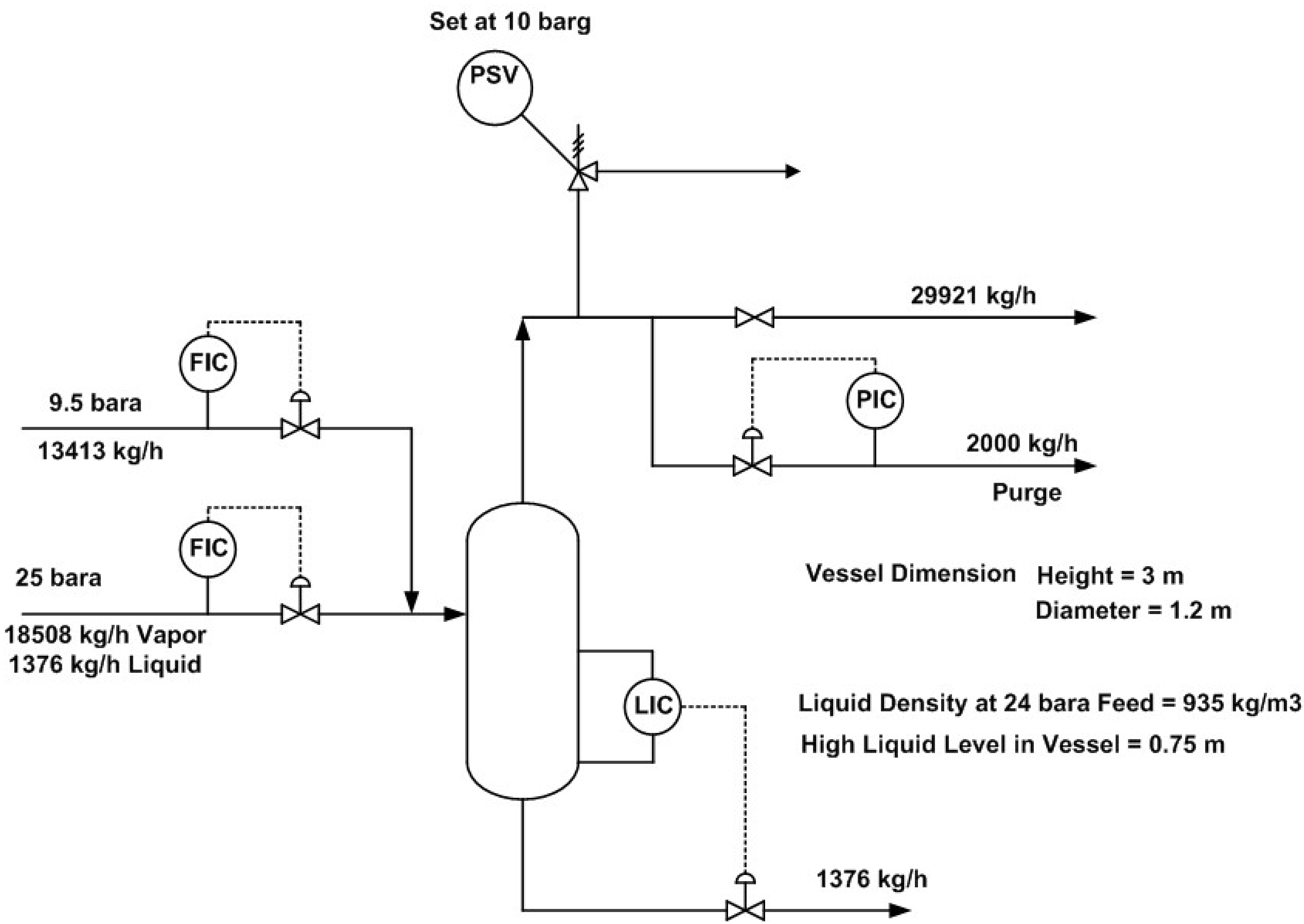
- Liquid overfill of a vessel results in a closed outlet case. As an alternative to providing an adequacy sized pressure relief valve, the following alternative options are available for preventing overpressure:

  1) Increase the system design pressure and/or pressure relief valve set pressure within code allowances.
  2) Provide a safety instrument system (HIPS) to isolate the inflow on increasing vessel inventory.
  3) Rely on operator intervention to prevent overfill from occurring.

- Where liquid overfill is eliminated on the basis of operator intervention, at least one additional and independent alarm shall be provided to indicate that the situation has not yet been brought under control. This alarm may monitor a parameter other than level (e.g. differential pressure)

Relief Scenarios

Example Closed Outlet (Blocked Outlet)



Relief Scenarios

External Fire

- Flammable fluids may escape from a vessel or pipe (from leaking joints or due to potential mishaps)
- They may be carried some distance from the source of leakage by the natural slope of the ground, by air currents, or by jetting stream (if originating from a pressure source) and may accidentally become ignited.
- There is therefore normally the potential for any pressure vessel (including heat exchangers, filters and air coolers) to be exposed to a fire at some time in its life, even though the contents of the vessel itself are not flammable.
- The heat of combustion from the fire, absorbed by radiation or by direct contact with hot gas and/or the flames, will cause any contained liquid to evaporate if the critical pressure of the fluid exceeds the relieving pressure.
- Where the relieving pressure exceeds the critical pressure, the rate of vapor discharge is dependent on the rate at which the fluid expands as a result of the heat input.
- In the case of liquid-full vessels (such as treaters), the initial release will be liquid due to thermal expansion. This will be followed by vapor as the liquid vaposrises.

Relief Scenarios

External Fire Protection

- All pressure vessels shall be protected from overpressure due to vaporization or expansion of contained fluid caused by exposure to fire by use of a pressure relief valve.
- The only exception is when the vessel is located in an area of minimal fire risk and where no credible fire scenario exists.
- In some cases of fire may heat the walls of pressure vessel to a temperature far beyond the specified metal design temperature, creating a real potential for the vessel to fail at a pressure below the set pressure of the pressure relief valve.
- Under these circumstances, the provision of other means of protection in addition to the pressure relief valve should be considered to prevent premature failure.

Relief Scenarios

External Fire Protection

- Additional measures may include one or more of the following:

1. A remotely controlled depressuring valve which allows the vessel pressure to be reduced at a rate which prevents the ultimate tensile strength of the metal at the prevailing fire temperature from being exceeded at any time.

2. Fire-resistant insulation

3. Water deluge system

4. Earth-covered storage or burying the pressure vessel underground.

Relief Scenarios

External Fire

- To determine vapor generation, it is necessary to recognize only that portion of the vessel that is wetted by its internal liquid and is equal to or less than 7,6 m (25 ft) above the source of flame.

Table 5 — Effects of fire on the wetted surfaces of a vessel

Class of vessel	Portion of liquid inventory	Remarks
Liquid-full, such as treaters	All up to the height of 7,6 m (25 ft).	—
Surge drums, knockout drums, process vessels	Normal operating level up to the height of 7,6 m (25 ft).	—
Fractionating columns	Normal level in bottom plus liquid hold-up from all trays dumped to the normal level in the column bottom; total wetted surface up to the height of 7,6 m (25 ft).	Level in reboiler is to be included if the reboiler is an integral part of the column.
Working storage	Maximum inventory level up to the height of 7,6 m (25 ft) (portions of the wetted area in contact with foundations or the ground are normally excluded).	For storage tanks and process tanks, see API Std 2000 or prEN 14015.
Spheres and spheroids	Up to the maximum horizontal diameter or up to the height of 7,6 m (25 ft), whichever is greater.	—

Relief Scenarios

<u>External Fire</u>

- Either the vapor thermal-expansion relief load or the boiling-liquid vaporization relief load, **but not both**, should be used. It is a practice that has been used for many years.

  There are no known experimental studies where separate contributions of vapor thermal expansion versus boiling-liquid vaporization have been determined.

Relief Scenarios

External Fire

- The following basic assumptions are used in calculating fire case relief loads:
  - The process is assumed to be shut down and isolated from other vessels, sources of process fluids or other relief paths.
  - Liquid inventories are assumed to be at their normal control point, or if not controlled, at their maximum normal operating level.
  - Heat input to process equipment is calculated based on empirical equations which include parameters for adjusting heat flux to reflect special circumstances associated with each installation.
  - All fire heat input is normally assumed to be available for vaporizing or heating vessel contents, even though it may take a long time to heat up the vessel contents.
  - Although the size of the assumed fire zone can vary. Experience generally indicates that a fire that can be confined to approximately 230 m^2 to 460 m^2 of plot. (Fire Circle with 21 diameter is more common)

Relief Scenarios

External Fire – Wetted Surfaces

- The basic heat flux equation recommended by API STD-521 for equipment containing liquid is:

$$Q = C_1 \cdot F \cdot A_{ws}^{0,82}$$

where

Q is the total heat absorption (input) to the wetted surface, expressed in W (Btu/h);

C_1 is a constant [= 43 200 in SI units (21 000 in USC units)];

F is an environment factor (see Table 6);

A_{ws} is the total wetted surface, expressed in square metres (square feet).

- As indicated, the factor of C1 includes credits for favorable conditions normally encountered in process units. These conditions are:
  - Sloping of the grading and drainage systems so that flammable liquid will not pool under process vessels.
  - Fire fighting activity is expected to begin soon after a fire starts.

Relief Scenarios

External Fire – Wetted Surfaces

- Where adequate drainage and firefighting equipment do not exist:

$$Q = C_2 \cdot F \cdot A_{ws}^{0,82}$$

where C_2 is a constant [= 70 900 in SI units (34 500 in USC units)].

- Fire case heat absorption calculations for storage tanks are governed by criteria provided by API, NFPA and OSHA in the United States. These methodologies differ primarily in the credits allowed for environmental factors and in the extent that increasing tank size is considered to reduce heat flux over the entire wetted surface.

Relief Scenarios

External Fire – Wetted Surfaces

Table 6 — Environment factor

Type of equipment		Environment factor [a] F
Bare vessel		1,0 [c]
Insulated vessel [b], with insulation conductance values for fire exposure conditions in $W/m^2 \cdot K$ ($Btu/h \cdot ft^2 \cdot °F$)	22,71 (4)	0,3
	11,36 (2)	0,15
	5,68 (1)	0,075
	3,80 (0,67)	0,05
	2,84 (0,5)	0,037 6
	2,27 (0,4)	0,03
	1,87 (0,33)	0,026
Water-application facilities, on bare vessel [c]		1,0 [e]
Depressurizing and emptying facilities [d]		1,0 [e]
Earth-covered storage		0,03
Below-grade storage		0,00
NOTE Local instantaneous pool fire heat fluxes as high as 190 kW/m^2 (60 000 Btu/ft^2-h) have been reported. When designing pressure-relief systems, consideration is generally given to the use of time-weighted average fire heat fluxes rather than instantaneous peaks as some time is required for the contents to reach relieving conditions.		

Relief Scenarios

External Fire- External Insulation

- Credit for thermal insulation is typically not taken because it usually does not meet the fire-protection insulation requirements.
- The designer should be certain that any system of insulating materials permits the basic insulating material to function effectively at temperatures up to 900 °C during a fire for up to 2 hr.
- The value of thermal conductivity used in calculating the environmental-factor credit for insulation should be the thermal conductivity of the insulation at the mean temperature between 904°C and the process temperature expected at relieving conditions. (Use of a conservative mean temperature of 1000°F (540°C) is suggested.)
- For insulated vessels, the environment factor is given by :

$$F = \frac{k(904 - T_f)}{66\ 570\delta_{ins}}$$

k is the thermal conductivity of insulation at mean temperature, expressed in W/m·K (Btu·in/h·ft^2·°F);

δ_{ins} is the thickness of insulation, expressed in metres (inches);

T_f is the temperature of vessel contents at relieving conditions, expressed in °C (°F).

Relief Scenarios

External Fire – Wetted area Calculation

- Generally, only the wetted area up to a height of 25 feet (7.6 meters) above the fire surface will be considered, based on API STD 521 criteria.

- Horizontal drum

  a. Up to 25 ft (7.6 m) above grade - Use total wetted vessel surface up to high liquid level.

  b. Greater than 25 ft (7.6 m) above grade - Use the wetted area of the vessel surface to high liquid level or up to the vessel center line whichever is less.

- Vertical Drums

  The wetted vessel surface within 25 ft (7.6 m) of grade, based on high liquid level, is used. If the entire vessel is more than 25 ft (7.6 m) above grade, then only the surface of the bottom head need be included. For vessels supported on skirts that do not require fireproofing of their inside surface the surface of the bottom head need not be included in the wetted area regardless of elevation.

Relief Scenarios

External Fire – Wetted area Calculation

- Vertical Vessels :

$$A_{wetted} = 1.089\, D^2 + \pi\, D\, h$$

Use this equation when the liquid surface elevation SE < 7.6 m. If the surface elevation of liquid level is above 7.6 m, replace h by h - (SE – 7.6)

- Horizontal Vessels :
  - Liquid level below centerline

    $S = D \cos^{-1}((r - h) / r)$

  - Liquid level above centerline

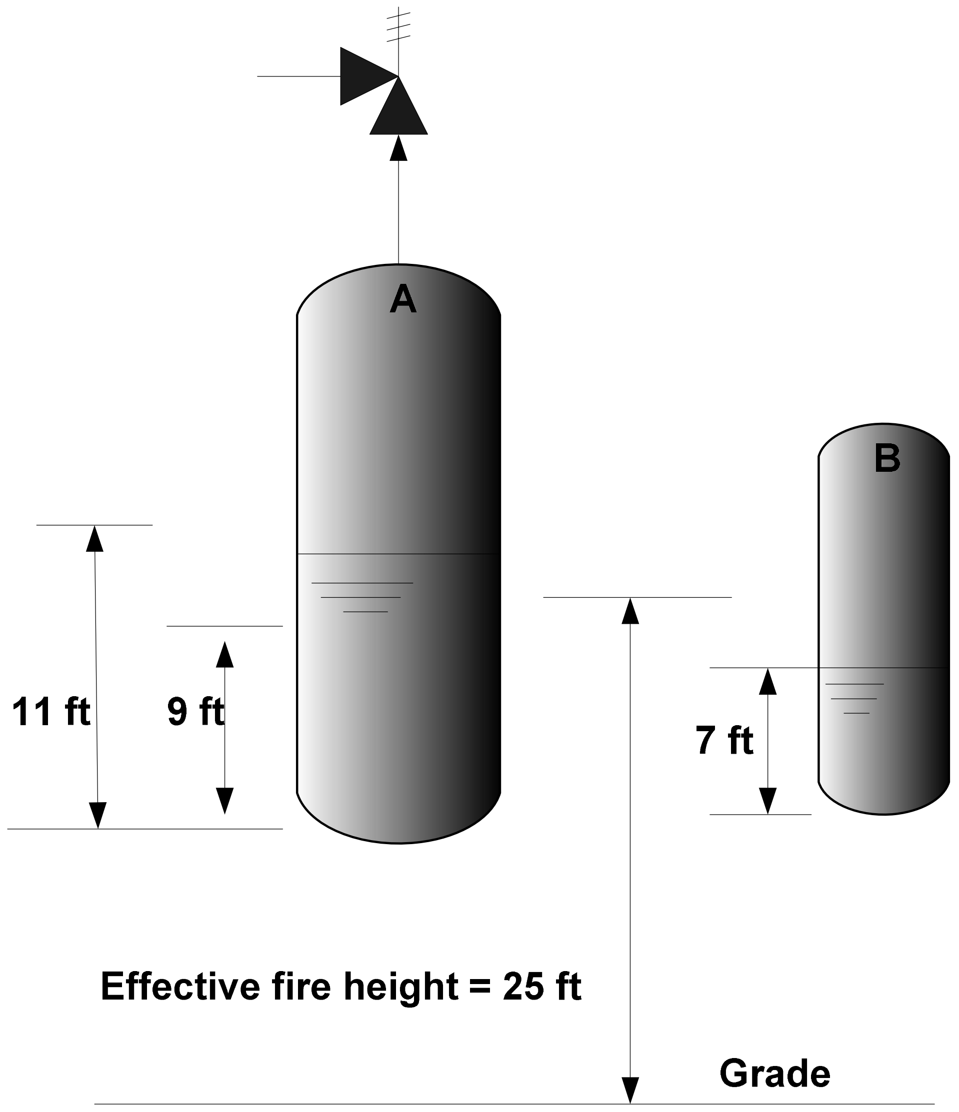
    $S = D \{\pi - \cos^{-1}((h - r) / r)\}$

$$A_{wetted} = (2.178D^2 + \pi DL)(S / \pi D)$$

- As with vertical vessels, these equations are directly useful when the liquid surface elevation S E < 7.6 m. If the surface elevation of liquid level is above 7.6 m, replace h by h - (S E – 7.6).

Relief Scenarios

External Fire- Effective Height Example



External Fire – Wetted area Calculation

- Trayed Column

  a. High liquid level in bottom plus liquid holdup from all trays.

  b. Level in reboiler is to be included if the reboiler is an integral part of the column.

  c. Total wetted surface up to the height of 7.6m (25 ft)

  d. Vessel heads protected by support skirts with limited ventilation are not normally included as wetted surface area.

- Liquid hold-up on each tray shall be equal to the weir height plus 50mm

Relief Scenarios

External Fire – Wetted area Calculation

- Air-Coolers

It is not necessary to consider the bare area for air-cooled condensers, whether partial or total condensing, as long as both of the following conditions are satisfied:

1. The tubes are sloped so that they are self-draining.
2. There is no control valve or pump connected directly to the condenser liquid outlet.

For air-cooled condensers that do not meet the above criteria, and for liquid coolers, the wetted area used to calculate the relief load should be the bare area of the tubes located within the fire risk area and within 25 feet (7.6 m) of grade (or any other surface at which a major fire could be sustained, such as a solid platform).

For tubes located higher than 7.6 m (25 ft), the wetted area shall be taken as follows.

- Forced Draft: Zero (fan hood shields tubes from radiant heat exposure)

- Induced Draft: Projected area (bundle length x width) of tube bundle

Relief Scenarios

External Fire – Wetted area Calculation

- Shell & Tube Exchangers

- No specific guidelines are provided for heat exchanger wetted areas.

- Wetted area should be calculated based on the outside area of the heat exchanger adjusted for the normal volume fraction of liquid in the shell side stream.

- Heat exchangers that are free-draining (e.g., a condenser that self-drains to a reflux drum) need not be considered in the calculation of relief loads arising from fire exposure.

Relief Scenarios

External Fire – Vapor Release rate

- For fluid with critical pressure above relieving pressure, all heat absorption from fire exposure is considered as latent heat and no credit is taken for the sensible heat capacity of the fluid in the vessel. The vapor release rate W is calculated from:

$$W = Q / \lambda$$

W = Vapor rate, lb/h (kg/s)

Q = Heat absorption calculated, Btu/h (kW)

λ = Latent heat of vaporization of liquid in the vessel, Btu/lb (kJ/kg)

Relief Scenarios

External Fire –Fluid with Critical Pressure above Relieving Pressure

- Single Component Systems

  For single component systems, the term λ equals the latent heat of vaporization at relieving conditions. It may be determined from a flash calculation at relieving pressure and dew point conditions in Hysys or similar simulation software, or it may be obtained from API STD 521, Appendix A, Figure A6 or other literature sources. For such systems, the latent heat, the vaporization temperature, and the physical properties of the liquid and vapor phases in equilibrium remain constant as the vaporization proceeds. The peak relief load will always occur at the start of the fire, when the wetted surface, Aw, and consequently, the heat input, Q, are both at a maximum. For PSV sizing refer to step 4 of Multi Component Systems.

- Multi-Component Systems

  For multi-component systems, the latent heat of the residual liquid will change as the lighter components are vaporized and removed from the system.

Relief Scenarios

External Fire –Fluid with Critical Pressure above Relieving Pressure

- For multi-component systems, the vaporization of the liquid initially in the vessel at the start of the fire proceeds as a “batch distillation” in which the temperature, vapor flow rate and physical properties of the vapor and liquid in equilibrium with each other change continuously as the vaporization proceeds.
- The peak relief load may or may not coincide with the start of the fire.
- In general, such systems require a time-dependent analysis to determine the required relief area and the corresponding relief rate. The following approach is suggested:

1. Using the composition of the residual liquid inventory in the vessel, perform a bubble point flash at the accumulated pressure. In doing this flash, the flow rate of the feed stream to the flash can be set at initial mass on the equipment.

$m=\rho.V$

m: initial liquid mass in the equipment

V: liquid volume in the equipment up to HLL

ρ: liquid mass density at normal operation

Relief Scenarios

External Fire –Fluid with Critical Pressure above Relieving Pressure

2. For each flash, sufficient heat is applied to vaporize a nominal 10 wt% of liquid, the remaining liquid passing to the next flash.

3. An estimate of the time for each flash should be made.

   time=required heat for each flash/calculated heat of fire

4. The flashes are continued until one of the following criteria is achieved:

- A flash temperature of 400°C is obtained.

  This is the temperature at which carbon steel vessel can be expected to lose integrity.
- The total vaporization time riches 2 hours.

  This is the time within it would be anticipated that a fire would be brought under control.

Relief Scenarios

External Fire –Fluid with Critical Pressure above Relieving Pressure

- For each stage, a latent heat of vaporization should be calculated and data for the flashed vapor used to compute the value of a factor A' which is indicative of the pressure relief valve orifice area required based on that stage of the vaporization of the original fluid.

$$A' = \frac{1}{\lambda}\sqrt{\frac{zT}{M}}$$

A'	pressure relief valve orifice area parameter (not the orifice area)
λ	latent heat of vaporization (kJ/kg)
z	vapor compressibility
T	vapor temperature (K)
M	vapor molecular weight

- The maximum value of A' determines the values of λ, z, T and M to be used for defining the fire relief load and for pressure relief valve sizing.

Relief Scenarios

External Fire –Fluid with Critical Pressure below Relieving Pressure

- For a fluid, whose vapor pressure equals or exceeds the critical pressure before the set pressure of the pressure relief valve is achieved, the relief load is given by the following equation:

$$W = Q.B/C$$

W relief load (kg/h)

Q heat absorbed by the vessel surface due to fire (kJ/h)

B volumetric coefficient of thermal expansion (1/°C)

C specific heat of liquid (kJ/kg.°C)

- The expression C/B has the units kJ/kg and is commonly regarded as a fictitious latent heat. Determination of a realistic value for B can be difficult and API-521 suggests that a minimum value of 115 kJ/kg is acceptable as an approximation.
- A better method is to use a process simulator such as HYSYS to calculate the rate of explosion of dense phase vapor from the vessel over a period of time. Refer to Fire Supercritical Fluid Calculation.

Relief Scenarios

External Fire- Notes

- Temperature generated by fire shall not be considered to specify the design temperature selection.
- Relieving temperatures are often above the design temperature of the equipment being protected. If the elevated temperature is likely to cause vessel rupture, additional protective measures should be considered.
- Relief vapor flow rate from the heat input to the vessel and from the latent heat of liquid contained in the vessel becomes invalid near the critical point of the fluid.

  At this point the latent heat approaches zero and the sensible heat dominates.
- If no accurate latent heat value is available for these hydrocarbons near the critical point, a minimum value of 115 kJ/kg (50 Btu/lb) is sometimes acceptable as an approximation.
- If pressure-relieving conditions are above the critical point, the rate of vapor discharge depends only on the rate at which the fluid expands as a result of the heat input because a phase change does not occur.

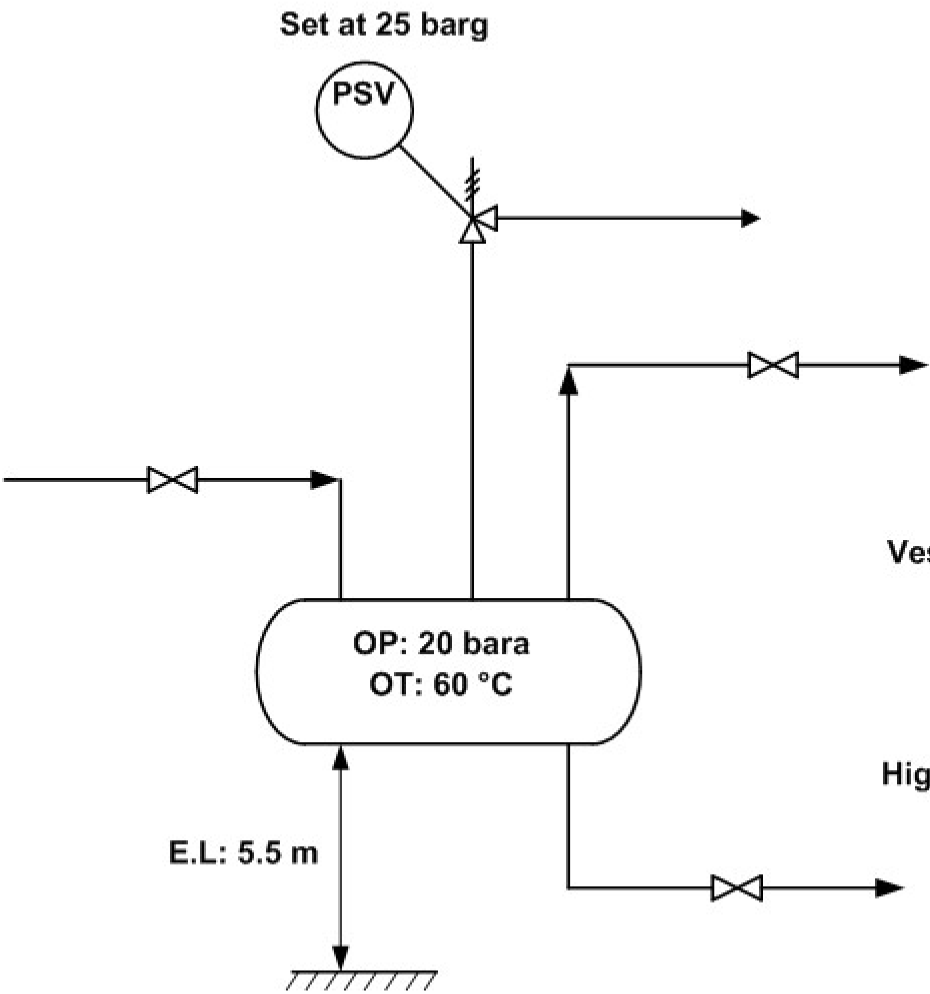
Relief Scenarios

External Fire- Notes

- Two-phase relief-device sizing is not normally required for the fire case, except for unusually foamy materials or reactive chemicals.
- There is an interim time period between the liquid-expansion and the boiling-vapor relief during which it is necessary to relieve the mixtures of both phases simultaneously,
- The above mixed-phase condition is usually neglected during sizing and selecting of the pressure-relief device.
- Experience has shown that the time required to heat a typical system from the relief-device set pressure to the relieving conditions allows for the relief of any two-phase flow prior to reaching the relieving conditions.
- Full disengagement of the vapor is realized at the relieving conditions and the assumption of vapor-only venting is appropriate for relief device sizing.

External Fire (Wetted Surface)-Example

Feed Composition	
	mol%
H2O	0.23
H2S	0.01
CO2	1.25
N2	0.01
C1	34.91
C2	9.8
C3	8.86
i-C4	2.56
n-C4	6.41
i-C5	3.78
n-C5	3.97
n-C6	28.21



Vessel Dimension Length = 6 m
Diameter = 2 m

High Liquid Level in Vessel = 1.25 m

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

- Unwetted wall vessels are those in which the internal walls are exposed to a gas, vapor or super-critical fluid, or are internally insulated regardless of the contained fluids.
- Vessels can be designed to have internal insulation (e.g. refractory) and such areas may be considered unwetted.
- If a vessel can become insulated by the deposition of coke or other materials, the vessel wall shall still be considered wetted for fire-relief sizing.
- Heat flow from the wall to the contained fluid is low as a result of the resistance of the contained fluid or any internal insulating material.
- Recent calculations indicate that the heat flux of the fire is in the range of approximately 80 kW/m2 to 100 kW/m2.
- no credit for fireproofing is recommended when determining fire relief requirements of gas-filled vessels because, in most cases, a relatively small relief device is required even without a fireproofing credit.

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

$$A = \frac{F'.A'.\sqrt{Z}}{K_b.K_c\sqrt{P_1}}$$

A is the effective discharge area of the valve, mm2 (in2)

A' is the exposed surface area of the vessel, m2 (ft2)

P_1 is the upstream relieving absolute pressure, kPa (psi)

$$F' = \frac{C_9}{C \cdot K_D}\left[\frac{(T_W - T_1)^{1.25}}{T_1^{0.6506}}\right]$$

$$C = C_{10}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

If calculated F' is less than 182 in SI units (0.01 in USC units), then use a recommended minimum value of F ' = 182 in SI units (0.01 in USC units),

If insufficient information is available to above equation), then use F ' = 821 in SI units (0.045 in USC units),

C9 is a constant [= 0.2772 in SI units (0.1406 in USC units)];

C10 *is a constant {= 0.0395 (kgmole.K)$^{0.5}$/(mm^2.kPa.h) in SI units [520 (lbmole.°R)$^{0.5}$/(lbf.h) in USC units]};*

K_D *is the coefficient of discharge (obtainable from the valve manufacturer);*

K_D *value of 0,975 is typically used for preliminary sizing of pressure-relief valves*

Tw is the recommended maximum wall temperature of vessel material, K (°R)

T_1 *is the gas absolute temperature, at the upstream relieving pressure, K (°R)*

k is the ideal gas specific heat ratio (Cp/Cv) of gas or vapor at relieving conditions;

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

Relieving Temperature Calculation

There are two methods for calculation of relieving temperature:

1) From equation of API-521

$T_1 = P_1/P_n \times T_n$

P_n is the normal operating gas absolute pressure, expressed in kPa (psia)

T_n is the normal operating gas absolute temperature, expressed in K (°R).

