

RELIEF SYSTEMS HANDBOOK

Cyril E Parry



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Cyril F. Parry

(IChemE Industrial Fellow)

Cyril Parry was one of the first graduates in chemical engineering at the University of Cambridge, where he studied under Terence Fox and two past Presidents of IChemE, Ernest Sellers and Peter Danckwerts.

The first part of his industrial career was spent in technical development and engineering management in the petroleum refining and synthetic rubber industries. During the second part he worked in process design in the engineering constructing business, where his speciality was the design of offsites and utilities for petroleum refineries and chemical plants.

He opted for early retirement in 1988 to devote more time to writing and consultancy.

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PREFACE

The Institution's Engineering Practice Committee (EPC) recognised a gap in the published literature on relief system design, operation and maintenance. This is in contrast to the extensive theoretical treatment available for sizing of reliefs and relieving rates which culminated in the DIERS work. To remedy this situation the EPC established an Industrial Fellowship whose terms of reference were:

- (1) To identify the types and varieties of relief devices, their relative reliabilities and their applications to specific circumstances. In particular to review the criteria used in deciding between the different devices, especially between relief valves and bursting discs.
- (2) To study the methods used to define the total relief systems for different applications, their installation, testing and maintenance. This includes containment systems, common venting, flaring and blowdown, vent side protection, access for maintenance and instrumentation.
- (3) To study the criteria used for vacuum protection of vessels provided with pressure relief.
- (4) To review data on the reliability of the various types of relief systems.
- (5) To review the performance of relief valves in practice, such as two-phase flow, high temperature and liquids containing solids, with reference to case studies.
- (6) To review recommended maintenance procedures for relief devices and users' practices, and to summarise current codes of practice for testing and maintenance.
- (7) To review and compare current methods for sizing relief systems when vessels are engulfed in fire.

The Fellowship received substantial support from the HSE and industry and was directed by a Steering Committee, the members of which are listed overleaf.

Mr Cyril F. Parry, formerly Principal Process Engineer with Foster Wheeler Energy Limited, was appointed Industrial Fellow to carry out the work which led to the publication of this handbook.

The Institution acknowledges with gratitude the work of the Fellowship, the Steering Committee, the HSE and the support of the sponsoring companies.

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1. INTRODUCTION

One of the most hazardous situations that can arise in the chemical process industry is the subjection of a closed system to a pressure higher than that for which it was designed. This can be caused by maloperation, instrument failure, external fire, thermal expansion, exotherm or some other reason. If the system is not protected, the overpressure may lead to a catastrophic failure of the system causing mechanical damage, loss of valuable material, emission of toxic chemicals and possibly loss of life.

It is therefore a prime responsibility of the process engineer to ensure that his or her process plant is adequately designed for the expected pressure and temperature conditions; and that any equipment under pressure is protected by a reliable pressure relief device that will limit the pressure rise to a permissible level. Following installation, the device must be carefully maintained to ensure that it continues to work effectively throughout its service life.

The pressure relief system may be considered in three separate parts: the pressure relief device itself, its connection to the equipment which it protects, and the disposal arrangement downstream of the relief device.

The purpose of this handbook is to advise on some of the most difficult aspects of the relief system: the choice of relief device and the selection of the disposal or containment system; and to discuss the reliability and maintenance of the chosen system. The sizing of the relief device is outside the scope of this handbook, but Section 1.6 considers the philosophy of relief with some further guidance in Appendices 1.4 and 1.5.

The terms of reference are quoted in the Preface whilst the scope of the handbook and its limitations are outlined in Sections 1.2 and 1.3. Section 1.4 describes the relevant British legislation and Section 1.5 deals with the application of Codes and Standards.

1.1 HOW TO USE THE HANDBOOK

The first question is: is pressure or vacuum relief required, or can the vessel be designed to be inherently safe? An inherently safe vessel is one which is designed

to withstand the highest pressure or vacuum to which it can be subjected. This question is discussed in the introduction to Chapter 2.

If pressure relief is essential then selecting the relief device or devices is the next step. The factors governing this selection are described in Chapter 2 with a decision tree in Figure 2.15. Chapter 5 deals with special devices for vacuum relief. The specification of the relief device is considered in Chapter 3 with particular emphasis on the pressure regime.

The selection of the containment or disposal system is treated in Chapter 4 with a decision tree in Figure 4.4.

As mentioned in the introduction, the sizing of the relief device is only discussed briefly in Section 1.6. However, fire relief and thermal relief are considered to be special cases and the sizing of devices for these contingencies is treated in Chapters 6 and 7.

The reliability and performance of relief devices are the subjects of Chapters 8 and 9.

Chapter 10 deals with the installation of relief devices, and Chapter 11 covers their operation and maintenance. Finally, Chapter 12 looks at alternative methods and future developments.

The handbook is primarily a review of the best current engineering practice and does not attempt to predict the short or long term future of relief systems. Some alternative methods of overpressure protection are discussed in Chapter 12 but these are not necessarily recommended as a proven replacement for the well-established current methods.

1.2 LIMITATIONS

In order to place some reasonable boundaries on the scope of the handbook the following topics have either been excluded or only treated briefly:

1.2.1 The design of relief systems for exothermic reaction vessels. This is the subject of a forthcoming document by the Design Institute for Emergency Relief Systems (DIERS) and another Institution Industrial Fellowship (see Section 12.4).

1.2.2 Explosion relief for gas, dust and powder systems.

1.2.3 Relief devices for the transportation of hazardous materials.

1.2.4 Special devices, used in conjunction with relief devices, that limit the

size of the relief device. An example of these is the slam shut valves used in the gas industry.

1.2.5 Surge relief devices for long pipelines.

1.2.6 Calculations of relief discharge rates.

1.3 TERMINOLOGY

As may be expected from the long history of pressure relief and the international nature of the industry, the terminology has evolved gradually and can be confusing.

The British Standards Institution has devoted some effort in BS 6759 to defining the common terms for pressure relief and these definitions are used in this handbook. In particular, as explained in Section 2.1, no distinction is made between safety valves and relief valves; the common term 'safety valves' is used throughout.

Process engineers who have grown familiar with the terms used by the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME) should take careful note of the BSI definitions.

A glossary of terms can be found at the end of the handbook.

1.4 LEGISLATION

Although the engineer's first responsibility is to design safe and reliable plant, he or she should also know what the law has to say. This applies equally outside the UK.

In the UK relevant legislation is contained in the following statutory documents:

- Factories Act (1961);
- Health and Safety at Work Act (1974);
- Control of Pollution Act (1974);
- CIMAH Regulations (1984);
- The Pressure Systems Regulations (1989) (see Note 1.3).

1.4.1 FACTORIES ACT (1961)

The Factories Act (1961) has been the controlling legislation for the past thirty years. After 1 July 1994 the requirements of the Factories Act for the protection

and inspection of certain types of pressure vessels will be replaced by the provisions of the Pressure Systems Regulations (1989) (see Section 1.4.5).

1.4.2 HEALTH AND SAFETY AT WORK ACT (1974)

The Health and Safety at Work Act places upon employers the duty to provide a safe workplace and safe systems of work. It requires of designers that any equipment installed in a place of work shall be safe and without risk to health. The specific requirements of this Act are set out in Appendix 1.2 (Note 1.1).

1.4.3 CONTROL OF POLLUTION ACT (1974)

The Control of Pollution Act requires the best practicable means for preventing the emission of noxious or offensive substances into the atmosphere and for rendering harmless and inoffensive any such substances that may be emitted.

1.4.4 CONTROL OF INDUSTRIAL MAJOR ACCIDENT HAZARDS REGULATIONS (1984)

The CIMAH regulations, as they are known, require certain manufacturers as defined in the Regulations to prepare a written report and send it to the HSE. Guidance on the content of the report is given in Schedule 6 to the Regulations (Appendix 1.3).

Amongst other matters the report should identify the types of major accident that might occur. The report should deal with the measures taken to control, prevent or minimise the consequences of any major accident. The report should also give information about the arrangements made to ensure that the means provided for safe operation of the industrial activity are properly designed, constructed, tested, operated, inspected and maintained.

Clearly safety reports submitted in compliance with the CIMAH Regulations will have to consider relief systems as these are an essential part of safe operation.

1.4.5 THE PRESSURE SYSTEMS REGULATIONS (1989) (NOTE 1.3)

These regulations are primarily concerned with the mechanical integrity of the pressure containing parts of a plant. They are concerned with all systems containing fluids at a pressure exceeding 0.5 bar g or steam at any pressure.

The intention of the Regulations is to prevent the risk of injury from stored energy in the event of the failure of a pressure system or any part thereof. The Regulations replace and expand upon the limited and outdated provisions of the Factories Act and other legislation (see Appendix 1.1 and Note 1.1).

It is important to recognise that the Regulations do not deal with all the hazards arising from the operation of pressure systems. The contents may be toxic or highly flammable and the plant may be part of a major hazard site. These other hazards are the subject of separate legislation (see Sections 1.4.3 and 1.4.4) and the operator is required to consider them when deciding on the level of protection required for a particular plant. For example, in addition to examinations required by the Regulations, operators may decide to make additional inspections of the plant to search for signs of leakage of toxic or highly flammable fluids.

The Regulations are supported by two Approved Codes of Practice and a Guide published by HMSO for the Health and Safety Executive:

- ACOP Safety of Pressure Systems (ISBN 011 885514 X);
- ACOP Safety of Transportable Gas Containers (ISBN 011 885515 8);
- HS(R)30 A Guide to the Pressure Systems and Gas Container Regulations (1989) (ISBN 011 885516 6).

The Regulations require operators of pressure systems to take several specific actions:

- establish the safe operating limits of the plant;
- prepare a written scheme of examination;
- arrange the examination of plant by a competent person;
- provide adequate operations;
- ensure the plant is properly maintained;
- keep adequate records of the foregoing activities.

The full content of these requirements is described in the legislation and summarised in the Guide HS(R)30 described above.

1.4.6 APPLICATION ABROAD

It cannot be assumed that a relief system design acceptable in the UK is acceptable abroad. Check the regulations and legislation of the country concerned before finalising the design.

1.5 CODES AND STANDARDS

Much of the foregoing legislation is of necessity general in content. For detailed requirements the designer must turn to the relevant codes and standards. Before designing any chemical plant it is essential to establish which codes and standards are applicable and, in case of any conflict, the order of precedence.

The following documents are particularly relevant:

1.5.1 BRITISH STANDARDS INSTITUTION

BS 853 :	1990	Calorifiers and storage vessels
BS 2915:	1990	Bursting discs and bursting disc devices
BS 4434:	1989	Refrigerating appliances
BS 5500:	1991	Pressure vessels (Appendix J)
BS 6759:	1984	Safety valves

1.5.2 AMERICAN PETROLEUM INSTITUTE

API RP 520	Design and installation of pressure-relieving systems in refineries
API RP 521	Guide for pressure-relieving and depressurising systems
API Std 526	Flanged steel safety relief valves
API Std 620	Design and construction of low pressure storage tanks
API Std 650	Welded steel storage tanks for oil storage
API Std 2000	Venting atmospheric and low pressure storage tanks

1.5.3.1 AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ASME Code Section I	Power boilers
ASME Code Section VIII	Unfired pressure vessels

1.5.3.2 INTERNATIONAL GASES COMMITTEE

IGC 24/83	Cryogenic pressure vessels protection devices
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1.5.3.3 COMPRESSED GAS ASSOCIATION

CGA S1.3	Pressure relieving devices
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1.5.4 AMERICAN NATIONAL STANDARDS INSTITUTE

ANSI Std B31.3	Chemical plant piping (Note 1.2)
ANSI Std B31.4	Liquid petroleum piping systems
ANSI Std B31.8	Gas transmission piping systems

1.5.5 INSTITUTE OF PETROLEUM

IP model code of practice:	
Part 3 — Refining safety code	
Part 6 — Pipeline safety code	
Part 9 — Liquefied petroleum gas	

1.5.6 INTERNATIONAL STANDARDS ORGANISATION

It is hoped that eventually most of these standards will be replaced by the international standards of the International Standards Organisation (ISO) and the following may be noted for reference:

ISO 4126 — Safety valves

ISO 5208 — Pressure testing of industrial valves

ISO 6718 — Safety devices for protection against excessive pressure

1.5.7 HEALTH AND SAFETY EXECUTIVE GUIDANCE NOTES

HSG 28 Bulk chlorine installations

HSG 30 Storage of ammonia

HSG 34 Storage of LPG at fixed installations

HSG 39 Compressed air

HSG 40 Chlorine from drums and cylinders

HSG 50 Storage of flammable liquids in fixed tanks

EH 40 Occupational exposure limits 1991

1.5.8 CONFLICTS BETWEEN STANDARDS AND CODES

Fortunately the above codes and standards tend to be complementary, with few notable conflicts. In general, the American standards are applicable to petroleum refinery practice whilst the British Standards are applicable to the chemical process industry.

1.5.8.1 BS 5500 requires that the maximum accumulation of pressure shall be 10% above design pressure. The provision of additional safety valve capacity in the event of fire is the responsibility of the designer.

ASME Code Section VIII requires that the maximum accumulation shall be 10% for all contingencies. For external fire a maximum accumulation of 21% above design pressure is permitted, using a supplementary valve.

1.5.8.2 BS 5500 requires that bursting discs used alone or in series with safety valves shall have a maximum bursting pressure not exceeding the design pressure.

When bursting discs are in parallel with safety valves to protect against rapid increase of pressure, the maximum bursting pressure under BS 5500 shall not exceed 130% of design pressure.

This latter dispensation is not permitted by the ASME code.

1.5.8.3 BS 6759 requires a capacity derating factor of 0.9 for a safety valve installed downstream of a bursting disc (see Section 2.4.2).

ASME Code Section VIII requires a derating factor of 0.8. In both cases, a higher derating factor can be used if a flow test of the combination is carried out.

1.6 RELIEF SYSTEM PHILOSOPHY

This section contains a brief summary of the relief system design method, starting with a list of the contingencies that can cause overpressure and a reference to the methods that can be used to calculate the required relief rate for each contingency. The ruling contingency or contingencies can then be identified, followed by the selection and specification of the relief device and containment system.

1.6.1 CAUSES OF RELIEF SITUATIONS

The causes of overpressure may be classified as follows:

- external fire;
- valve failures;
- ambient fire;
- equipment failures;
- operator errors;
- utility failures;
- instrument failures;
- other effects.

These contingencies and their associated relief rates are considered in a systematic manner in Appendices 1.4 and 1.5. Some of these contingencies can create undesirable vacuum conditions as discussed in Chapter 5.

NOTES

1.1 This appendix contains only selected relevant parts of the legislation. The engineer should be familiar with the complete legislation.

1.2 The full title of ANSI Std B31.3 is Chemical Plant and Petroleum Refinery Piping. This standard has been anglicised and issued as EEMUA 153, replacing BS 3351.

1.3 The full title of this legislation is Pressure Systems and Transportable Gas Containers Regulations (1989).

2. RELIEF DEVICES

A vessel or containment system can be designed to withstand any pressure to which it may be subjected. More usually it is designed to withstand predetermined maximum and minimum pressures (the design pressures) and then provided with a reliable relief device that will protect the system against any pressure outside this range. The relief device should be independent of any pressure measurement or control and ideally should not share the same piping connection. The relief device should only function in the event of some recognised abnormal contingency and should not be required during normal operating modes such as start-up or shut-down.

The most commonly used relief devices are safety valves and bursting discs, either singly or in combination, although there are other devices that can be used in special circumstances.

This chapter describes the relief devices in common use for protection against overpressure, and discusses the criteria that should be applied when selecting an appropriate device. Devices specifically for protection against vacuum, fire and thermal expansion are treated in later chapters.

It is worth remembering that not all tanks and vessels require a dedicated pressure relief device. Only those where the pressure can exceed the design pressure, need a relief device.

For example, tanks operating at atmospheric pressure and vented to atmosphere do not require a pressure relief device other than an adequately sized vent pipe (see Section 2.3.1).

2.1 SAFETY VALVES

The most widely used relief device is the spring loaded safety valve, which has been used since the early days of the steam engine.

The safety valve is also known as the relief valve, safety relief valve, pressure relief valve and pressure safety valve. Although API RP 520 attempts to define these different terms, the British Standards Institution has decided that this is impossible without ambiguity. BS 6759 (1984) describes all mechanical

valves designed for the automatic relief of excessive pressure as safety valves. This handbook follows suit.

To understand the various types of safety valve which may be used for overpressure protection, we need to define some important terms:

SET PRESSURE: The predetermined gauge pressure at which the safety valve commences to lift.

OVERPRESSURE: The increase in pressure above the set pressure as the valve continues to lift. The overpressure is usually expressed as a percentage of gauge set pressure.

RELIEVING PRESSURE: The set pressure plus the overpressure.

BLOWDOWN: The difference between the set pressure and the reseating pressure as the safety valve returns to its normal position of rest. The blowdown is usually expressed as a percentage of set pressure.

BACK PRESSURE: The static pressure existing at the outlet of a safety valve. The back pressure may be superimposed by the flow conditions in the discharge system or built up by the flow from the safety valve through the discharge system.

Other terms are defined in Chapter 3 and in the Glossary.

2.1.1 DIRECT-LOADED SAFETY VALVE (Figure 2.1)

A safety valve in which the loading due to the fluid pressure underneath the valve disc is opposed only by a direct mechanical loading such as a spring, a weight, or a lever and weight. This is the simplest type of safety valve in common use, without any special features to improve its performance. It will normally attain its certified discharge capacity at an overpressure of 10% for gases and vapours and an overpressure of 10% or 25% for liquids.

2.1.2 ASSISTED-OPENING SAFETY VALVE

A direct-loaded safety valve with a power-assisted mechanism which will lift the safety valve at a pressure below the normal unassisted pressure. The power assistance may be pneumatic, hydraulic or electrical solenoid. If this mechanism fails the valve will function at its normal set pressure.

This type of valve may be used for depressurisation down to a predetermined pressure level. It is particularly useful for fire relief service.