2) From Hysys software (more accurate)

1. Define one stream in hysys
2. In this stream

    Temperature= normal operating temperature

    Pressure= normal operating pressure

    Vessel Composition

    Set molar flow to arbitrary value (e.g. 100 kmol/h)

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

Relieving Temperature Calculation

3. Read and copy actual volume flow from properties page
4. Change operating pressure to relieving pressure
5. Define *Adjust*, set stream temperature as adjusted variable
6. Set actual volume flow as target object and define calculated value from step 3
7. Run *Adjust* to calculate relieving temperature

- The recommended maximum vessel wall temperature, Tw, for the usual carbon steel plate materials is 1100 °F (593°C)
- If F ' ≥ 182 in SI units (F ' ≥ 0.01 in USC units):

$$q_{\mathrm{m,relief}} = C_{12}\sqrt{M \cdot p_1}\left[\frac{A'(T_{\mathrm{w}} - T_1)^{1.25}}{T_1^{1.1506}}\right]$$

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

W *relief rate, kg/h (lb/h)*

M *molecular weight,*

C12 *is a constant [= 0.2772 in SI units (0.1406 in USC units)].*

- The minimum relief load recommended for sizing where F ' < 182 in SI units (F ' < 0.01 in USC units) is calculated by setting F ' = 182 in SI units (F ' = 0.01 in USC units).

$$q_{\mathrm{m,relief}} = \mathrm{C}_{13}\mathrm{C}A'\sqrt{\frac{Mp_1}{T_1}}$$

C13 *is a constant [= 182 in SI units (0.01 in USC units)]*

- To derive above equations, Z, Kb, and Kc in API 520-1:2014 have each been assumed to have a value of 1.

Relief Scenarios

External Fire- Gas Expansion (Unwetted)

Assumptions :

- It is based on the physical properties of air and the perfect gas Law.
- Assume that the vessel is uninsulated and has no mass.
- Vessel wall temperature do not reach rupture-stress temperature
- There is no change in fluid temperature.
- the relationship is empirical and hence there is no engineering basis for providing an environmental factor for this equation.

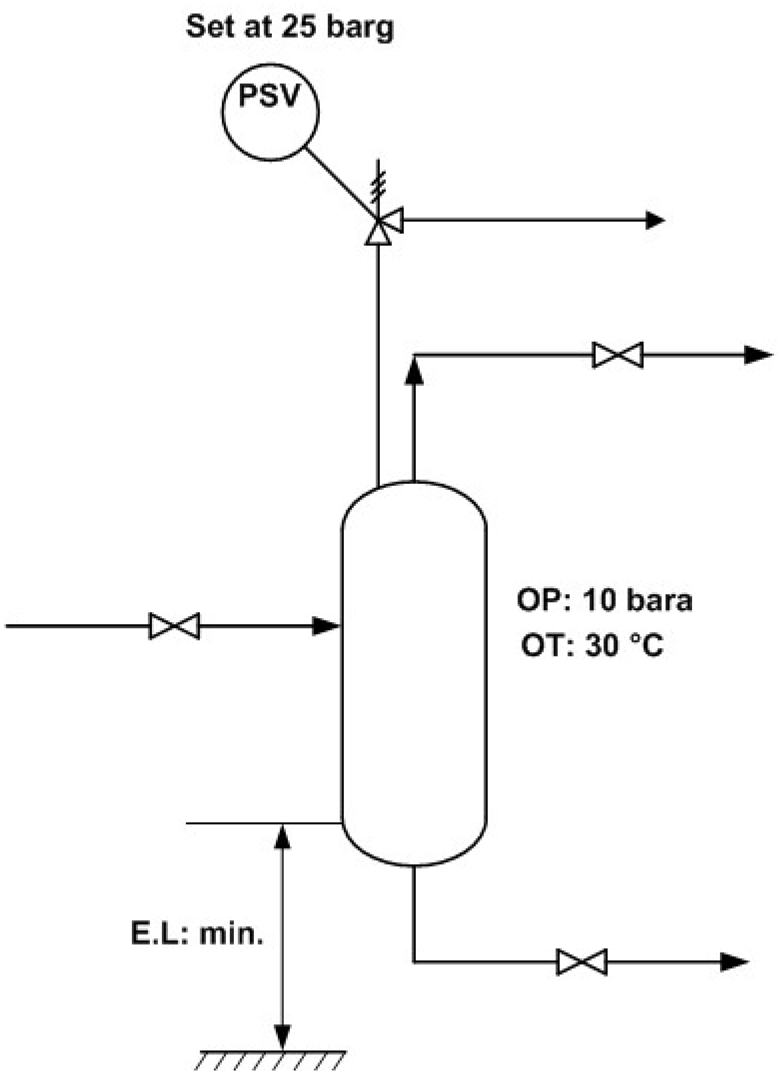
- Exposed Area :

1. **Horizontal Drums**
   - Up to 25 ft (7.6 m) above grade -> Use total exposed surface.
   - Greater than 25 ft (7.6 m) above grade -> Use the horizontal projected area of the vessel
2. **Vertical Vessels**

The exposed surface within 25 ft (7.6 m) of grade is used. If the entire vessel is more than 25 ft (7.6 m) above grade, then only the surface of the bottom head need be included.

Gas Expansion (Unwetted)- Example

Feed Composition	
	mol%
C2	0.25
C3	97.8
i-C4	0.95
n-C4	1



Vessel Dimension Length = 5.2 m
Diameter = 3 m

High Liquid Level in Vessel = 0

Relief Scenarios

External Fire- Jet Fire

- Protection from jet-fire exposure is typically addressed through means other than pressure-relief devices because failure often occurs due to localized overheating for which a pressure-relief device is ineffective.
- An impinging jet fire can cause vessel failure in less than 5 min, depending on the vessel's wall thickness and material.
- Jet fires can occur when almost any combustible/flammable fluid under pressure is released to atmosphere.
- Examples of different jet-fire characteristics are unpredictable flame-impingement points, significantly increased heat loading to the vessel's wetted and unwetted surfaces, mainly due to higher flame temperatures.
- Local instantaneous heat fluxes within jet fires as high as 300 kW/m2 (94500 Btu/ft2·h) have been reported.
- Instead of a pressure-relief system, protection against jet fires focuses on prevention of leaks through proper maintenance and/or mitigation systems such as fireproofing, depressuring systems, isolation of leaks, equipment and/or flange orientation and minimization and emergency response.

Relief Scenarios

External Fire- Supercritical Fluids

- Supercritical fluids exhibit characteristics typical of both liquids and vapors. Transport properties, such as viscosity and diffusion rate, are closer to those of typical vapors, while solvent strength resembles that of typical liquids.

- This is a rigorous procedure to calculate the relief rate and size the relief valve for supercritical fluids. The relief rate is modeled over time for a blocked-in vessel using small increments of temperature. The relief valve is sized by modeling mass flux through an isentropic orifice up to the limit of choked flow.

- This procedure embodies such a dynamic model for the relief device, and includes the sizing procedure from calculating the relief rate through sizing the orifice. The dynamic model is controlled by the increase in temperature of the vessel contents. For each temperature, the relief rate is first calculated based on the fluid physical properties and the heat input; then the relief valve is sized by assuming isentropic orifice flow.

External Fire- Supercritical Fluids

- Procedure for *Supercritical Fluids Fire* Calculation :

Step 1: Assemble the relief case information:

P, T, ΔT, V, a, f, t, n.

P = relieving pressure, psia

T = initial temperature, °R

ΔT= temperature change, °R

V = Relief- or vessel-fluid volume, ft^3

A = fire case, total wetted surface area, ft^2

t = time since onset of fire, min

f = environmental factor from API 521

n = number of iterations

Step 2: Select the property-estimation method and assemble the data:

Pc, Tc, ω, Mw.

ω = fluid acentric factor, dimensionless

Step 3: Update the iteration count.

External Fire- Supercritical Fluids

- Procedure for *Supercritical Fluids Fire* Calculation :

Step 4: Calculate the heat input, Q. For this fire case, the heat absorption rate for the vessel is calculated by assuming that Eq. 3 from API 521, Section 3.15.2 *(3) represents* the heat absorbed by a supercritical fluid with adequate drainage and prompt firefighting:

$Q=21{,}000\, f\, A^{0.82}$ *Q: Btu/h*

Step 5: Calculate the physical properties of the fluid:

$\hat{V}, \hat{H}, \hat{S}, \Delta\hat{V}, \Delta\hat{H}$

H = relief- or vessel-fluid enthalpy, Btu

S = relief- or vessel-fluid entropy, Btu/°R

^ = mass, /lb

Step 6: Calculate the required relief rates: $\dot{V}$ *and* $\dot{m}$

The required relief rates for the first iteration are found using the heat input and physical properties from Steps 4 and 5:

$$\dot{V} = Q\frac{\Delta\hat{V}}{\Delta\hat{H}} \qquad \dot{m} = \dot{V} / \hat{V}$$

Relief Scenarios

External Fire- Supercritical Fluids

- Procedure for *Supercritical Fluids Fire* Calculation :

Step 7: Calculate the time elapsed since the onset of the fire, *t (this step is optional)*

$$\hat{V}_{ave} = \frac{(\hat{V}_{n+1} + \hat{V}_n)}{2}$$

$$\mathrm{m} = \mathrm{V} / \hat{\mathrm{V}}_{\mathrm{ave}}$$

$$t_{n+1} = t_n + m \frac{\Delta \hat{H}}{Q / 60}$$

Step 8: Calculate the isentropic-nozzle mass flux, G.

$$G = \frac{\sqrt{2\left(\hat{H}_0 - \hat{H}_b\right)}}{\hat{V}_b} 3{,}955.77$$

0 = at inlet of relief valve orifice

b = at outlet of relief valve orifice

* Each backpressure representing a 2% decrease in the gage pressure

External Fire- Supercritical Fluids

- Procedure for *Supercritical Fluids Fire* Calculation :

Step 9: Calculate the orifice area, A.

$$A = \frac{\dot{m}}{G\,K_b\,K_c K_d K_v}$$

* Since compressible flow theory is used to calculate the mass flux for the example, the effective coefficient of discharge for the vapor ($K_d = 0.975$) *is assumed.*
* K_c is the combination correction factor for installations with a rupture disk upstream of the PRV; K_c equals 1.0 when a rupture disk is not installed. K_c *equals 0.9 when a rupture disk is installed in combination* with a PRV and the combination does not have a certified value.
* Normally, no viscosity correction is required for a supercritical fluid, thus, $K_v = 1.0$.

Step 10: Tabulate the results. Summarize the calculations for each temperature iteration by adding a row to a results table.

External Fire- Supercritical Fluids

- Procedure for *Supercritical Fluids Fire* Calculation :

Step 11: Are $\dot{m}$, $\dot{V}$ and A decreasing?

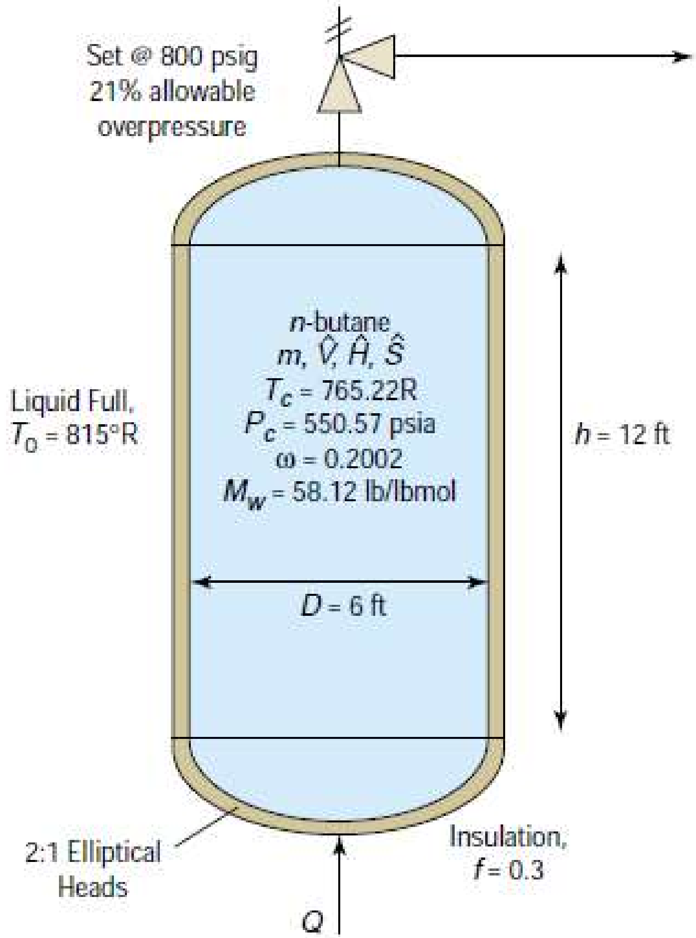
Determine if the procedure is complete. In most cases, the relief-valve sizing is complete when the required mass and volumetric relief rates, as well as the required orifice area, all decrease from the previous iteration. However, further iterations may be needed, since the orifice area may begin to increase again or if the vessel-wall temperature is being modeled for a specific time interval. The orifice area may increase again if the fluid is a liquid and has not reached supercritical conditions, since a supercritical fluid typically has a greater expansion rate than does a liquid.

Step 12: Calculate the temperature for the next iteration, T.

Step 13: Select the relief-valve orifice size.

External Fire- Supercritical Fluids

Example: Consider a blocked-in vessel initially full of *n-butane at* the conditions shown in below figure. Calculate PSV size which is needed due to a fire.



Relief Scenarios

Thermal (Hydraulic) Expansion

- Hydraulic Expansion is the increase in liquid volume caused by an increase in temperature.

- the most common of which are the following:

  - a) Piping or vessels are blocked in while they are filled with cold liquid and are subsequently heated by heat tracing, coils, ambient heat gain or fire.
  - b) an exchanger is blocked in on the cold side with flow in the hot side.
  - c) Piping or vessels are blocked in while they are filled with liquid at near-ambient temperatures and are heated by direct solar radiation.

Relief Scenarios

Thermal (Hydraulic) Expansion

- Protection against thermal expansion overpressure may be provided by the one of the following methods:

1. Installation of a PR valve.

2. Installation of a small permanently open bypass around one of the block valves. An alternative to a permanently open bypass could be a drilled hole in all of the block valves (or check valve) as long as leakage is acceptable and accounted for in the design.

3. Procedures ensuring that blocked-in equipment is drained of liquid.

Relief Scenarios

Thermal (Hydraulic) Expansion – Sizing and Set pressure

- Since every application is for a relieving liquid, the required relieving rate is small; specifying an oversized device is, therefore, reasonable.
- A DN 20 x DN 25 (NPS ¾” x NPS 1”) relief valve is commonly used.
- Proper selection of the set pressure for these relieving devices should include a study of the design rating of all items included in the blocked-in system.
- The thermal-relief pressure setting should never be above the maximum pressure permitted by the weakest component in the system being protected.

Relief Scenarios

Thermal (Hydraulic) Expansion – Sizing and Set pressure

- Two general applications for which thermal relieving devices larger than a 3/4-inch x 1-inch nominal pipe size (NPS 3/4” x NPS 1) valve might be required are long pipelines of large diameter in un-insulated aboveground installations and large vessels or exchangers operating liquid full.
- A pressure-relief device might not be required to protect piping from thermal expansion if :
  - a) the piping always contains a pocket of non-condensing vapor.
  - b) the piping is in continuous use and drained after being blocked-in using well supervised procedures or permits;
  - c) the fluid temperature is greater than the maximum temperature expected from solar heating [usually approximately 60 °C to 70 °C]
  - d) the estimated pressure rise from thermal expansion is within the design limits of the equipment or piping.
  - e) Short sections of piping less than 100 ft (30 m) in length but not exceeding 250 gallons (900 lit) in volume which can be blocked in, generally do not need thermal relief valves.

Relief Scenarios

Thermal (Hydraulic) Expansion – Sizing and Set pressure

- For liquid-full systems, expansion rates for the sizing of relief devices that protect against thermal expansion of the trapped liquids can be approximated using below, in SI units:

$$q = \frac{\alpha_V \cdot \phi}{1\,000 d \cdot c}$$

q is the volume flow rate at the flowing temperature, expressed in cubic metres per second;

α_V is the cubic expansion coefficient for the liquid at the expected temperature, expressed in 1/°C;

ϕ is the total heat transfer rate, expressed in watts;

NOTE For heat exchangers, this can be taken as the maximum exchanger duty during operation.

d is the relative density referred to water (d = 1,00 at 15,6 °C), dimensionless;

NOTE Compressibility of the liquid is usually ignored.

c is the specific heat capacity of the trapped fluid, expressed in J/kg·K.

Relief Scenarios

Thermal (Hydraulic) Expansion – Sizing and Set pressure

- The basic equation for calculating the pressure increase due to thermal expansion in a piping system is as follows:

$$\Delta P = \frac{(\Delta T)\,(\beta - 3\alpha) - (q\,t\,/\,v)}{K + \left(\frac{R}{E\,h}\right)\,(2.5 - 2\sigma)}$$

where:

	ΔP	=	Pressure increase, psi (kPa)
	ΔT	=	Temperature increase, °F (°C)
	β	=	Coefficient of cubic expansion for the liquid, in.^{3}/(in.^{3} °F) [m^3/(m^3 °C)]
	α	=	Coefficient of linear expansion for the metal wall, in./(in.-°F) [m/(m-°C)]
	K	=	Compressibility of the liquid, in.^{3}/(in.^{3} psi) [m^3/(m^3 kPa)]
	E	=	Modulus of elasticity for the metal wall, psi (kPa)
	R	=	Inside radius of the pipe, in. (m)
	h	=	Wall thickness, in. (m)
	σ	=	Poisson's ratio, usually 0.3
	q	=	Liquid leakage rate, in.^{3}/s (m^3/s)
	t	=	Elapsed time for leakage, s
	v	=	Pipe volume, in.^{3} (m^3)

- This equation accounts for the thermal expansion of the liquid, thermal expansion of the pipe, and leakage out of the trapped section of piping.

Thermal (Hydraulic) Expansion – Sizing and Set pressure

SERVICE	K, in.^{3}/(in.^{3}-psi) [m^3/(m^3-kPa)]	β, in.^{3}/(in.^{3}-°F) [m^3/(m^3-°C)]
Propane	0.189×10^{-4} (2.74×10^{-6})	0.119×10^{-2} (2.14×10^{-3})
Butane	0.123×10^{-4} (1.78×10^{-6})	0.085×10^{-2} (1.53×10^{-3})
Gasoline	0.052×10^{-4} (0.75×10^{-6})	0.060×10^{-2} (1.08×10^{-3})
Diesel	0.044×10^{-4} (0.64×10^{-6})	0.050×10^{-2} (9.0×10^{-4})
Water	0.034×10^{-4} (0.49×10^{-6})	0.024×10^{-2} (4.3×10^{-4})
PIPE MATERIAL	E, psi [kPa]	α, in./(in.-°F) [m/(m-°C)]
CS	30×10^6 (207×10^6)	6.0×10^{-6} (1.08×10^{-5})
2.25 Cr	30×10^6 (207×10^6)	5.65×10^{-6} (1.02×10^{-5})
5 Cr	28×10^6 (193×10^6)	5.6×10^{-6} (1.01×10^{-5})
SS	28×10^6 (193×10^6)	9.0×10^{-6} (1.62×10^{-5})

- Typical pressure change versus temperature change for an 8 in. CS line without leakage are offered as follows:

SERVICE	ΔP / ΔT, psi/°F	ΔP / ΔT, kPa/°C
Propane	60	745
Butane	64	794
Gasoline	98	1216
Diesel	91	1129
Water	53	657

Relief Scenarios

Inadvertent Control Valve opening

- The scenario to consider is that one inlet valve is in a fully opened position regardless of the control-valve failure position. Opening of this control valve can be caused by instrument failure or misoperation.
- The required relieving rate is the difference between the maximum expected inlet flow and the normal outlet flow, adjusted for relieving conditions and considering unit turndown.
- An important consideration is the effect of having a manual bypass on the inlet control valve(s) at least partially open.
- If, during operation, the bypass valve is opened to provide additional flow, then this total flow (control valve wide open and bypass valve normal position) shall be considered in the relieving scenario.
- If the bypass is used only during maintenance to permit the control valve to be blocked in and removed from service, then the maximum flow of either the control valve or bypass valve needs to be considered.

Relief Scenarios

<u>Inadvertent Control Valve opening</u>

- The potential for the bypass valve to be inadvertently opened while the control valve is operating should also be considered unless administrative controls are in place. If the pressure resulting from the opening of the bypass valve can exceed the corrected hydrotest pressure reliance on administrative controls as the sole means to prevent overpressure might not be appropriate.

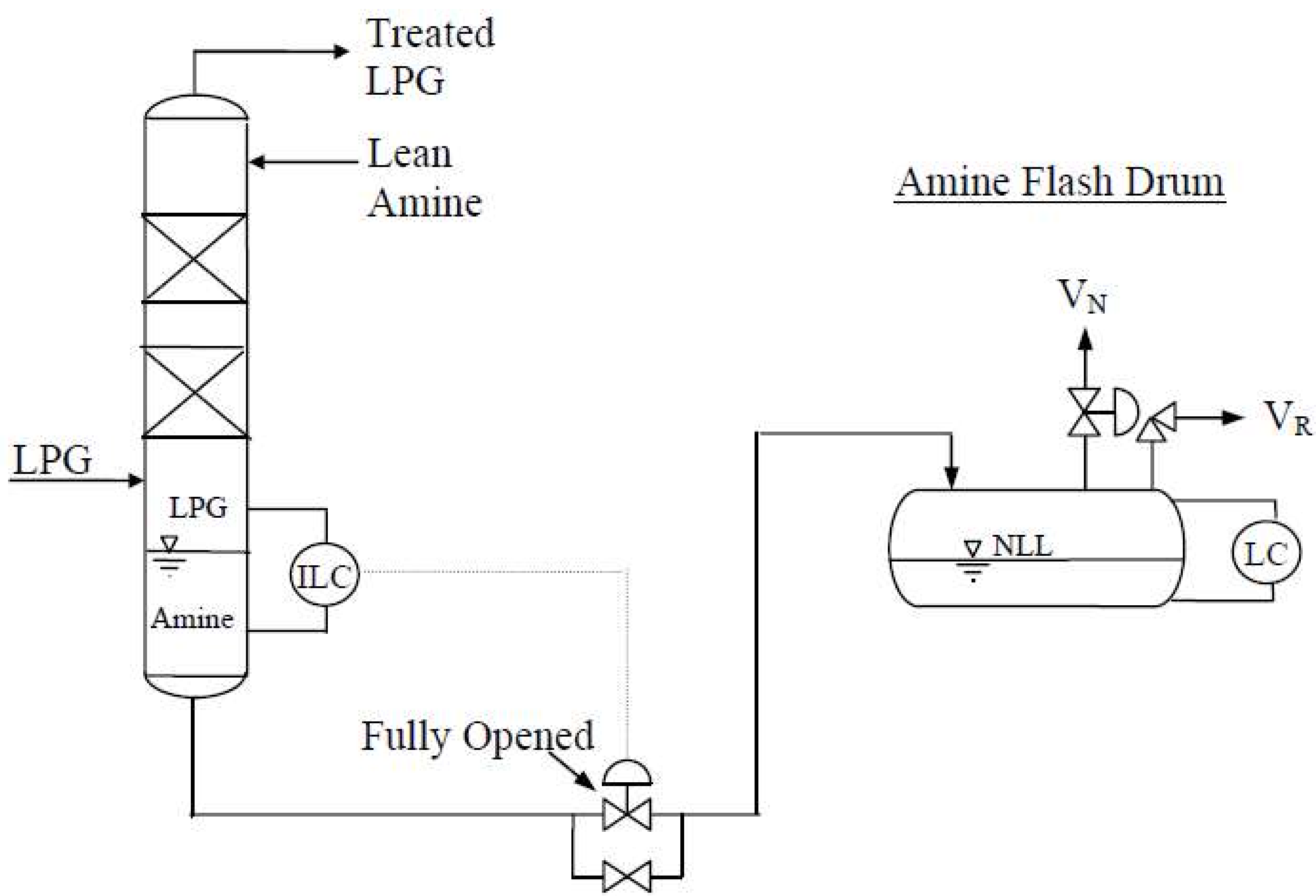
- The designer should consider that vapor flows into the low-pressure system if loss of liquid level occurs in the vessel at higher pressure.

- If the volume of the source of incoming vapors is large compared with the volume of the low-pressure system or if the source of vapor is unlimited, serious overpressure can rapidly develop. When this occurs, it can be necessary to size relief devices on the low-pressure system to handle the full vapor flow through the liquid control valve.

- Gas breakthrough across a control valve can result in slug-flow high liquid velocities. The resultant transient loads on the piping shall be taken into account, including the mechanical design and pipe supports.

Relief Scenarios

Inadvertent Control Valve Opening Flashing of Liquid Example



Relief Scenarios

<u>Inadvertent Control Valve Opening Flashing of Liquid Example</u>

Relieving load calculation procedure

(a) Calculate ΔP of the control valve at the relieving condition

(b) Breakthrough flow rate should be calculated on a liquid phase basis by using the selected CV value,

since LPG is in liquid phase at the inlet of the control valve.

(c) Calculate the flashed vapor flow rate (VF) by the flash calculation at the relieving pressure.

(d) If the vapor space is enough to accommodate the let down liquid for the operator's response time, the relieving load (VR) = VF – VN

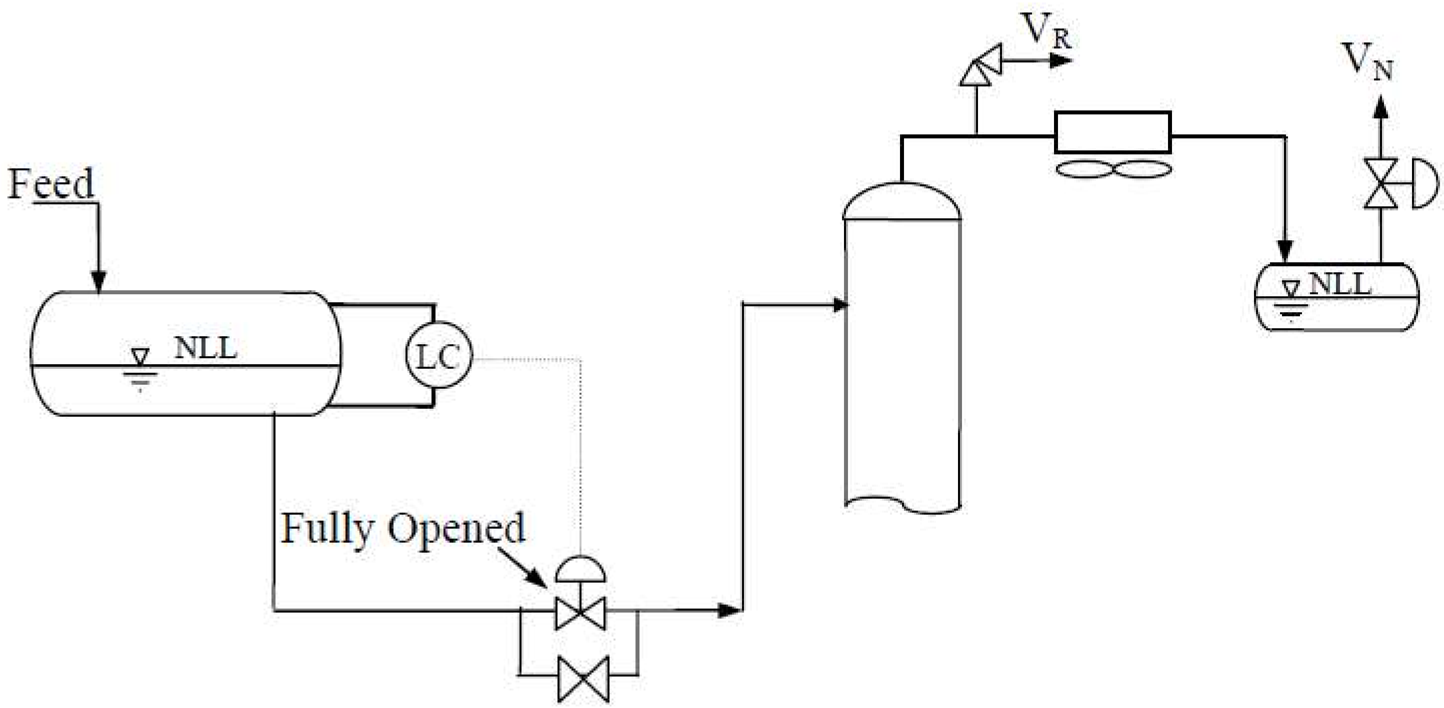
(VN = vapor flow rate at turndown operation).

(e) If the vapor space is not enough, consider the relieving of vapor-liquid mixture.

(f) In this case, pay attention to an occurrence of slug flow in two phase lines.

Relief Scenarios

Inadvertent Control Valve Opening Gas Breakthrough Example



Relieving load calculation procedure

(a) Calculate ΔP of the control valve at the relieving condition.

(b) Gas breakthrough flow rate (VB) should be calculated by using the selected CV value.

(c) Relieving load (VR) = VB - VN (VN = vapor flow rate at turndown operation).

(d) In this case, pay attention to an occurrence of slug flow in two phase lines.

Relief Scenarios

Inadvertent Control Valve Opening Flashing of Liquid Example

Relieving load calculation procedure

(a) Calculate ΔP of the control valve at the relieving condition

(b) Breakthrough flow rate should be calculated on a liquid phase basis by using the selected CV value,

since LPG is in liquid phase at the inlet of the control valve.

(c) Calculate the flashed vapor flow rate (VF) by the flash calculation at the relieving pressure.

(d) If the vapor space is enough to accommodate the let down liquid for the operator's response time, the relieving load (VR) = VF – VN

(VN = vapor flow rate at turndown operation).

(e) If the vapor space is not enough, consider the relieving of vapor-liquid mixture.

(f) In this case, pay attention to an occurrence of slug flow in two phase lines.

Relief Scenarios

Inadvertent Control Valve opening

- The following three scenarios must be analyzed for all fail open contingencies for control valves and the larger relief requirement used to evaluate the adequacy for overpressure protection:

1. The control valve fails wide open with its bypass valve partly open. This scenario is evaluated as a design contingency.

Cv for the partially open bypass valve equal to 50% of the Cv of the control valve in its normally operating position, regardless of the actual size of the bypass valve.

Credit may be taken for vapor being relieved through the normal channels.

2. The control valve fails wide open with its bypass valve also wide open (open 100%)., This scenario is evaluated as a remote contingency and considering 1.5 rule.

Credit may be taken for vapor being relieved through the normal channels.

Relief Scenarios

<u>Inadvertent Control Valve opening</u>

3. The control valve fails wide open with the bypass fully closed during startup. This scenario is evaluated as a design contingency.

In calculating the relieving rate for this case, assume that the downstream vessel is not yet operational. Therefore relief is only through the PR valve.

Relief Scenarios

<u>Control Valve Selection Guide</u>

- Key Variables: Total pressure drop, design flow, operating flow, minimum flow, pipe diameter, specific gravity.

- The usual rule of thumb is that a valve should be designed to use 10-15% of the total pressure drop or 10 psi, whichever is greater.

- In general, valve body sizes are smaller than the piping size. However, the valve body size shall not be smaller than half the adjacent pipe size or two (2) nominal pipe sizes smaller, whichever is larger.

- Avoid using the lower 10% and upper 20% of the valve stroke. The valve is much easier to control in the 10-80% stroke range.

Relief Scenarios

Selection Valve Type

- *Equal Percentage:* equal increments of valve travel produce an equal percentage in flow change. (most commonly used valve control)

  a. Used in processes where large changes in pressure drop are expected

  b. Used in processes where a small percentage of the total pressure drop is permitted by the valve

  c. Used in temperature and pressure control loops

- *Linear:* valve travel is directly proportional to the valve stoke

  a. Used in liquid level or flow loops

  b. Used in systems where the pressure drop across the valve is expected to remain fairly constant (ie. steady state systems)

- *Quick opening:* large increase in flow with a small change in valve stroke

  a. Used for frequent on-off service

  b. Used for processes where "instantly" large flow is needed (ie. safety systems or cooling water systems)

Relief Scenarios

Control Valve Sizing Formula

- The basic formulas for control valve sizing in different services that can be used for calculating control valve flowrate at the fully open condition are:

- Liquid Service

$$Q_{WO} = 0.865 C_V \sqrt{\frac{P_1 - P_2}{K_f S_g}}$$

$$W_{WO} = 27.3 C_V \sqrt{\frac{\rho_1 (P_1 - P_2)}{K_f}}$$

If no flashing occurs downstream of the control valve, K_f=1.0, otherwise:

$$K_f = 2\sqrt{1 - \frac{\left(\frac{\rho_1}{\rho_{2L}}\right)}{2 + f\left(\frac{\rho_{2L}}{\rho_{2g}} - 1\right)}}$$

f	vapor weight fraction at control valve downstream
K_f	Flash ratio

Relief Scenarios

Control Valve Sizing Formula

- Gas Service

$$W_{WO} = 65.7C_V\sqrt{\frac{M\left(P_1^2-P_2^2\right)}{T_1+273.15}} \qquad \text{if} \qquad \frac{P_2}{P_1} > 0.5$$

$$W_{WO} = 56.8P_1C_V\sqrt{\frac{M}{T_1+273.15}} \qquad \text{if} \qquad \frac{P_2}{P_1} < 0.5$$

1	Control valve upstream
2	Control valve downstream
Q	Control valve volumetric flowrate, m3/hr
W	Control valve mass flowrate, kg/hr
ρ	Density, kg/m^3
T	Temperature, °C
Cv	Control valve rated flow coefficient
M	Molecular weight
P	Pressure, *kg/cm2* (absolute)
S_g	Liquid specific gravity

Relief Scenarios

Effects of time and volume

- Since the differential pressure between high-pressure and low pressure equipment is the driving force of fluid movement, it is essential to check whether the differential pressure exists when the pressure of the low-pressure side reaches its design pressure (or relieving pressure) before beginning the relief rate calculation.

- **Liquid service.** Consider a pressure vessel operating at a high pressure where the bottom liquid is discharged into a lower pressure system under level control. If the liquid control valve fails fully open, the following procedure should be followed to find the relief requirements:

  - If V2 > V1 and the emptying time of upstream volume, θ_e, is lower than the time required for the operator to act properly (typically 10 minutes) the gas flow will be established. This emergency case is called gas breakthrough in most references. The emptying time of the upstream volume can be calculated with the following relation:

$$\theta_e = \frac{60V_1}{(CQ_{WO} - Q_{NO})}$$

Q_{NO}: Liquid Inlet to Upstream Vessel Due Turndown Conditions

Q_{WO}: Liquid Outlet from Upstream Vessel Due Control Valve Failure

Relief Scenarios

Effects of time and volume

- If V2 > V1 and θ_e > 10 minutes neither upstream equipment has been totally evacuated, nor has the downstream equipment been totally filled and liquid flow is continued after 10 minutes of the control valve full opening. It is envisaged that 10 minutes is enough time for an operator to take proper action by dosing the bypass valve as well as manual control of the system especially when the downstream vessel is equipped with a reliable control system (high alarm, high-high alarm). If you take a credit for operator action, then there is no pressure relief valve required.

- If V2 < V1 and the filling time of the downstream free volume, θ_f, is lower than the time required for the operator to take proper action, the downstream equipment will be filled with liquid and then pressurized to the relieving pressure. The following formula can be utilized for calculating the filling time of the downstream free volume: valve full opening.

$$\theta_f = \frac{60V_2}{(CQ_{WO} - Q_{NO})}$$

Q_{NO}: Liquid Outlet from Downstream Vessel Due Turndown Conditions

Q_{WO}: Liquid Inlet to Downstream Vessel Due Control Valve Failure

Relief Scenarios

Effects of time and volume

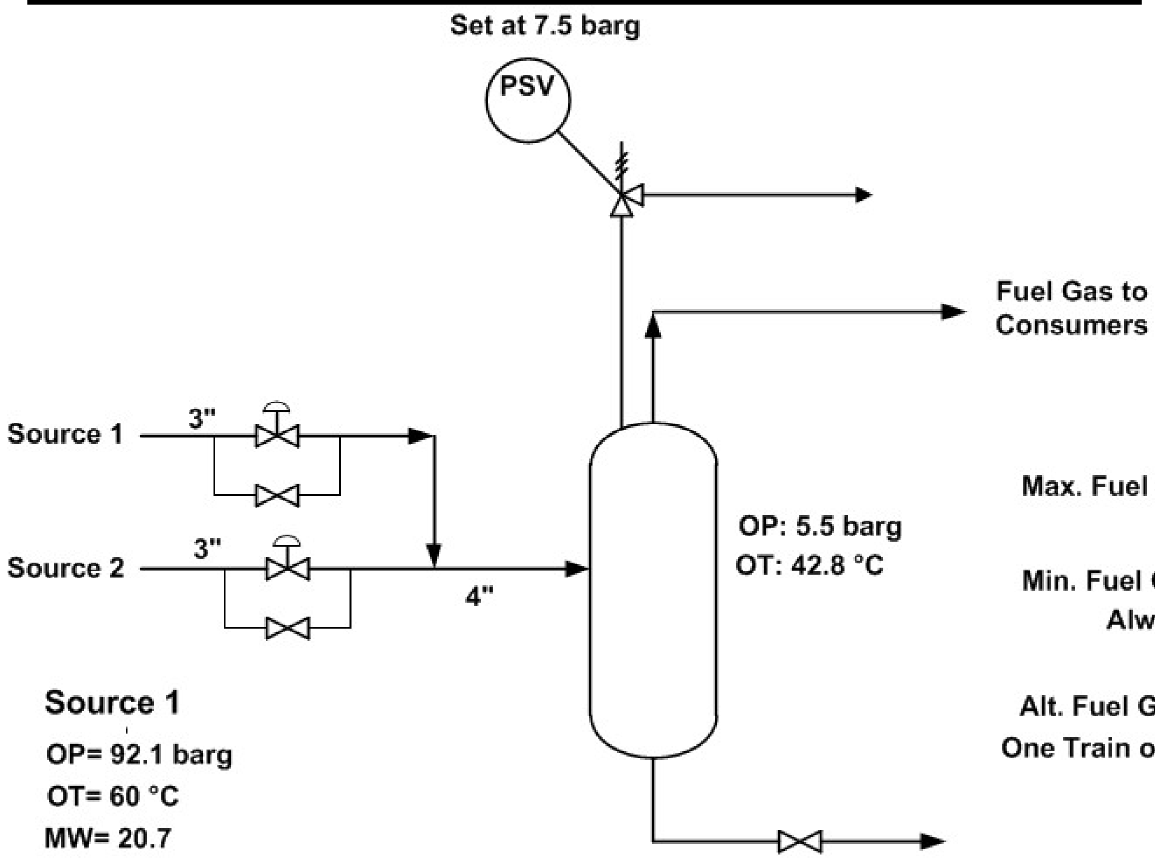
- If V2 < V1 and θ_f > 10 minutes this situation is the same as if V2 < V1 and θ_e > 10 minutes. Therefore, there is no relief requirement due to the control valve full opening.

- V1 is the liquid volume of the upstream vessel below the low liquid level (LLL).

- V2 is the free volume of the downstream vessel above high liquid level (HLL).

- **Gas Service.** For control valves installed on gas lines, especially with high pressure drop, it is worthwhile to calculate the fully open flowrate.

Inadvertent Control Valve Opening-Example



Max. Fuel Gas Consumption = 7300 Nm3/h

Min. Fuel Gas Consumption = 170 Nm3/h
Always in Service (Start Up)

Alt. Fuel Gas Consumption = 3500 Nm3/h
One Train of Process in Service (Turndown)

Source 1

OP= 92.1 barg
OT= 60 °C
MW= 20.7
ρ = 4.8 kg/m3

Source 2

OP= 28.9 barg
OT= 57.6 °C
MW= 16.9
ρ = 19 kg/m3

Relief Scenarios

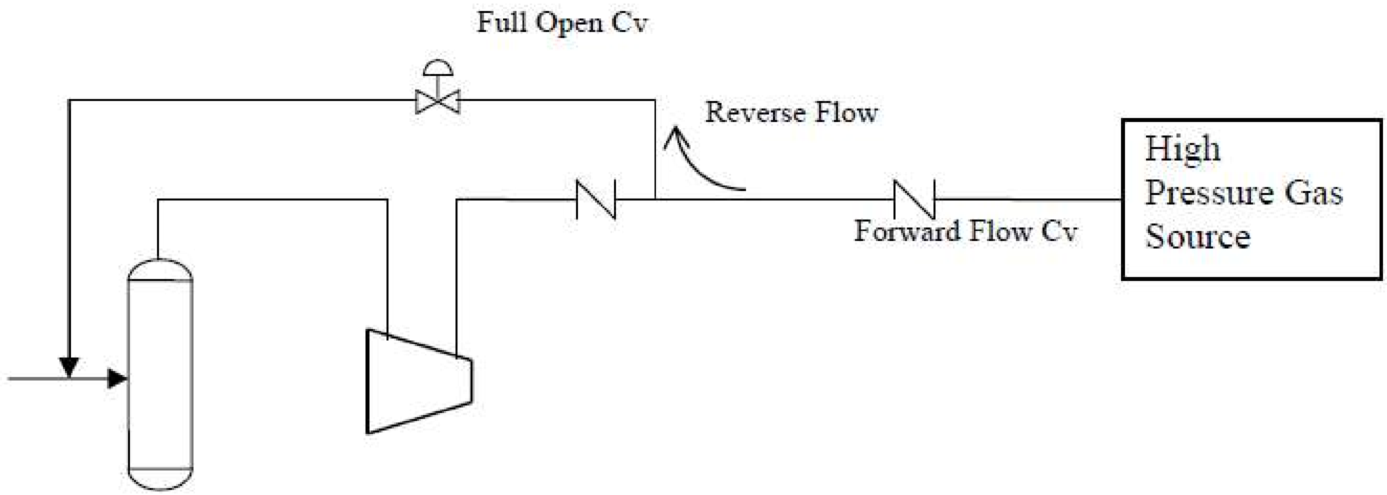
Check Valve Malfunction

- A single check valve is not always an effective means for preventing overpressure by reverse flow from a high-pressure source.
- For example, if a fluid is pumped into a system that contains vapor at significantly higher pressure than the design rating of the equipment upstream of the pump, loss of pumped flow with leakage or latent failure of a check valve in the discharge line results in a reversal of the liquid's flow.
- When sizing a pressure-relief device to prevent exceeding the allowable accumulation of the protected equipment for the latent check-valve failure, the reverse flow rate through a single check valve may be determined using the normal flow characteristics (i.e., forward-flow Cv) of the check valve.
- Experience shown that when inspected and maintained to ensure reliability and capability to limit reverse flow, two back-flow-prevention devices in series are sufficient to eliminate significant reverse flow.

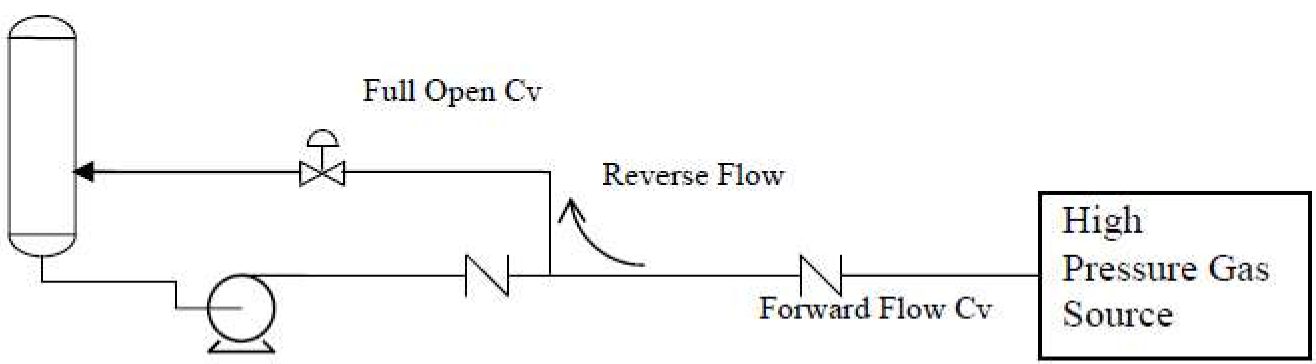
Relief Scenarios

<u>Check Valve Malfunction</u>

- Compressor Circuit with Anti-Surge Bypass



- Pumped Circuit with Minimum Flow Bypass



Check Valve Malfunction

SCENARIO NO.	NUMBER OF CHECK VALVES IN SERIES	POTENTIAL OVERPRESSURE SCENARIO	TYPE OF CONTINGENCY
1	1	**Partial failure of check valve.** Assume failed check valve behaves as a restriction orifice with a diameter equal to 1/3 the nominal diameter of the check valve. Use this basis for reverse flow of liquid, vapor and liquid followed by vapor.	Design
2	1	**Total failure of check valve.** Calculate reverse flow rate (liquid and/or vapor) as if the check valve were not there.	Remote
3	2 or more	**Partial failure of one check valve.** Failed check valve behaves as a restriction orifice with a diameter equal to 1/3 the nominal diameter of the check valve. Each of the remaining check valves in series is assumed to behave as a restriction orifice with a diameter equal to 1/10 the nominal diameter of the check valve.	Design
4	2 or more	**Total failure of one check valve.** Failed check valve is ignored. If only two check valves in series are installed, assume the second check valve fails partially open and calculate back flow per Scenario 1. If more than two check valves in series are installed, assume that each of the remaining check valves behaves as a restriction orifice with a diameter equal to 1/10 of the nominal diameter of the check valve.	Remote
5	2 or more	**Two or more check valves in series fail fully open.** This contingency need not be considered.	Not credible.

Relief Scenarios

Equipment Failure : Compressors

- PR valves are required for any compressor where the maximum pressure which can be generated during surge or restricted discharge conditions exceeds the design pressure of the discharge piping, downstream equipment compressor seals, or compressor casing.

Centrifugal compressors

- If the design pressure for the compressor discharge system is higher than the pressure of surge point at maximum speed, overpressure does not occur. If the design pressure is lower than that, overpressure protection should be considered.

- For centrifugal compressors, it is usually economical to set the design pressure lower than the maximum possible pressure that the compressor can develop, and to provide appropriate PR valve protection on the discharge.

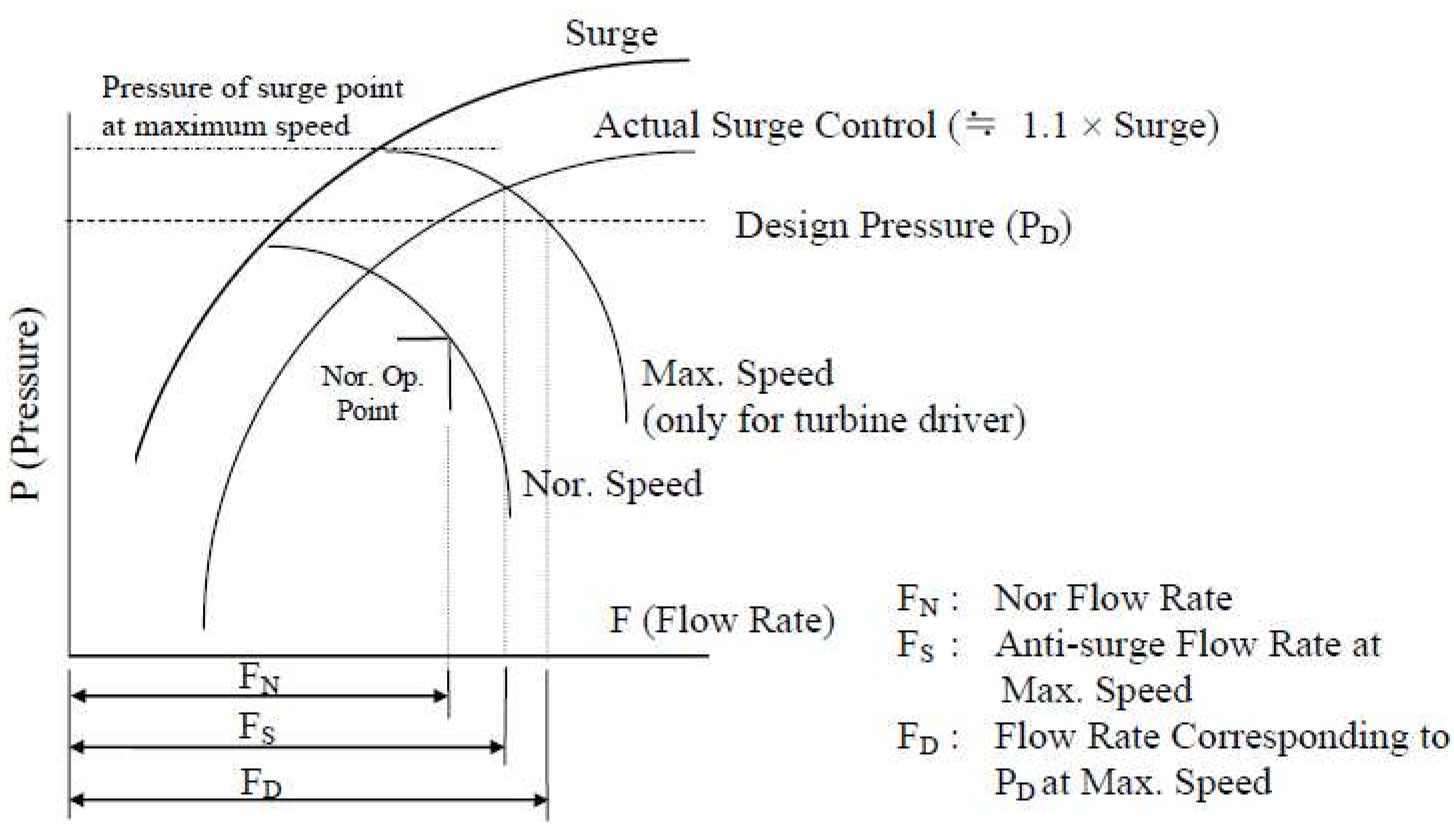
- Pressure relief valves for centrifugal compressors should be set higher than the normal operating pressure by 25 psi (170 kPa) or 10% of operating pressure, whichever is greater.

Relief Scenarios

Equipment Failure : Compressors

Centrifugal compressors

- The relieving load should be the flow rate (FD) at the head equivalent to the design pressure (PD) at maximum speed or should be the anti-surge flow (FS) at maximum speed, whichever is greater. That value is usually obtained from such compressor performance curve as shown below:



Equipment Failure : Compressors

Centrifugal compressors

Calculation procedure is as follows.

Step 1: Assume the discharge pressure at 1.1 times of the design pressure. Based on the calculated discharge pressure, estimate the suction pressure of the compressor assuming the compressor is running on the surge control line. In case of variable speed compressor, whole range of the operating speed to be investigated.

Step 2: Calculate weight flow through the compressor and required power of the compressor based on the suction and discharge pressures calculated in Step 1.

Step 3: Check the calculated weight flow if it is available from upstream side of the compressor.

Step 4: Check the required power if it is available from the driver.

Relief Scenarios

Equipment Failure : Compressors

- Relieving load is the maximum weight flow rate calculated in Step 2 considering the limitation of available flow rate and power checked in Step 3 and 4.

- In case the calculated suction pressure is equal to or higher than the design pressure of the suction side in Step 1, re-calculate the suction pressure assuming that the compressor is still running on the surge control line while the 1.1 times of the design pressure is replaced with the design pressure of discharge side.

Relief Scenarios

<u>Equipment Failure : Compressors</u>

- For positive displacement compressors, discharge PR valves are nearly always required.
- Interstage PR valves should be set at least as high as the compressor settling-out pressure, to avoid valve lifting during compressor shutdowns.
- Where interstage PR valves are required, PR valve capacity should be equal to the compressor capacity at the emergency conditions.

Relief Scenarios

Equipment Failure : Pumps

- A PR valve is required for a pump when the shutoff pressure of the pump is greater than the design pressure of the pump casing, the discharge piping, or any downstream equipment that may be blocked-in against the pump.
- Positive displacement pumps normally require a PR valve for overpressure protection since the pump shutoff pressure can not generally be defined.
- The relief valve setting shall be at least 10 % or 175 kPa (25 psi) over the rated discharge pressure, whichever is greater.
- In most cases centrifugal pumps do not require a PR valve for overpressure protection since the pump shutoff pressure can be defined and the pump and downstream equipment is generally designed for this pressure.
- The capacity of a pump discharge PR valve should equal the capacity of the pump at the pressure conditions existing while the PR valve is relieving. To reduce the size of a PR valve installed at the discharge of a centrifugal pump with a known pump curve, advantage can be taken for the reduction in pump capacity as it backs up on its performance curve.

Relief Scenarios

<u>Utility Failure</u>

- The consequences that can develop from the loss of any utility service, whether plant-wide or local, shall be carefully evaluated.

- In some cases, a partial utility failure can cause a higher relief load than a total failure because some equipment that contributes to the relief load would remain in operation.

- In situations in which the equipment fails but operates in parallel with equipment that has a different energy source, operating credit may be taken for the unaffected and functioning equipment to the extent that service is maintained.

<u>Electrical Failure</u>

- The failure of electrical or mechanical equipment that provides cooling or condensation in process streams can cause overpressure in process vessels.

Relief Scenarios

Utility Failure

Table 1 — Possible utility failures and equipment affected

Utility failure	Equipment affected
Electric	Pumps for circulating cooling water/medium, boiler feed, quench, or reflux
	Fans for air-cooled exchangers, cooling towers, or combustion air
	Compressors for process vapour, instrument air, vacuum or refrigeration
	Instrumentation
	Motor-operated valves
Cooling water/medium	Condensers for process or utility service
	Coolers for process fluids, lubricating oil or seal oil
	Jackets on rotating or reciprocating equipment
Instrument air	Transmitters and controllers
	Process regulating valves
	Alarm and shutdown systems
Steam	Turbine drivers for pumps, compressors, blowers, combustion air fans, or electric generators
	Reciprocating pumps
	Equipment that uses direct steam injection
	Eductors
Steam/heating medium	Heat exchangers (e.g. reboilers)
Fuel (oil, gas, etc.)	Boilers
	Reheaters (reboilers)
	Engine drivers for pumps or electric generators
	Compressors
	Gas turbines
Inert gas	Seals
	Catalytic reactors
	Purge for instruments and equipment

Relief Scenarios

Utility Failure

Electrical Failure

- The following general power failures on a plant-wide scale must be considered :
  - Failure of purchased power supply to the plant or refinery.
  - Failure of internally generated power supply to the plant or refinery.

Cooling Water

- The following design contingencies should be considered as the basis for evaluating overpressure that can result from cooling water failures:
  - Individual failure of water supply to any one cooler or condenser.
  - Total failure of any one lateral supplying a process unit which can be valved off from the offsite main.
  - Failure of any section of the offsite cooling water main.
  - Loss of all the cooling water pumps that would result from any design contingency in the utility systems supplying or controlling the pump drivers.
  - Loss of all the fans on a cooling tower that would result from any design contingency in the utility systems supplying or controlling the fan drivers.

Relief Scenarios

Utility Failure

Steam

- The following design contingencies should be considered as the basis for evaluating overpressure that can result from steam failures:

  - Individual steam failure to any one item of consuming equipment (e.g., turbine drivers, reboilers, strippers, ejectors, etc.).
  - Total failure of any one lateral supplying a process unit which can be valved off from the offsite main.
  - Failure of any section of the offsite steam main.
  - Loss of any one steam generator.
  - Loss of purchased steam in any one supply line.

Instrument Air

- The following design contingencies should be considered as the basis for evaluating overpressure that can result from an instrument air failure:
  - Loss of instrument air supply to any one individual control instrument or control valve. It is assumed that the correct air failure response occurs.
  - Loss of instrument air from a valved sub-header as well as total failure of any one valved lateral supplying a process unit from the offsite main
  - Failure of any section of the offsite instrument air main.
  - Loss of flow through any one set of instrument air dryers.

Relief Scenarios

Heat Exchanger Tube Rupture

- Heat exchangers and similar vessels should be protected with a relieving device of sufficient capacity to avoid overpressure in case of an internal failure.

- In a shell and tube exchanger, the tubes are subject to failure from a number of causes, such as thermal shock, vibration or corrosion.

- Loss of containment of the low-pressure side to atmosphere is unlikely to result from a tube rupture where the pressure in the low-pressure side (including upstream and downstream systems) during the tube rupture does not exceed the corrected hydrotest pressure.

- The use of maximum possible system pressure instead of design pressure may be considered as the pressure of the high-pressure side on a case-by-case basis where there is a substantial difference in the design and operating pressures for the high-pressure side of the exchanger.

- In practice, an internal failure can vary from a pinhole leak to a complete tube rupture. A simplifying assumption of two orifices may be used.

Relief Scenarios

Heat Exchanger Tube Rupture

- The tube rupture scenario can be mitigated by increasing the design pressure of the low-pressure exchanger side (including upstream and downstream systems), and/or assuring that an open flow path can pass the tube rupture flow without exceeding the stipulated pressure, and/or providing pressure relief.

- If the low-pressure side is in the vapor phase, full credit can be taken for the vapor-handling capacity of the outlet and inlet lines, provided that the inlet lines do not contain check valve that could prevent backflow.

- If the low-pressure side is liquid-full, the effective relieving capacity for which the piping system may be credited shall be based on the volumetric flow rate of the low-pressure side liquid that existed prior to the tube rupture.

- In calculating relieving-capacity credit for the piping system, one should consider the valves used for control purposes to be in a position equivalent to the minimum normal flow requirements of the specific process.

Relief Scenarios

<u>Heat Exchanger Tube Rupture</u>

- It may be necessary to locate the relieving device to be located either directly on the exchanger or immediately adjacent on the connected piping. This is especially important if the low-pressure side of the exchanger is liquid-full.

- Double pipe exchangers that use schedule pipe for tube are no more likely to rupture the inner pipe than any other pipe in the system. Therefore, it is not necessary to consider a complete tube rupture as requiring a provision for pressure relief.

- However, all exchanger types should be evaluated considering leakage through a 0.25 in. (6 mm) hole due to corrosion.