2.1.3 SUPPLEMENTARY-LOADED SAFETY VALVE

A safety valve which has an additional force (the supplementary load) on top of the valve disc to increase the sealing force and improve the tightness of the valve seat. The additional force is provided by an external power source (which may be pneumatic, hydraulic or electrical solenoid) which is reliably released when

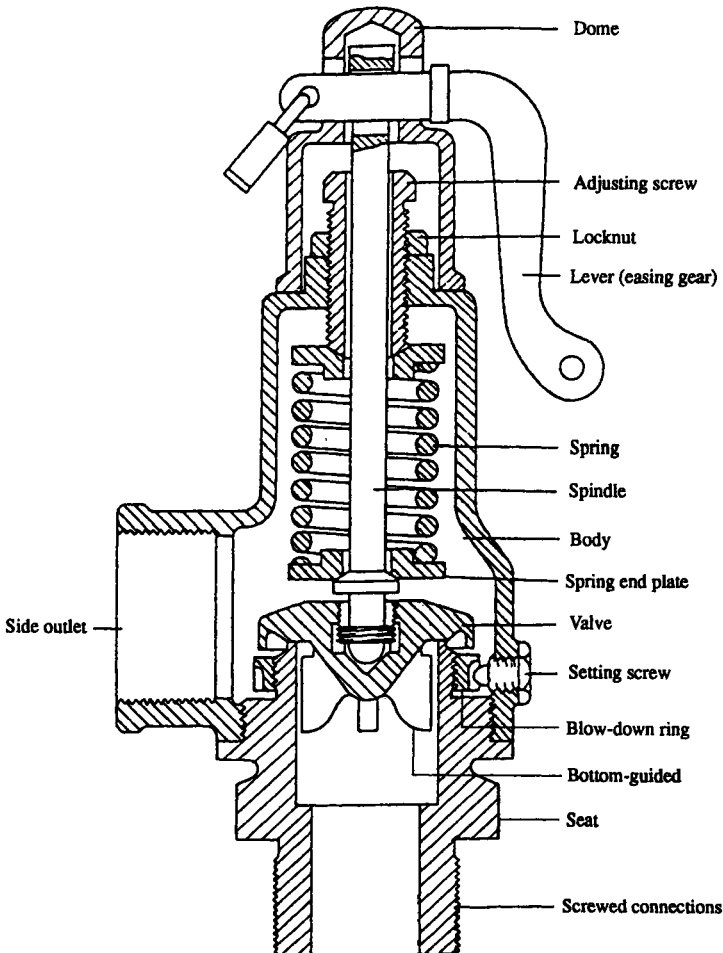


Figure 2.1 Direct-loaded safety valve. (Courtesy of Imperial Chemical Industries Plc.)

the set pressure is reached. This additional force is reapplied, to assist the reseating of the safety valve, when the pressure drops below the set pressure. The amount of supplementary loading is limited such that if by some malfunction the loading is not released at its set pressure, then the certified discharge capacity of the valve will still be reached at an overpressure of 15% (for gases or vapours). This requirement means that the set pressure will frequently be less than the design pressure, so that the relieving pressure does not exceed the maximum allowable accumulated pressure as defined in Section 3.3.

2.1.4 PILOT-OPERATED (INDIRECT-LOADED) SAFETY VALVE (Figure 2.2)

A safety valve which is operated by the movement of a pilot valve which is itself a direct-loaded safety valve as described in Section 2.1.1. In a typical arrangement the seating load of the main valve is provided by the fluid pressure acting over a larger area than the fluid area below the valve disc. When the set pressure is reached the pilot valve opens, releasing the fluid pressure above the main valve disc and permitting the main valve to open.

The main advantage of the pilot-operated safety valve is to reduce the margin between operating pressure and set pressure (see Chapter 3) and to function at low set pressures. Also for a given valve orifice size, the height and weight of the valve are reduced. The main disadvantage is that the pilot valve will only operate satisfactorily in clean service such as steam and water. The small passages of the pilot valve are subject to blockage in dirty service or where solidification or precipitation can occur in the discharge. Reliability and testability can be increased by duplicating the pilot valves, but even so the reliability cannot be guaranteed if the valve loading is provided entirely by the fluid. The modified valve described in Section 2.1.5 is an attempt to make an improvement in this respect.

2.1.5 PILOT-ASSISTED SAFETY VALVE (Figure 2.3 — page 14)

A safety valve which is operated by the movement of a pilot valve where the seating pressure is provided by a combination of fluid pressure and coiled spring. In a typical arrangement the spring contributes some 75% of the total load. In this case, the pilot-assisted safety valve will still function as a direct-loaded safety valve, albeit at a higher relieving pressure, if the pilot fails to open. The pilot-assisted safety valve will also remain closed under vacuum, which is not the case with the pilot-operated safety valve.

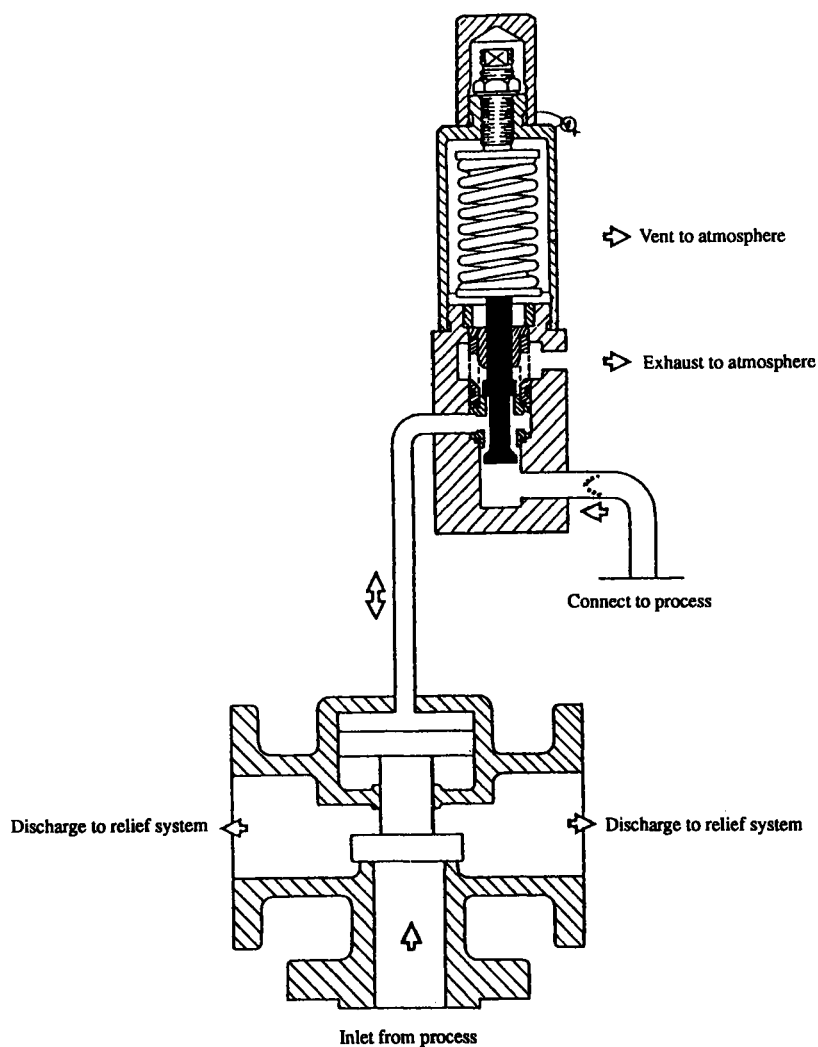


Figure 2.2 Pilot-operated safety valve. (Courtesy of the American Petroleum Institute.)

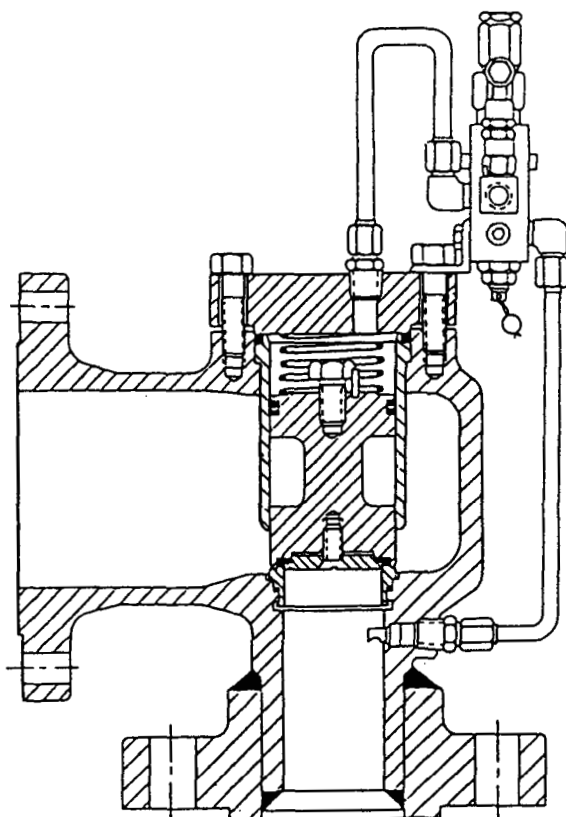


Figure 2.3 Pilot-assisted safety valve.

2.1.6 CONVENTIONAL SAFETY VALVE (Figure 2.4)

A safety valve of the direct-loaded type in which the set pressure is affected by changes in the superimposed back pressure.

This valve is the most commonly used safety valve in the chemical process industry. It is normally a spring-loaded valve with a full nozzle below the seat, an open or closed bonnet around the spring and adjusting rings to vary the blowdown. It is manufactured in fourteen orifice sizes designated by letter D at 9.5 mm diameter (3/8" nominal) to letter T at 146.14 mm diameter (6" nominal), although larger sizes can be made for very large duties. The full list of standard sizes can be consulted in BS 6759.

The valve is normally top-guided as in Figure 2.4 compared with the bottom-guided valve shown in Figure 2.1 (see Section 8.1.1).

Since the top of the valve disc is subjected to the back pressure at the valve outlet, the load imposed by the spring must equal the difference between

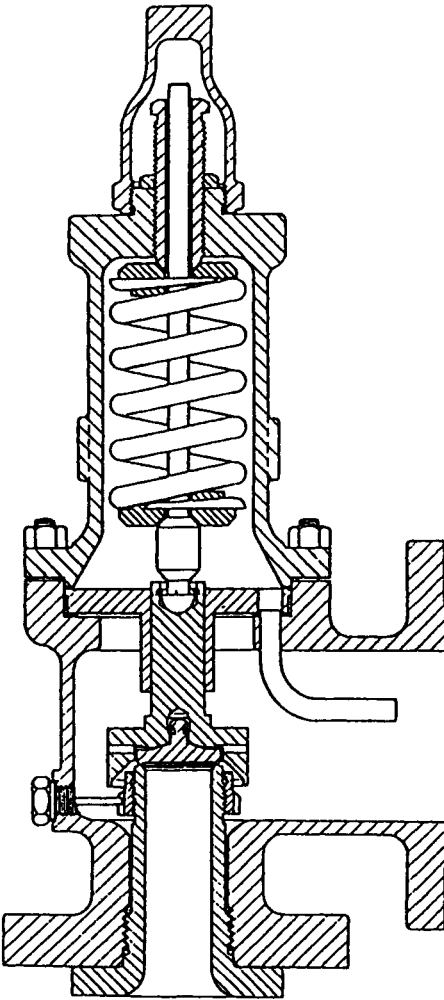


Figure 2.4 Conventional safety valve. (Courtesy of the American Petroleum Institute.)

set pressure and back pressure. If the back pressure varies, the set pressure will also vary, and this can be undesirable.

In view of this last point, the use of conventional safety valves is usually confined to applications where the back pressure does not exceed 10% of the set pressure. When the back pressure exceeds 10% of the set pressure it is recommended to employ a balanced safety valve, which permits back pressures up to 50% of the absolute set pressure (Note 2.9). (These percentages are for guidance only.)

The limits in any particular case will depend on the manufacturer and the relative proportion of fixed and variable back pressure.

2.1.7 BALANCED BELLOWS SAFETY VALVE (Figure 2.5)

A safety valve incorporating a bellows seal which prevents discharging fluid entering the bonnet space. The bellows has an effective area equal to the area of the valve seat so that the effect of back pressure on set pressure is eliminated.

In the event of bellows failure, fluid can enter the bonnet space and escape through the bonnet vent (Note 2.6). It is essential that any flow through the vent should be detected since this will affect the set pressure of the valve. If a sudden bellows failure cannot be tolerated, use a balanced piston or balanced bellows with auxiliary piston.

2.1.8 BALANCED PISTON SAFETY VALVE (Figure 2.6 — page 18)

A safety valve incorporating a piston between the valve disc and the spring. The piston has an effective area equal to the area of the valve seat so that the effect of back pressure on set pressure is eliminated.

A small continuous flow of fluid past the piston into the bonnet is inevitable with this type of valve. This flow should be vented to a safe location at atmospheric pressure.

2.1.9 BALANCED BELLOWS SAFETY VALVE WITH AUXILIARY PISTON (Figure 2.7 — page 19)

A balanced bellows safety valve (see Section 2.1.7) incorporating an auxiliary piston which has an effective area equal to that of the valve seat. In the event of bellows failure the valve will operate as a balanced piston safety valve thus avoiding the disadvantage of the balanced bellows safety valve. The bonnet must still be vented to a safe location.

Section 2.5 describes in more detail how to choose a safety valve.

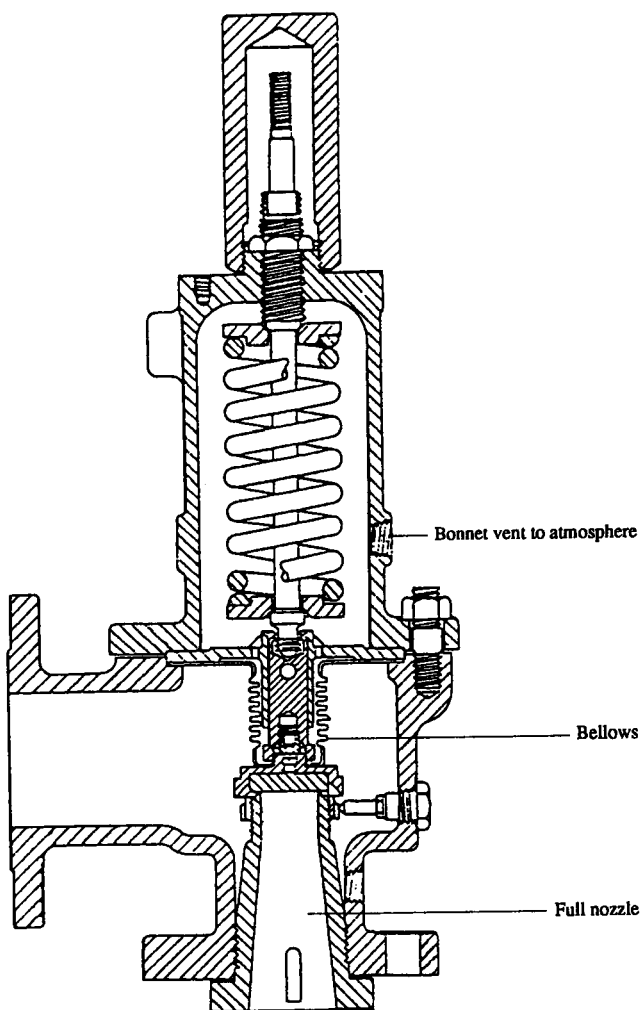


Figure 2.5 Balanced bellows safety valve. (Courtesy of Imperial Chemical Industries Plc.)

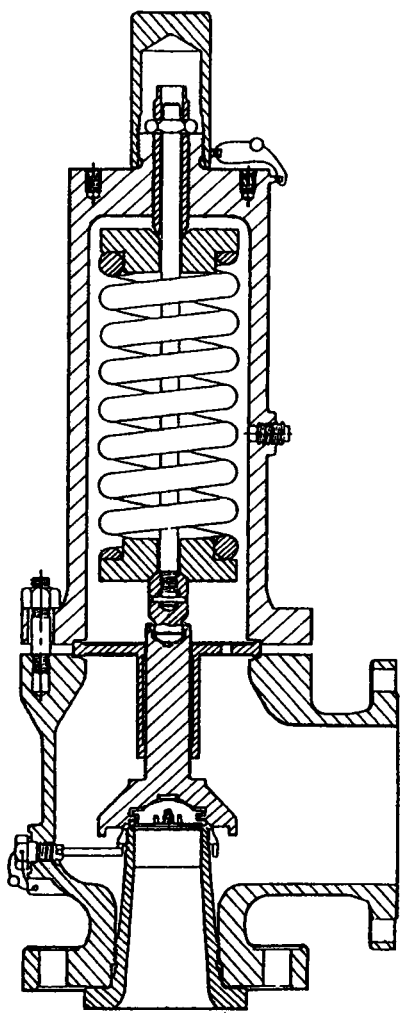


Figure 2.6 Balanced piston safety valve. (Courtesy of Crosby Valve & Eng. Co. Limited.)

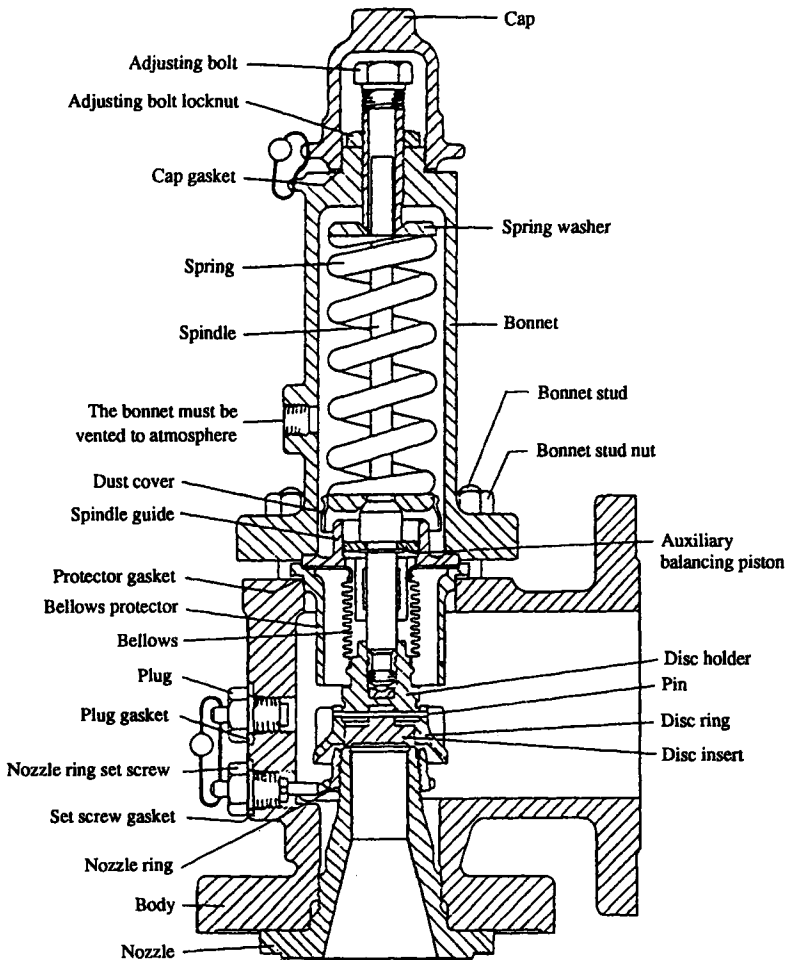


Figure 2.7 Balanced bellows safety valve with auxiliary piston. (Courtesy of Imperial Chemical Industries Plc.)