Relief Scenarios

Heat Exchanger Tube Rupture – Flowrate determination

- The following equations can be used to (preliminary) calculate the flow from the high to the low pressure side :

K_G : 2.93 (Metric), 385 (USC)

K_L : 1.77 (Metric), 2645 (USC)

Vapors $$W_G = K_G\, d^2\, P_1 \sqrt{\frac{M}{zT}}$$

Liquids $$W_L = K_L\, d^2 \sqrt{\rho_L (P_1 - P_2)}$$

W_G	:	gas flow through tube break, kg/hr or lb/hr
W_L	:	liquid flow through tube break, kg/hr or lb/hr
d	:	tube inside diameter, mm or inch
P_1(*)	:	HP side normal pressure, bara or psia (alternatively the HP side design pressure may be considered for P_1, as required by some clients).
P_2(*)	:	relieving pressure of the low pressure side, usually 1.1 x gauge set pressure, bara or psia
M	:	molecular weight
z	:	compressibility factor
T(*)	:	vapor temperature, °K or °R
ρ_L(*)	:	liquid density, kg/m3 or 1b/ft3

Heat Exchanger Tube Rupture – Flowrate determination

- The liquid equation will be used in the following cases :

  – The liquid flow stays liquid as it flows through the tube break :

$P_2 > P_{VL}$

P_{VL} vapor pressure of the liquid (high pressure fluid)

– The liquid flashes as it flows through the tube break

$P_2 < P_{VL}$

Then

a) if the upstream pressure P_1 is significantly above the liquid vapor pressure ($P1 > P_{VL}$), use P_{VL} instead of P_2 and calculate W_L based on $P_1 - P_{VL}$.

Relief Scenarios

Heat Exchanger Tube Rupture – Flowrate determination

b) If the liquid is at boiling conditions on the high pressure side (or close to these conditions), the liquid flow WL can be calculated based on :

The pressure differential P_1 - P_2 with :

$\mathbf{P_1 = P_{VL}}$

$\mathbf{P_2}$: higher pressure of :

− critical flow downstream pressure (Pc). Experience has shown that P_C should be calculated as $P_C = 0.55\ P_1$, with Pc and P_1 in absolute pressure units here,

− Relieving pressure P_2.

−The mixed phase density (at relieving or critical flow conditions) instead of the liquid density

Relief Scenarios

Heat Exchanger Tube Rupture – Flowrate determination

- Review of the temperature condition

(*) The high pressure side temperature is used to determine : T, ρ_L, P_{VL}

A reasonable value is to consider the average operating temperature of this high pressure side. Nevertheless if the range of temperature is very large, flow through tube break should be calculated both at inlet and at outlet conditions.

- Review of the calculated flowrate through tube break

− If the calculated discharge exceeds the normal total flow in the high pressure side, the latter flow should be used, except when sufficient volume on the HP side may supply the calculated flowrate above the normal flowrate.

Relief Scenarios

Heat Exchanger Tube Rupture – Flowrate determination

- For more rigorous calculations :

  For liquids that do not flash when they pass through the opening, the discharge rate through the failure should be computed using incompressible-flow equations. (See Crane Technical Paper No.410 (1998) Sec. 3-14)

  For vapor passing through the ruptured tube opening, compressible-flow theories apply. (See Crane Technical Paper No.410 (1998) Sec. 3-26)

  A two-phase flow method should be used in determining the flow rate through the failure for flashing liquids or two-phase fluids. (HEM from API-520)

- Two approaches are available for determining the required use of the relief device: (a) steady-state and (b) dynamic analysis.

Relief Scenarios

Column Relief Scenarios

- The required relieving rate is determined by a heat and material balance on the system at the relieving pressure.
- The enormous differences between distillation systems, such as column controls, types of condensers and reboilers, heating and cooling media, pumparounds and side reboilers, etc., make it impossible to create a universal method for all distillation columns.
- Common column relief scenarios :
  - Power Failure
  - Loss of Reflux
  - Loss of Feed
  - Loss of Condenser
  - Abnormal Heat Input by Reboiler
  - Vapor Blocked Outlet

Relief Scenarios

Column Relief Scenarios

- Power Failure

- The only contribution is given by the Reboiler for its residual heat. The relief load is the vapor according to heat exchanger design at relieving pressure and dew point.

- In the event of power failure, a fired heater may still contribute to the relief load because of the heat retained in the fire bricks.

- Residual duty may vary between 10% of normal duty for a large, forced-draught heater to 70% of normal duty for small, natural-draught heater.

- During FEED, a residual heat duty of 30% should be assumed.

- During EPC, once the type of heater and preliminary dimensions have been established, a more detailed calculation should be undertaken to determine the reduction in residual heater duty with time and to confirm that sufficient vapor can be generated to overpressure the tower.

Relief Load = Heater Residual Duty / Mass Heat of Vap.

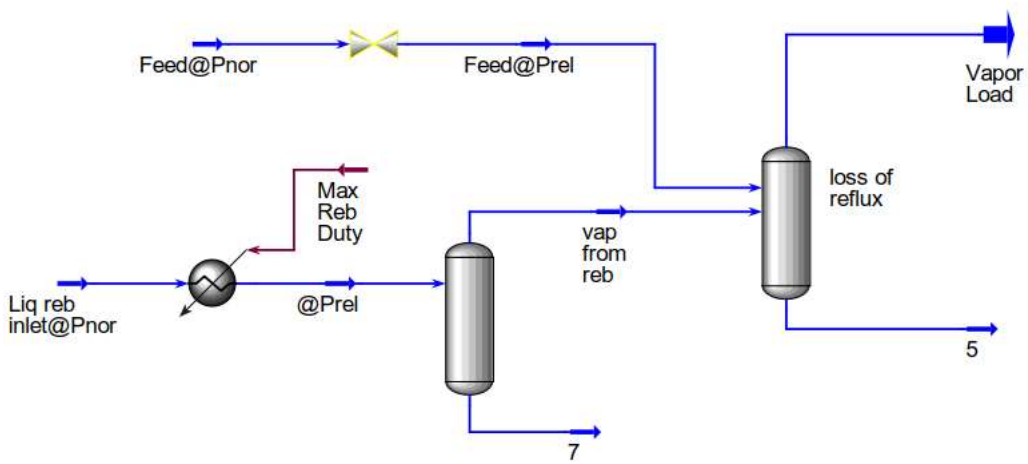
Mass Heat of Vap. To be calculated for both tray no. 1 and n

Column Relief Scenarios

- Loss of Reflux

In order to maintain product separation the duty of the reboiler would be driven towards a maximum (Qreb_max).

Maximum Rebolier Duty= Uc x A x LMTD

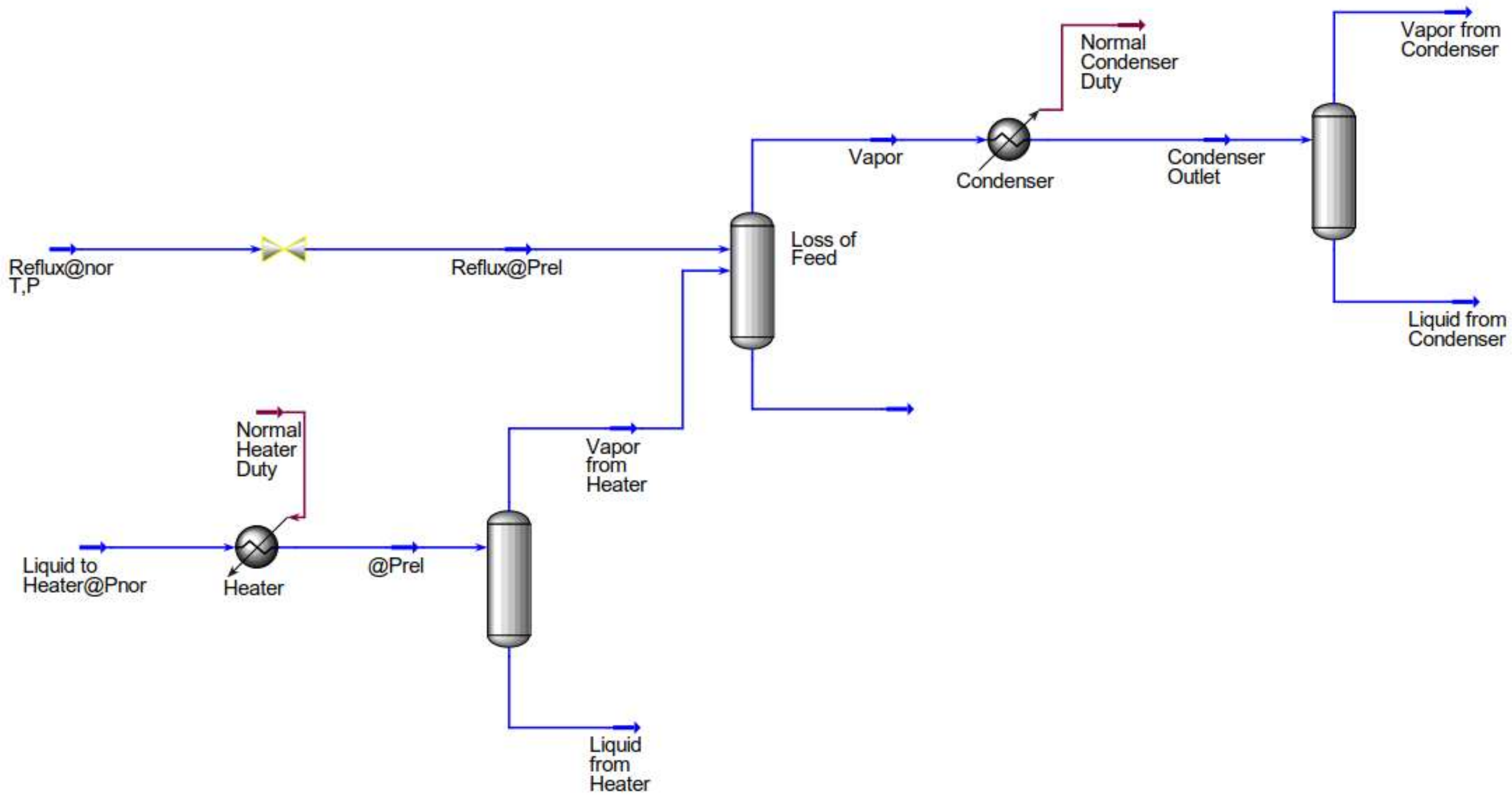


For Fired Heater reboiler, normal duty to be considered instead of maximum duty.

Relief Scenarios

Column Relief Scenarios

- Loss of Feed

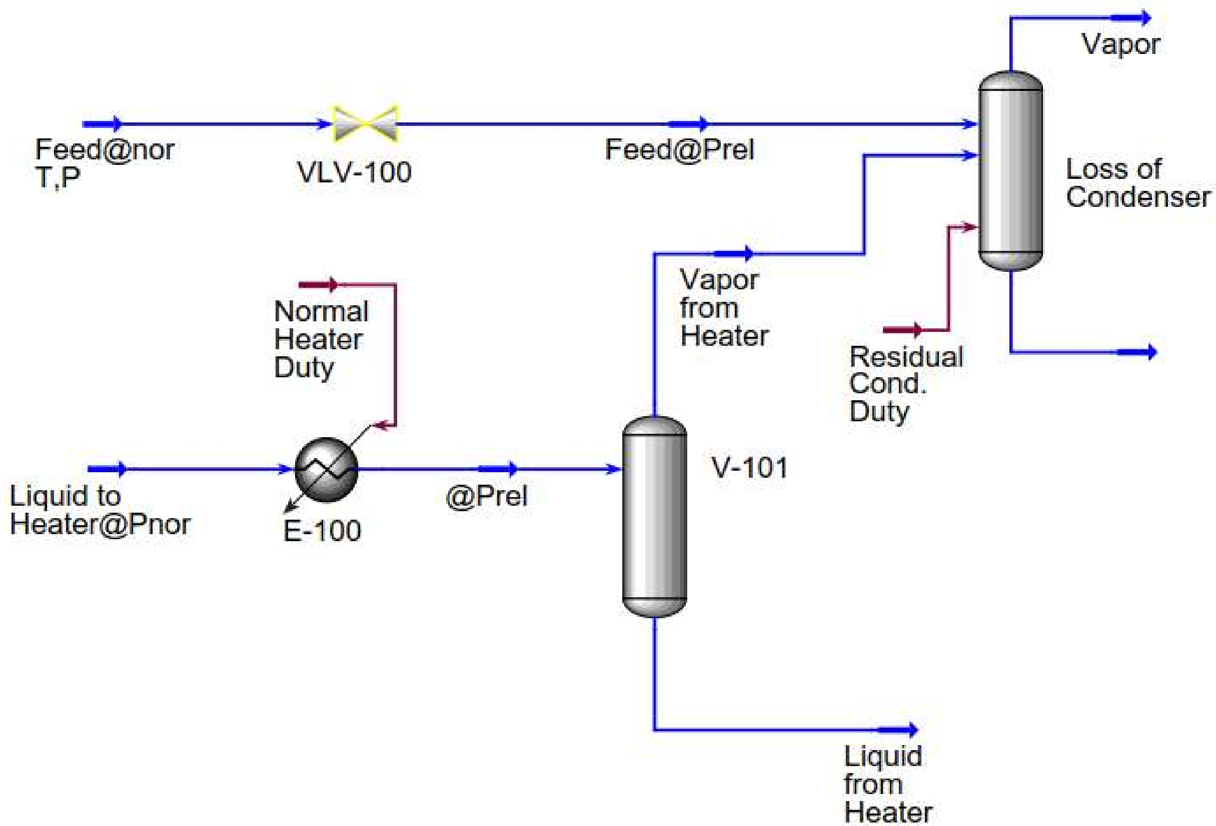


Required Relief Load = Relief Load @ conditions of stream 'Vapor' equivalent to volumetric flow of stream 'Vapor from Condenser' - Normal Vapor from Condenser

Relief Scenarios

Column Relief Scenarios

- Loss Condenser



Required Relief Load = Vapor – Normal Vapor from Condenser

Relief Scenarios

Column Relief Scenarios

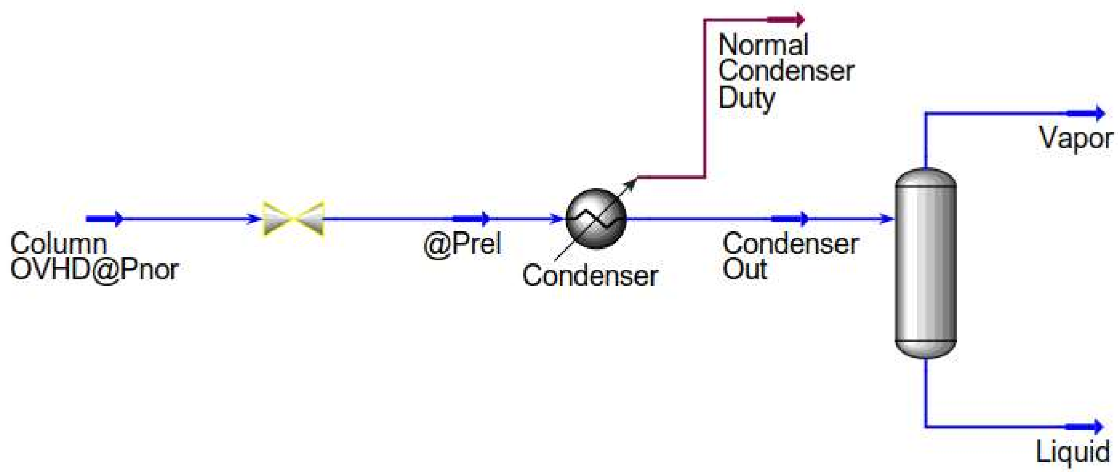
- Abnormal Heat Input
- Reboilers and other process heating equipment are designed with a specified heat input. When they are new or recently cleaned, additional heat input above the normal design can occur.
- The required relieving rate is the maximum rate of vapor generation at relieving conditions (including any noncondensables produced from overheating) less the rate of normal condensation or vapor outflow.
- Burners are capable of providing 125% of heater design heat input.
- If a mechanical stop is installed and is adequately documented, use of the limited capacity can be appropriate.
- In shell-and-tube heat exchange equipment, heat input should be calculated on the basis of clean, rather than fouled, conditions.

Relief Load = Reb_nor_vap x (Qreb_max / Qreb_nor – 1)

Relief Scenarios

Column Relief Scenarios

- Vapor Blocked Outlet



Relief Load @ conditions of stream @Prel equivalent to volumetric flow of stream 'Vapor'

Pressure Relief Devices

These devices include spring-loaded and pilot-operated Pressure Relief Valves (PRVs), rupture disk devices, and other pressure relief devices.

- *Spring-Loaded PRVs*

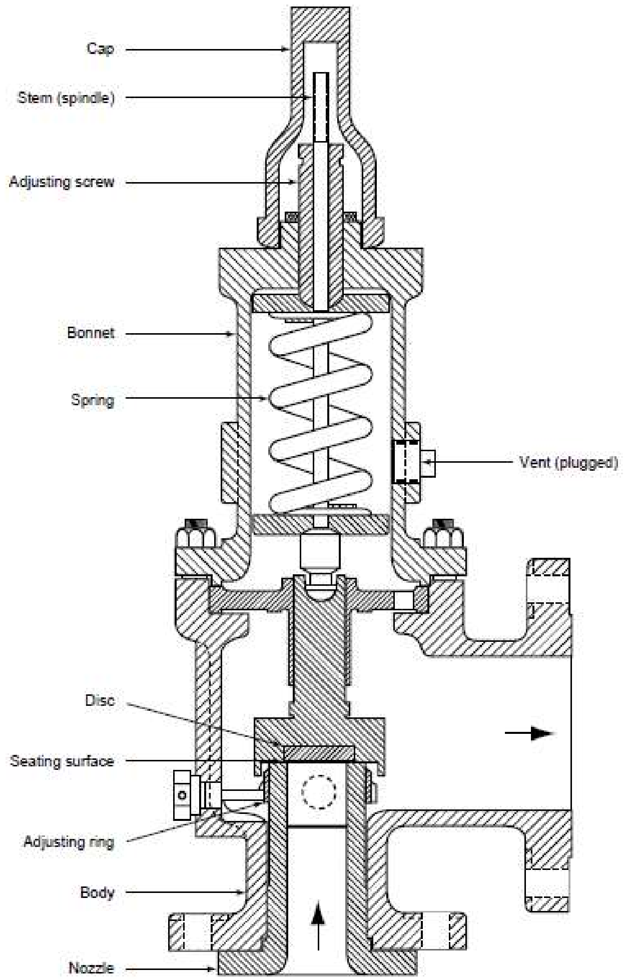


Figure 2—Conventional Pressure Relief Valve with a Single Adjusting Ring for Blowdown Control

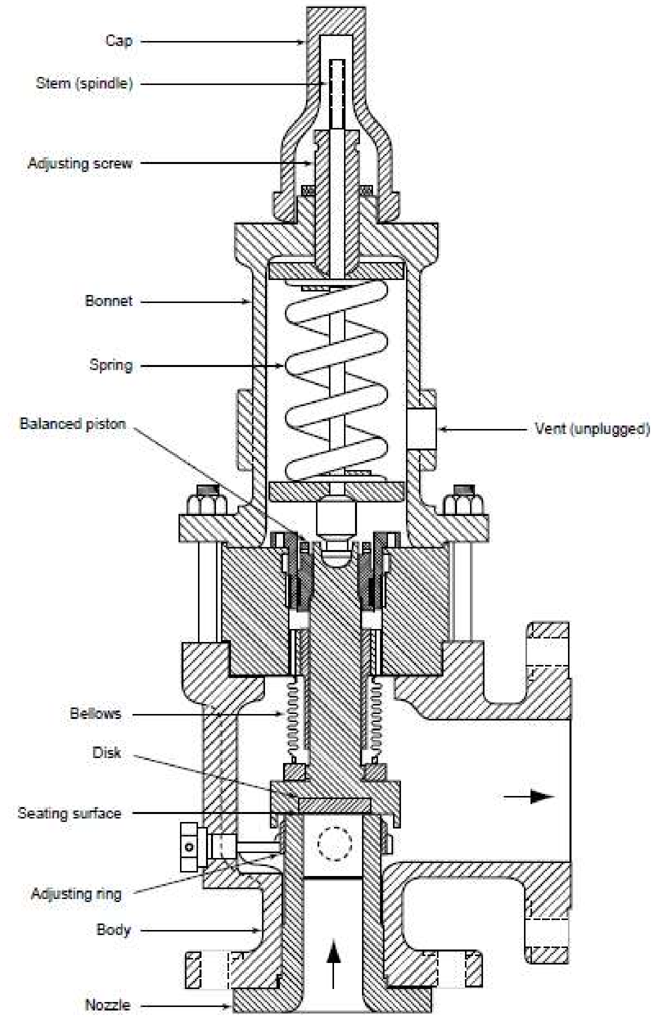


Figure 4—Balanced-Bellows Pressure Relief Valve with an Auxiliary Balanced Piston

Pressure Relief Devices

Conventional PRVs

- A conventional PRV is a self-actuated spring-loaded PRV which is designed to open at a predetermined pressure and protect a vessel or system from excess pressure by removing or relieving fluid from that vessel or system.
- Under normal system operating conditions, the pressure at the inlet is below the set pressure and the disc is seated on the nozzle preventing flow through the nozzle.
- The operation of a conventional spring-loaded PRV is based on a force balance.
- The spring load is preset to equal the force exerted on the closed disc by the inlet fluid when the system pressure is at the set pressure of the valve.
- In vapor or gas service, the valve may “simmer” before it will “pop.”

Conventional PRVs – Vapor Service

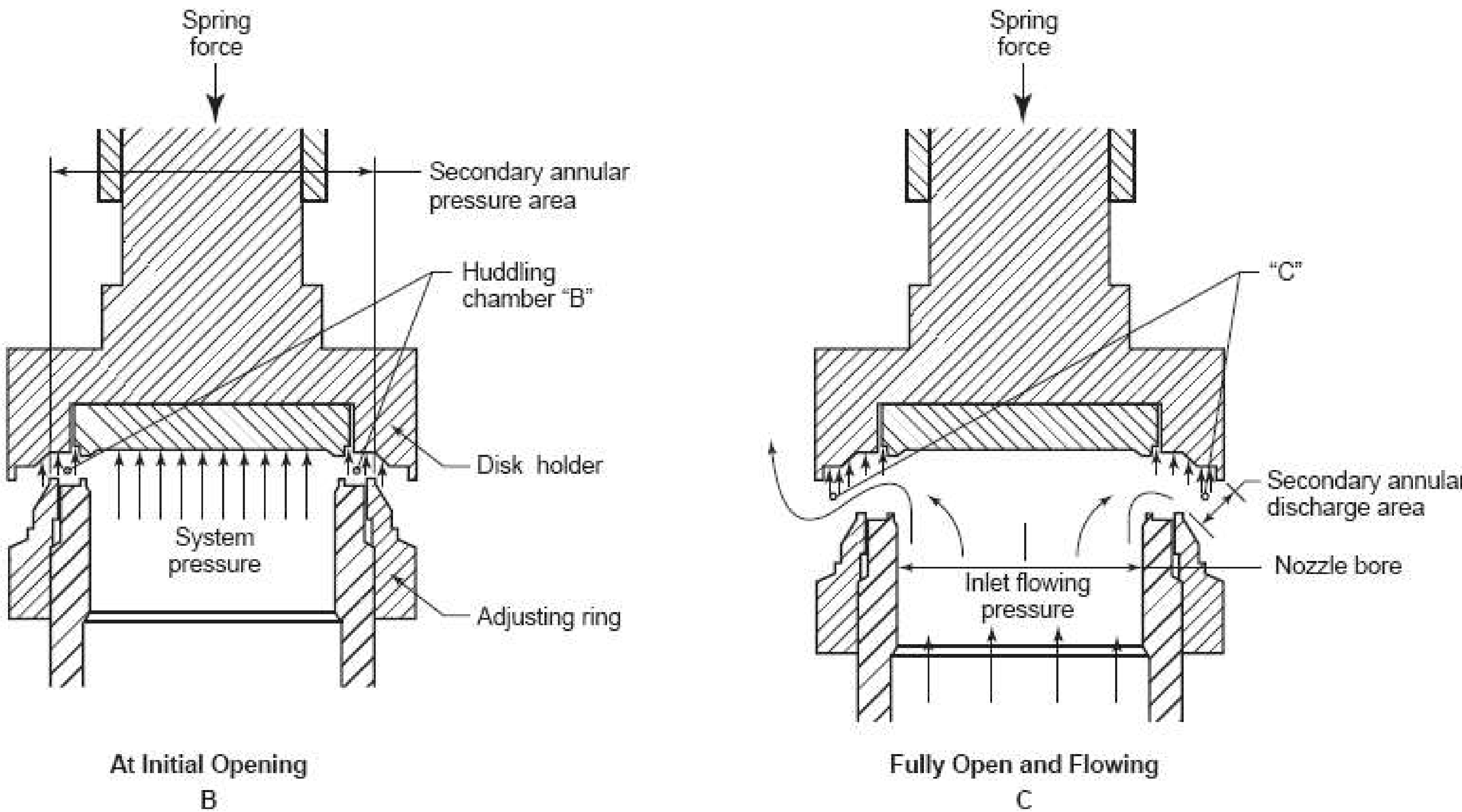
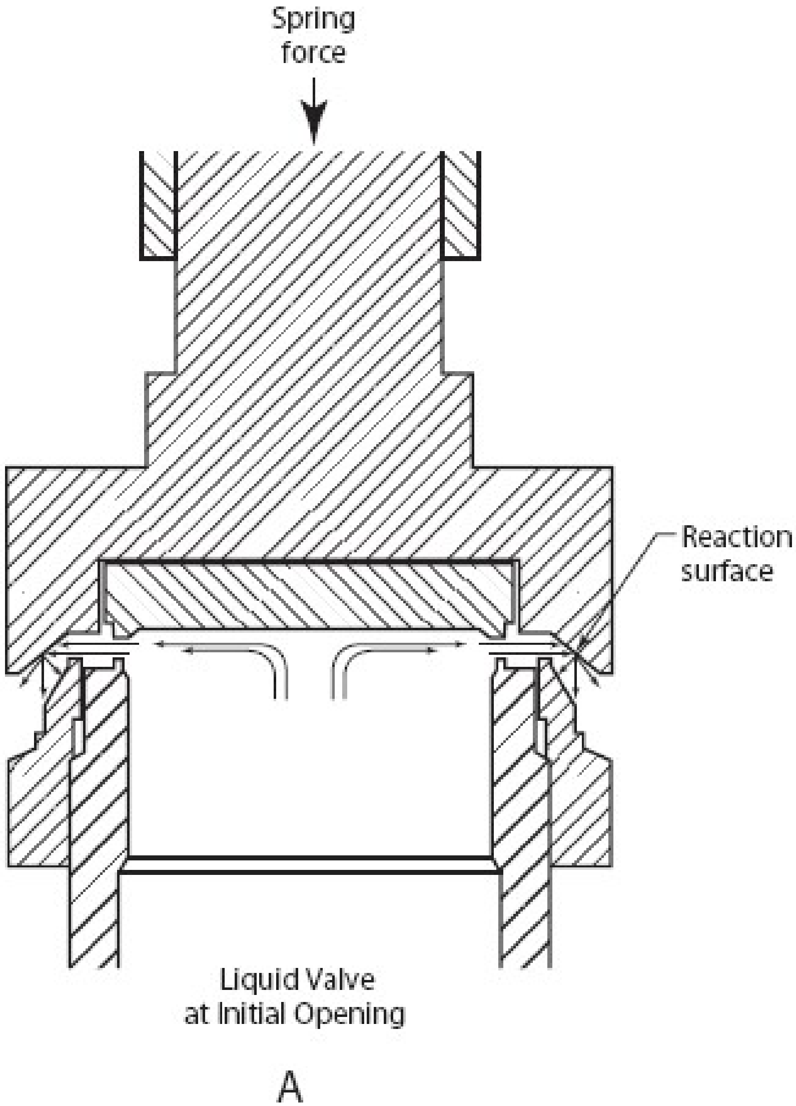
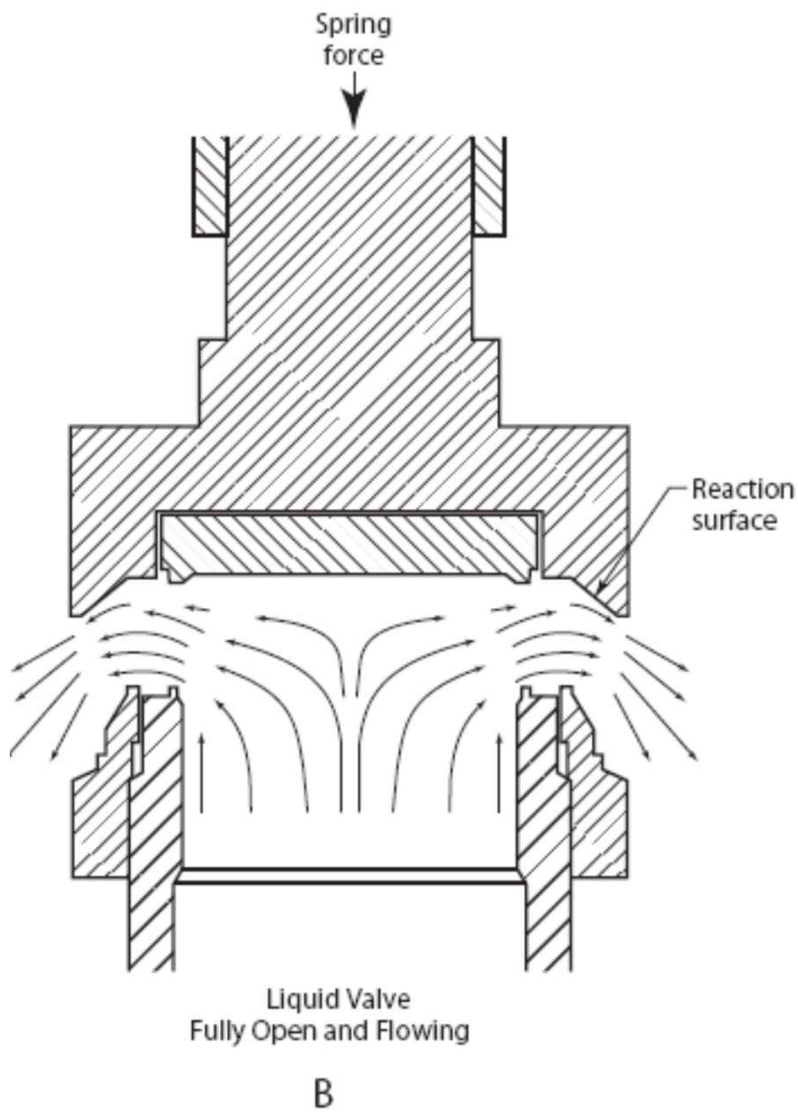


Figure 5—PRV Operation—Vapor/Gas Service

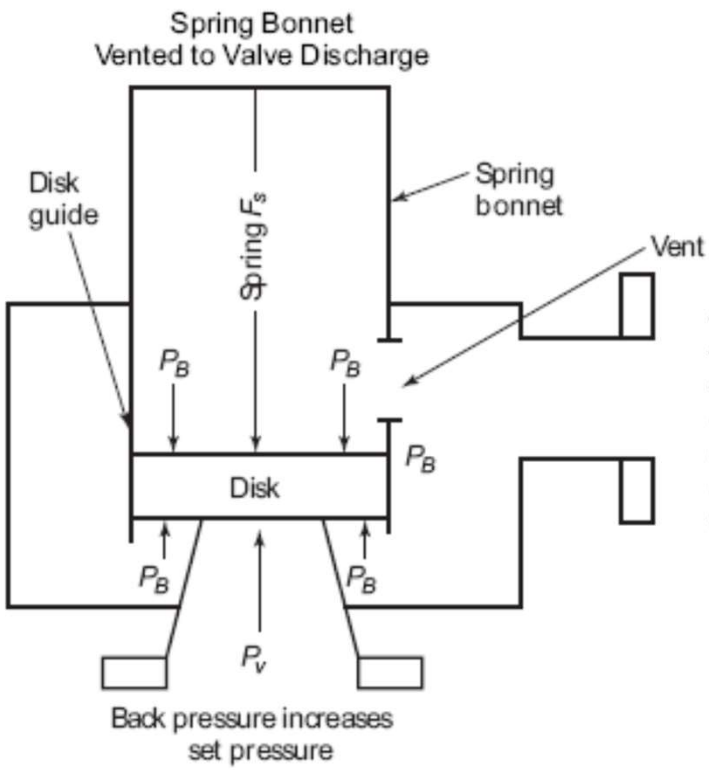
Pressure Relief Devices

Conventional PRVs – Liquid Service





Conventional PRVs – Effects of Backpressure

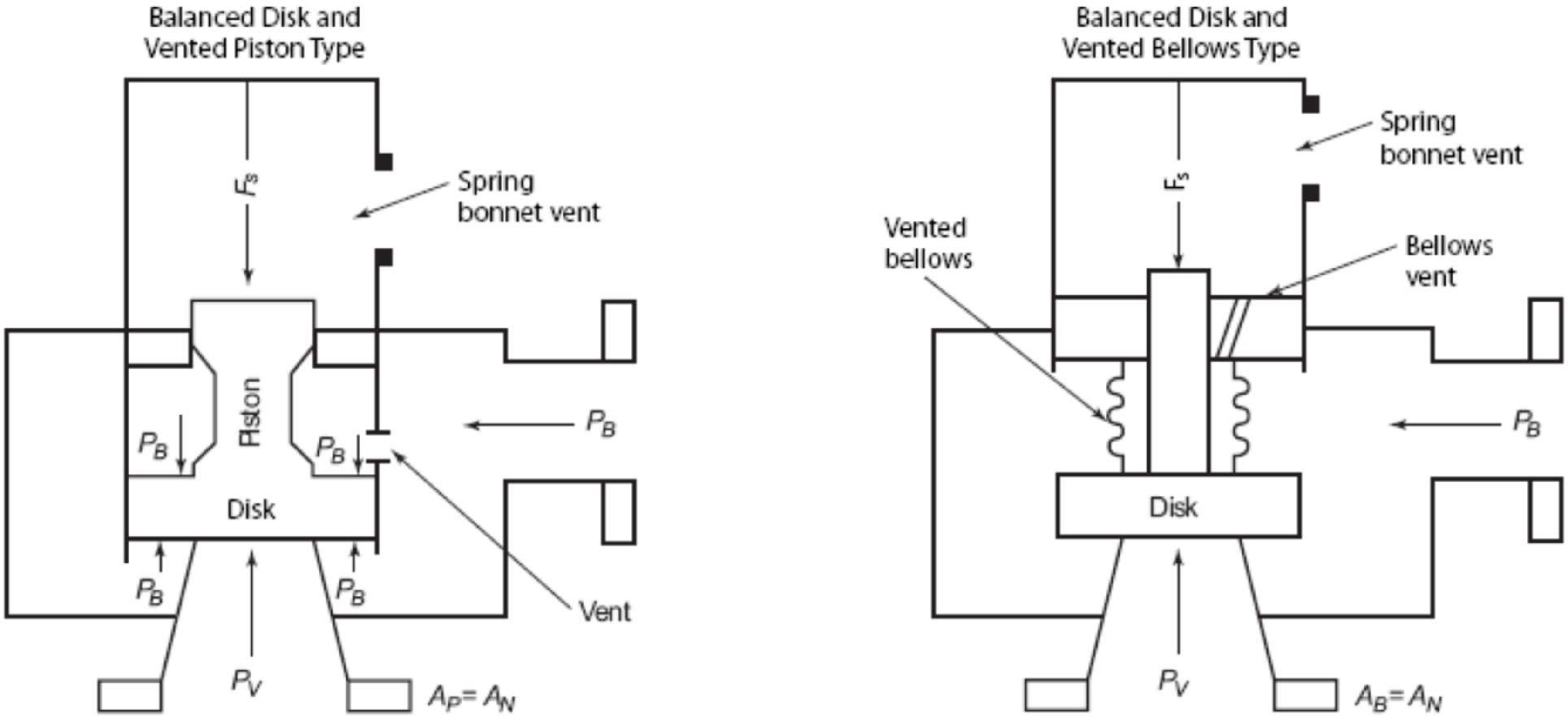


$P_V A_N = F_S + (P_B A_N)$

$A_D > AN$
A_D = disk area,
A_N = nozzle seat area,
F_S = spring force,
P_V = vessel pressure in pounds per square inch gauge,
P_B = superimposed back pressure, in pounds per square inch gauge.

Figure 8—Typical Effects of Superimposed Backpressure on the Opening Pressure of Conventional PRVs

Balanced PRVs – Effects of Backpressure



A_B = effective bellows area,
A_D = disk area,
A_N = nozzle seat area,
A_P = piston area (top),
F_S = spring force,
P_V = vessel gauge pressure,
P_B = superimposed back pressure, in pounds per square inch gauge,
P_S = set pressure, in pounds per square inch gauge.

NOTE In this figure, $P_V = P_S$; $(P_V)(A_N) = F_S$ (typical); and $P_S = F_S / A_N$.

Pressure Relief Devices

Pilot-Operated PRVs

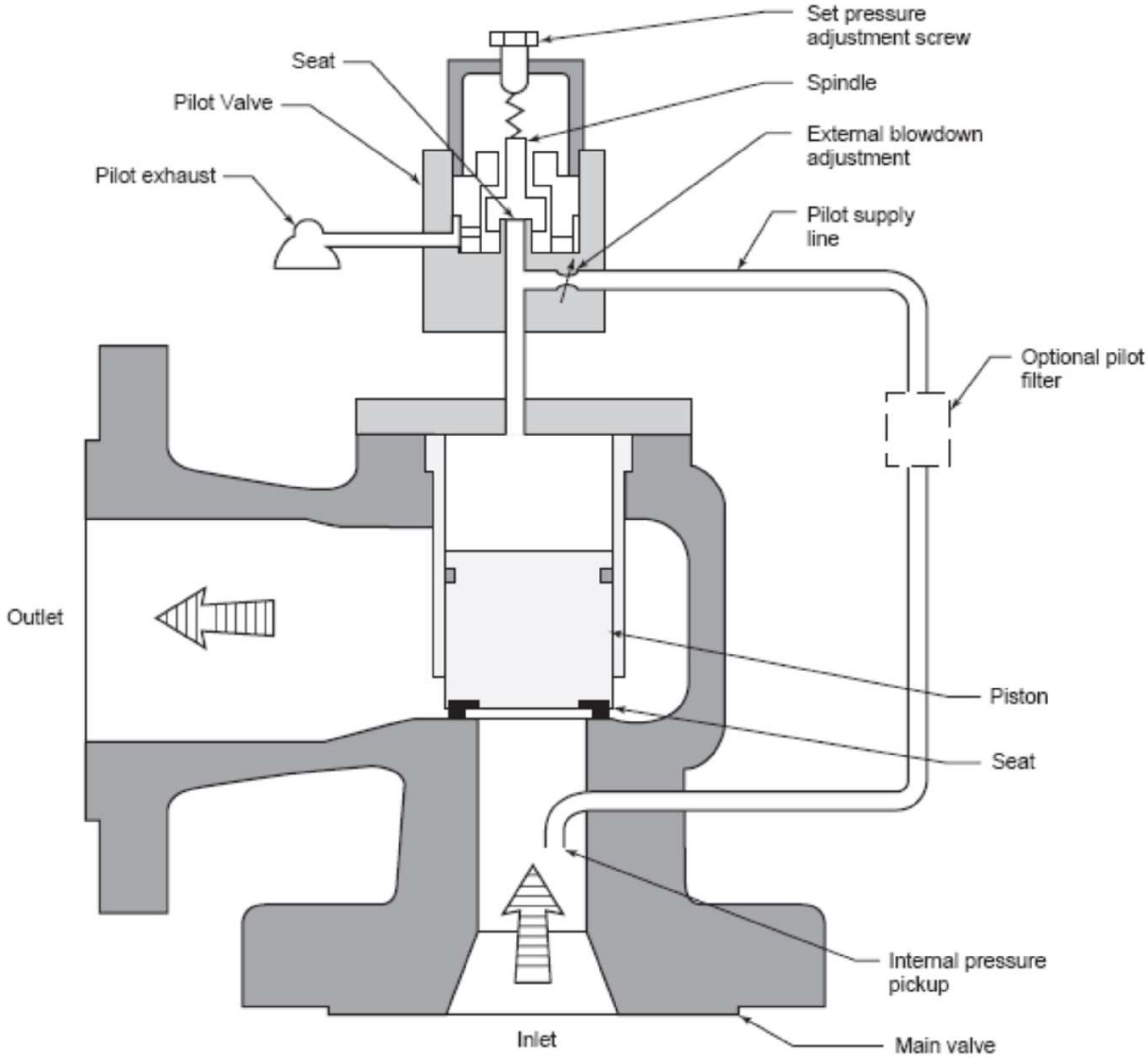


Figure 10—Pop-action Pilot-operated Valve (Flowing-type)

Pressure Relief Devices

Conventional PRVs (Applications & Limitations)

- Conventional spring opposed pressure relief valves are used in virtually all relief services which discharge to atmosphere or to a constant pressure system.

- They should not be used in applications which have variable back pressures

- They should not be used in applications which built-up back pressures in excess of the valve's tolerance.

- Wherever possible, they are preferred to Balanced type PSVs.

- In a conventional PRV application, built-up backpressure should not exceed 10 % of the set pressure at 10 % allowable overpressure. A higher maximum allowable built-up back pressure may be used for allowable overpressures greater than 10% provided the built-up back pressure does not exceed the allowable overpressure.

Balanced Bellows PRVs (Applications & Limitations)

- They can be of two main types: balanced piston and balanced bellows. Balanced bellows shall be given preference where the fluid is corrosive or fouling.

- Application - Balanced bellows PR valves should be specified where any of the following apply:

  1. Excessive fluctuation in superimposed back pressures.

  2. The built up back pressure exceeds 10% of the set pressure, based on gauge pressure; or it exceeds 21% of set pressure in the case of fire.

  3. The service is fouling or corrosive, since the bellows shields the spring from process fluid.

- Balanced bellows PR valves may be used satisfactorily in vapor and liquid service with a total back pressure (superimposed plus built-up) as high as 50% of set pressure.

Pressure Relief Devices

Pilot-Operated PRVs (Applications & Limitations)

- They can be of two main types: piston or diaphragm. Safety-wise, none of these is given preference but only types with non-flowing pilots shall be used.
- The pilots may be either a flowing or non-flowing type. The flowing type allows process fluid to continuously flow through the pilot when the main valve is open; the non-flowing type does not. The non-flowing pilot type is generally recommended for most services to reduce the possibility of hydrate formation (icing) or solids in the lading fluid affecting the pilot's performance.

- **Advantages -** The advantages of pilot-operated PR valves are as follows:

1. A pilot-operated valve is capable of operation at close to the set point and remains closed without simmer until the inlet pressure reaches above 98% of the set pressure.

2. It may be less subjective to chattering. A modulating pilot valve may also be considered where chattering is a potential problem.

Pressure Relief Devices

Pilot-operated PRVs (Applications & Limitations)

- **Advantages**

  3. Its opening pressure is unaffected by back pressure, and high built-up back pressure does not result in chattering. No decrease in capacity occurs as long as flow through the valve is critical.

  4. Back pressure up to 75% of set pressure may be used, The valve manufacturer should be consulted on any application where the total back pressure may exceed 75% of set pressure.

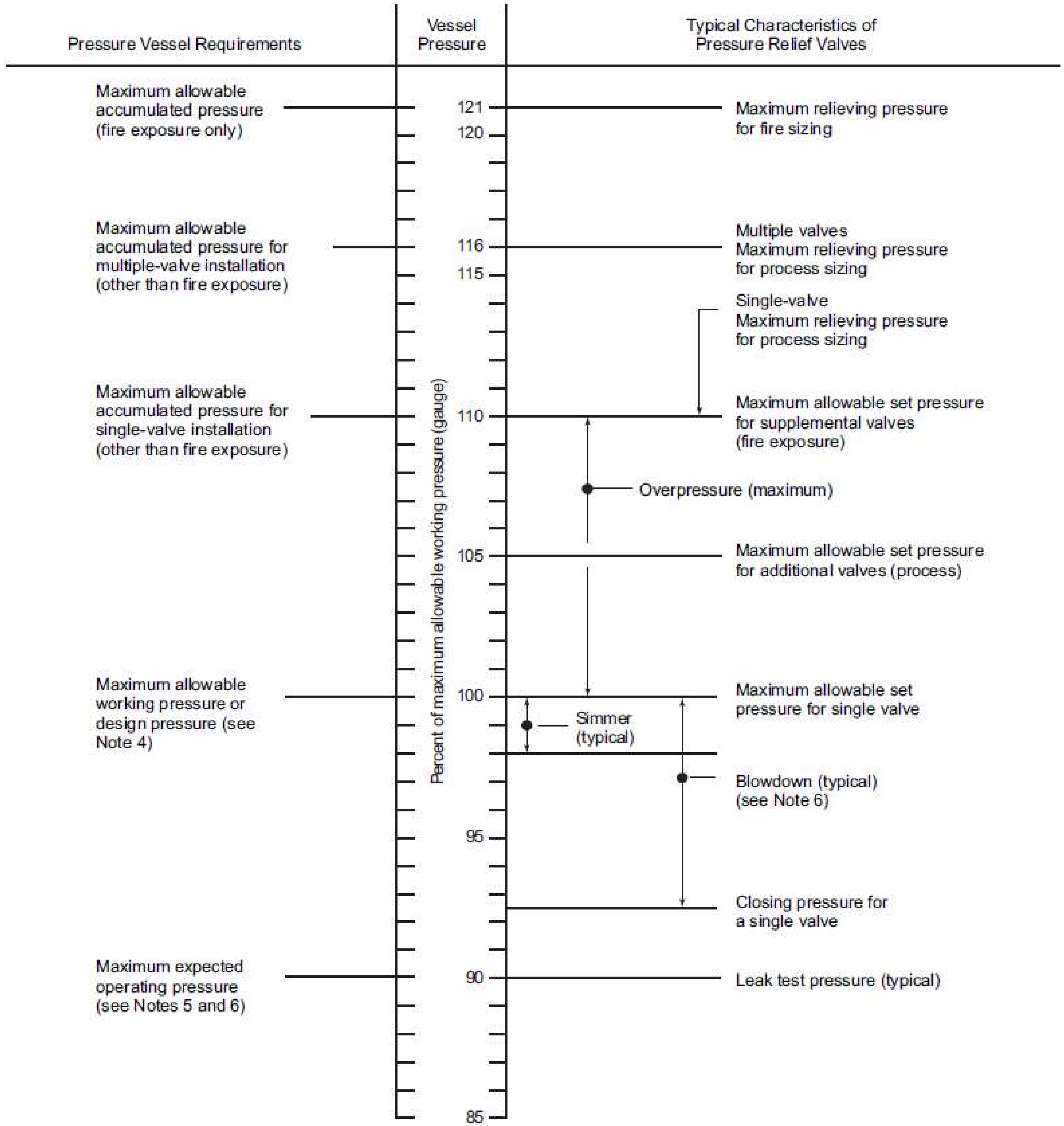
- **Disadvantages -** Pilot-operated PR valves are subject to the following disadvantages:

  1. They are not recommended for dirty or fouling services, because of plugging of the pilot valve and small-bore pressure sensing lines.

  2. They are normally limited to a maximum inlet temperature of 450°F (280°C) by the “O" ring piston seals.

  3. In smaller sizes (below 6”), pilot operated PR valves are more costly than spring operated PR valves.

Pressure Relief Devices



Pressure Relief Devices

PSV Bonnet (Open or Close)

- Conventional
  - Generally closed
  - In case of non hazardous fluid at high temperature should be open
  - Thermal relief valve: closed
- Balance
  - Vented to atmosphere
  - If venting would present a hazard, the vent shall be piped to a safe location.
  - Thermal relief valve: closed
- Pilot
  - Generally closed
  - Thermal relief valve: closed

Pressure Relief Devices

Table 9.1 Maximum backpressure percentages on gas/vapour applications

Backpressure Type	Effects on valves				Selection
	Value (% of set)	**Conventional**	**Balanced Spring Valve**	**Pilot Operated**	
Constant	<30% [1]	Set point increased by backpressure [3]	No effect	No effect	Conventional, balanced or POSRV
	30%–50%		Lift/capacity reduced (coefficient) [6]		
	>50% [2]	Set point increased by backpressure; flow becomes subsonic [4]	Generally unstable *Do not use*	Flow becomes subsonic [4]	Conventional or POSRV
Variable superimposed	<10%	Set point varies with backpressure [5]	No effect	No effect	Balanced or POSRV
	10%–30% [1]	Unstable			
	30%–50%	*Do not use*	Lift/capacity reduced (coefficient) [6]		
	>50% [2]		Generally unstable *Do not use*	Flow becomes subsonic [4]	POSRV only
Variable built-up	<10%	No effect	No effect	No effect	Conventional, balanced or POSRV
	10%–30% [1]	Unstable			Balanced or POSRV
	30%–50%	*Do not use*	Lift/capacity reduced (manufacturer coefficient) [6]		
	>50% [2]		Generally unstable *Do not use*	Flow becomes subsonic [4]	POSRV only

Pressure Relief Devices

Notes :

1. This limit varies among different valve types.

2. In extreme case, some spring valve models can perform with higher backpressures if a pilot-operated valve is absolutely not acceptable.

3. Then the ‘ Cold Differential Set Pressure ’ (set pressure on the test bench) must be reduced by the amount of the backpressure to obtain the correct set pressure on the installation: CDSP=Set – BP.

4. Because of the Δ P , the flow is not choked, but subsonic or subcritical. This obviously has an effect on the sizing of the valve (coefficient). Subsonic can occur at 25% to 30% backpressure: Always check first!

5. The superimposed backpressure varies, so the set pressure of the conventional valve will vary proportionally. This is acceptable if the valve set pressure increased by the maximum backpressure is equal to or below the maximum allowable pressure of the protected installation.

6. There is a coefficient for gas applications and one for liquid applications, which usually varies among valve types.

Chattering

- Chattering is the rapidly alternating opening and closing of a PR valve.
- This vibration may result in misalignment and leakage when the valve returns to its normal closed position. If chattering continues for a sufficient period, chattering may result in mechanical failure of valve internals or associated piping fittings.
- The principal identified causes of PR valve chattering are oversized valve, excessive inlet pressure drop, excessive built-up back pressure incorrect blow-down ring setting, and liquid surge.

Oversized Valve:

- Typically, a flow through the valve in vapor service equal to at least 25% of its rated capacity is necessary to keep the disc in the open position.
- Liquid service valves are less likely to chatter at low relieving rates, and they will modulate down to about 10% of rated capacity before chatter becomes a problem.

Excessive Inlet Pressure Drop:

- Experience as well as manufacturers' recommendations dictate an inlet pressure drop of no more than 3% of set pressure at the PR valve rated capacity.

Chattering

Excessive Built-up Back Pressure:

- Built-up back pressure resulting from discharge flow through the outlet system of a conventional PR valve results in a force on the valve disc tending to return it to the closed position. If this returning force is sufficiently large, it may cause the valve to close, only to reopen immediately when the effect of built-up back pressure is removed.

Blowdown Ring Settings:

- In some cases, incorrect blowdown ring settings have resulted in valve chattering.

Multiple Pressure Relief Valve

- In certain cases it is necessary to install two or more PR valves in parallel for a single service.

- Large Release : The magnitudes of some large releases may be greater than the capacity of the largest single PR valve that is commercially available at the desired pressure rating, necessitating the use of two or more valves.

- Preventing Chattering: Where different contingencies of equal probability require substantially different capacities, it is always best to use two or more PR valves with staggered settings. The lower capacity valve in this case would be at the lower staggered set pressure.

- Preventing Chattering: When a fire contingency is the largest contingency and the next largest contingency is less than 25% of the fire relieving rate, multiple PR valves with staggered settings should always be used. However, when the fire contingency is the smallest load, it is generally ignored.

- Preventing Chattering: When the fire contingency is the smallest load, it is generally ignored. This is because fire is a rare occurrence and chattering under fire conditions is not a significant concern.

Pressure Relief Devices

<u>Multiple Pressure Relief Valve</u>

- Capacities and set points should be specified in accordance with the ASME Code, as follows:
- Only one of them needs to be set at the maximum allowable working pressure (MAWP); the additional valves stagger the setting up to 105% of the MAWP.
- If multiple valves are installed to handle a non-fire “operating contingency” then they should be designed to handle the required relieving rate at an accumulated pressure not exceeding 116% of the design pressure.
- Where fire is the governing situation, a supplemental valve designed to handle the additional fire load can be set as high as 110% of design pressure and the capacity is calculated with an accumulation in the vessel of 21%

Pressure Relief Sizing

<u>Sizing Procedure</u>

- PRVs may be initially sized using the equations presented API-520 as appropriate for vapors, gases, liquids, or two phase fluids.
- These equations utilize effective coefficients of discharge and effective areas which are independent of any specific valve design. In this way, the designer can determine a preliminary PRV size.
- The designer can use API 526 to select a PRV. API 526 is a purchase specification for steel flanged valves.
- When a valve is specified per this standard, the orifice size is expressed in terms of a letter designation ranging from the smallest, "D," to the largest, "T." An effective area is specified for each letter orifice.
- The rated coefficient of discharge for a PRV, as determined per the applicable certification standards, is generally less than the effective coefficient of discharge used in API 520.

Pressure Relief Sizing

Sizing Procedure

- For this reason, the actual discharge or orifice area for most valve designs is greater than the effective discharge area specified for that valve size per API 526.

- In summary, the effective orifice size and effective coefficient of discharge specified in API standards are assumed values used for initial selection of a PRV size from configurations specified in API 526, independent of an individual valve manufacturer's design.

Table 1—Set Pressure and Accumulation Limits for Pressure Relief Devices

Contingency	Single Device Installations		Multiple Device Installations	
	Maximum Set Pressure %	Maximum Accumulated Pressure %	Maximum Set Pressure %	Maximum Accumulated Pressure %
Non-fire Case				
First relief device	100	110	100	116
Additional device(s)	—	—	105	116
Fire Case				
First relief device	100	121	100	121
Additional device(s)	—	—	105	121
Supplemental device	—	—	110	121
NOTE All values are percentages of the maximum allowable working pressure.				

Pressure Relief Sizing

Sizing Procedure – Gas or Vapor Relief

- The sizing equations for pressure relief devices in vapor or gas service assume the pressure-specific volume relationship along an isentropic path.

- Critical Pressure :

$$\frac{P_{cf}}{P_1} = \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}}$$

where

P_{cf} is the critical flow nozzle pressure;

P_1 is the upstream relieving pressure;

k is the ratio of specific heats (C_p/C_v) for an ideal gas at relieving temperature.

- If the pressure downstream of the nozzle is less than, or equal to, the critical flow pressure, then critical flow will occur.

- If downstream pressure exceeds the critical flow pressure, then subcritical flow will occur.

Sizing Procedure – Gas or Vapor Relief – Critical flow

In USC units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

$$A = \frac{V\sqrt{TZM}}{6.32CK_dP_1K_bK_c}$$

$$A = \frac{V\sqrt{TZG_v}}{1.175CK_dP_1K_bK_c}$$

In SI units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

$$A = \frac{2.676 \times V\sqrt{TZM}}{CK_dP_1K_bK_c}$$

$$A = \frac{14.41 \times V\sqrt{TZG_v}}{CK_dP_1K_bK_c}$$

USC:

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

SI :

$$C = 0.03948\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

where

A is the required effective discharge area of the device, in.^{2} (mm^2)

W is the required flow through the device, lb/h (kg/h);

C is a function of the ratio of the ideal gas specific heats ($k = C_p/C_v$) of the gas or vapor at inlet relieving temperature.

K_d is the effective coefficient of discharge; for preliminary sizing, use the following values:

— 0.975, when a PRV is installed with or without a rupture disk in combination,

— 0.62, when a PRV is not installed and sizing is for a rupture disk

Pressure Relief Sizing

Sizing Procedure – Gas or Vapor Relief – Critical flow

In USC units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

$$A = \frac{V\sqrt{TZM}}{6.32\,CK_dP_1K_bK_c}$$

$$A = \frac{V\sqrt{TZG_v}}{1.175\,CK_dP_1K_bK_c}$$

In SI units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

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USC:

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

SI :

$$C = 0.03948\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

P_1 is the upstream relieving pressure, psia (kPa); this is the set pressure plus the allowable overpressure

K_b is the capacity correction factor due to backpressure

K_c is the combination correction factor for installations with a rupture disk upstream of the PRV equals 1.0 when a rupture disk is not installed. K_c equals 0.9 when a rupture disk is installed in combination with a PRV and the combination does not have a certified value.