2.2 BURSTING DISCS

Although the safety valve is the most widely used relief device, in certain circumstances it cannot give complete protection. The bursting disc should then receive full consideration and its selection is treated more fully in Section 2.5.

Briefly, the conditions that favour the bursting disc are:

- rapid pressure rise;
- toxic fluids where no leakage past the safety valve is permitted;
- corrosive fluids that may cause progressive deterioration of the safety valve;
- fluids that may deposit solids or gums that interfere with safety valve operation (Note 2.1).

The bursting disc device completely isolates the operating fluid from the discharge side of the device and this is its main advantage. Bursting discs are also cheaper to buy and maintain than safety valves. On the other hand, the bursting disc is a non-reclosing device and after it has ruptured, the process must be shut down to allow the disc to be replaced (Note 2.2). This disadvantage can be partly overcome by combining a bursting disc with a safety valve, or by using two bursting discs in parallel.

The bursting disc has some other disadvantages:

- it normally requires a larger margin between operating pressure and design pressure;
- pressure pulsations can cause premature failure of the disc if the operating pressure is too close to the bursting pressure;
- being a differential pressure device, a bursting disc is sensitive to changes in back pressure.

There are several types of bursting discs available and some definitions of terminology will help with the descriptions. The definitions are taken from BS 2915: 1990.

BURSTING DISC DEVICE: A non-reclosing pressure relief device actuated by differential pressure and designed to function by bursting or venting of the bursting disc.

BURSTING DISC: The pressure-containing and pressure-sensitive element of a bursting disc device.

BURSTING PRESSURE: The value of the pressure differential across the bursting disc at which a bursting disc device functions.

COINCIDENT TEMPERATURES: The temperature used in conjunction with a bursting pressure.

MAXIMUM (MINIMUM) SPECIFIED BURSTING PRESSURE: The maximum (minimum) pressure quoted with a coincident temperature when specifying

the bursting disc performance. The disc supplied will burst within this range of pressures.

PERFORMANCE TOLERANCE: The difference between the maximum and minimum specified bursting pressure at a coincident temperature.

RUPTURE DISCS, SAFETY DISCS, FRANGIBLE DISCS: Alternative names for bursting discs but not used by BSI.

2.2.1 THE CONVENTIONAL DOMED BURSTING DISC (Figure 2.8)

A bursting disc which is domed with its concave surface facing the bursting pressure and designed to fail in tension.

The conventional domed bursting disc can be either a simple dome or composite slotted. A simple domed disc is of uniform thickness across the

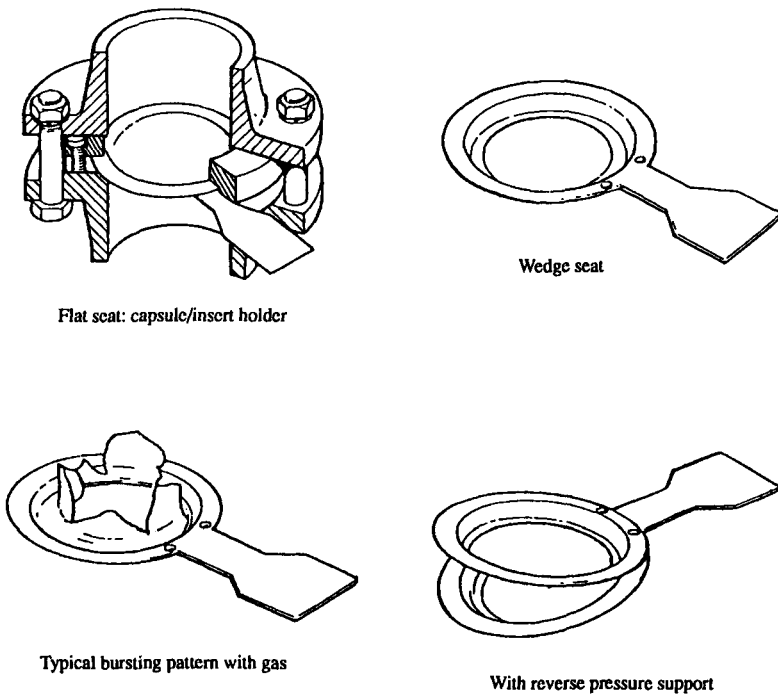


Figure 2.8 Conventional domed bursting disc. (Courtesy of Imperial Chemical Industries Plc.)

diameter, while a composite slotted disc is multi-layered with one of the layers slit or slotted to reduce its strength and control the bursting pressure. The slotted lined disc is more robust than the simple domed type and is less susceptible to damage.

The conventional domed bursting disc fits into a holder. It requires a reverse pressure support if it can be subjected to reverse pressure and is not intrinsically strong enough to withstand the pressure reversal. The reverse pressure support should either be permanently attached to the bursting disc or so designed that it can only be installed on the correct side of the disc.

2.2.2 THE REVERSE DOMED BURSTING DISC (Figure 2.9)

A bursting disc which is domed with its convex surface facing the bursting pressure and designed to fail by buckling, bending or shearing forces.

The failure of the reverse domed bursting disc can be assisted by:

- Knife blades on the downstream side of the disc which cut the disc during reversal of the dome. This method is now out of favour and is not permitted by some large users owing to its unpredictability.
- Prescoring, which forms lines of weakness so that the disc fails along these lines during reversal.
- Slip or tearaway design that fails by being expelled downstream from the holder. A catching device is normally required to capture the debris.

The reverse domed bursting disc is normally several times thicker than the equivalent conventional domed disc and therefore can withstand higher levels of reverse pressure and vacuum without the need for a reverse pressure

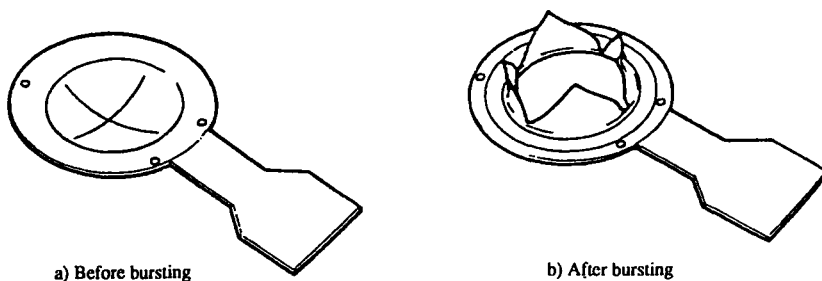


Figure 2.9 Reverse domed bursting disc. (Courtesy of Imperial Chemical Industries Plc.)

support. 'Rollover' of a reverse domed disc is a possible danger with some designs; a slow rise in pressure, or a lowered response pressure due to damage, can reverse the convexity of the disc, without bursting it, so that it becomes a thick conventional disc. The required bursting pressure is then much greater than the certified bursting pressure, with dangerous consequences.

2.2.3 THE FLAT BURSTING DISC (Figure 2.10)

The flat bursting disc can be plane or recessed. When used in conjunction with a separate holder it is known as a replaceable element bursting disc.

2.2.4 MONOBLOC BURSTING DISC (Figure 2.11 — page 24)

A monobloc bursting disc is a recessed bursting disc with an integral holder, normally made of resin-impregnated graphite.

The monobloc can be recessed on the inlet side, the outlet side, or both sides with the smaller recess on the inlet side. It is vital that the correct side of the monobloc faces the process pressure.

2.2.5 GENERAL HANDLING

With all bursting disc devices it is essential to follow the manufacturer's instructions on handling, installation, maintenance and replacement. A bursting disc is a sensitive piece of equipment that can easily be damaged by rough treatment and is frequently installed incorrectly (Note 2.7). Many premature disc failures can be attributed to clumsy handling, incorrect installation or unspecified operation conditions.

For high-temperature applications the bursting disc may be protected by a heat shield.

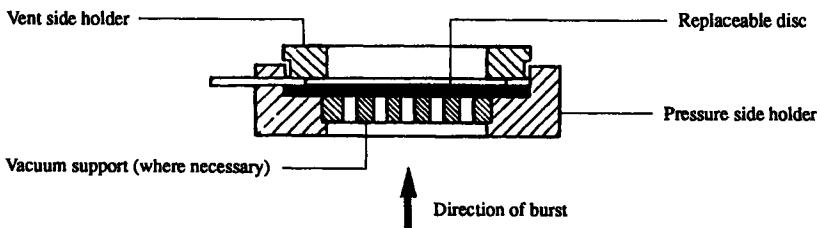


Figure 2.10 Flat bursting disc. (Courtesy of the British Standards Institution.)

2.3 OTHER DEVICES

The relief devices described in Sections 2.1 and 2.2 account for most of the overpressure protection devices used in industry. There are other devices that can be used in special conditions, such as for low pressure storage tanks and explosion protection.

2.3.1 ATMOSPHERIC VENTS

Low-pressure storage tanks containing non-toxic, non-corrosive and non-volatile liquids may be protected by a simple pipe vent to atmosphere. The sizing of the vent is important and should be approached with the same thoroughness as the sizing of a more sophisticated device. The size of the vent should take account of the maximum filling and emptying rate and the

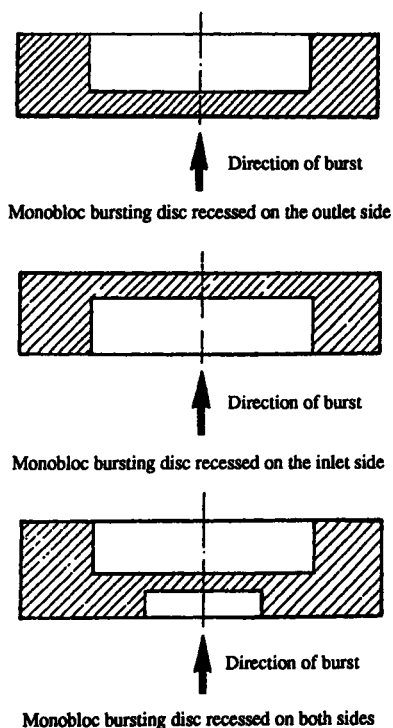


Figure 2.11 Monobloc bursting disc. (Courtesy of the British Standards Institution.)

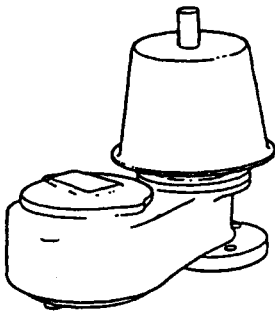
breathing of the tank due to changes in atmospheric pressure and temperature (see API Std 2000).

Some storage tanks are provided with a combined vent and overflow pipe. This practice is definitely not recommended, since the tank vent may be required precisely when the tank is overflowing and the restriction applied by the overflowing liquid will seriously reduce the capacity of the vent.

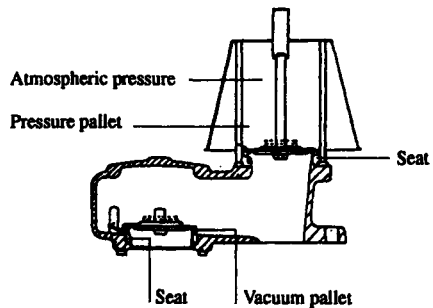
When the tank contents are above their flash point, a flame arrestor is advisable. This advice is amplified in Section 4.4.

2.3.2 PRESSURE/VACUUM (P/V) BREATHER VALVES (Figure 2.12)

For low pressure storage tanks, an improvement on the atmospheric vent is a pressure/vacuum breather valve as supplied by most reputable tank manufacturers.



Operating principle: pressure relief



Operating principle: vacuum relief

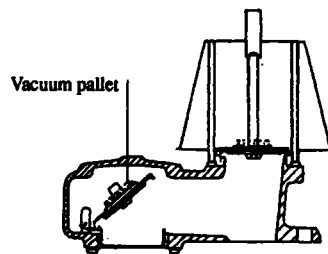
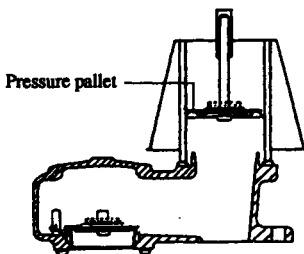


Figure 2.12 Pressure/vacuum breather valve. (Courtesy of Imperial Chemical Industries Plc.)

When the level in the tank is static and atmospheric conditions are constant, the breather valve isolates the tank contents from the atmosphere. If the equilibrium is disturbed and the tank pressure rises above or falls below the set pressure, the breather valve opens to permit breathing and then reseats when the pressure returns to normal.

Since the sealing force is applied by a dead weight, the P/V breather valve is normally supplied for a fixed set pressure that cannot be adjusted at site. The low pressures involved mean that the seating force is low and tight closure is very difficult to achieve. A flame arrester is not considered necessary with a P/V breather valve since the flame speeds are less than the venting velocity through the valve.

2.3.3 EMERGENCY VENTS

When the emergency discharge capacity required, for instance in the case of fire, is larger than can be conveniently provided by the vent or breather valve, it is customary to provide a low-pressure storage tank with an emergency vent. This is usually designed as a hinged weighted cover that will lift at a slightly greater pressure than the P/V breather valve. It can be combined with a roof manhole cover to save the cost of an extra nozzle.

2.3.4 WEAK ROOF TO SHELL ATTACHMENT

If a large tank has a weak roof to shell attachment as defined by API 650 (ie a single fillet weld less than 3/16" wide) then under emergency conditions the weld will fracture and the whole roof of the tank will lift to relieve the overpressure. In these circumstances an emergency vent is not required.

2.3.5 LIQUID SEAL

A low pressure vessel at ambient temperature can be protected with a liquid seal. The height of the liquid in the leg of the seal connected to atmosphere determines the set pressure. When the vessel pressure (or vacuum) exceeds the set pressure (or vacuum) the liquid seal is blown (or sucked) out and the vessel vents to atmosphere.

It is essential to provide a reliable means of monitoring the level and replenishing the liquid in the seal to allow for evaporation or leakage. When the liquid in the seal is water, the seal must be protected against freezing in winter

conditions. A typical example is the water seal on a flare seal drum (see Section 4.13).

Apart from low pressure relief devices, there are some other specialised relief devices for special applications:

2.3.6 EXPLOSION HATCHES

Explosion hatches may be fitted to vessels, such as fired heaters or furnaces, operating near atmospheric pressure where the risk of sudden explosion exists. An explosion hatch consists of a hinged weighted metal cover placed over a corresponding opening in the vessel. If an explosion occurs, the cover flies open. Explosion hatches are unsuitable for high pressures or pulsating conditions. In the former case the weight of the hatch becomes excessive and in the latter case the hatch will tend to flap and destroy the seal.

2.3.7 EXPLOSION PANELS

Explosion panels may be used instead of explosion hatches. Explosion panels consist of large bursting devices fitted across vessel apertures, and are designed to burst when the set pressure is reached. They provide a better seal than explosion hatches and can operate at higher pressures.

On the other hand, being non-reclosing they are more difficult to replace after bursting.

2.3.8 BREAKING PINS (Figure 2.13 — page 28)

A breaking pin is a mechanical closing device that fails if subjected to excessive pressure, releasing the operating fluid and lowering the pressure. It is obviously a non-reclosing device with the disadvantages of a bursting disc but without some of the advantages.

It is sometimes found in a proprietary device in conjunction with a safety valve. In this combination the breaking pin is upstream of the valve where it protects the valve against corrosion and dirt. It has largely been displaced by the bursting disc and is rarely found today.

However it can still be useful in some high-temperature applications in the range 350–540°C. The disc is replaced by a thin edge seal welded membrane supported on a backing door. When the bursting pressure is reached, the shear pin fails and the door support is removed. The unsupported membrane is then ruptured by a knife edge.

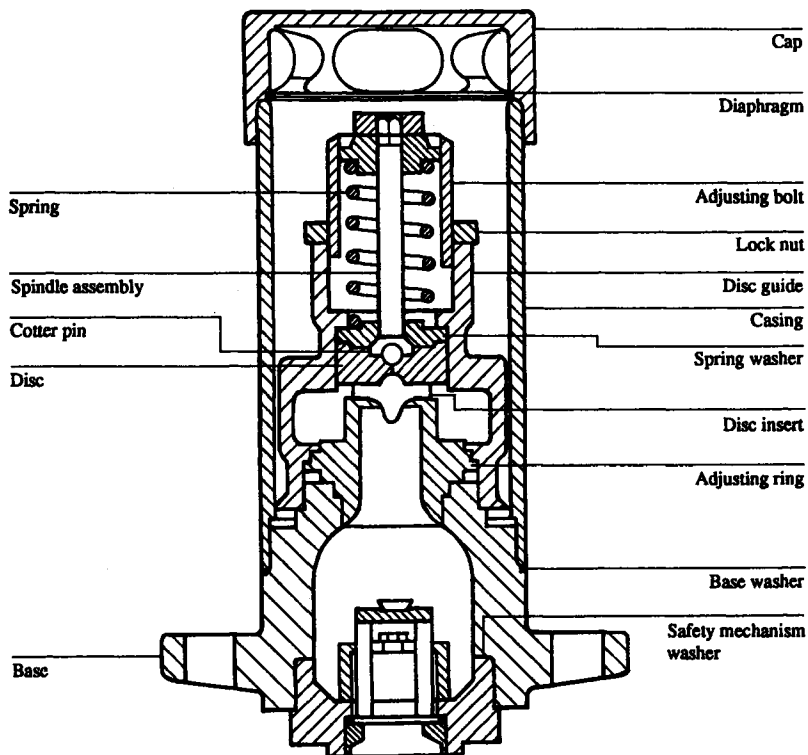


Figure 2.13 Breaking pin. (Courtesy of Crosby Valve & Eng. Co. Limited.)

2.3.9 PRESSURE SURGE DEVICES (Figure 2.14)

There are specialised proprietary devices for the relief of hydraulic pressure surges in long pipelines. Since the pressure surge is a transient phenomenon the relief device must respond rapidly and reliably to relieve the surge and then reclose immediately to prevent major loss of fluid.

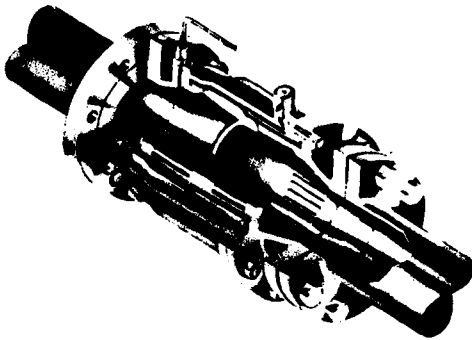
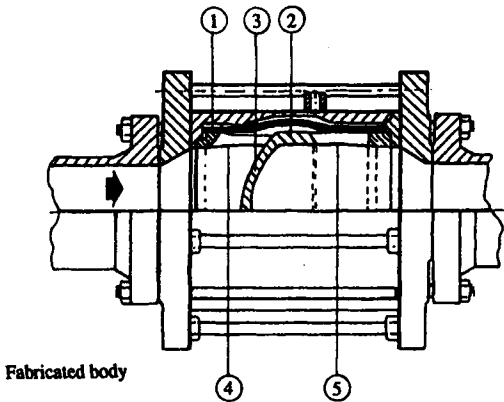


Figure 2.14 Pressure surge relief device. The synthetic rubber tube (1) surrounds, and is stretched upon, a cylindrical metal core (2) containing a series of longitudinal slots separated by a barrier. The flow of incoming fluid is directed radially outward through the inlet slots (4) by the central core barrier (3), expanding the tube and exiting through outlet slots (5). (Courtesy of Grove Valve & Regulator Co..)

2.4 COMBINATIONS OF RELIEF DEVICES

To overcome some of the disadvantages of single relief devices mentioned in Section 2.5 it is permissible to use a combination of relief devices. With few exceptions (eg Section 2.3.8) this will be a combination of a safety valve and a bursting disc. With a combination of relief devices the determination of set pressure and discharge capacity is even more critical than with single devices, and the bursting disc should not adversely affect the operation of the safety valve or impose excess pressure on the protected system.

The combination of safety valve and bursting disc can conveniently be discussed in three alternative arrangements:

2.4.1 SAFETY VALVE AND BURSTING DISC IN PARALLEL

In this combination the bursting disc is provided:

- As an additional safeguard where there is some doubt concerning the efficacy of the safety valve. In this case the disc and safety valve would be sized for the same relief rate and the minimum bursting pressure of the disc would be equal to the set pressure of the safety valve.
- To provide additional discharge capacity, where a larger safety valve may be impracticable or the safety valve is designed for a more likely contingency and the bursting disc is designed for a rare contingency. In this case the set pressure of the safety valve is slightly lower than the minimum bursting pressure of the disc.
- To provide instant pressure relief in case the rise in pressure is too rapid for the safety valve alone (see Note 2.11).

2.4.2 BURSTING DISC IN SERIES UPSTREAM OF SAFETY VALVE

The objective here is:

- to protect the safety valve against conditions in the pressurised system which may be corrosive, fouling or arduous in some other way;
- to prevent leakage through the safety valve; or
- to prevent total loss of contents following a bursting of the disc.

In this combination the following conditions are essential:

- The maximum bursting pressure should not exceed the design pressure of the system being protected (Note 2.8).
- The discharge area of the bursting disc device should not impose any restriction on the inlet to the safety valve.

- The space between the disc and the safety valve should be monitored for any pressure build-up due to leakage in either direction. The monitoring device should be a local pressure gauge as a minimum, but preferably a pressure indicator and an independent high pressure alarm displayed in a permanently manned control room. The space between the disc and the safety valve should also be vented to a safe location. The vent may be fitted with an excess flow valve to prevent loss of contents in the event of a burst (Note 2.3).
- The safety valve inlet should be protected from any debris from a ruptured disc (Note 2.4).
- The discharge capacity of the combination should be reckoned as 0.9 of the certified discharge capacity of the safety valve alone (see Section 1.5.8.3). A higher factor may be permitted if the combination has been type flow tested.

In most cases a bursting disc in series with a safety valve would be installed upstream of the valve. However in exceptional circumstances, eg a clean pressurised fluid but an aggressive discharge system, a bursting disc can be used downstream of a safety valve.

2.4.3 BURSTING DISC IN SERIES DOWNSTREAM OF A SAFETY VALVE

In this case the objective is to protect the safety valve from aggressive conditions in the discharge system and to prevent leakage.

In this combination it is essential that:

- The safety valve should open at its set pressure. This means that the space between safety valve and bursting disc must be monitored and vented (as in Section 2.4.2).
- The maximum bursting pressure of the bursting disc plus any back pressure in the discharge system should not exceed the design pressure of (i) the protected system, (ii) the outlet portion of the safety valve, or (iii) the pipework between the safety valve and bursting disc.
- Fragmentation of the bursting disc should not impair the performance of the safety valve, or any downstream equipment.
- The discharge area of the bursting disc should not impose any restriction on the outlet of the safety valve.
- The contents of the protected system should be clean, to prevent any accumulation of dirt in the space between the safety valve and the disc.
- The safety valve should be the balanced pressure type (see Sections 2.1.7 to 2.1.9).

2.4.4 BURSTING DISCS IN SERIES UPSTREAM AND DOWNSTREAM OF THE SAFETY VALVE

This unusual combination is expensive and consequently should only be used in rare circumstances when the safety valve must be protected from aggressive conditions on both inlet and outlet sides, or where loss of fluid due to weepage through the safety valve cannot be tolerated.

In all combination cases, the manufacturers of both safety valve and bursting disc should be notified and consulted.

2.5 SELECTION OF RELIEF DEVICE(S) (see Figure 2.15)

As explained in 2.3 most pressure relief devices used in industry are safety valves and bursting discs. The other devices described in Section 2.3 are applicable to low-pressure storage tanks, explosion protection and surge relief.

If, therefore, we confine our attention to pressurised systems without explosion risk, the selection process can be restricted to safety valves or bursting discs or a combination of both.

The logic of selection can be treated in two main stages:

- (i) Deciding whether to use a safety valve, a bursting disc or a combination of both.
- (ii) Selecting the type of safety valve or bursting disc.

2.5.1 SAFETY VALVE OR BURSTING DISC? (Figure 2.15)

If there is a completely free choice, use a bursting disc because of its lower cost. Otherwise the process designer must address the following questions:

- (a) Is the expected pressure rise so rapid that the inertia of a safety valve would prevent a satisfactory response (Note 2.10)?
- (b) Is the fluid so toxic that any leakage through a safety valve would not be acceptable?
- (c) Is the fluid so corrosive that the life of the safety valve would be limited?
- (d) Is the fluid likely to produce solids, gums or icing that would impair the operation of the safety valve (Note 2.1)?
- (e) Is the fluid in the discharge system aggressive to the discharge side of the safety valve?

If the answer to all five questions is no, use a safety valve; either a single valve or several valves in parallel to provide the required discharge capacity. If the answer to one or more questions is yes, use a bursting disc either alone or in combination with a safety valve.

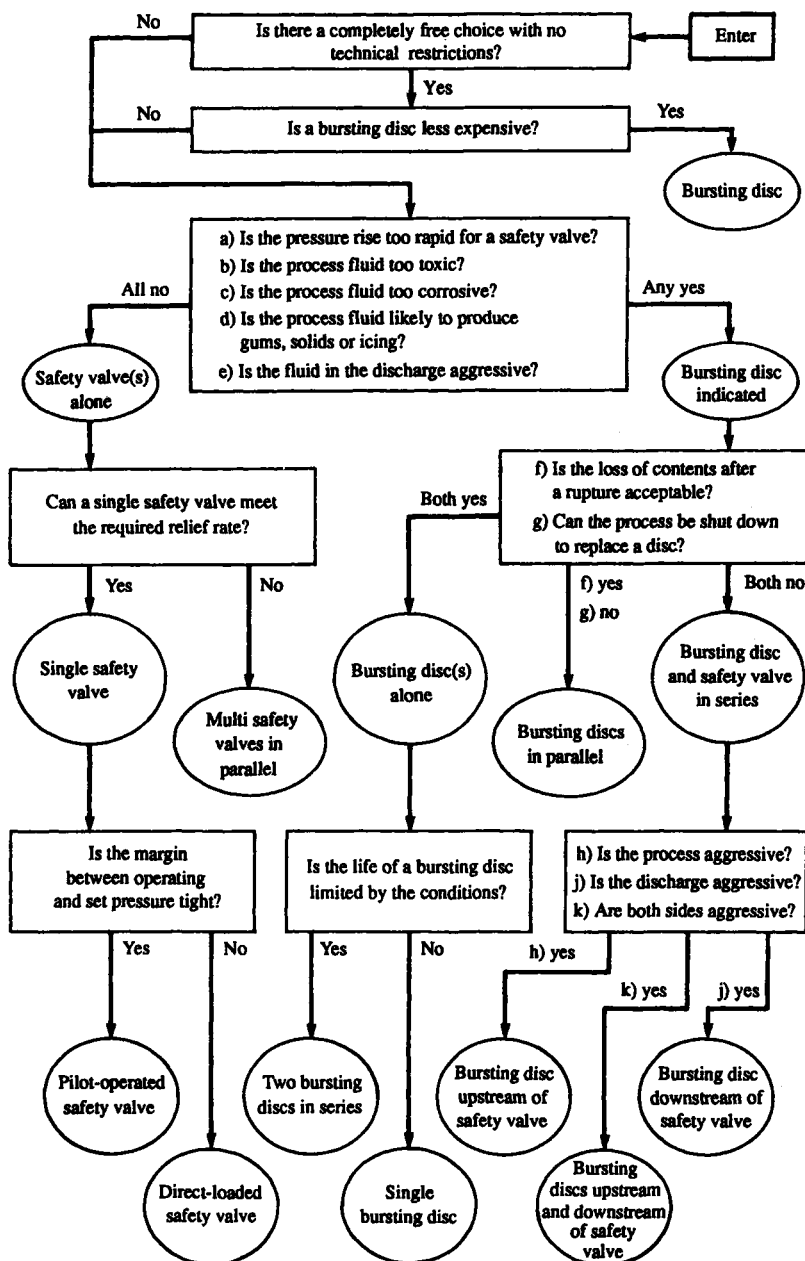


Figure 2.15 Decision tree for selection of relief devices.

Although the questions are simple, the answers require considerable judgement when the conditions are borderline. Consult a reputable safety valve manufacturer before selecting an unprotected safety valve. This consultation should involve preparing a safety valve data sheet (eg BS 6759 Part III page 30) together with a detailed description of the process conditions.

However, providing sufficient data or experience from previous applications is available, it should be possible to decide whether or not to use a bursting disc. Once you have decided to use a bursting disc, you must decide:

- (f) Is the loss of contents acceptable, following the rupture of the bursting disc, both economically and environmentally?
- (g) Can the process be shut down immediately to replace a ruptured bursting disc?

If the answer to both questions is yes, use a single bursting disc. If the answer to (f) is yes but (g) is no, consider two bursting discs in parallel, with interlocked valves. If the answer to both questions is no, use a combination of bursting disc and safety valve. If the process conditions are aggressive and the discharge system is either open or non-aggressive then a bursting disc upstream of a safety valve is preferred. If these conditions are reversed, use a bursting disc downstream of the safety valve. If conditions are unfavourable on both sides, use bursting discs upstream and downstream of the safety valve.

Where the process conditions are so aggressive that the life of a bursting disc is very limited, consider two bursting discs in series. This avoids a discharge in the event that the disc in contact with the process fails prematurely.

Figure 2.15 is a decision tree for the selection process.

2.5.2 CHOOSING A SAFETY VALVE

The main decision of a process designer is whether to employ a conventional or a balanced safety valve. The pressure conditions at the outlet of the safety valve govern this choice.

If the absolute back pressure is variable and it also exceeds 10% of the absolute set pressure, use a balanced safety valve.

The most common balanced safety valve is the balanced bellows type described in Section 2.1.7. The operations of the valve depends entirely on the integrity of the bellows. Failure of the bellows can alter the set pressure, or leak fluid from the process or the containment system into the bonnet of the valve (Note 2.5).

If either contingency is unacceptable, use duplicate valves in parallel so that bellows which have failed can be replaced.

You should also decide:

- is the set pressure very close to the operating pressure?
- is the tightness of the valve a primary concern to eliminate any leakage of process fluid?
- is rapid opening of the safety valve essential?

If the answer to any of these questions is yes, then the following modified valves are advisable:

- pilot-operated (see Section 2.1.4);
- supplementary-loaded (see Section 2.1.3);
- assisted-opening (see Section 2.1.2).

Having made a preliminary selection, consult the safety valve manufacturer, giving full details of the application.

2.5.3 CHOOSING A BURSTING DISC

The type of bursting disc is governed by:

- the position of the bursting disc within the relief system;
- the required working pressure and the bursting pressure;
- whether the temperature and pressure upstream of the disc are steady or pulsating;
- the actual temperature at the disc;
- whether corrosive conditions exist; and
- whether the disc must withstand reverse pressure.

The conventional domed disc (described in Section 2.2.1) is the most basic disc available but its application is limited to simple situations without pulsating pressure and with a large margin (30% or more) between working pressure and design pressure.

In more demanding situations, decide:

- is the disc subject to pulsating pressure?
- does the available margin between working pressure and design pressure demand a tight tolerance of bursting pressure?
- is a long working life (more than 2 years) essential?
- is the disc to be used in series with a safety valve?

If the answer to any of these questions is yes, consider the following

types of bursting discs:

- reverse domed;
- composite slotted.

Modern bursting discs have many special features, so always consult the manufacturer and provide a detailed specification sheet.

NOTES

2.1 Formation of solids and gums can also affect the performance of bursting discs by adhering to the disc but the effect is not as serious. In some cases the disc may be protected by heat tracing, or by other methods described in Section 9.5.

2.2 The loss of material is likely to be greater with a bursting disc whilst the system depressurises.

2.3 An excess flow valve will permit a limited flow, but will close if this limit is exceeded. The interspace will thus be vented if a small leak occurs. A major leak or disc failure will close the excess flow valve and actuate the pressure alarm (see Figure 2.16).

2.4 This can be achieved by putting a strainer between the bursting disc and the safety valve or preferably by using a bursting disc that does not shatter on bursting.

2.5 Apart from bellows failure, any solids or gums which collect in the convolutions of the bellows can affect the bellows characteristics.

2.6 The bonnet vent must vent to atmosphere and must not be plugged, or the valve will not function as a balanced safety valve.

2.7 There are several proprietary methods for minimising the risk of incorrect fitting. One of these methods is shown in Figure 2.17 on page 38.

2.8 As required by BS 5500. ASME Code Section VIII requires that the nominal bursting pressure does not exceed the design pressure.

2.9 When the absolute back pressure exceeds 50% of the absolute set pressure, the capacity of a balanced safety valve falls dramatically; so that 50% back pressure is a realistic maximum for a safety valve (Reference 2.1).

2.10 A safety valve opens in tenths of a second, while a bursting disc responds in milliseconds.

2.11 In this particular case, the maximum bursting pressure should not exceed 130% of the design pressure according to BS 5500.

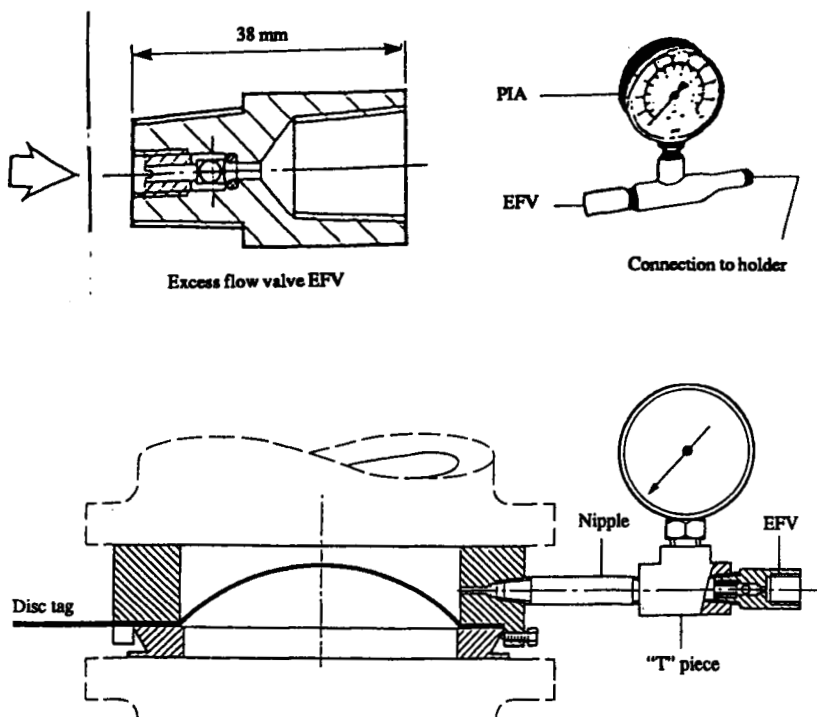


Figure 2.16 Cross section of an excess flow valve. Defined as a device which permits limited flow, but where the limit is exceeded will close, thus stopping the flow.

A free moving ball is located in the central chamber. In normal operation any gradual pressure rise escapes around the ball. A sudden increase in pressure forces the ball onto the valve seat, closing the valve. Standard material is stainless steel.

EFV's may be attached to the vent side of safety disc holders in combination with pressure gauges or pressure indicator alarms. In these cases the PIA should be mounted between the holder and the EFV. (Courtesy of Marston Palmer Limited (Safety Systems Group).)