T is the relieving temperature of the inlet gas or vapor, °R (°F + 460) [K (°C + 273)]

Z is the compressibility factor for the deviation of the actual gas from a perfect gas, a ratio evaluated at inlet relieving conditions;

M is the molecular weight of the gas or vapor at inlet relieving conditions

Pressure Relief Sizing

Sizing Procedure – Gas or Vapor Relief – Critical flow

In USC units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

$$A = \frac{V\sqrt{TZM}}{6.32CK_dP_1K_bK_c}$$

$$A = \frac{V\sqrt{TZG_v}}{1.175CK_dP_1K_bK_c}$$

In SI units:

$$A = \frac{W}{CK_dP_1K_bK_c}\sqrt{\frac{TZ}{M}}$$

$$A = \frac{2.676 \times V\sqrt{TZM}}{CK_dP_1K_bK_c}$$

$$A = \frac{14.41 \times V\sqrt{TZG_v}}{CK_dP_1K_bK_c}$$

USC:

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

SI :

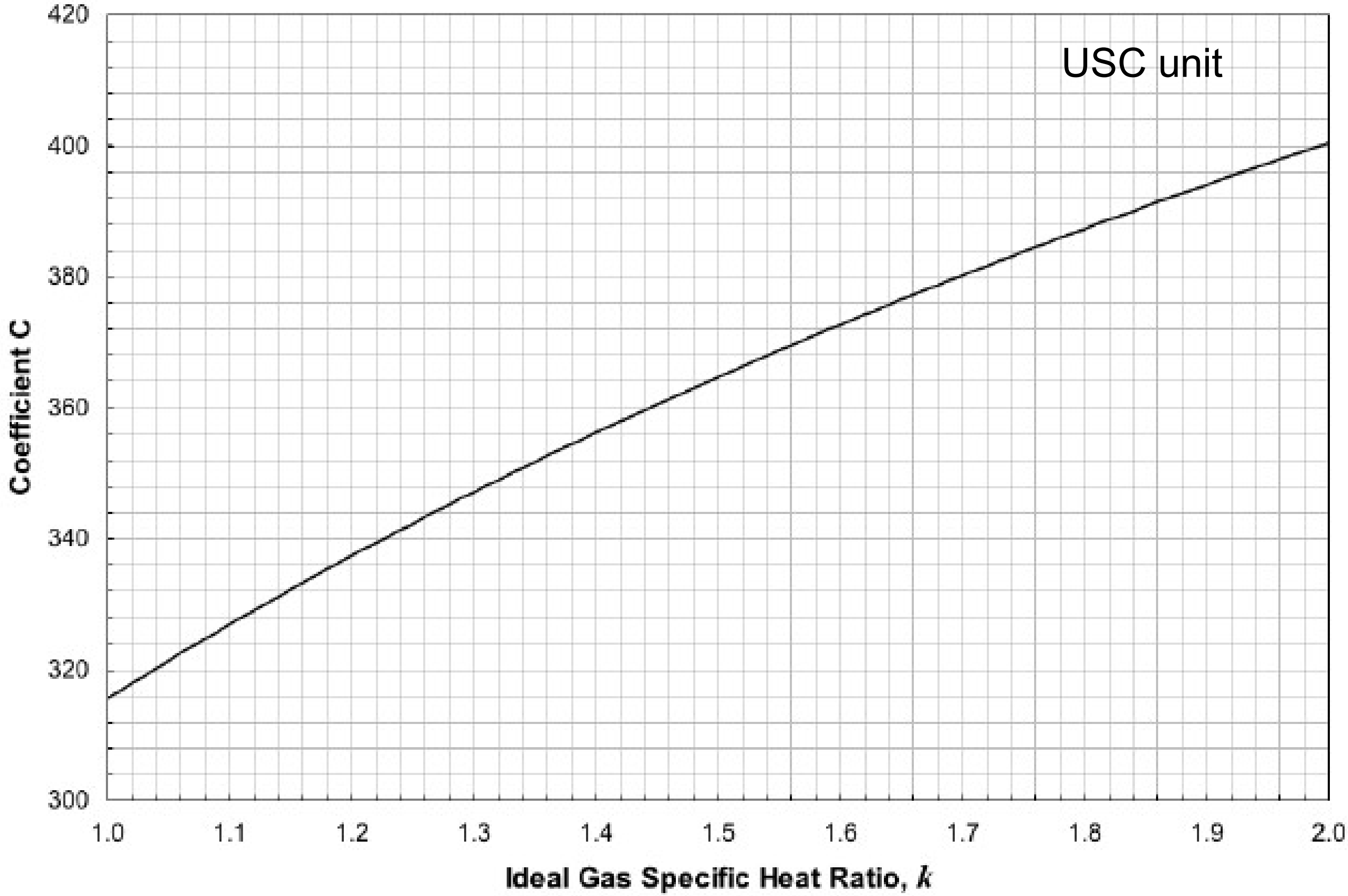
$$C = 0.03948\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

V is the required flow through the device, scfm at 14.7 psia and 60 °F (Nm^3/min at 0 °C and 101.325 kPa);

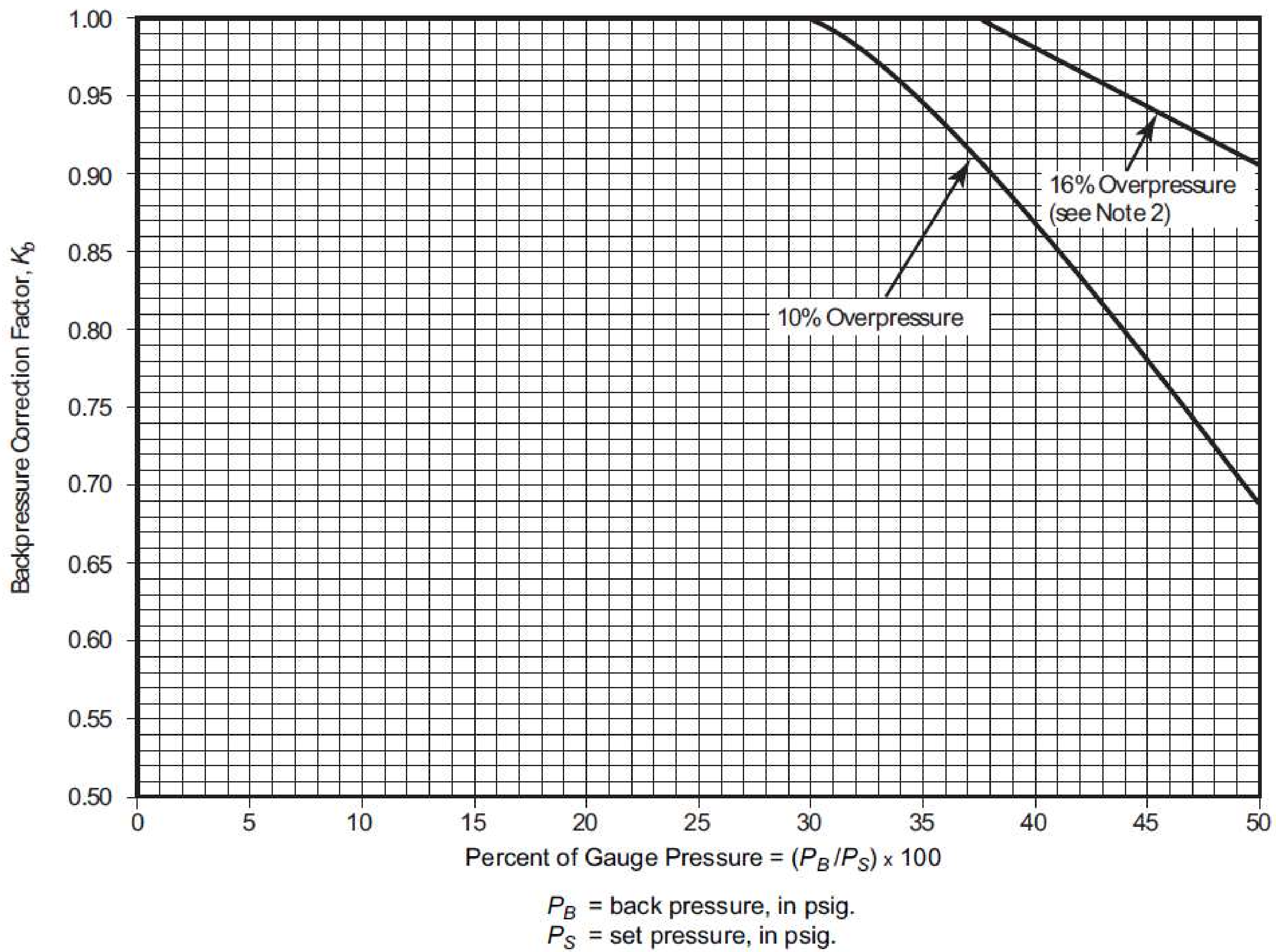
G_v is the specific gravity of gas at standard conditions referred to air at standard conditions (normal conditions). In other words, G_v = 1.00 for air at 14.7 psia and 60 °F (101.325 kPa and 0 °C).

Pressure Relief Sizing

Sizing Procedure – Gas or Vapor Relief – Critical flow



Sizing Procedure – Gas or Vapor Relief – Critical flow



Pressure Relief Sizing

<u>Sizing Procedure – Gas or Vapor Relief – Critical flow</u>

- In most applications, the allowable overpressure is 10 % and the backpressure correction factor for 10 % overpressure shall be used.
- In the special case of multiple valve installations, the low set valve may operate at overpressures up to 16 %. A backpressure correction factor for 16 % overpressure may be used for that low set valve. The high set valve is actually operating at a maximum overpressure of 10 % (assuming the high set valve is set at 105 % of the MAWP), however, and the backpressure correction factor for 10 % overpressure shall be used for that high set valve.
- A supplemental valve used for an additional hazard created by exposure to fire, may be set to open at 10 % above MAWP. In this case, the backpressure correction factor for 10 % overpressure shall be used because the valve is actually operating at 10 % overpressure, even though the accumulation is at 21 %. When calculating the additional capacity for the first (nonfire) valve at 21 % overpressure, a backpressure correction factor of 1.0 may be used.
- For 21% overpressure, Kb equals to 1up to Pb/Pset=50%.

Pressure Relief Sizing

Sizing Procedure – Gas or Vapor Relief – Sub Critical flow

- When the ratio of backpressure to inlet pressure exceeds the critical pressure ratio Pcf /P1, the flow through the pressure relief device is subcritical. For Conventional and Pilot-operated PRVs below equation could be used.

In USC units:

$$A = \frac{W}{735 \times F_2 K_d K_c}\sqrt{\frac{ZT}{M \times P_1(P_1 - P_2)}}$$

$$A = \frac{V}{4645 \times F_2 K_d K_c}\sqrt{\frac{ZTM}{P_1(P_1 - P_2)}}$$

$$A = \frac{V}{864 \times F_2 K_d K_c}\sqrt{\frac{ZTG_v}{P_1(P_1 - P_2)}}$$

In SI units:

$$A = \frac{17.9 \times W}{F_2 K_d K_c}\sqrt{\frac{ZT}{M \times P_1(P_1 - P_2)}}$$

$$A = \frac{47.95 \times V}{F_2 K_d K_c}\sqrt{\frac{ZTM}{P_1(P_1 - P_2)}}$$

$$A = \frac{258 \times V}{F_2 K_d K_c}\sqrt{\frac{ZTG_v}{P_1(P_1 - P_2)}}$$

A is the required effective discharge area of the device, in.^{2} (mm^2)

W is the required flow through the device, lb/h (kg/h);

F_2 is the coefficient of subcritical flow,

$$F_2 = \sqrt{\left(\frac{k}{k-1}\right) r^{\left(\frac{2}{k}\right)} \left[\frac{1 - r^{\left(\frac{k-1}{k}\right)}}{1 - r}\right]}$$

r is the ratio of backpressure to upstream relieving pressure, P_2/P_1

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs Requiring Capacity Certification

- The ASME Code requires that capacity certification be obtained for PRVs designed for liquid service. The procedure for obtaining capacity certification includes testing to determine the rated coefficient of discharge for the liquid PRVs at 10 % overpressure.

In USC units:

$$A = \frac{Q}{38 \times K_d K_w K_c K_v} \sqrt{\frac{G_l}{P_1 - P_2}}$$

In SI units:

$$A = \frac{11.78 \times Q}{K_d K_w K_c K_v} \sqrt{\frac{G_l}{P_1 - P_2}}$$

P_1 is the upstream relieving pressure, psig (kPag);

P_2 is the total backpressure, psig (kPag).

K_w is the correction factor due to backpressure; if the backpressure is atmospheric, use a value for K_w of 1.0. Balanced bellows valves in backpressure service will require the correction factor determined from Figure 31. Conventional and pilot-operated valves require no special correction (see 5.3);

K_d is the rated coefficient of discharge that should be obtained from the valve manufacturer; for preliminary sizing, an effective discharge coefficient can be used as follows:

— 0.65, when a PRV is installed with or without a rupture disk in combination,

— 0.62, when a PRV is not installed and sizing is for a rupture disk in accordance with 5.11.1.2.1.

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs Requiring Capacity Certification

In USC units:

$$Re = \frac{Q(2800 \times G_l)}{\mu\sqrt{A}}$$

or

$$Re = \frac{12{,}700 \times Q}{U\sqrt{A}}$$

In SI units:

$$Re = \frac{Q(18{,}800 \times G_l)}{\mu\sqrt{A}}$$

or

$$Re = \frac{85{,}220 \times Q}{U\sqrt{A}}$$

Re is the Reynold's Number;

Q is the flow rate at the flowing temperature in U.S. gal/min (L/min);

G_l is the specific gravity of the liquid at the flowing temperature referred to water at standard conditions;

μ is the absolute viscosity at the flowing temperature, centipoise;

A is the effective discharge area in in.^{2} (mm^2); (from API 526 standard orifice areas);

U is the viscosity at the flowing temperature in Saybolt universal seconds (SSU).

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs Requiring Capacity Certification

K_c is the combination correction factor for installations with a rupture disk upstream of the PRV (see 5.11.2); use the following values for the combination correction factor:

— 1.0, when a rupture disk is not installed;

— 0.9, when a rupture disk is installed in combination with a PRV and the combination does not have a certified value;

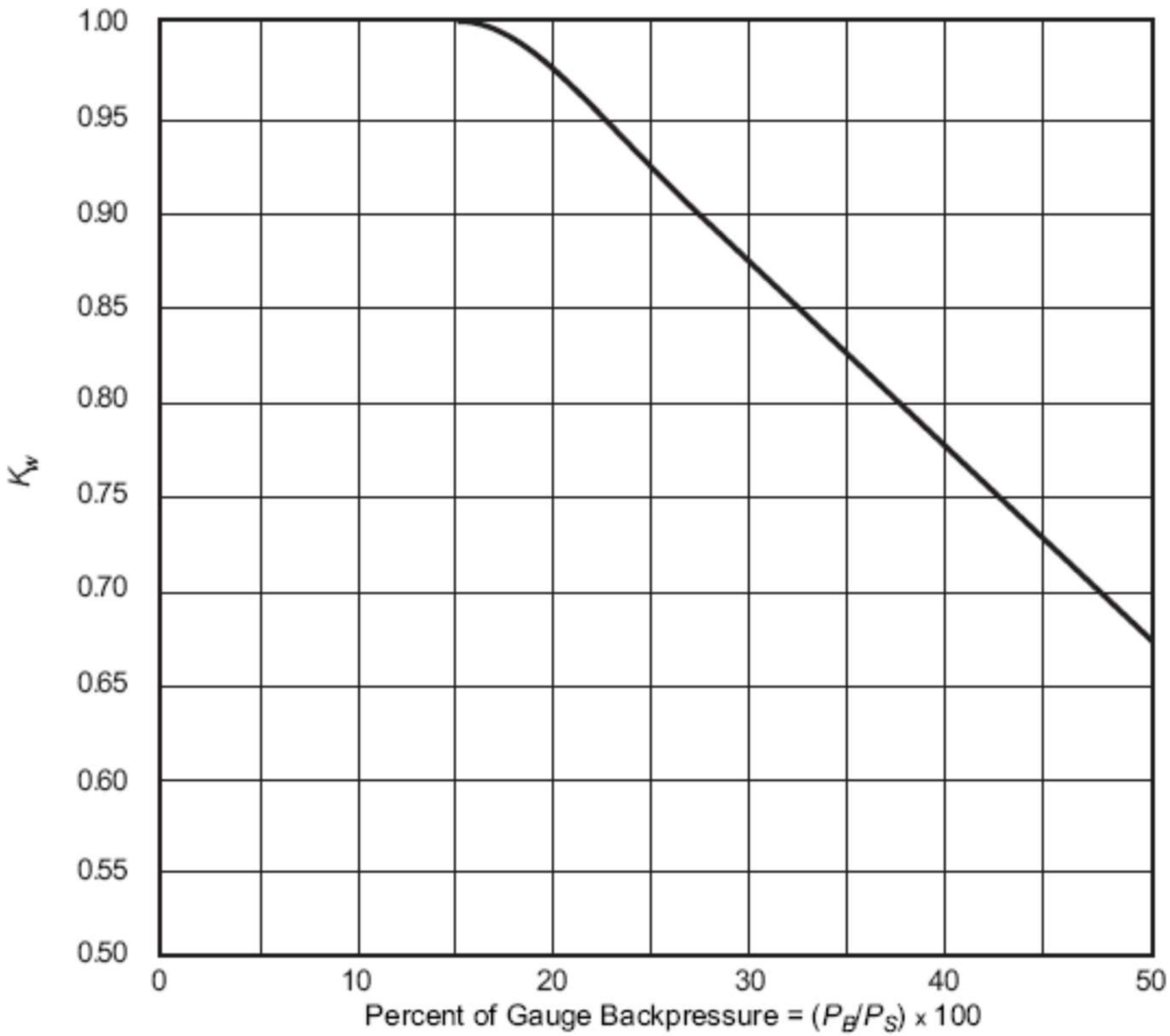
K_v is the correction factor due to viscosity, as determined from Figure 37 or from Equation (30);

$$K_v = \left(0.9935 + \frac{2.878}{Re^{0.5}} + \frac{342.75}{Re^{1.5}}\right)^{-1.0}$$

- After the Reynold's Number, Re, is determined, the factor *K*v is obtained from above. *K*v is then applied in PSV Area Calculation Equation to correct the preliminary required discharge area. If the corrected area exceeds the chosen standard orifice area, the above calculations should be repeated using the next larger standard orifice size.

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs requiring capacity Certification



Kw = correction factor due to back pressure.
P_B = back pressure, in psig.
P_S = set pressure, in psig.

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs not requiring capacity Certification

In USC units:

$$A = \frac{Q}{38 \times K_d K_w K_c K_v K_p} \sqrt{\frac{G_l}{1.25 P_s - P_2}}$$

In SI units:

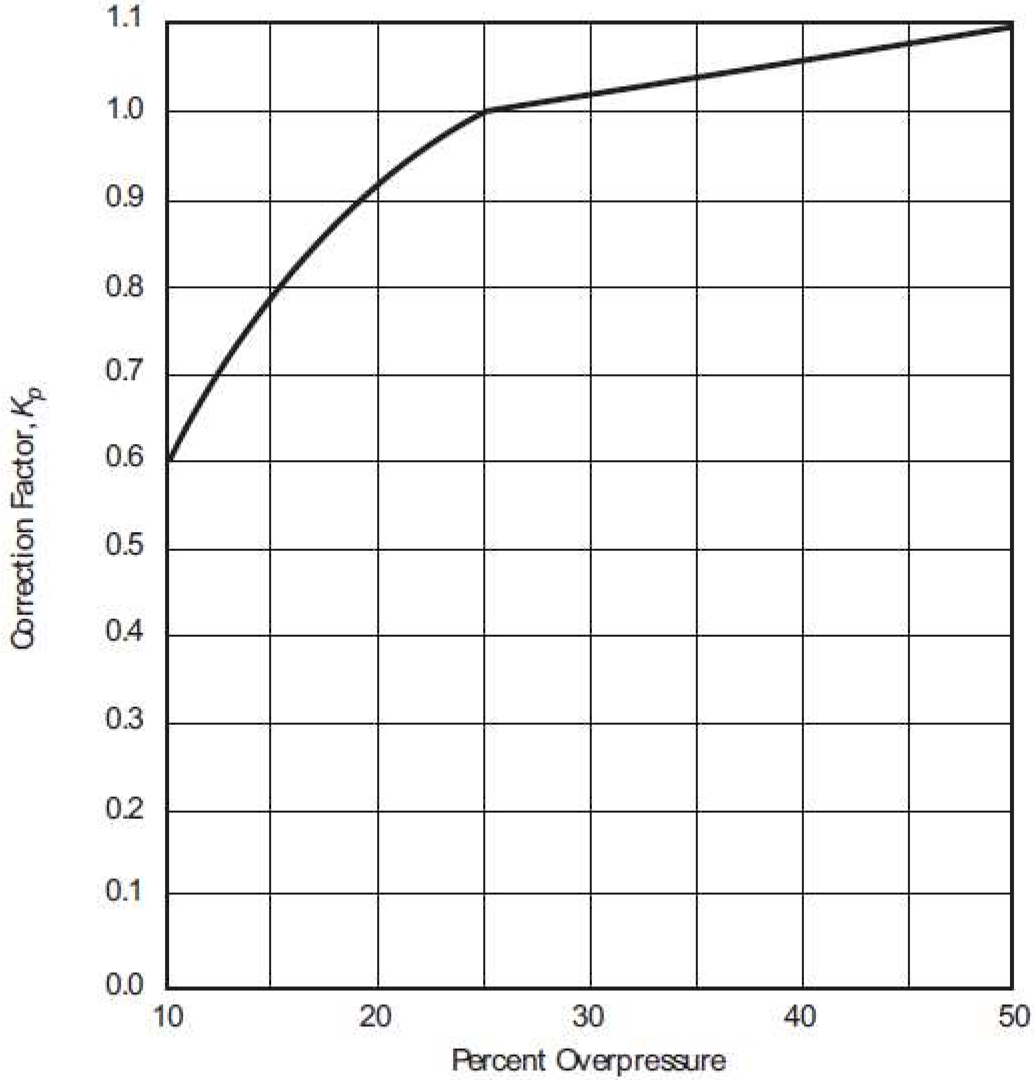
$$A = \frac{11.78 \times Q}{K_d K_w K_c K_v K_p} \sqrt{\frac{G}{1.25 P_s - P_2}}$$

K_d is the rated coefficient of discharge that should be obtained from the valve manufacturer; for a preliminary sizing estimation, an effective discharge coefficient of 0.62 can be used;

K_p is the correction factor due to overpressure; at 25 % overpressure, K_p is equal to 1.0. For overpressures other than 25 %, K_p is determined from Figure 38;

Pressure Relief Sizing

Sizing Procedure – Liquid Relief : PRVs not requiring capacity Certification



Pressure Relief Sizing

Sizing Procedure – Liquid- Example

a) required crude oil flow caused by blocked discharge, Q, of 1800 gal/min (6814 L/min);

b) the specific gravity, G_l, of the crude oil is 0.90. The viscosity of the crude oil at the flowing temperature is 2000 Saybolt universal seconds; (394 cp)

c) PRV set at 250 psig (1724 kPag), which is the design pressure of the equipment;

d) backpressure is variable from 0 to 50 psig (345 kPag);

e) overpressure of 10 %.

Sizing Procedure – Vapor- Example

a) required hydrocarbon vapor flow, W, caused by an operational upset, of 53,500 lb/h (24,270 kg/h);

b) the hydrocarbon vapor is a 50/50 (by mole) mixture of n-butane (C_4) and propane (C_3). The molecular weight of the vapor, M, is 51;

c) relieving temperature, T, of 627 °R (167 °F) (348 K);

d) PRV set at 75 psig (517 kPa), which is the design pressure of the equipment;

e) backpressure of 14.7 psia (0 psig) [101.325 kPa (0 kPag)];

f) overpressure of 10 %.

Pressure Relief Sizing

Sizing Procedure – Vapor Service Example

W= 7773 kg/h
MW= 33.35
z=1
cp/cv= 1.14
T= 138.6 °C
Set Pressure= 8.7 barg
Scenario= Blocked Outlet (vapor)
MABP= 1.75 barg

W= 138696 kg/h
MW= 21.28
z=1
cp/cv= 1.4
T= 60 °C
Set Pressure= 107 barg
Scenario= Blocked Outlet (vapor)
MABP= 9 barg

W= 928700 kg/h
MW= 17.17
z= 0.8
cp/cv= 1.38
T= -58°C
Set Pressure= 33.5 barg
Scenario= Control Valve Failure
MABP= 15 barg

Pressure Relief Sizing

<u>Sizing Procedure – Two Phase Flow</u>

- In all of two-phase scenarios either a two-phase mixture enters the PRV or a two-phase mixture is produced as the fluid moves through the valve.
- The equations presented in this section are based on the Homogeneous Equilibrium Method (HEM) .
- This model assumes the fluid mixture behaves as a "pseudo-single phase fluid," with a density that is the volume-averaged density of the two phases.
- This method is based on the assumption that thermal and mechanical equilibrium exist as the two-phase fluid passes through the PRV
- For high momentum discharges of two-phase systems in nozzles longer than 4 in. (10 cm), both thermal and mechanical equilibrium can be assumed.

Sizing Procedure – Two Phase Flow

Two-phase Liquid/Vapor Relief Scenario	Example
Two-phase system (liquid vapor mixtures, including saturated liquid) enters PRV and flashes. No non-condensable [a] gas present. Also includes fluids both above and below the thermodynamic critical point in condensing two-phase flow.	Saturated liquid/vapor propane system enters PRV and the liquid propane flashes.
Two-phase system (highly subcooled [b] liquid and either non-condensable gas, condensable vapor or both) enters PRV and does not flash.	Highly subcooled propane and nitrogen enters PRV and the propane does not flash.
Two-phase system (the vapor at the inlet contains some non-condensable gas and the liquid is either saturated or subcooled) enters PRV and flashes. Non-condensable gas enters PRV.	Saturated liquid/vapor propane system and nitrogen enters PRV and the liquid propane flashes.
Subcooled liquid (including saturated liquid) enters PRV and flashes. No condensable vapor or non-condensable gas enters PRV.	Subcooled propane enters PRV and flashes.

Sizing Procedure – Two Phase Flow

Sizing by Direct Integration of the Isentropic Nozzle Flow (Applicable to all cases)

- To determine the maximum mass flux through a converging nozzle, the nozzle is assumed to be adiabatic and reversible (Isentropic).

In USC units:

$$G^2 = (\rho_t^2) \times \left(-9266.1 \times \int_{P_o}^{P_t} \frac{dP}{\rho} \right)$$

In SI units:

$$G^2 = (\rho_t^2) \times \left(-2 \times \int_{P_o}^{P_t} \frac{dP}{\rho} \right)$$

G is the mass flux, lb/s·ft^2 (kg/s·m^2);

v is the specific volume of the fluid, ft^3/lb (m^3/kg);

ρ is the mass density of the fluid, lb/ft^3 (kg/m^3);

P is the stagnation pressure of the fluid, psia (Pa);

o is the fluid condition at the inlet to the nozzle;

$$\int_{Po}^{Pt} \frac{dP}{\rho} \approx \sum_{Pi=Po}^{Pi=Pt} 2\left(\frac{P_{i+1} - P_i}{\rho_{i+1} + \rho_i} \right)$$

$$\sum_{Pi=Po}^{Pi=Pt} 2\left(\frac{P_{i+1} - P_i}{\rho_{i+1} + \rho_i} \right) = 2\left(\frac{P_1 - P_o}{\rho_1 + \rho_o} \right) + 2\left(\frac{P_2 - P_1}{\rho_2 + \rho_1} \right) + \ldots\ldots$$

t is the fluid condition at the throat of the nozzle where the cross-sectional area is minimized.

Sizing Procedure – Two Phase Flow

Sizing by Direct Integration of the Isentropic Nozzle Flow (Applicable to all cases)

- Once the value for the mass flux has been determined, the required orifice area can be calculated :

In USC units:

$$A = \frac{0.04\,W}{K_d K_b K_c K_v G}$$

A is the required effective discharge area, in.^{2} (mm^2);

W is the mass flow rate, lb/h (kg/h);

In SI units:

$$A = \frac{277.8 \times W}{K_d K_b K_c K_v G}$$

Kd :

- For two-phase flow, $K_d = 0.85$
- For saturated liquids, $K_d = 0.85$
- For sub-cooled liquid, $K_d = 0.65$

Sizing Procedure – Two Phase Flow

- Omega parameter is calculated based on specific volume data obtained from a flash calculation. This is often referred to as a two-point method since fluid properties are determined at the inlet relieving conditions and at flashed conditions at a lower pressure.

- In most cases, a flash pressure at 90 % of the initial pressure provides a reasonable correlation parameter; however, lower flash pressures may be more appropriate under some conditions (e.g. near the thermodynamic critical point).

$$\omega = \frac{\frac{\rho_o}{\rho_x} - 1}{\frac{P_o}{P_x} - 1} = \frac{\frac{v_x}{v_o} - 1}{\frac{P_o}{P_x} - 1}$$

where

P is the pressure from the flash calculation (absolute);

ρ is the overall two-phase density from the flash calculation;

v is the overall two-phase specific volume from the flash calculation;

o is the initial condition (e.g. PRV inlet condition) for the flash;

x is the flash result at one lower pressure.

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Two-phase Flashing or Non-flashing Flow Through a PRV Using the Omega Method
- Step 1—Calculate the Omega parameter :

$$\omega = 9\left(\frac{v_9}{v_o} - 1\right)$$

where

v_9 is the specific volume evaluated at 90 % of the PRV inlet pressure, P_o in ft^3/lb; when determining v_9, the flash calculation should be carried out isentropically, but an isenthalpic (adiabatic) flash is sufficient for low-quality mixtures far from the thermodynamic critical point.

v_o is the specific volume of the two-phase system at the PRV inlet, ft^3/lb.

- Step 2—Determine if the flow is critical or sub-critical :

$$P_c \geq P_a \Rightarrow \text{critical flow}$$

$$P_c < P_a \Rightarrow \text{subcritical flow}$$

where

P_a is the downstream backpressure (psia or Pa).

P_c is the critical pressure, psia (Pa);

$$P_c = \eta_c P_o$$

where

η_c is the critical pressure ratio from Figure C.1.