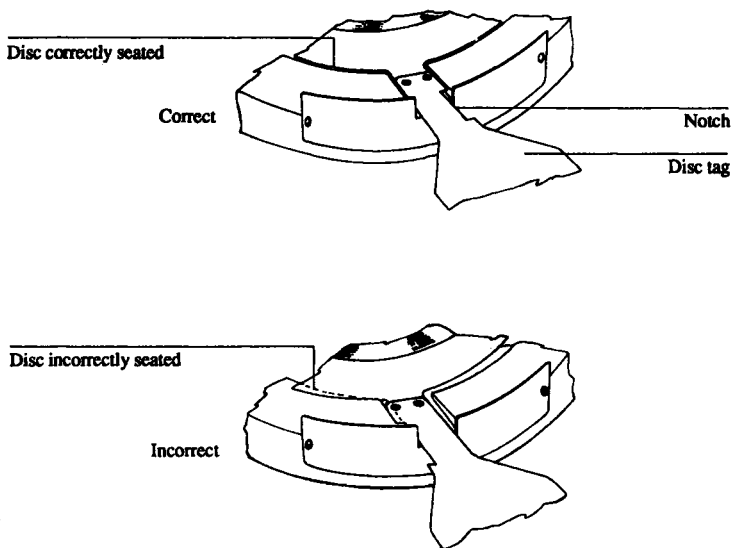


Figure 2.17 Assembly of bursting disc. Holders have identity labels securely attached to them. These serve two purposes: (1) To uniquely identify the assembly, and (2) In combination with the disc identity label to produce a foolproofing arrangement which prevents incorrect assembly of the disc to the holder.

The disc identification tag is notched on one side of its neck and a notched label on the ring makes it impossible to seat the disc in an upside-down position. Even in poor light the operator can feel that the disc is incorrectly seated; in any event the pressure side of the holder will not seat properly and premature failure will occur. (Courtesy of Marston Palmer Limited (Safety Systems Group).)

3. DETERMINING THE SET PRESSURE AND BURSTING PRESSURE

The two most important parameters of a safety valve are the relief rate at relieving conditions and the set pressure, that is the pressure at which the safety valve commences to lift.

The relief rate is found by examining all the possible causes of over-pressure, such as power failure, cooling failure, fire, and calculating the required relief rate of the safety valve for each contingency. The largest rate for any one contingency or credible combination of contingencies is the specified relief rate (Section 1.6).

The set pressure is determined by reference to the vessel's design pressure, which in turn is related to its maximum operating pressure. The set pressure may not exceed the design pressure but it may be lower. The procedure can be followed as a series of steps starting with the operating pressure as illustrated in Figures 3.1 (see page 40) and 3.2 (see page 41).

3.1 MAXIMUM OPERATING PRESSURE

For a pressure vessel, the designer must know the normal operating pressure together with the possible operating excursions up to the maximum operating pressure. The maximum operating pressure may arise from the exhaustion of a catalyst, the fouling of a filter or the flooding of a column, or it may occur during an occasional operation such as regeneration, backflow or cleaning.

In a liquid-filled system the maximum operating pressure may be determined by the performance curve of a centrifugal pump, by liquid level in a connected vessel, or by a combination of both.

3.2 DESIGN PRESSURE

The design pressure is determined by the maximum operating pressure plus a design margin to allow for contingencies and for the blowdown of the safety valve (the pressure differential required to reseal the safety valve after opening).

For compressible fluids at normal operating pressures, say between 10 bar g and 100 bar g, the design margin is normally 10% of the maximum

operating pressure. For pressures below 10 bar g the design margin can be maintained at 10%, or rounded up to 1 bar. For pressures above 100 bar g the design margin can be reduced to 5% providing that a suitable safety valve, such as a pilot operated safety valve (see Section 2.1.4), is selected. Smaller margins can be contemplated in special circumstances but will require great accuracy in setting the safety valve(s).

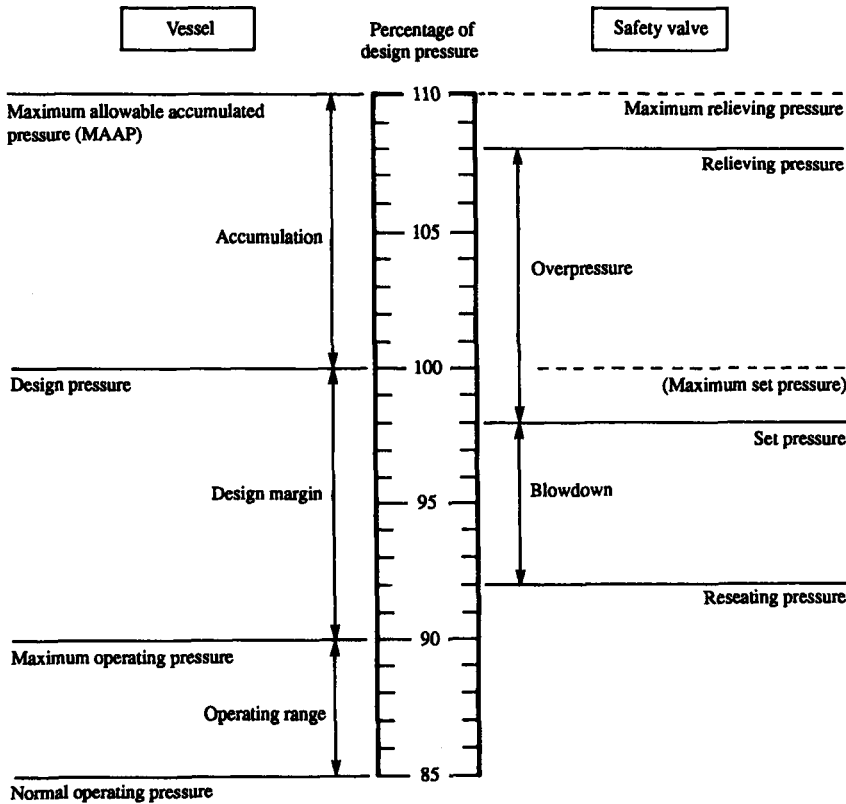


Figure 3.1 Pressure regime for a safety valve with 10% overpressure.

DETERMINING THE SET PRESSURE AND BURSTING PRESSURE

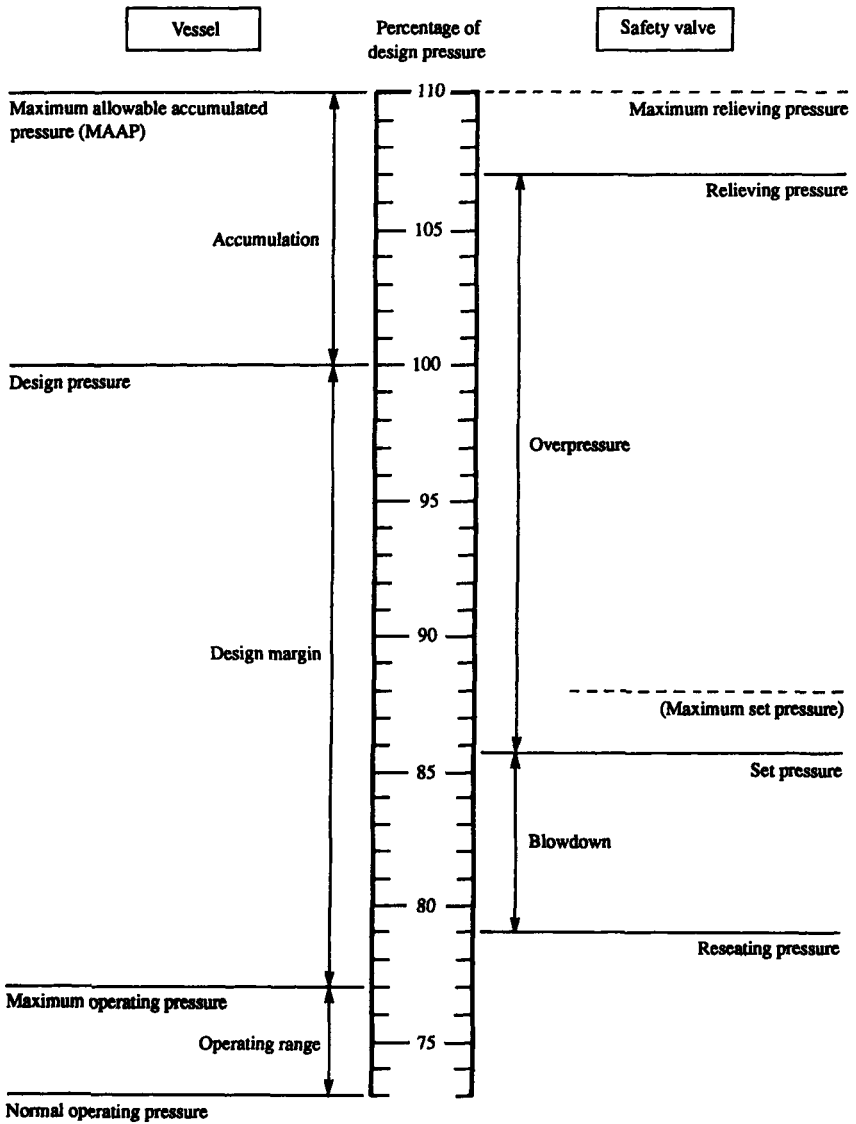


Figure 3.2 Pressure regime for a safety valve with 25% overpressure.

For liquid-filled systems pressurised by a centrifugal pump, the design pressure is frequently determined by the shut-off pressure of the pump. If the performance curve is not available, the shut-off head can be estimated. For electrical drives the shut-off head can be limited to 125% of the design head. For steam turbine drives the shut-off head can be limited to 133% of the design head.

In some cases the design pressure may be chosen higher than the above considerations would indicate; for example, it may be dictated by the design pressure in other parts of the system. Or, in the case of heat exchangers, making the design pressure of the shell equal to that of the tubes avoids overpressurising the shell if a tube should fail.

In systems with process vessels operating at low pressures (below 5 bar g) the temptation to select a design pressure below 5 bar g should be treated with caution. Most normal-sized vessels can be designed to 5 bar g without any increase in wall thickness above that required for vessel stability. And design pressures below 5 bar g can lead to difficulties when discharging into a containment system owing to the relatively high back pressure.

3.3 ACCUMULATION

The accumulation is the permitted increase in system pressure above the design pressure in an emergency overpressure situation.

The accumulation permitted by BS 5500 is 10% of the design pressure, and this is the recommended accumulation for all unfired pressure vessels and most contingencies. The ASME codes permit higher accumulations in certain circumstances: 16% for multi-safety valves and 21% for fire relief. The designer must establish at the outset of a project which codes take precedence.

The sum of design pressure plus accumulation is called the maximum permitted regulated pressure in BS 5500 and the maximum allowable accumulated pressure in the ASME codes. For simplicity we shall use the latter term, abbreviated to MAAP.

3.4 OVERPRESSURE

As defined in Section 2.1, the overpressure of a safety valve is the increase in pressure above the set pressure as the safety valve achieves its full capacity. It is frequently quoted as a percentage of the set pressure.

The relieving pressure is the sum of the set pressure plus overpressure, and must not exceed the MAAP of the vessel or protected system.

3.5 SET PRESSURE

The maximum value of the set pressure can now be determined: it is the relieving pressure less the overpressure of the safety valve. If the safety valve is subject to any additional pressure due to liquid head, this pressure must also be subtracted from the relieving pressure.

For compressible fluids the overpressure is 10%, so that for most contingencies the maximum set pressure cannot exceed the design pressure.

For incompressible fluids the overpressure is either 10% or 25% depending on the margin available between operating pressure and design pressure. If it is 10%, the maximum set pressure cannot exceed the design pressure. If it is 25%, the maximum set pressure cannot exceed 88% of the design pressure.

3.6 RESEATING PRESSURE

As defined in Section 2.1, the reseating pressure is the pressure at which the valve returns to rest or the lift becomes zero; and the blowdown is the difference between set pressure and reseating pressure. For most safety valves the blowdown is adjustable (Note 3.1); for compressible fluids the range is typically 5% to 10%. For incompressible fluids the range is typically 5% to 20%. It is obviously desirable that the reseating pressure should exceed the maximum operating pressure.

The relationship between operating pressure and set pressure is shown in Figure 3.1 for compressible fluids and Figure 3.2 for incompressible fluids, where an overpressure of 25% has been selected.

3.7 SET PRESSURE FOR MULTI-SAFETY VALVES

Where more than one safety valve is fitted to achieve the desired discharge capacity, it is permissible for the additional safety valves to be set higher than the design pressure up to a maximum of 105%, provided that the maximum relieving pressure of the combined safety valves does not exceed the MAAP (Note 3.2).

3.8 ADJUSTING THE SET PRESSURE

Having determined the set pressure under working conditions, the safety valve must be adjusted on the test stand in the workshop under ambient conditions (see Section 11.2). Once the valve has been installed it may be possible to check its set pressure *in situ*.

With a conventional safety valve, the cold differential test pressure is given by the set pressure less the back pressure, with a small correction for operating temperature. It is essential therefore to define the back pressure, operating temperature and relieving temperature when specifying a safety valve. With a balanced pressure safety valve, the correction for back pressure may be ignored.

Note that the operating temperature of a safety valve is not necessarily the same as the operating temperature of the vessel to which it is connected, due to a temperature differential along the connecting pipe. Predicting the operating temperature at the safety valve can be done by calculation, but measurement in a similar environment is preferable. Keeping the safety valve close to the vessel being protected will obviously minimise the temperature differential.

3.9 BURSTING PRESSURE

With a bursting disc, the maximum bursting pressure should not exceed the design pressure of the vessel or system (see BS 5500).

The minimum bursting pressure must exceed the maximum operating pressure by a margin which depends on the type of disc selected. The tolerance of the bursting disc can be accommodated within the design margin between maximum operating pressure and design pressure.

The tolerance of a bursting disc depends on the bursting pressure, the operating temperature and the type of disc, and can vary from 2% to 20%. The acceptable margin between maximum operating and minimum bursting pressure can vary from 5% to 50%, depending on the type of disc selected.

The tolerance of the bursting disc is then a critical factor in the choice of design margin. The relationship between bursting pressure and operating pressure is shown in Figure 3.3 with 5% tolerance and in Figure 3.4 (see page 46) with 10% tolerance.

The bursting pressure is critically dependent on the temperature of the disc, so that accurate prediction of this temperature is essential. As mentioned in Section 3.8, the disc temperature is not necessarily the same as the operating temperature of the vessel. The differential will depend on the location, the environmental temperature and the provision of insulation and heat tracing. The temperature drop may be calculated but measurement in similar circumstances is preferable. Keeping the disc close to the vessel will minimise the temperature differential although in high or low temperature applications it may be desirable to increase the distance to increase the temperature differential.

3.10 COMBINATION OF RELIEF DEVICES

With a combination of relief devices the determination of set pressure and bursting pressure becomes more complicated.

3.10.1 SAFETY VALVE AND BURSTING DISC IN PARALLEL (2.4.1)

The set pressure of the safety valve should be equal to or less than the minimum bursting pressure of the bursting disc, so that the safety valve opens first and the disc is preserved for a rare contingency or heavy discharge. The set pressure and bursting pressure should be consistent with the philosophy of Sections 3.5 and 3.9 (see also Section 2.4.1).

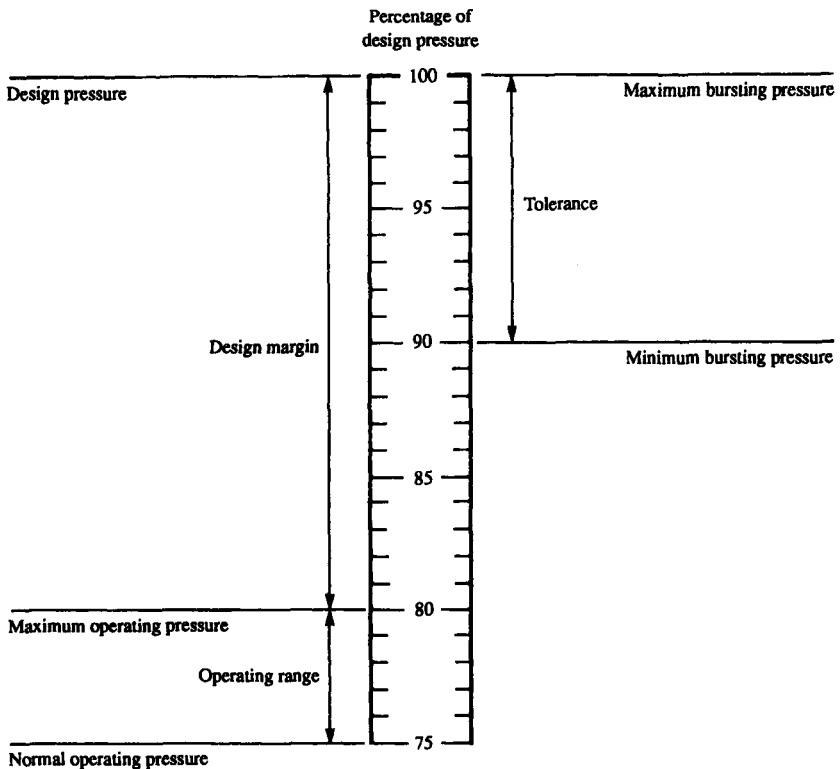


Figure 3.3 Pressure regime for a bursting disc with $\pm 5\%$ tolerance.