Sizing Procedure – Two Phase Flow

- Sizing for Two-phase Flashing or Non-flashing Flow Through a PRV Using the Omega Method

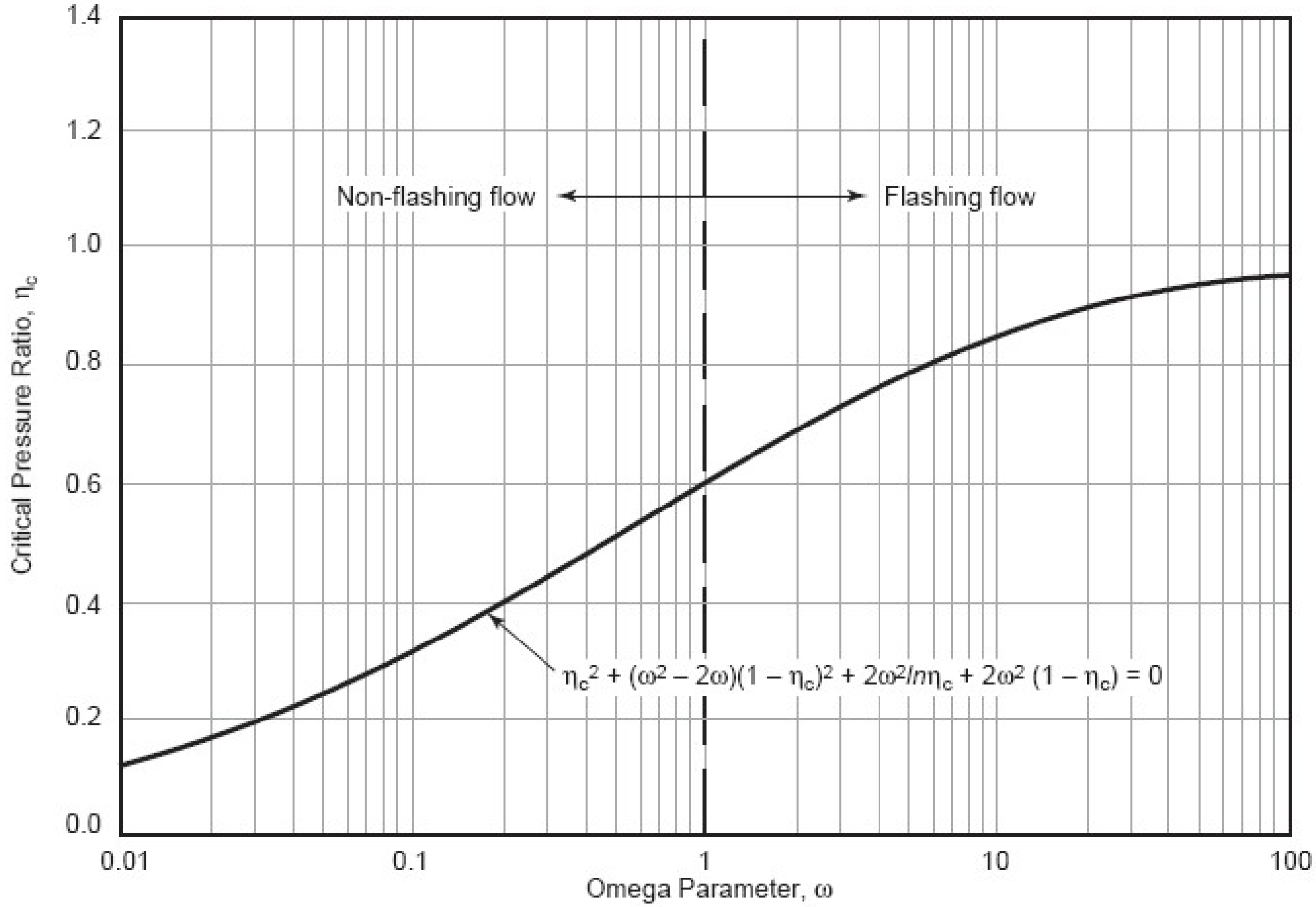


Figure C.1—Correlation for Nozzle Critical Flow of Flashing and Nonflashing Systems

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Two-phase Flashing or Non-flashing Flow Through a PRV Using the Omega Method

$$\eta_c = [1 + (1.0446 - 0.0093431 \times \omega^{0.5}) \times \omega^{-0.56261}]^{(-0.70356 + 0.014685 \times \ln\omega)}$$

- Step 3—Calculate the mass flux.

Critical :

In USC units:

$$G = 68.09 \times \eta_c \sqrt{\frac{P_o}{v_o \omega}}$$

In SI units:

$$G = \eta_c \sqrt{\frac{P_o}{v_o \omega}}$$

Sub-Critical :

$$G = \frac{68.09 \times \{-2[\omega \ln \eta_a + (\omega - 1)(1 - \eta_a)]\}^{1/2}}{\omega\left(\frac{1}{\eta_a} - 1\right) + 1} \sqrt{P_o / v_o}$$

$$G = \frac{\{-2 \times [\omega \ln \eta_a + (\omega - 1)(1 - \eta_a)]\}^{1/2}}{\omega\left(\frac{1}{\eta_a} - 1\right) + 1} \sqrt{P_o / v_o}$$

G is the mass flux, lb/s·ft^2 (kg/s·m^2);

P_o is the pressure at the PRV inlet in psia (Pa);

v_o is the specific volume of the two-phase system at the PRV inlet in ft^3/lb (m^3/kg);

η_a is the backpressure ratio, $\eta_a = \frac{P_a}{P_o}$.

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Two-phase Flashing or Non-flashing Flow Through a PRV Using the Omega Method

- Step 4—Calculate the required area of the PRV.

In USC units:

$$A = \frac{0.04W}{K_d K_b K_c K_v G}$$

In SI units:

$$A = \frac{277.8W}{K_d K_b K_c K_v G}$$

A is the required effective discharge area, in.^{2} (mm^2);

W is the mass flow rate, lb/h (kg/h);

K_d is the discharge coefficient. For a preliminary sizing estimation, a discharge coefficient of 0.85 can be used;

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Two-phase Flashing or Non-flashing Flow Through a PRV Using the Omega Method
- Example :

— required crude column overhead two-phase flow rate caused by an operational upset of 477,430 lb/h (216,560 kg/h). This flow is downstream of the condenser;

— temperature at the PRV inlet of 200 °F (659.7 °R = 366.5 K);

— PRV set at 60 psig (413.7 kPag), the design pressure of the equipment;

— downstream total backpressure of 15 psig (29.7 psia) (204.7 kPa) (superimposed backpressure = 0 psig, built-up backpressure = 15 psi);

— two-phase specific volume at the PRV inlet of 0.3116 ft^3/lb (0.01945 m^3/kg);

— allowable overpressure (accumulation) of 10 %;

— for this example problem, a viscosity correction factor, K_v, of 1.0 is assumed.

The specific volume evaluated at 0.9 × 80.7 = 72.63 psia (500.8 kPa) using the results of an isenthalpic (adiabatic) flash calculation from a process simulator is 0.3629 ft3/lb (0.02265 m3/kg).

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method
- Step 1—Calculate the saturated omega parameter

$$\omega_s = 9\left(\frac{\rho_{lo}}{\rho_9} - 1\right)$$

where

ρ_{lo} is liquid density at the PRV inlet, lb/ft^3 (kg/m^3);

ρ_9 is density, lb/ft^3 (kg/m^3) evaluated at 90 % of the saturation (vapor) pressure, P_s, corresponding to the PRV inlet relieving temperature, T_o, lb/ft^3 (kg/m^3). For a multi-component system, use the bubble point pressure corresponding to T_o for P_s. When determining ρ_9, the flash calculation should be carried out isentropically, but an isenthalpic (adiabatic) flash is sufficient for low-quality mixtures far from the thermodynamic critical point.

- Step 2—Determine the subcooling region :

$$P_s \geq \eta_{st} P_o \Rightarrow \text{low subcooling region (flashing occurs upstream of throat)}$$

$$P_s < \eta_{st} P_o \Rightarrow \text{high subcooling region (flashing occurs at the throat)}$$

where

η_{st} is transition saturation pressure ratio,

$$\eta_{st} = \frac{2\omega_s}{1 + 2\omega_s}$$

P_o is pressure at the PRV inlet, psia (Pa). This is the PRV set pressure, psig (Pag) plus the allowable overpressure (psi or Pa) plus atmospheric pressure.

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method

- Step 3—Determine if the flow is critical or sub-critical.
- For the low subcooling region, use the following comparisons:

$$P_c \ge P_a \Rightarrow \text{critical flow}$$

$$P_c < P_a \Rightarrow \text{subcritical flow}$$

- For the high subcooling region, use the following comparisons:

$$P_s \ge P_a \Rightarrow \text{critical flow}$$

$$P_s < P_a \Rightarrow \text{subcritical flow (all-liquid flow)}$$

where

P_c is the critical pressure in psia (Pa).

$$P_c = \eta_c P_o$$

where

η_c is the critical pressure ratio from Figure C.2 using the value of η_s.

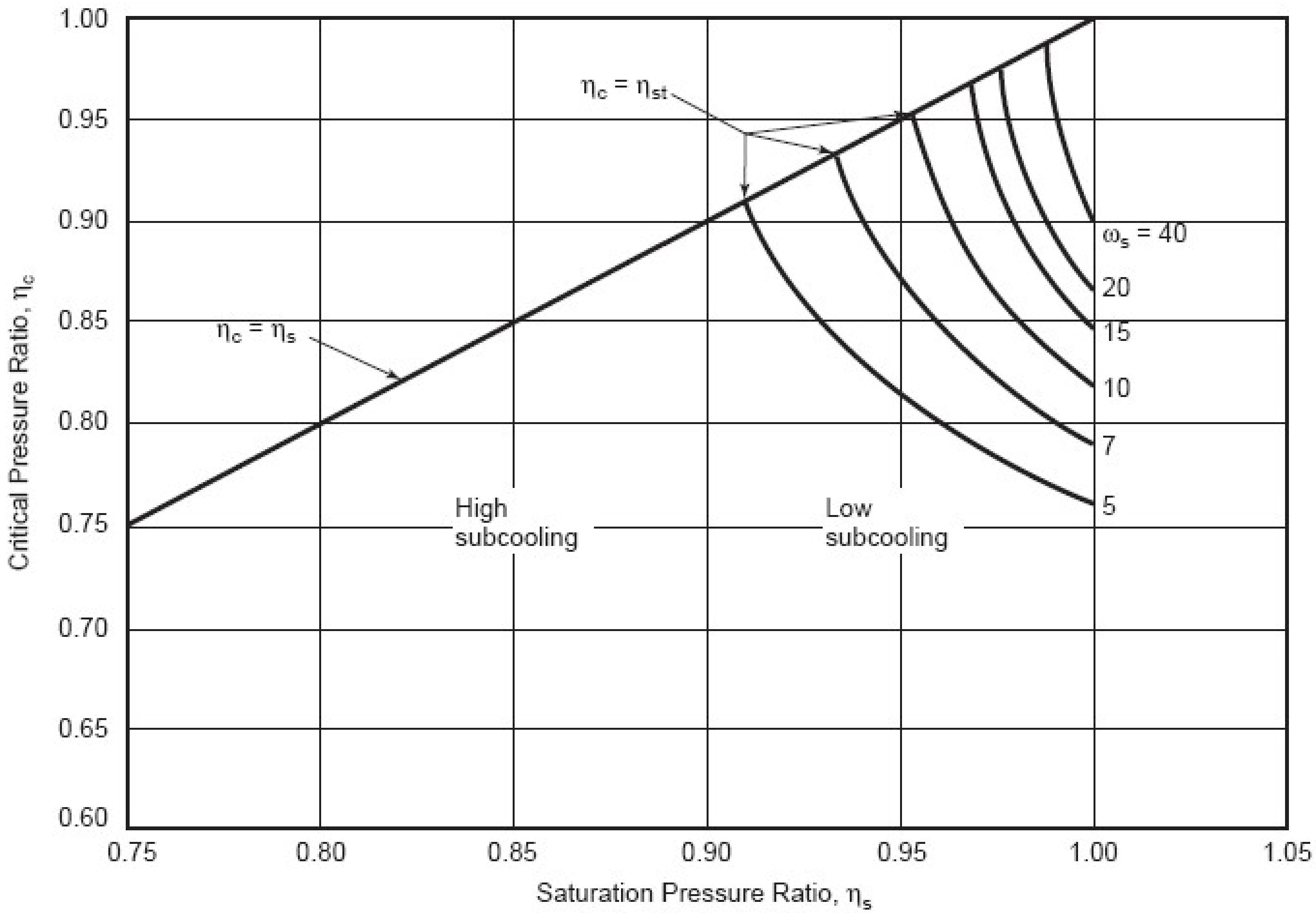


Figure C.2—Correlation for Nozzle Critical Flow of Inlet Subcooled Liquid

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method

For $\eta_s \leq \eta_{st}$:

$$\eta_c = \eta_s$$

For $\eta_s > \eta_{st}$

$$\eta_c = \eta_s \times \left(\frac{2 \times \omega}{2 \times \omega - 1}\right) \times \left[1 - \sqrt{1 - \frac{1}{\eta_s} \times \left(\frac{2 \times \omega - 1}{2 \times \omega}\right)}\right]$$

where

η_s is the saturation pressure ratio

$$\eta_s = \frac{P_s}{P_o}$$

P_a is the downstream backpressure in psia (Pa);

η_a is the subcritical pressure ratio per Equation (C.40).

$$\eta_a = \frac{P_a}{P_o}$$

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method
- Step 4—Calculate the mass flux. In the low subcooling region, use Equation (C.41) or Equation (C.43). If the flow is critical, use ηc for η and if the flow is sub-critical, use ηa for η. In the high subcooling region, use Equation (C.42) or Equation (C.44). If the flow is critical, use Ps for P and if the flow is sub-critical (all-liquid flow), use Pa for P.

In USC units:

$$G = \frac{68.09 \times \left\{2(1-\eta_s) + 2\left[\omega_s \eta_s \ln\left(\frac{\eta_s}{\eta}\right) - (\omega_s - 1)(\eta_s - \eta)\right]\right\}^{1/2}}{\omega_s\left(\frac{\eta_s}{\eta} - 1\right) + 1}\sqrt{P \times \rho_{lo}} \quad \text{(C.41)}$$

$$G = 96.3 \times \left[\rho_{lo}(P_o - P)\right]^{1/2} \quad \text{(C.42)}$$

In SI units:

$$G = \frac{\left(2(1-\eta_s) + 2\left[\omega_s \eta_s \ln\left(\frac{\eta_s}{\eta}\right) - (\omega_s - 1)(\eta_s - \eta)\right]\right)^{1/2}}{\omega_s\left(\frac{\eta_s}{\eta} - 1\right) + 1}\sqrt{P \times \rho_{lo}} \quad \text{(C.43)}$$

$$G = 1.414\left[\rho_{lo}(P_o - P)\right]^{1/2} \quad \text{(C.44)}$$

where

G is the mass flux, lb/s·ft^2 (kg/s·m^2);

η is the backpressure ratio.

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method

- Step 5—Calculate the required area of the PRV.

In USC units:

$$A = 0.3208 \frac{Q\rho_{lo}}{K_d K_b K_v G}$$

In SI units:

$$A = 16.67 \frac{Q \times \rho_{lo}}{K_d K_b K_v G}$$

where

A is the required effective discharge area, in.^{2} (mm^2);

G is the mass flux, lb/s·ft^2 (kg/s·m^2);

Q is the volumetric flow rate, gal/min (L/min);

K_d is the discharge coefficient. For a preliminary sizing estimation, a discharge coefficient 0.65 for subcooled liquids and 0.85 for saturated liquids can be used. A value of 0.65 for slightly subcooled liquids may result in a conservative valve size.

Pressure Relief Sizing

Sizing Procedure – Two Phase Flow

- Sizing for Subcooled Liquid at the PRV Inlet Using the Omega Method
- Example :
  - required propane volumetric flow rate caused by blocked in pump of 100 gal/min (378.5 L/min);
  - PRV set at 260 psig (1,792.6 kPag), the design pressure of the equipment;
  - downstream total backpressure of 10 psig (24.7 psia) (170.3 kPa) (superimposed backpressure = 0 psig, built-up backpressure = 10 psi);
  - temperature at the PRV inlet of 60 °F (519.67 °R) (288.7 K);
  - liquid propane density at the PRV inlet of 31.920 lb/ft^3 (511.3 kg/m^3);
  - liquid propane specific heat at constant pressure at the PRV inlet of 0.6365 Btu/lb·°R (2.665 kJ/kg·K);
  - saturation pressure of propane corresponding to 60 °F of 107.6 psia (741.9 kPa);
  - specific volume of propane liquid at the saturation pressure of 0.03160 ft^3/lb (0.00197 m^3/kg);
  - specific volume of propane vapor at the saturation pressure of 1.001 ft^3/lb (0.0625 m^3/kg);
  - latent heat of vaporization for propane at the saturation pressure of 152.3 Btu/lb (354.2 kJ/kg);
  - for this example problem, a viscosity correction factor, K_v, of 1.0 is assumed.

The specific volume evaluated at 0.9 × 107.6 = 96.84 psia (667.7 kPa) using the results of an isenthalpic (adiabatic) flash calculation from a process simulator is 0.06097 ft3/lb (0.00381 m3/kg). This gives a fluid density of 16.40 lb/ft3 (262.7 kg/m3).

Pressure Relief Devices

Rupture Disk

- Rupture disk devices are non-reclosing pressure relief devices .They are used in single and multiple relief device installations.

- With no moving parts, rupture disks are simple, reliable, and faster acting than other pressure relief devices.

- Advantages :
  - No simmering or leakage prior to bursting.
  - Rupture discs can open fully within 1 millisecond for vapor/gas systems, thus making them more effective than PR valves when the overpressure is caused by sudden pressurization (for example as a result of a tube failure in a high pressure heat exchanger).
  - Less expensive to provide corrosion resistance.
  - Less tendency to foul or plug.
  - Can provide both depressuring and overpressure protection.
  - Lower initial cost than for an equivalent service PR valve.

Pressure Relief Devices

Rupture Disk

- Disadvantages :
  - Non-reclosing pressure relief device. Replacement of the burst rupture disc is required to allow continued operation if it is the only protective device.
  - Require periodic replacement.
  - Greater sensitivity to mechanical damage.
  - Greater sensitivity to temperature.

Pressure Relief Devices

<u>Rupture Disk</u>

A stand-alone rupture disk is used when:

- You are looking for capital and maintenance savings
- You can afford to loose the system contents
- The system contents are relatively benign
- You need a pressure relief device that is fast acting
- A relief valve is not suitable due to the nature of the system contents

When to use combination of RD and PSV?

- The system contains a toxic substance and you are concerned that the relief valve may leak.
- The system contains solids that may plug the relief valve over time.
- If the system is a corrosive environment, the rupture disk is specified with the more exotic and corrosion resistant material.

Pressure Relief Devices

<u>Rupture Disk (Sizing)</u>

- There are two recognized methods that can be used
  - Resistance to Flow Method
  - Coefficient of Discharge Method.

Resistance to Flow Method

- The Resistance to Flow Method analyzes the flow capacity of the relief piping. The analysis takes into account frictional losses of the relief piping and all piping components.

- Piping component losses may include nozzle entrances and exits, elbows, tees, reducers, valves and the rupture disk

- Calculations are performed using accepted engineering practices for determining fluid flow through piping systems such as the Bernoulli equation for liquids, the Isothermal or adiabatic flow equations for vapor/gas and DIERS methodology for two-phase flow.

Pressure Relief Devices

Rupture Disk (Sizing)

Resistance to Flow Method (cont.)

- RD contribution to the overall frictional loss in the piping system is accomplished by using "Kr", which is analogous to the K value of other piping components.
- Kr is determined experimentally in flow laboratories by the manufacturer for their line of products.
- If at the time of sizing the manufacturer and model of the rupture disk are unknown, API STD 520 recommends using a Kr of 1.5.
- ASME Section VIII, Division 1 states that a Kr of 2.4 shall be used.

Rupture Disk (Sizing)

Resistance to Flow Method (cont.) – Procedure :

- 1. Known are the two terminal pressures, these being the relieving pressure (upstream) and the downstream pressure.
- 2. Known are the fluid properties and required relieving rate.
- 3. Choose a pipe size. This will be the size to use for all components, including the rupture disk.
- 4. For vapor/gas or two-phase flow, use one of the accepted calculation methods to determine the maximum flow through the system. The maximum flow through the system is commonly known as critical flow or choked flow.

  For liquids, use the Bernoulli equation to calculate the flow that will balance the system pressure losses.

Pressure Relief Devices

Rupture Disk (Sizing)

Resistance to Flow Method (cont.) – Procedure :

- 5. Per ASME Section VIII, Division 1, multiply this flow by 0.9 to take into account inaccuracies in the system parameters. Compare the adjusted calculated flow to the required relieving rate.

If it is greater, then the calculation is basically done. However, the next smaller line size should also be checked to make sure the system is optimized

Pressure Relief Devices

Example: Rupture Disk Sizing

Determine rupture disk capacity for 100% vapor flow system.

a) Step 1—Determine required information.

MAWP = 100 psig;

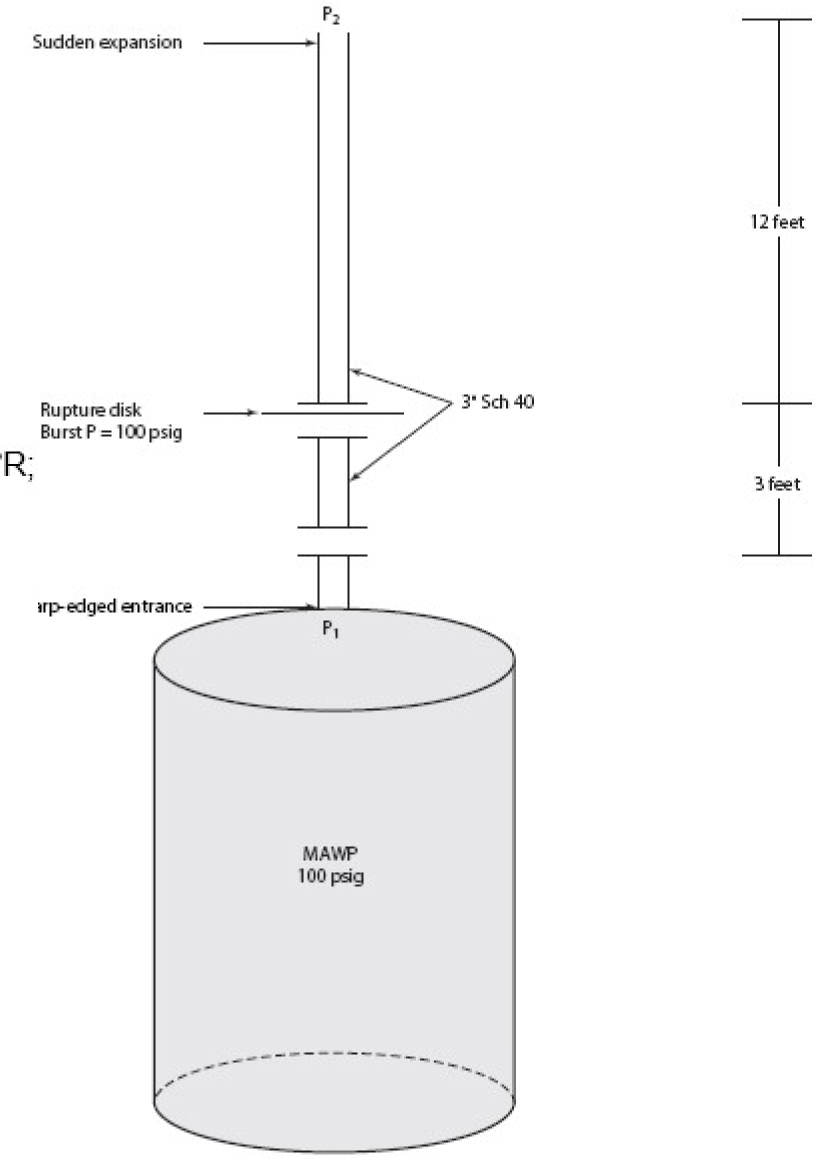
P_1 = relieving pressure = 110 % = 124.7 psia;

T_1 = relieving temperature = 200 °F + 460 °F = 660 °R;

Z_1 = relieving compressibility = 1.0;

M = molecular weight = 20;

P_2 = backpressure = 14.7 psia.



b) Step 2—Determine overall piping resistance factor, K, from Table E.1.

Table E.1—Determination of Overall Piping Resistance Factor, K

Description	K Value	Source of K Value Data
Sharp-edged Entrance	0.50	Crane [17], Page A29
Rupture Disk	1.50	Consult the rupture disk manufacturer
15 ft NPS-3 Schedule 40 Pipe	1.04	$K = \frac{fL}{D}$ $f = 0.0178$ $L = 15$ ft $D = \frac{3.068}{12} = 0.2557$ ft
Sudden Expansion	1.00	API 521, Table 12
Total System K	4.04	

c) Step 3—Determine Y_{sonic} and $\frac{dP_{sonic}}{P_1}$ based on total system K.

This step is based on the Crane 410 Chart A-22 Method [17] for obtaining Y_{sonic} and $\frac{dP_{sonic}}{P_1}$. From the chart and table on A-22, k (C_p/C_v) = 1.4.

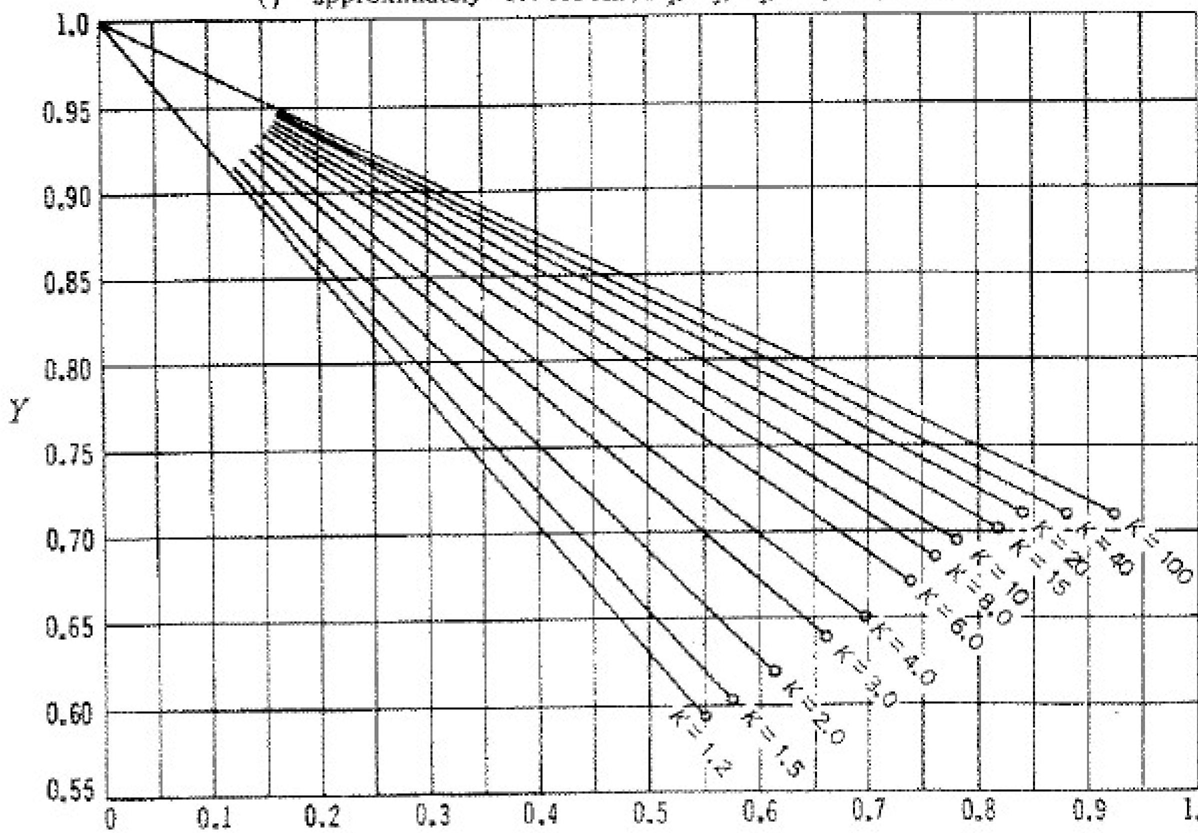
$$Y_{sonic} = 0.653$$

$$\frac{dP_{sonic}}{P_1} = 0.70$$

Pressure Relief Devices

$\gamma = 1.4$

(γ = approximately 1.4 for Air, H_2, O_2, N_2, CO, NO, and HCl)



$\dfrac{\Delta p}{p'_1}$

Limiting Factors For Sonic Velocity

$\gamma = 1.4$

K	$\dfrac{\Delta p}{p'_1}$	Y
1.2	.552	.588
1.5	.576	.606
2.0	.612	.622
3	.662	.639
4	.697	.649
6	.737	.671
8	.762	.685
10	.784	.695
15	.818	.702
20	.839	.710
40	.883	.710
100	.926	.710

$$\frac{\Delta p}{p'_1} = \frac{\Delta P}{P'_1}$$

Pressure Relief Devices

d) Step 4—Compare $\frac{dP_{sonic}}{P_1}$ to $\frac{dP_{actual}}{P_1}$.

$$\frac{dP_{actual}}{P_1} = \frac{(124.7 - 14.7)}{124.7} = 0.88$$

Since $\frac{dP_{sonic}}{P_1} < \frac{dP_{actual}}{P_1}$, the flow will be sonic (critical). Use Y_{sonic} and $\frac{dP_{sonic}}{P_1}$

f) Step 6—Calculate capacity based on Crane 410, Equation (3-20):

$$W = 0.9\left(1891 \times Y \times d^2 \sqrt{\frac{dP}{K \times V_1}}\right)$$

g) Step 7—Using the Chart Method values and Equation (E.6):

1) $Y = Y_{sonic} = 0.65$;

2) d = pipe ID (in.) = 3.068 in.;

3) $dP = \left(\frac{dP_{sonic}}{P_1}\right)(P_1) = 87.3 \text{ psi}$;

4) K = overall resistance = 4.04;

5) V_1 = vapor specific volume = 2.84 ft^3/lb (Obtained using ideal gas law and compressibility).

$$W = 0.9\left(1891 \times 0.65 \times 3.068^2 \sqrt{\frac{87.3}{4.04 \times 2.84}}\right) = 28{,}700 \text{ lb/hr}.$$

Pressure Relief Devices

Rupture Disk (Sizing)

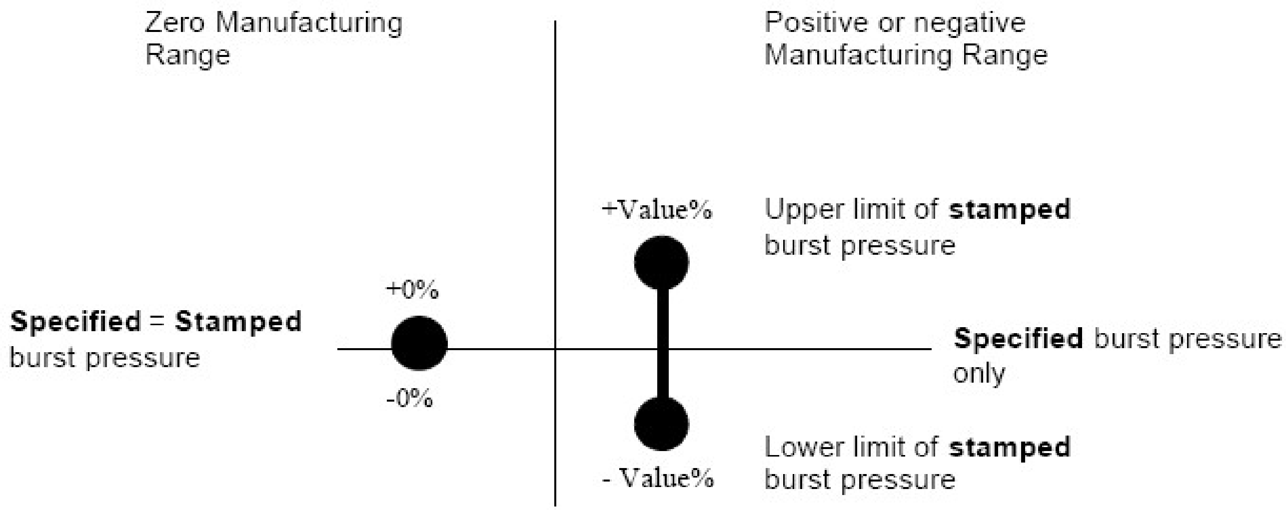
Coefficient of Discharge Method (not recommended)

- The rupture disk is treated as a relief valve with the flow area calculated utilizing relief valve formulas and a fixed coefficient of discharge, ‘Kd’, of 0.62.
- In order to use this method to size the rupture disk ALL of the following four conditions MUST be met (Per ASME SECVIII, Div 1) :
  - The rupture disk must be installed within 8 pipe diameters of the vessel.
  - The rupture disk discharge pipe must not exceed 5 pipe diameters.
  - The rupture disk must discharge directly to atmosphere.
  - The inlet and outlet piping is at least the same nominal pipe size as the rupture disk.

Pressure Relief Devices

Rupture Disk

- Manufacturing Range :



RUPTURE DISC TYPE PRE-SCORED REVERSE BUCKLING PRE-SCORED TENSION-LOADED	TYPICAL MANUFACTURING RANGE, % 0, -5, OR -0
P_b, psig (kPa gage)	
20 to 45 (138 to 310)	-7/+14
46 to 90 (311 to 620)	-6/+12
91 to 270 (621 to 1860)	-5/+10
271 to 500 (1861 to 3450)	-4/+8
above 500 (above 3450)	-3/+6

Rupture Disk

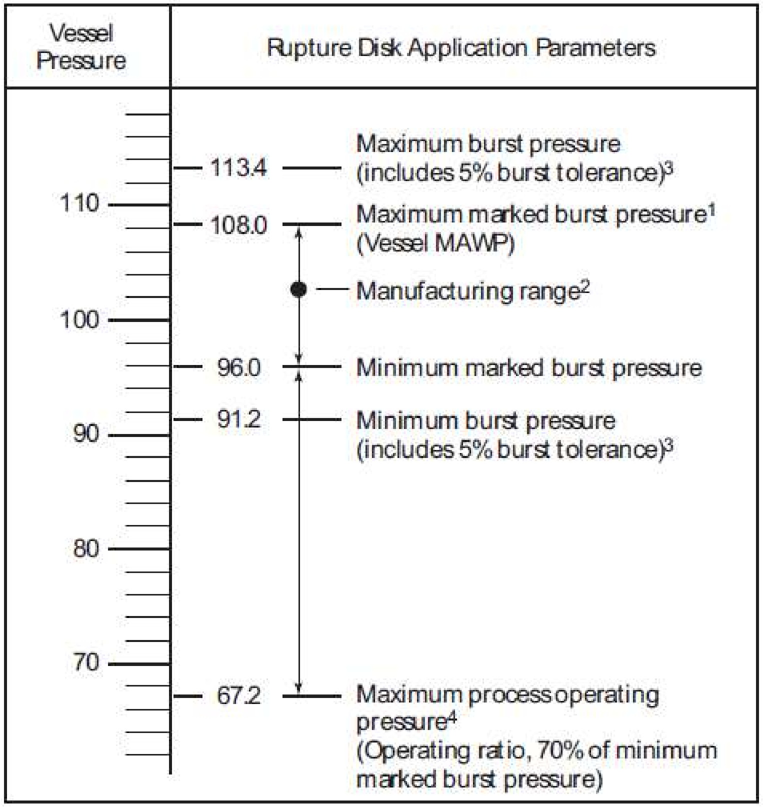
- Operating Ratio (OR):

The operating ratio is defined as the ratio of the maximum operating pressure to the lowest stamped burst pressure.

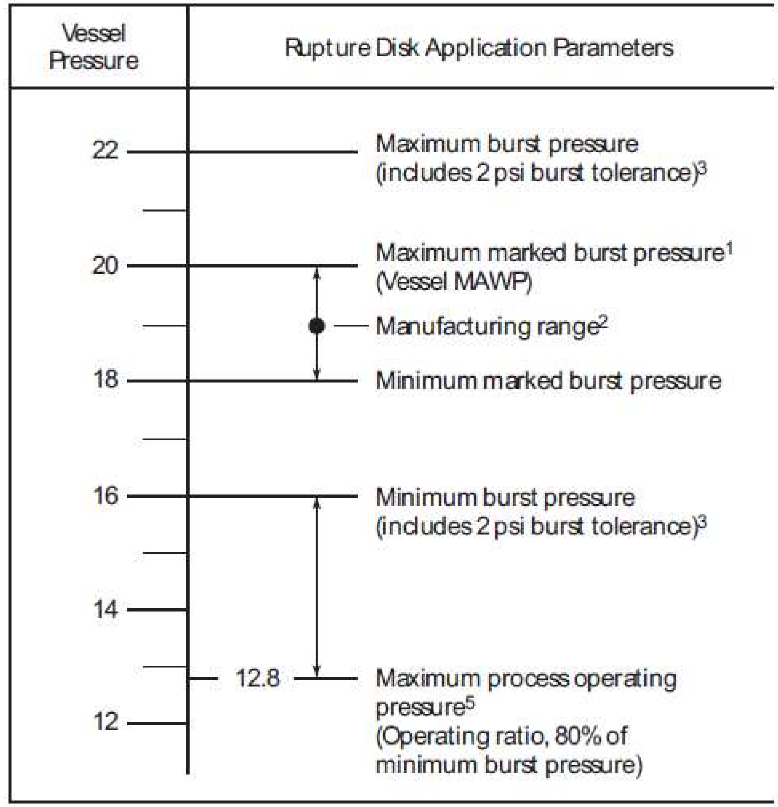
SERVICE	ACCEPTABLE RUPTURE DISK TYPES	USE LIMITATIONS	MAX. OPERATING PRESSURE[2]
Gas, Vapor, or Two-Phase	Pre-scored Conventional (Tension-Loaded) Rupture Disc	None	0.85 P_{set}
	Pre-scored (Cross Score Pattern) Reverse Buckling Rupture Disc	None	0.90 P_{set}
	Semi-circular Score Reverse Buckling Rupture Disc in special disc holder (such as the BS&B Model CSR-7RB)	None	0.90 P_{set}
	Semi-circular Score Reverse Buckling Rupture Disc in conventional disc holder (such as the BS&B Model CSR-7RS)	Not under a PR Valve	0.90 P_{set}
Liquid (only) or Combinations	Pre-scored Conventional (Tension-Loaded) Rupture Disc	None[1]	0.85 P_{set}
	Semi-circular Score Reverse Buckling Rupture Disc in special disc holder (such as the BS&B Model CSR-7RB)	None[1]	0.90 P_{set}
	Semi-circular Score Reverse Buckling Rupture Disc in conventional disc holder (such as the BS&B Model CSR-7RS)	Not under a PR Valve[1]	0.90 P_{set}

Pressure Relief Devices

Rupture Disk-Example

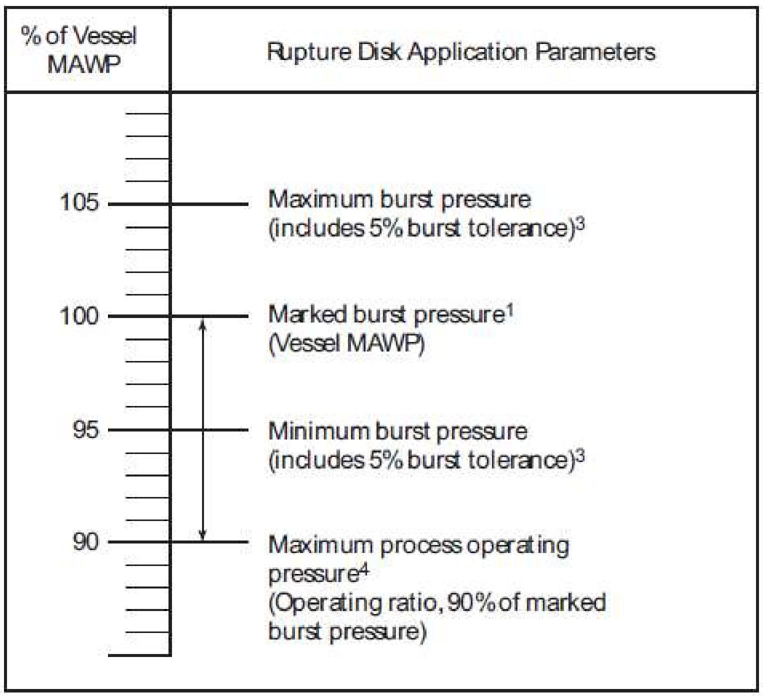


A. Example of a rupture disk with a specified burst pressure of 100 psig, manufacturing range of +8/-4%, burst tolerance of ± 5%, and a 70% operating ratio.



C. Example of a rupture disk with a specified burst pressure of 20 psig, manufacturing range of +0/-10%, burst tolerance of ± 2 psig, and an 80% operating ratio.

Rupture Disk-Example



B. Example of a rupture disk with a specified burst pressure of 100 psig, zero manufacturing range, burst tolerance of ± 5%, and a 90% operating ratio.

NOTE

1. See Figure 18 for limits on marked burst pressure.

2. Marked burst pressure may be any pressure within the manufacturing range, see Figure 27.

3. For marked burst pressures above 40 psig, the burst tolerance is ± 5%. For marked burst pressures at 40 psig and below, the burst tolerance is ± 2 psi.

4. For marked burst pressures above 40 psig, the maximum process operating pressure is calculated by multiplying the minimum marked burst pressure by the operating ratio.

5. For marked burst pressures at 40 psig and below, the maximum process operating pressure is calculated by subtracting the burst tolerance from the minimum marked burst pressure, then multiplying the difference by the operating ratio.

Pressure Relief Devices

Rupture Disk

- Temperature:

  The burst pressure of a rupture disc is a function of the temperature the disc experiences when it bursts.

  The sensitivity of the disc burst pressure to temperature depends on the material used

  Rupture disc temperature is a critical parameter since, in most instances, the disc is installed at the end of a piping section where there is normally no flow.

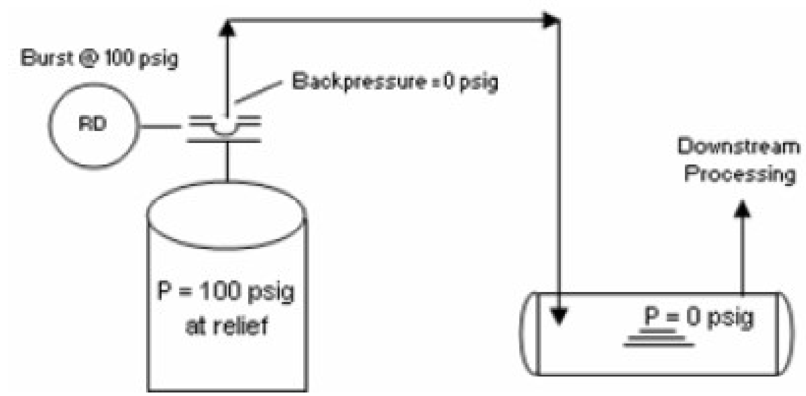
- In general, burst pressure varies inversely with temperature. For some rupture disks, the burst pressure can be as much as 15 psi greater than stamped if the actual temperature is 100°F lower than specified

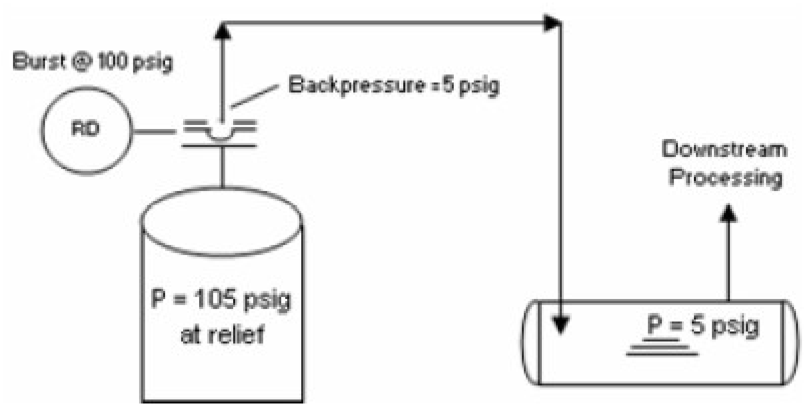
Pressure Relief Devices

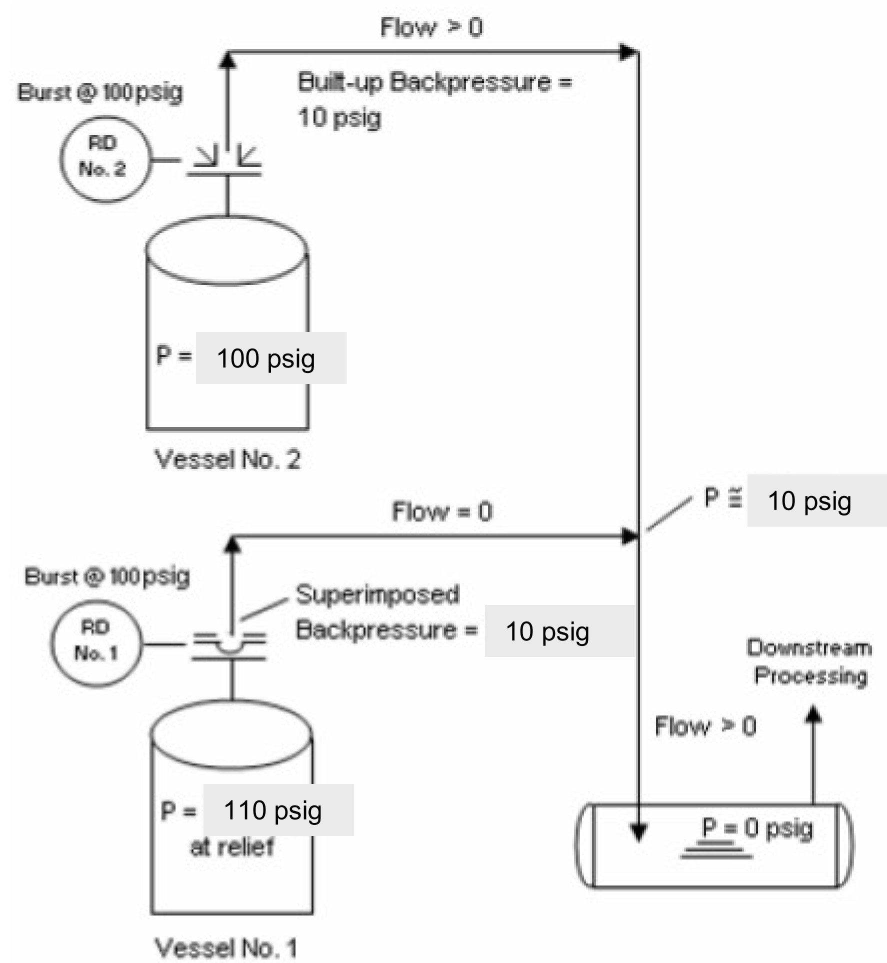
Rupture Disk

- Effect of Back Pressure :

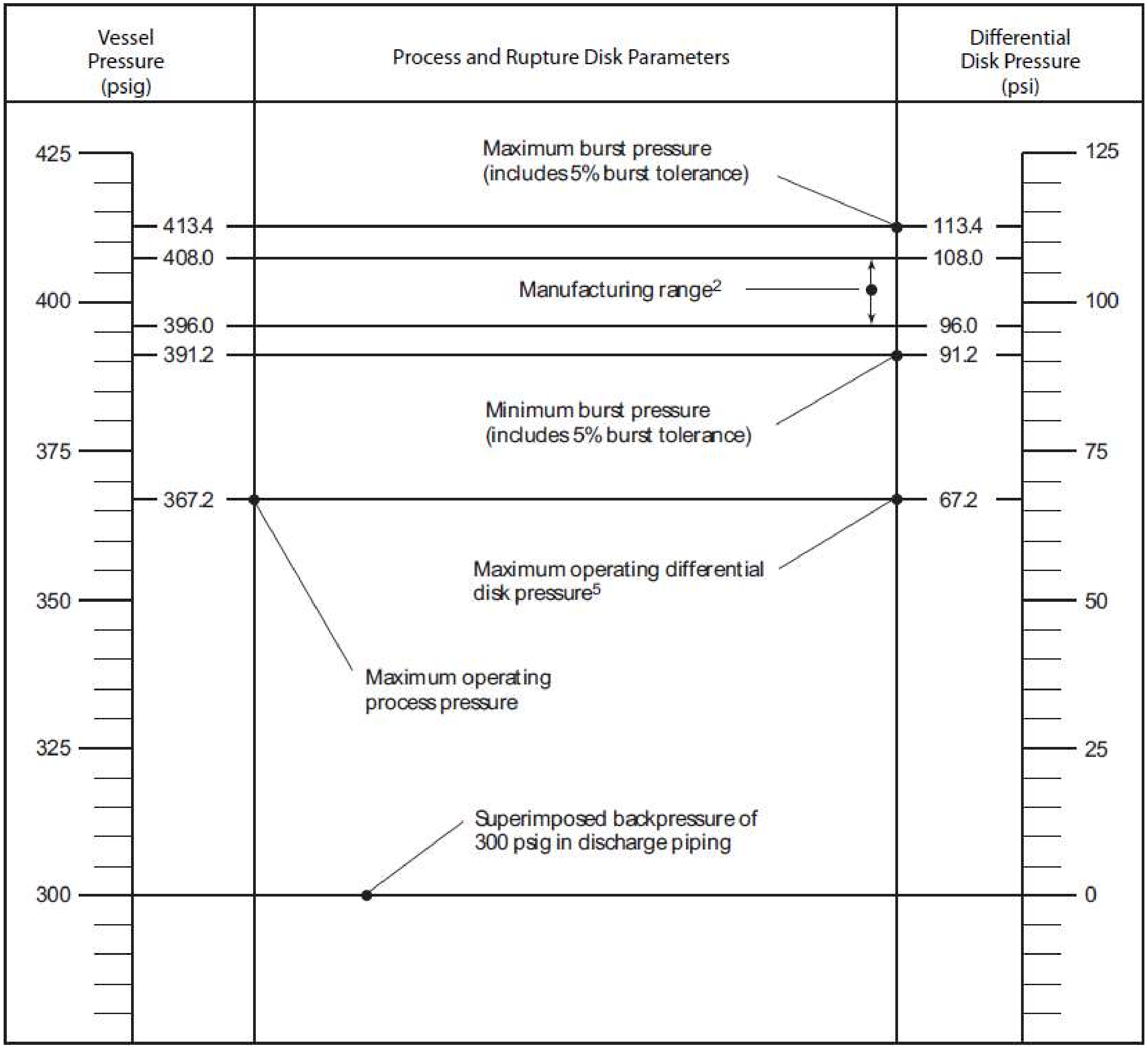
$$P_{burst} = P_{vessel} - P_{backpressure}$$







Rupture Disk-Effect of Back Pressure Example



a. Specified burst pressure of 100 psi.
b. Manufacturing range of +8/-4%.
c. Burst pressure tolerance of ± 5%.
d. Operating ratio of 70% (0.7 x 96.0 psi = 67.2 psi).
e. Superimposed backpressure of 300 psig.
f. Vessel MAWP equal to or greater than 408 psig.

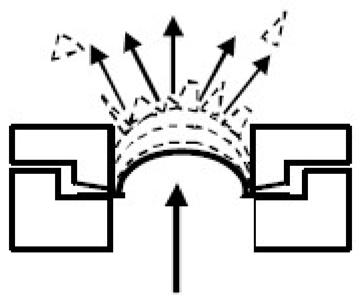
Pressure Relief Devices

Rupture Disk

- Type of Rupture Disks :

  This rupture disk typically has an angular seat design and provides a satisfactory service life when operating pressures are up to 70 % of the marked burst pressure of the disk (70 % operating ratio).

  These disks have a random opening pattern and are considered fragmenting designs that are not suitable for installation upstream of a PRV.



Process Side

-Forward-acting Solid Metal Rupture Disk

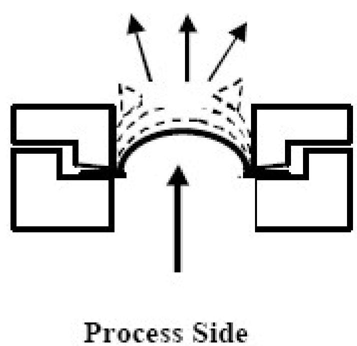
Pressure Relief Devices

Rupture Disk

- Type of Rupture Disks :

  Some designs provide satisfactory service life when operating pressures are up to 85 % to 90 % of the marked burst pressure of the disk (85 % to 90 % operating ratio).

  Because the score lines control the opening pattern, this type of disk can be manufactured to be non-fragmenting and is acceptable for installation upstream of a PRV.



Forward-acting Scored Rupture Disk

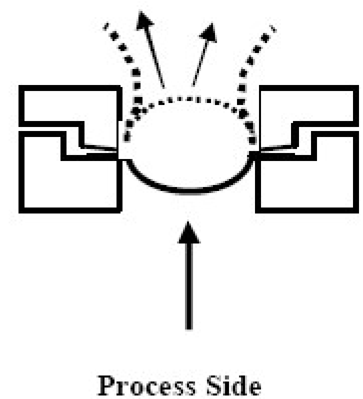
Pressure Relief Devices

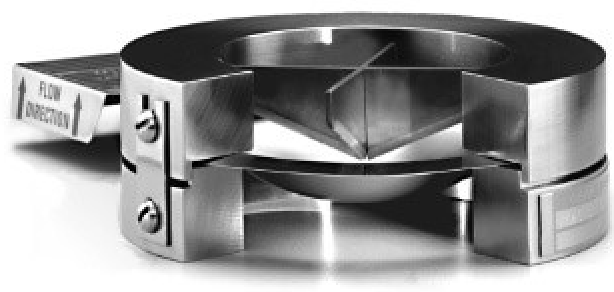
Rupture Disk

- Type of Rupture Disks :

Reverse-acting rupture disks may be manufactured as non-fragmenting and are suitable for installation upstream of PRVs. These disks provide satisfactory service life when operating pressures are 90 % or less of marked burst pressure (90 % operating ratio).

Because a reverse-acting rupture disk is operated with pressure applied on the convex side, thicker disk materials may be used, thereby lessening the effects of corrosion, eliminating the need for vacuum support, and providing longer service life under pressure/vacuum cycling conditions and pressure fluctuations.





-Reverse-acting Rupture Disk

Pressure Relief Devices

Inlet Of PRVs Pressure Drop

- When a pressure-relief valve is installed on a line directly connected to a vessel, the total non-recoverable pressure loss between the protected equipment and the pressure-relief valve should not exceed 3 percent of the set pressure of the valve.

- The pressure loss should be calculated using the rated capacity of the pressure-relief valve.

- In cases involving incompressible fluids (i.e., a subcooled liquid that does not flash prior to or within the pressure relief valve) where the flow through a liquid-trim pressure relief valve is physically limited to the relief requirement, the pressure loss may be calculated using the required relief rate.

- Examples of cases where flow is physically limited include hydraulic expansion of an isolated liquid in a small volume or flow directly from a pump.

- NONRECOVERABLE losses is mainly the line frictional loss exclude the static pressure loss.

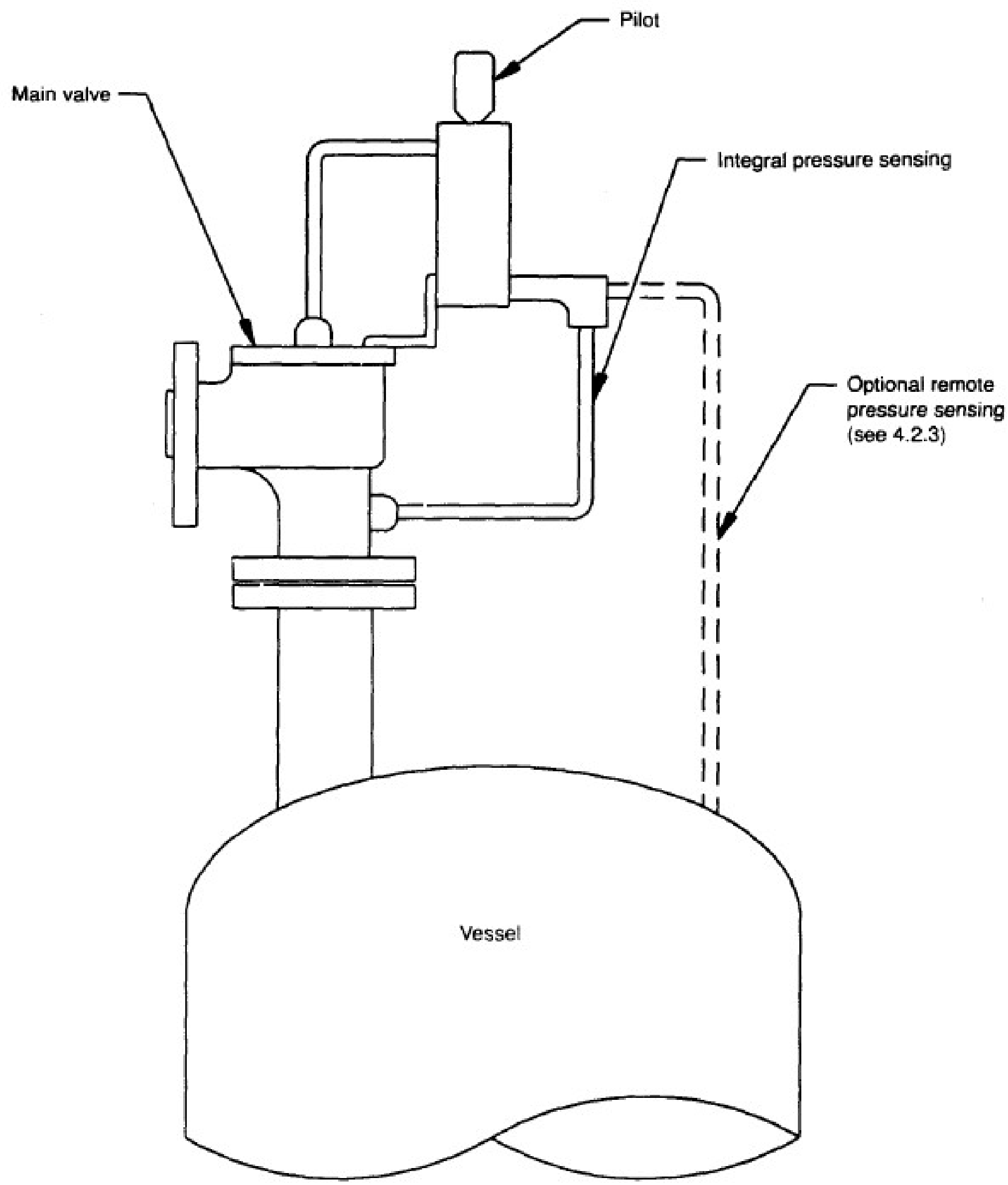
Pressure Relief Devices

<u>Inlet Of PRVs Pressure Drop</u>

- If the initial inlet configuration results in excessive frictional loss, the following options can be considered as a next step:

  1. Pressure losses can be reduced by rounding the entrance to the inlet piping, by reducing the inlet line length, or by enlarging the inlet piping.
  2. Change valve selection for lower orifice/inlet area ratio valve(s) which still meet relief load requirements.
  3. Change to pilot operated valve with remote sensing.
  4. Change to modulating pilot valve to reduce flow used for calculation.
  5. Obtain vendor agreement to exceed 3% guideline.

Pressure Relief Devices



Pilot Operated Valve with remote sensing