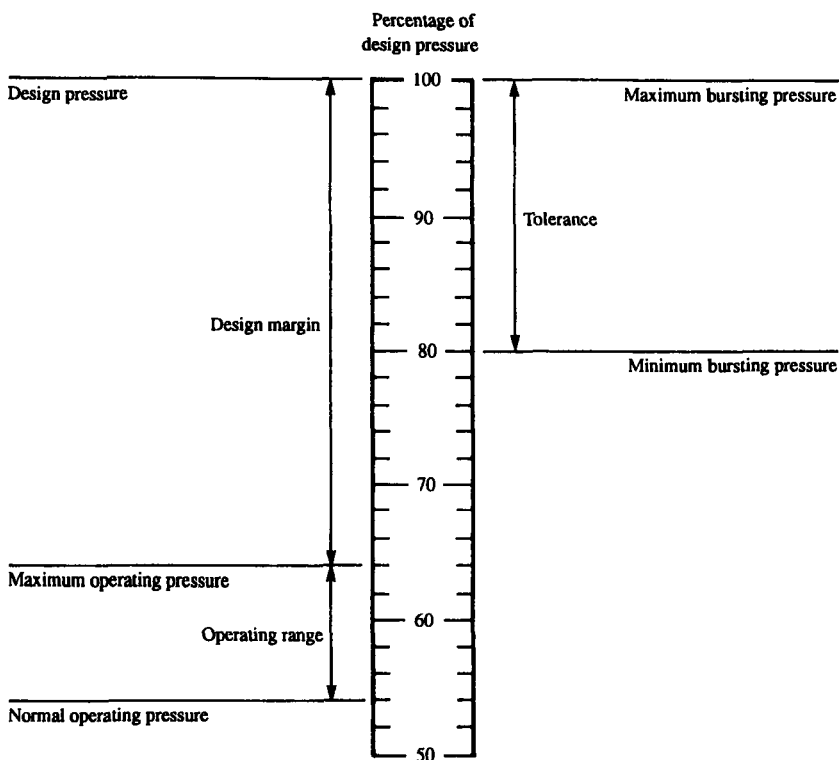


Figure 3.4 Pressure regime for a bursting disc with $\pm 10\%$ tolerance.

3.10.2 BURSTING DISC UPSTREAM OF THE SAFETY VALVE (2.4.2)

The set pressure of the safety valve should be equal to or less than the minimum bursting pressure of the disc, so that the minimum bursting pressure always opens the safety valve. The bursting pressure should be determined by reference to Section 3.9.

3.10.3 BURSTING DISC DOWNSTREAM OF THE SAFETY VALVE (2.4.3)

The set pressure of the safety valve should be equal to or greater than the maximum bursting pressure of the disc, so that the disc will rupture immediately the safety valve opens. The set pressure of the safety valve should be determined by reference to Section 3.5.

3.10.4 BURSTING DISCS UPSTREAM AND DOWNSTREAM OF THE SAFETY VALVE (2.4.4)

In this unusual combination, the set pressure of the safety valve should be equal to or less than the minimum bursting pressure of the upstream disc and greater than the maximum bursting pressure of the downstream disc. The bursting pressure of the upstream disc should be in accordance with Section 3.9.

3.11 CERTIFIED DISCHARGE CAPACITY

3.11.1 SAFETY VALVE

The certified discharge capacity of a safety valve may be calculated from the theoretical capacity:

- The discharge area of the safety valve is the minimum cross-sectional area between inlet and seat; it controls the flow of fluid through the valve.
- The theoretical discharge capacity is the calculated capacity of a theoretically perfect nozzle having a cross-sectional area equal to the discharge area of the safety valve (Note 3.3).
- The coefficient of discharge k_d is the

$$\frac{\text{actual discharge capacity found by test}}{\text{theoretical discharge capacity}}$$

- The derating factor f is the factor used to take account of manufacturing tolerances and permitted variations in test results. It is usually 0.9.
- The certified discharge capacity is then given by either:
 - the measured discharge capacity $\times f$ or;
 - the theoretical discharge capacity $\times f \times k_d$.

3.11.2 BURSTING DISC

- The discharge area of the bursting disc is the minimum area of the device after bursting as specified by the manufacturer.
- The theoretical discharge capacity is the calculated capacity of a sharp-edged orifice having a cross-sectional area equal to the discharge area of the bursting disc (Note 3.4). In this case the coefficient of discharge is included in the calculation of theoretical capacity.

NOTES

- 3.1 The adjustment should only be performed by the manufacturer.**
- 3.2 The additional safety valves must be certified for an overpressure of 5%.**
- 3.3 See formulae in BS 6759 Part III Clause 19.**
- 3.4 See formulae in BS 2915 Appendix E.**

4. TOTAL RELIEF SYSTEMS

Having selected the relief device and determined the set pressure or bursting pressure, the next task for the process engineer is the design philosophy of the total relief system. This comprises:

- the position of the relief device in relation to the pressure vessel or system;
- the connections between the pressure vessel or system and the relief device;
- the discharge connections between the relief device and the atmosphere or the appropriate containment system;
- the design of the containment or disposal system, if required;
- there could be an element of design iteration in this procedure. For example, the containment system could influence the choice of relief device.

4.1 INLET CONNECTIONS

In general, the preferred position for the relief device is mounted directly on the pressure vessel or pipe which it is protecting, using a dedicated and properly designed nozzle. A safety valve should be installed in the vertical position with bottom inlet and side outlet. A bursting disc should be installed with the inlet side towards the process and the outlet side towards the vent, as indicated on the bursting disc tag.

There are several possible reasons for not mounting the relief device directly on the vessel:

- in the case of a high (or low) temperature service, the relief device can be mounted some distance from the vessel to reduce (increase) the temperature at which it has to operate;
- to improve access to the device;
- if valves are required between the vessel and the device (see Section 10.2);
- to increase the elevation of the device to improve the drainage of the discharge pipework (see Section 4.14);
- to avoid pressure fluctuations caused by compressors or fittings (Note 4.8);
- to permit the location of a relief device outside insulation.

If for any of the foregoing reasons the relief device is not mounted directly on the vessel, then the inlet piping between the vessel and the device requires careful design to avoid any restriction to flow or accumulation of liquid.

The pipework should be designed with the following requirements:

- the nominal bore of the pipework and the vessel nozzle should be at least equal to the nominal bore of the inlet nozzle of the relief device (Note 4.7);
- the pipework should be predominantly vertical, so that it is self-draining back to the vessel;
- the pipework should be as short as possible;
- in the case of safety valves, the frictional pressure drop through the inlet pipework, inlet fittings and valves at the maximum possible relief rate should not exceed 3% of the set gauge pressure (Note 4.2). The calculation of pressure drop should include the entrance loss into the pipework;
- the pipework and supports should put minimum stress on the flanges of the relief device;
- any pressure impulse lines (Note 4.9) should be connected to the process as far as possible from the safety valve.

Once the inlet side has been designed, the discharge arrangements can be considered.

4.2 VENTING DIRECTLY TO ATMOSPHERE

Where the relief discharge can be vented directly to atmosphere, this enormously simplifies the discharge side of the relief device.

If the discharge is entirely innocuous — a non-toxic, non-corrosive, non-odorous and non-flammable gas or vapour — then venting to atmosphere is recommended. For example, steam and compressed air can safely be vented to atmosphere, providing that the discharge is directed to a safe location. The discharge can of course be noisy but as it is normally brief and infrequent, this is usually acceptable. Frequent or lengthy discharges from relief devices indicate that the system has been designed badly. Noise can be reduced by the installation of a silencer (Figure 4.1) but a silencer will contribute to back pressure and is subject to fouling.

Non-hazardous cryogenic fluids may be discharged to atmosphere providing that the discharge manifolds can withstand cryogenic temperatures (Note 4.3) and a suitable catchment system for any liquid is provided.

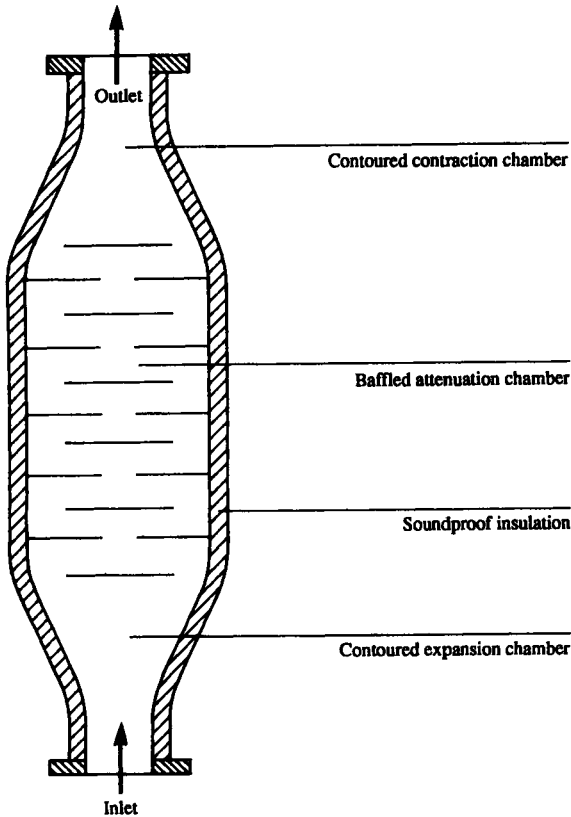


Figure 4.1 Silencer.

According to HS(G) 34 (Note 4.1), which covers the storage of LPG at fixed installations, pressure relief valves can be vented directly to atmosphere in a safe location, although Clause 64 mentions the alternative of venting to flare for large LPG vessels.

Some noxious or flammable discharges can be considered for atmospheric venting providing that:

- the discharge is entirely gas or vapour;
- the concentration of dangerous vapours at ground level or any manned elevated level is below the permitted exposure limit (Note 4.11);

- there is no danger of a vapour cloud accumulating;
- the discharge can be vented to a safe location as described in Section 4.2.1.

4.2.1 SAFE LOCATION

This subject is one of the most difficult to deal with in general terms due to the widely differing circumstances to be found in the chemical process industry and the many conflicting recommendations in the codes and standards.

Some companies have their own standards of safe location which may take precedence over all other standards except statutory regulations. The chemical engineer must first establish the hierarchy of codes and standards governing his or her design, and then extract the relevant definition of safe location.

If the engineer cannot find any guidance from these sources and there is no restriction on the space available, the following remarks will be helpful in the preliminary design stage. The dimensions can then be refined and optimised by calculation and by discussion with other specialists and approving authorities.

- Atmospheric discharges should emerge into the open air at least 0.3 m above the relief valve or roof level and at least 3 m from any building, operating platform or walkway.
- If the discharge is flammable, the point of discharge should be at least 5 m above ground level, at least 3 m from any property boundary and at least 3 m from any air intake or any source of ignition. The discharge pipe can also be fitted with a steam snuffing device so that inadvertant ignition of the discharge can be extinguished.
- If there are any high buildings or structures in the vicinity, the effect of these obstructions on vapour dispersal should be considered.
- In all cases the predicted concentration of toxics and flammables should be checked at ground level and at any operating platform in the vicinity. This procedure is best performed by computer modelling as discussed in Appendix 4.3. The local geography and topology should be represented in the model.
- If there is hydrogen or any highly flammable vapour in the discharge, the discharge pipe should be earthed (Note 4.4) to prevent any build-up of electrostatic charge. The pipe end should also be carefully rounded into a toroidal ring.

The provision of a flame arrestor is discussed in Section 4.4.

4.2.2 HIGH VELOCITY DISCHARGES

If the discharge is noxious, entirely vapour but heavier than air, discharge to atmosphere can still be considered providing that the discharge velocity is sufficiently high *at all times* to disperse the contents into the atmosphere.

A minimum velocity can be calculated (Appendix 4.1) to ensure adequate mixing and dispersion, but the proviso 'at all times' means that all possible discharges and leakages must be considered. Unless the designer can be completely confident of the discharge velocity under all circumstances, discharge into a safe containment system is preferable. Batch reactors with bursting discs are a good example of variable discharge velocity. The initial velocity at rupture will be a maximum, with the velocity decaying to zero as the reactor depressurises.

If dangerous liquids or solids (Note 4.5) are present in the discharge, atmospheric discharge is unlikely to be acceptable.

However, under HS(G) 34 (Note 4.1), which covers the storage of LPG at fixed installations, LPG can be discharged to atmosphere in a safe location.

4.3 COMMON VENTING

Where atmospheric venting is permissible (see Section 4.2) and there is more than one relief device, the discharges may be combined to limit the number of discharge points. As each point of discharge must have a safe location (which is normally at high level) the advantage of providing a single discharge point is obvious.

In certain cases relief vents may be combined with normal vents but the superimposed back pressure on the relief devices must be considered.

The arrangement and sizing of the manifolding of the discharge pipes requires careful consideration.

4.3.1 ARRANGEMENT OF DISCHARGE MANIFOLDS

The arrangement of the discharge manifolds depends on the possible presence of liquids and the consideration of pressure drop. In the absence of liquids the discharges can be manifolded in any convenient manner.

If liquids are present, the discharge pipework should be vertical, or horizontal with a slight fall (1 in 500) in the direction of flow. Any accumulation of liquid should be self-draining (see Section 4.6) so that branches enter horizontal manifolds from the top.

Where the minimisation of pressure drop is important, tees into manifolds should be angled or swept.

4.3.2 SIZING OF THE DISCHARGE MANIFOLDS

The nominal bore of the discharge pipe should be equal to or greater than the nominal bore of the discharge connection of the safety valve (Note 4.10).

The maximum discharge rate through any portion of the discharge system must be established from the combined discharges of the relief devices feeding that portion of the system, taking into account the simultaneous lifting of several devices due to one contingency. For example, the single contingency of power failure could trigger several relief devices simultaneously but leave the other relief devices in that portion of the system unaffected. In the case of safety valves, the discharge pipes and manifolds should be sized to keep the back pressure (built-up and superimposed) below 10% of the set pressure in the case of conventional safety valves and 50% of the set pressure in the case of balanced safety valves. For balanced safety valves, the manufacturer may limit the back pressure to less than 50%.

In order to keep pressure drop minimal, bends should be long radius and tees should be swept. To minimise noise and vibration the vapour velocity in the discharge manifolds should be kept within the range Mach 0.25–0.65 (see Appendix 4.2).

4.3.3 INTERACTION BETWEEN RELIEF DEVICES

Consider carefully the effect of the relief discharge from one device on the other devices in the combination. In the case of a combination of safety valves, some protection can be afforded by fitting downstream bursting discs as discussed in Section 3.10.

4.4 FLAME ARRESTORS (Figure 4.2)

When venting flammable vapours direct to atmosphere, it is prudent to consider providing a flame arrestor at the discharge exit. Some companies restrict the installation of flame arrestors to open vents on low pressure storage tanks.

With a common venting system a flame arrestor can prevent a flashback in the manifolds, so in these circumstances it is worth considering. The major consideration is the cleanliness of the discharge. Since the principle of the flame arrestor depends on a multiplicity of fine passages, any dirt or debris in the discharge will tend to block the arrestor and a blocked arrestor can be more dangerous than a possible flashback. Where the situation is not clearcut, a risk analysis should be performed to assess the hazard potential with and without the flame arrestor.

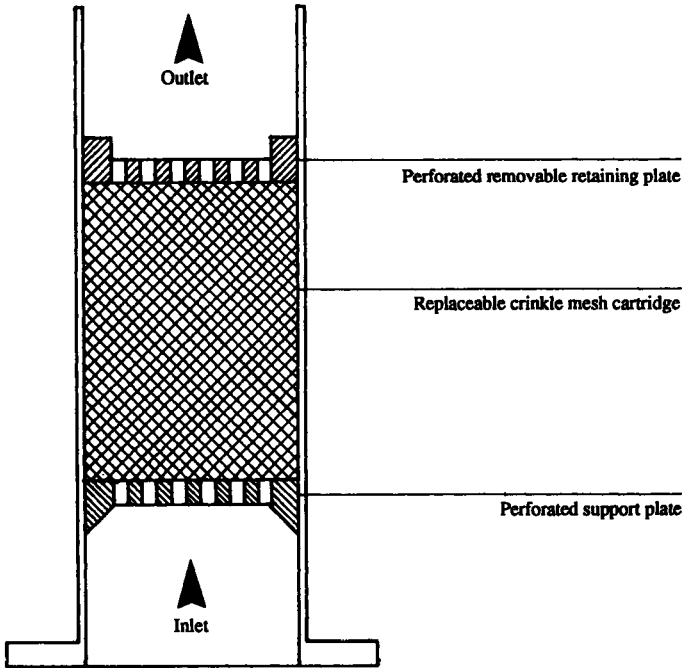


Figure 4.2 Flame arrester.

Providing that the discharge is clean and the built-up back pressure of the arrester is acceptable, then provision of a flame arrester can provide some extra protection.

Various proprietary designs are available and selection is usually based on price, availability, weight and material. Having selected a particular design, the manufacturer can quote the pressure drops for a range of sizes at a specified maximum discharge rate, thus enabling the size of the flame arrester to be determined.

In all cases, the flame arrester requires regular inspection to detect any signs of corrosion or blockage. The frequency of inspection should be clearly defined and should be advised to the plant operator by a planned maintenance system.

4.5 CONTAINMENT AND DISPOSAL SYSTEMS

If direct atmospheric venting is not acceptable, then the discharges from the relief devices must be directed into a containment or disposal system that will prevent any noxious discharge reaching the atmosphere.

The systems worth considering can be classified as follows:

- another part of the process;
- a compatible storage tank;
- a dump tank or blowdown tank;
- a process sewer;
- a quench vessel;
- a quench tower;
- an absorber or scrubber;
- an incinerator or furnace;
- a ground level or elevated flare.

These systems may be used singly or in combination.

4.5.1 DISCHARGE TO PROCESS

If a convenient, lower pressure part of the same process can be identified for receipt of the discharge, then the advantages are obvious. This solution is particularly useful for the discharge of relief valves fitted to positive displacement pumps and compressors, where the discharge can safely be returned to the suction side of the process, or where the flow from a high pressure to a low pressure system can be blocked in by a control valve. Check the effect of the back pressure on the relief device and, in the case of a recycle relief, the rise in temperature if the relief continues without detection. Take care to ensure that the contents of the receiving vessel or system are compatible with the discharge, and that the receiving vessel or system can withstand the conditions of the discharge. If the receiver is overpressured by the discharge, then another relief device will be actuated and this discharge will require containment. The low pressure relief device must also be sized for the discharge from the upstream device. Careful judgement is required to verify that an improvement has been made.

4.5.2 DISCHARGE TO A STORAGE TANK

This option is similar to Section 4.5.1 except that the receiver is now a storage tank rather than a process vessel. It is useful for the discharge of thermal relief

valves installed on the inlet and outlet pipework of the storage tank.

However, this application is severely limited by the distance from the process, the mild design conditions permitted in the storage tank and the limited space in the tank if it happens to be full. There is also the risk of contamination or a mixing of incompatible fluids.

4.5.3 DISCHARGE TO A BLOWDOWN TANK (DUMP TANK)

This method is designed to contain the liquid and vent the vapour safely.

In the case of liquid discharges at modest temperatures, a dedicated receiver can be designed to accommodate the maximum discharge. This is frequently used at the discharge of surge relief valves on long pipelines where the maximum volume of discharged fluid can be accurately predicted. The blowdown tank is otherwise known as a total containment vessel.

Reference 4.1 gives some guidance on the design of a blowdown tank. To limit the size of the tank, it can be provided with a pump to empty the contents once a certain level has been exceeded. However, the integrity of the pump-out system is crucial and the fluid needs a safe destination.

With higher-temperature discharges, the design temperature of the blowdown tank and the effect of vaporisation at blowdown pressure must be considered. In a hydrocarbon system the vaporisation is usually sufficient to require a vapour containment system downstream of the blowdown tank. In this case the function of the blowdown tank is simply to exclude liquid from the vapour containment system.

With low boiling point discharges, consider the effect of auto-refrigeration, particularly in relation to the design temperature of the blowdown tank. Again, in the case of a hydrocarbon system, flash vaporisation can occur so that a vapour containment system is required.

With flammable discharges, the containment system must be earthed to prevent build-up of electrostatic charge.

Section 4.7 discusses the sizing of the blowdown tank. Further guidance can be obtained from Reference 4.2.

4.5.4 DISCHARGE TO SEWER

Small liquid discharges to the process sewer are sometimes permissible. For example, thermal relief valves on process lines inside battery limits can discharge to a convenient oily sewer connection when the discharge is non-toxic and the sewer can withstand the discharge temperature. Similarly the thermal

relief valves on the cooling water side of process coolers can safely discharge to sewer, but take care if the relief valves are also guarding against a heat exchanger tube failure.

In all cases of discharge to sewer, the character of the discharge must be compatible with the design of the sewer system. Any possibility of releasing flammable vapours into the sewers must be avoided. The entry into the sewer must be designed to avoid splashing above ground level.

4.5.5 DISCHARGE TO A QUENCH VESSEL

In the case of a difficult but limited discharge, eg from a relief device on a batch reactor, the discharge may be sparged into a quench vessel containing a compatible fluid which will quench the reaction either chemically or simply by cooling. Reference 4.3 discusses the sizing of a suitable quench vessel.

4.5.6 DISCHARGE TO A QUENCH TOWER (Figure 4.3)

In the case of high-temperature discharges of liquid/vapour mixtures, some quenching action may be required to reduce the temperature of the discharge before it can safely be contained. This is particularly relevant to high-temperature discharges from relief devices protecting fired heaters and heat exchangers.

The quench vessel usually consists of a vertical tower with a side inlet from the discharge side of the relief device. The upper part of the tower forms the quench section and contains a set of horizontal baffles cooled by a circulating flow of quench fluid. The quench fluid may be water or a heavy hydrocarbon (such as gas oil) depending on compatibility with the relief discharge.

Following a relief, the hot vapours rising up the tower begin to heat the quench fluid. When the quench fluid reaches a predetermined temperature, an emergency supply of quench fluid is triggered and this supply increases automatically on temperature control. This emergency flow of quench fluid is then drained away through a liquid seal or pumped out on level control.

The lower part of the quench tower provides liquid hold-up, level and temperature measurement and the facilities for drainage or pump-out. Quench water plus quench products are normally drained to process sewer whilst quench oil is pumped to slops storage.

Any uncondensed vapour leaving the quench tower can be vented to atmosphere or a vapour containment system depending on the considerations discussed in Section 4.2.

The integrity of the normal and emergency circulating flows require

careful study and design. As a minimum, pumps and instruments should be duplicated. A proper hazard and operability study is essential.

4.5.7 DISCHARGE TO AN ABSORBER/SCRUBBER

In the case of a toxic or corrosive vapour discharge or a discharge containing particulate matter, it is desirable to remove these pollutants by scrubbing or absorption.

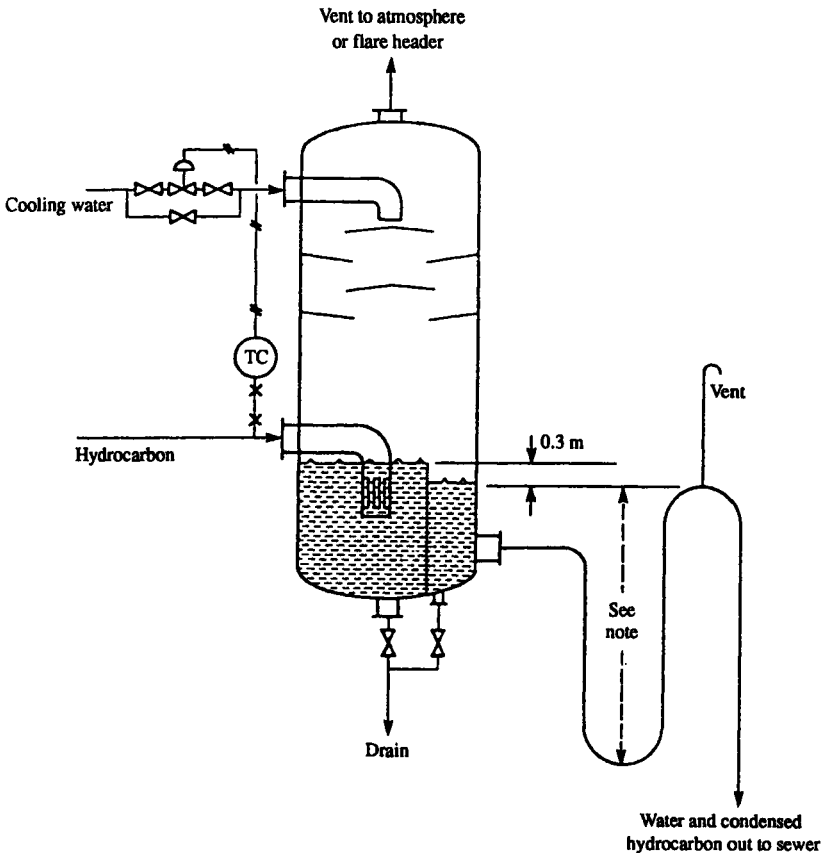


Figure 4.3 Quench tower.

Note: it is suggested that the sewer seal be designed for a minimum of 175% of the drum's maximum operating pressure. (Courtesy of the American Petroleum Institute.)

The design of such a system cannot be generalised here but should be treated as part of the total process design. It may be that the process already contains a suitable absorber or scrubber. Otherwise a dedicated system must be designed. Discharge to an absorber/scrubber which is running continuously is obviously preferable. The system flows can be stabilised by recirculation and a relief discharge can immediately be detected by some change in the condition of the circulating fluid.

If the absorber/scrubber is not designed to run continuously, the integrity of the system must be carefully investigated as described in Section 4.5.6.

With a high relief rate, the design flow rate through the absorber/scrubber may be reduced by installing an expansion or surge vessel between the relief device and the absorber/scrubber.

Some guidance on the arrangements for chlorine vessels may be found in HSG 28 (Note 4.1).

4.5.8 DISCHARGE TO AN INCINERATOR

If the toxic discharge cannot be effectively and safely handled by scrubbing or absorption, then incineration may be the only remedy.

The incinerator is again part of the total process and can only be designed by considering the properties and flow regime of the relief discharge. A controlled supply of fuel and combustion air must be provided to incinerate the maximum flow rate of the discharge at the required temperature. The incinerator requires a combustion chamber, fuel burners, combustion controls, flame failure detectors and a stack for venting the flue gas.

If a process furnace is available, this can be used as an incinerator providing that it is always in operation when a relief discharge occurs. Check the capacity of the furnace to receive the discharge and the effect on the pressure regime in the combustion chamber, to avoid the possibility of back pressure and consequent gas leakage to the atmosphere.

If the discharge is flammable and has a calorific value sufficient to maintain combustion without auxiliary fuel, then consider the alternative of flaring (see Section 4.5.9).

4.5.9 DISCHARGE TO FLARE

For many relief discharges, particularly of hydrocarbons in the petroleum refining and petrochemicals industries, the only practical method of disposal is

by flaring — either at ground level, elevated, or both (see Appendix 4.9.7).

Flaring can be considered where the calorific value of the discharge is sufficient to maintain combustion, so that once the discharge is ignited the flame can be maintained at the point of discharge.

The choice of ground flare or elevated flare is a matter of economics, space and environmental impact. The elevated flare is usually more expensive due to the supporting structure and the complexity of monitoring and maintaining an elevated flame.

On the other hand a ground flare must be well isolated from any flammable materials, public property or personnel. Depending on the size of the discharge, the 'sterile radius' around a ground flare is 100–150 m. This means that a ground flare needs a lot of valuable space. If the value of this ground area can be quantified it should enter into the economic analysis. From an environmental standpoint, a ground flare can be shielded from public view or hearing whereas shielding an elevated flare is impractical.

The choice of a ground flare or an elevated flare requires careful consideration and economic analysis, and cannot be usefully generalised. However, as the maximum relief rate increases, the design of a ground flare becomes increasingly more difficult and space-consuming. Once the maximum relief rate exceeds 25 tonnes/hour the feasibility of a ground flare becomes questionable and at 50 tonnes/hour it is impracticable.

Appendices 4.8 and 4.9 treat the arrangements of ground flares and elevated flares in more detail.

4.5.10 THE SELECTION PROCEDURE

Figure 4.4 (see page 62) is a decision tree for selecting a containment system.

4.6 VENT SIDE PROTECTION

The vent (discharge) side of a relief device requires protection against corrosion, erosion, polymerisation, deposits or condensation from the relieving fluid, and against the environment.

If the device is discharging directly to atmosphere the protection may consist simply of a loose weather shield to prevent ingress of rainwater and a drain pipe at the lowest point downstream of the device to release any condensation. The drain pipe should be small bore (15 mm max) and piped in such a way that any discharge from the open end will not hit people or equipment. Any flammables should be piped out of doors. The drain pipe should be teed into the

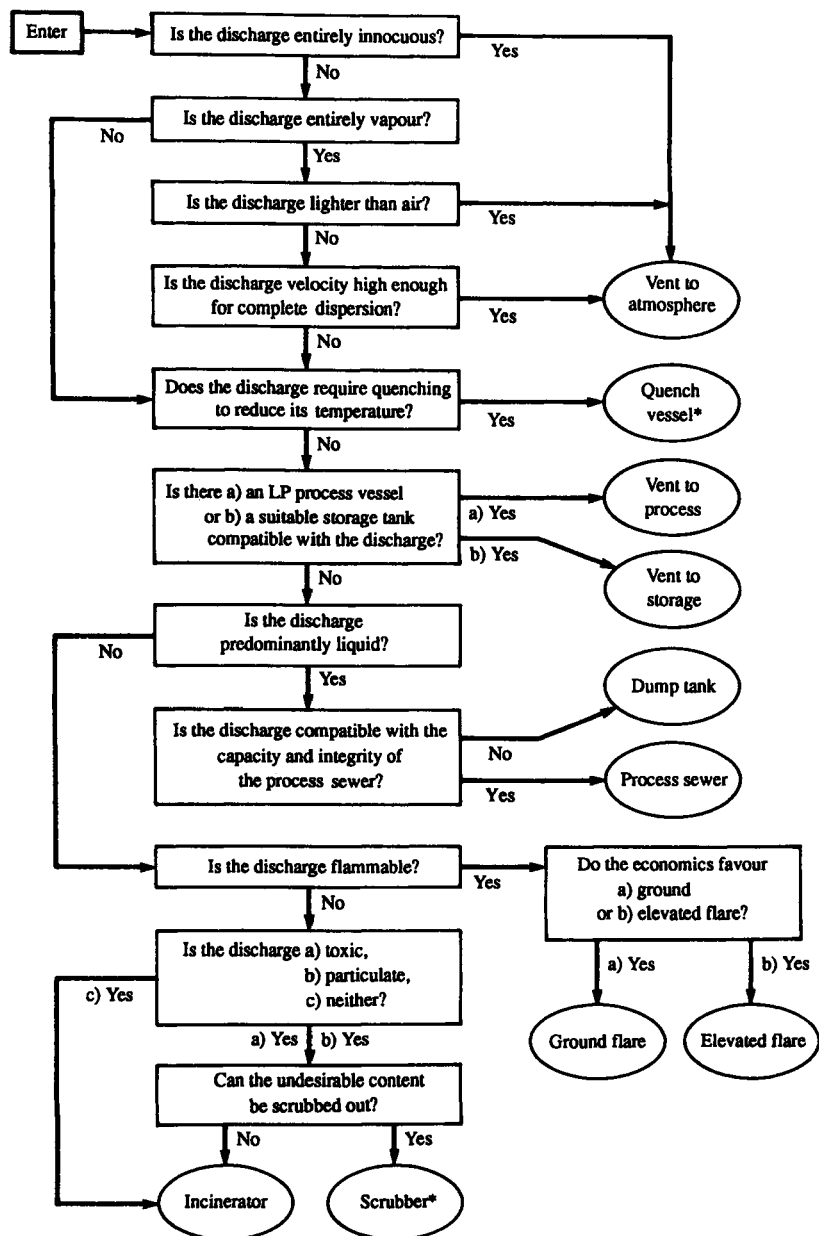


Figure 4.4 Selection of containment or disposal system. *The disposal of any vapour discharge must follow the same selection procedure.

discharge pipe with a 25 mm × 15 mm reducer to avoid blocking the tee with scale and dirt.

The weather shield should not impose any additional back pressure on the relief device, reduce the discharge velocity or redirect any dangerous vapours downwards (Note 4.6).

If the device is discharging into a common containment system, the vent side will also require protection against any other aggressive fluid discharging into the common system. This could involve using corrosion-resistant materials or heat tracing and insulation. In the case of a safety valve, a low pressure downstream bursting disc can be used.

Rust can block mild steel vents exposed to atmosphere, and protective lining or coating is recommended. Stainless steel construction costs more but needs less maintenance.

4.7 BLOWDOWN SYSTEMS

When the discharge is predominantly liquid or a liquid/vapour mixture, discharge into a blowdown tank or drum is recommended with the separated vapour venting into a vapour containment system. The liquid collected in the blowdown drum can then be recovered by pumping out to process or to a slop system. If the liquid tends to foam, take care to avoid foam carryover (Reference 4.4).

Sizing the blowdown drum is similar to the procedure outlined in Section 4.12, using careful judgement on the amount of liquid hold-up. With large liquid discharge rates (over 100 m³/h) the amount of liquid hold-up can be reduced to 10–15 minutes providing that the pump-out system is reliable and generously sized; the capacity of each pump should be at least equal to the maximum discharge rate plus a design margin of 10%. For large, expensive systems it is worth making an economic study of the possible size combinations of vessel and pump, and the size of the reception facilities for the pump-out.

To make sure that the pump-out system is sufficiently reliable the pumps should be duplicated, the pump drives should be dissimilar (eg one electric and one steam driven) and the level switches for starting the pumps should at least be duplicated and preferably triplicated with a two-out-of-three voting system.

In this context the blowdown tank is also known as a knock-out or KO drum.

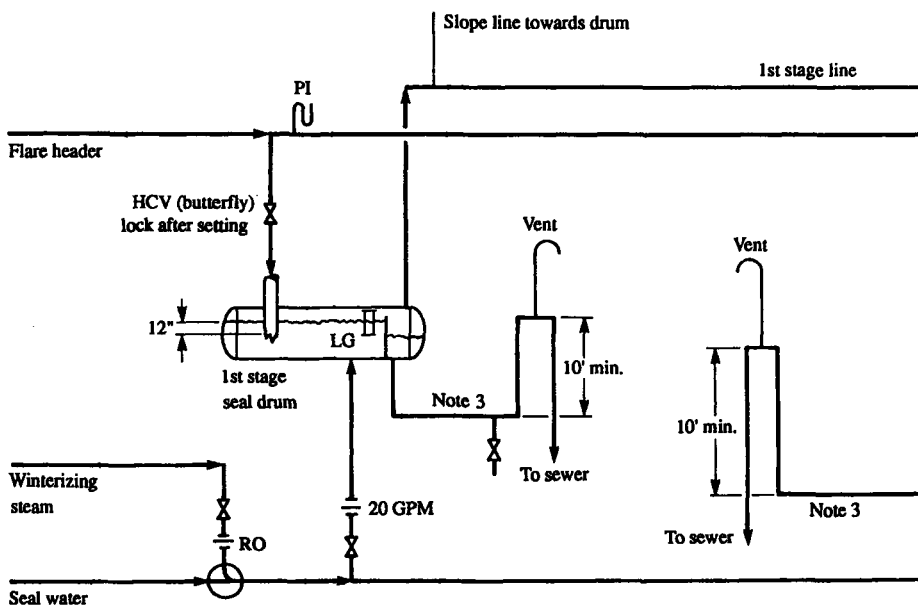


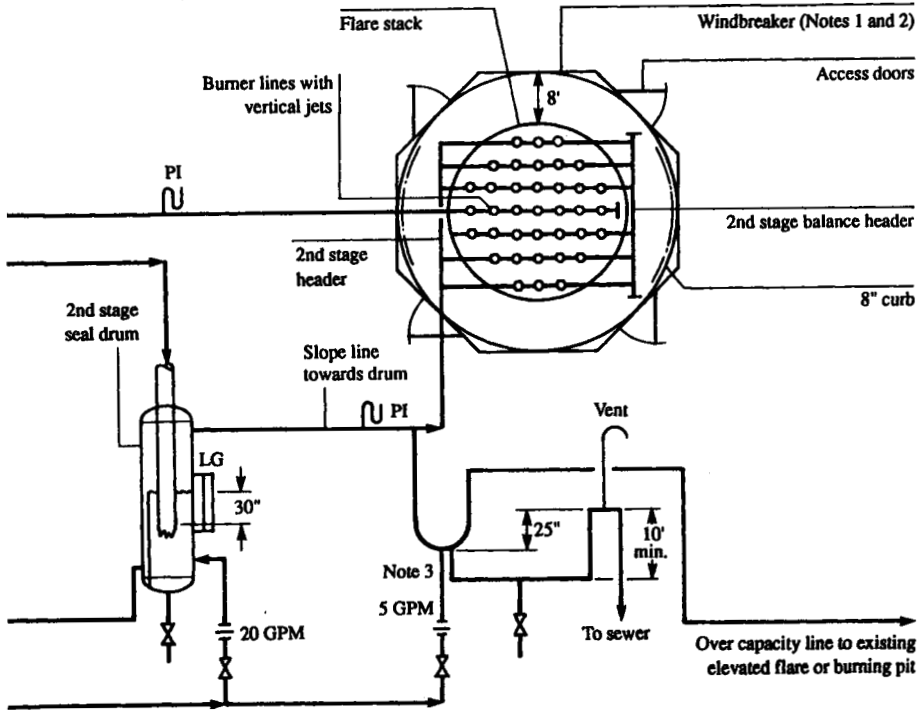
Figure 4.5 Ground flare.

Notes: (1) Locate drums as close as possible to windbreaker; (2) Catch basins for seal water should be a minimum of 50 ft from the windbreaker; (3) Design for 0.4 ft/sec to allow vapour disengaging. (Courtesy of the American Petroleum Institute.)

4.8 GROUND FLARES

A ground flare consists of the following elements, as shown in Figure 4.5:

- flare knock-out drum;
- seal drums;
- burner system;
- stack;
- wind shield;
- ignition system.



The flare knock-out drum and seal drum are common elements of the ground flare and elevated flare which are dealt with in Sections 4.12 and 4.13. Appendix 4.8 describes in detail the remaining elements of the ground flare.

As Figure 4.5 shows, the levels in the seal drums control the number of burners in operation, according to the pressure in the flare header. The combined back-pressure of the burners and seal drums tends to be higher with a ground flare than an elevated flare.

4.9 ELEVATED FLARES

An elevated flare consists of the following elements, as shown in Figure 4.6:

- flare knock-out drum;
- seal drum;
- flare stack;
- flare tip;
- molecular seal;
- ignition system;
- steam injection;
- purging system.

The flare knock-out drum and seal drum are dealt with in Sections 4.12 and 4.13. The remaining elements are described in detail in Appendix 4.9.

4.10 CORROSIVE RELIEFS TO FLARE

When the relief discharge is particularly corrosive, eg containing high percentages of H_2S , Cl_2 , SO_2 , etc, it is worth considering a separate containment system for these corrosive discharges. The decision should be based on the economics of upgrading the total system to corrosion-resistant materials compared with the additional cost and complexity of a separate system for corrosive relief.

In many refineries and petrochemical sites the corrosive reliefs are comparatively small compared with the major reliefs from the main distillation and cracking units, and in these cases a separate containment system for corrosive reliefs is well justified.

The corrosive relief system runs in parallel with the main relief system and shares most of the elements described in Section 4.9 for an elevated flare. The smaller corrosive flare stack can be supported by the main flare stack and share the same flare tip and ignition system.

4.11 COLD RELIEFS TO FLARE

In this context a cold relief discharge means a discharge of vapour at a temperature below 0°C , or alternatively a liquid or two-phase discharge that can produce a temperature of less than 0°C by auto-refrigeration. In practice this means any liquid discharge with an atmospheric boiling point below 0°C . Cryogenic fluids are specifically excluded from this category since they can be vented directly to a safe location (see Section 4.2.1).

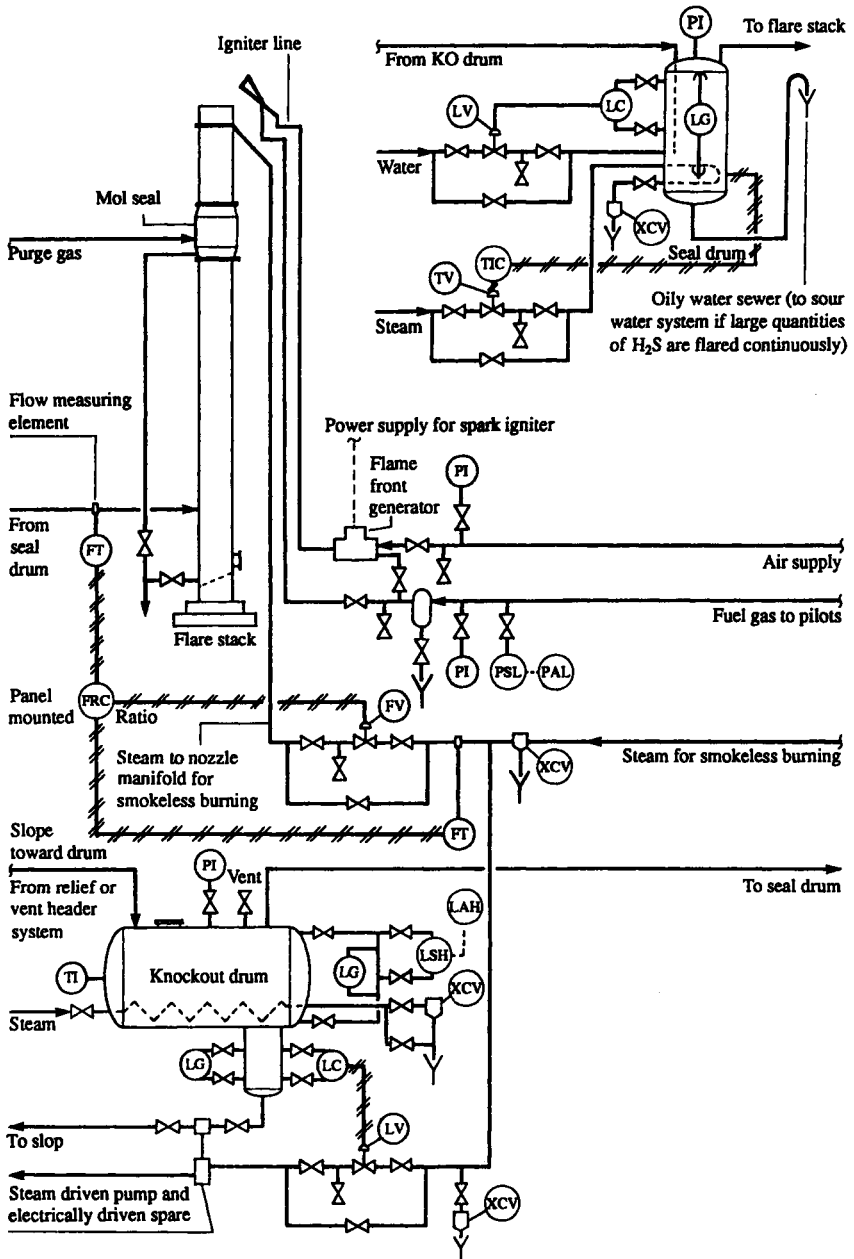


Figure 4.6 Elevated flare. (Courtesy of the American Petroleum Institute.)

If these cold streams are discharged directly into the main relief system, the consequences can be disastrous due to either embrittlement of carbon steel pipework or freezing of water in the system. To avoid the need to use special low-temperature alloys for the whole relief system, the cold reliefs are collected and warmed before being released into the main containment system.

The cold reliefs are therefore discharged into one or more blowdown drums where the liquids are separated and the flashed vapours are heated above 0°C before joining the main containment system. The separated liquids can either be recovered by pumping to a safe destination, or vaporised and heated above 0°C to join the flashed vapours in the main containment system.

The heating system for the vaporisation of low boiling point liquids and the heating of cold vapours requires careful design to avoid freezing of the heating medium. This can best be achieved by using methanol or glycol mixture as the heating medium in contact with cold fluids and maintaining the temperature of the heating medium with steam or hot water.

4.12 KNOCK-OUT DRUMS (Figure 4.7)

Ground flares and elevated flares are designed to burn vapours. Any liquid droplets are liable to leave the flame partially unburnt and consequently likely to reach ground level as dangerous sources of ignition.

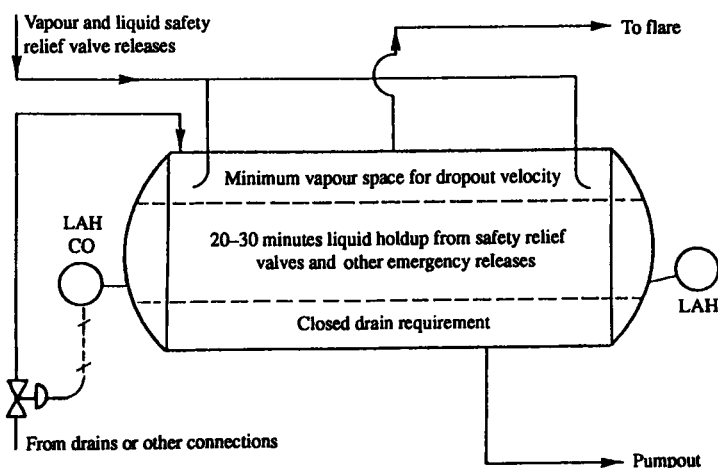


Figure 4.7 Knock-out drum. (Courtesy of the American Petroleum Institute.)

An efficient liquid separator or knock-out drum is therefore an essential element of all flare systems. The knock-out drum may be vertical or horizontal but for large flowrates (over 100 tonnes/hour) a horizontal drum is more economical.

The sizing of the drum is based on the flowrate of liquids and vapours entering the drum. Thirty minutes of liquid hold-up is normally provided, with sufficient vapour space above maximum liquid level to reduce the vapour velocity to the terminal velocity of the smallest droplet size to be disengaged.

The terminal velocity of a given droplet size can be calculated from the following:

$$\mu_t^2 = \frac{4gd(\rho_L - \rho_v)}{3C\rho_v}$$

where

μ_t = terminal velocity, m/s

d = droplet diameter, m

C = drag coefficient

ρ_L = liquid density, kg/m³

ρ_v = vapour density, kg/m³

g = acceleration due to gravity, 9.81 m/s²

where C is a function of Reynolds number (Appendix 4.7).

Obviously the smaller the droplet size to be disengaged the larger the knock-out drum. It has been found by experience that flares can safely handle droplets below 150 microns in diameter and in most cases up to 600 microns. For large flares (greater than 1 m diameter) a minimum droplet size of 300 microns may be used with some confidence.

The knock-out drum requires level measurement and alarms to detect the presence of liquid accumulating in the drum, and a pump-out system to transfer the contents to sour slops storage for subsequent recovery or disposal.

An arrangement with one electrically-driven and one steam-driven pump, each sized for the maximum anticipated flow of liquid into the drum, is recommended, so that the drum can be emptied even during a period of power failure that may be the cause of the relief situation.

The pumps should be energised by suitably positioned level switches in the drum; these should be duplicated and independent of the level measurement. The drum should be sloped at a gradient of 1:100 to the liquid outlet and designed for a pressure of 3.5 bar g and full vacuum.

4.13 SEAL DRUM IN FLARE SYSTEM (Figure 4.8)

Any flare requires a seal drum at its inlet to provide a liquid seal to prevent any possibility of flash-back from the flare into the rest of the relief system. It also prevents any suck-back of gas from the flare if there should be a partial vacuum in the relief header. This condition is possible following a hot relief and subsequent cool-down. The sealing fluid is almost always water, either process water alone or a glycol mixture to prevent freezing.

The height of the seal, ie the depth of submergence of the inlet pipe below the normal liquid level, should be at least 100 mm and typically 300 mm to provide sufficient seal volume. To prevent any possibility of drawing sealing fluid into the flare header, the final portion of the inlet pipe should be vertical and at least 3 m long. The seal volume should be sufficient to fill this vertical portion of the inlet pipe.

The end of the inlet pipe is usually provided with tapered slots to ensure a smooth passage of vapour bubbles through the sealing fluid for a large range of vapour velocities. To maintain a constant liquid level, an internal weir is installed in the drum with a small constant supply of fresh water to replace any losses due to evaporation or leakage.

With a constant supply of fresh water, the surplus water which overflows the weir is drained through an external seal to the process sewer. The height of this external seal should be equivalent to at least twice the maximum operating pressure of the drum, ie the back pressure at the flare inlet at maximum discharge rate.

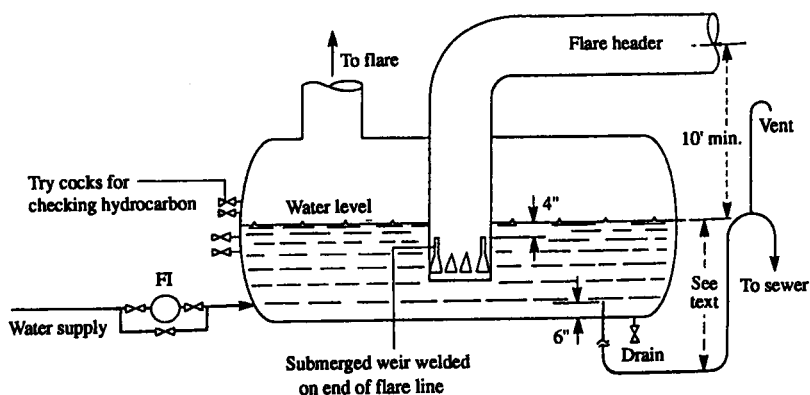


Figure 4.8 Seal drum. (Courtesy of the American Petroleum Institute.)

The height of the disengaging space above normal liquid level should be at least 1 m and the design pressure of the drum should be 3.5 bar g minimum and full vacuum. The supply of water should be flow controlled and winterised to prevent freezing. It also helps to install a steam sparge (direct steam heater) in the water space to maintain a warm temperature and strip out any undesirable dissolved gas such as H_2S .

4.14 RELIEF DISCHARGE HEADERS

In any containment system it is usually necessary to collect the relief discharges from several sources into a common header. The design of the discharge pipework, manifolds and headers is similar to the procedure described in Section 4.3 with the important difference that the discharges are likely to be two-phase and noxious.

Where liquids are present, it is essential to eliminate any undrained pockets where liquid can accumulate and cause plugging. All horizontal headers and manifolds should therefore be sloped down at least 1:500 in the direction of flow, terminating at a blowdown drum or knock-out drum where liquids can be separated. Any sub-headers should enter the top of the main horizontal header through vertical swept tees. To meet these requirements it is often necessary to elevate the relief device, hence the check required on inlet pressure drop in Section 4.1.

Size the manifolds using the guidelines in Section 4.3, bearing in mind that calculating pressure drop in two-phase regimes is laborious by manual methods (see Section 9.6).

The discharge headers also require purging (see Section A4.9.6), both continuously and intermittently, following a major relief. The continuous purge rate can be calculated to achieve the desired purge velocity (Appendix 4.6). The intermittent purge rate is pressure controlled to maintain a positive pressure in the header following a major relief. With a properly designed seal drum (See Section 4.13) the continuous purge of the discharge headers may be omitted on economic grounds. Intermittent purging of the discharge headers and continuous purging of the flare stack should be included.

NOTES

4.1 Health & Safety Executive Guidance Notes (HMSO):

HSG 28 Bulk chlorine installations

HSG 34 Storage of LPG at fixed installations

- 4.2 The maximum possible relief rate is equal to the actual discharge capacity (see Section 3.11.1) of the safety valve at the relieving pressure.
- 4.3 The materials of construction can be austenitic stainless steel, copper, copper alloys or cryogenic grade aluminium.
- 4.4 See BS 951: 1986 for guidance.
- 4.5 Dangerous in this context means flammable, toxic, corrosive or malodorous.
- 4.6 This can be achieved with a lightweight hinged plastic shield that flies open immediately a full discharge occurs. Another device is a larger concentric pipe standing proud of the vent, so that only absolutely vertical rain — which is rare — can enter the vent.
- 4.7 In the case of multiple relief devices in parallel, the cross-sectional area of the vessel nozzle and connecting pipework should be at least equal to the combined cross-sectional area of the relief devices.
- 4.8 API RP 520 Pt. II gives some guidance on this subject in Section 3.2.
- 4.9 As required by the safety valves described in Sections 2.1.2 to 2.1.5.
- 4.10 The pressure rating of the discharge flange of a standard safety valve is usually lower than the inlet flange.
- 4.11 See Health & Safety Executive Guidance Note EH 40/91 Occupation exposure limits 1991.

5. VACUUM RELIEF

Vessels and systems expected to operate under vacuum are normally designed for full vacuum conditions and consequently do not require vacuum relief.

Vessels and systems designed to operate under pressure or at atmospheric pressure may be subjected to vacuum due to an unexpected combination of circumstances.

Partial vacuum is one of the most dangerous hazards that can occur to a vessel or piping system. Unless the system is designed for vacuum, or adequate vacuum relief is provided, the consequences can be disastrous.

The following circumstances can create an unexpected partial vacuum:

- pumping out a vessel at a rate faster than the liquid can be replaced with gas or vapour;
- emptying a vessel or pipe by gravity without adequate venting;
- condensing vapour in a closed vessel, for example following steaming out;
- connecting a vessel inadvertently to the suction side of a compressor or vacuum pump, or to another vacuum vessel;
- suddenly stopping a column of moving liquid so that the column separates, creating a partial vacuum in the intervening space;
- lowering the temperature of a closed vessel containing a volatile liquid (eg butane) below its atmospheric boiling point.

The most satisfactory way of safeguarding the situation is to design the system for the highest vacuum expected, and if this condition is unpredictable to design the system for full vacuum.

Most pressure vessels designed for 3.5 bar g and above can withstand full vacuum providing that the ratio of length to diameter (L/D) is not too high, say below 3:1. For design pressures below 3.5 bar g and L/D ratios above 3, the design must be checked for partial or full vacuum. Even when the design looks favourable it is prudent to check the vacuum design pressure. In many cases a modest increase in wall thickness or the addition of a stiffening ring will be sufficient to uprate the design to full vacuum or the highest partial vacuum envisaged.

In the case of storage tanks, vessels constructed in plastic or special alloys, large diameter pipework or rectangular shapes, the cost of uprating may prove exorbitant. In this case, the system must be provided with a vacuum relief device.

5.1 VACUUM RELIEF VALVES

The vacuum relief valve is a direct-loaded safety valve in which the loading due to the vacuum underneath the valve disc is opposed by the compression of a spring. When the valve opens at its set pressure (or set vacuum in this case) air is admitted to prevent the design vacuum being exceeded.

Since there are no complications due to back pressure or emission of noxious products, the valve construction may be kept simple without introducing the sophisticated features of the assisted or balanced safety valve described in Chapter 2.

The set vacuum must not exceed the design vacuum but may well be less, particularly in the case of a vessel normally operating above atmospheric pressure. The set vacuum must of course provide sufficient differential force to open the valve fully.

If the admission of air into the system is hazardous, it is advisable to provide a reliable and sufficient supply of inert gas through a regulator, so that vacuum relief to atmosphere only occurs if the supply of inert gas fails.

5.2 PRESSURE/VACUUM RELIEF VALVES

When a vessel containing an innocuous fluid requires both pressure and vacuum relief, it is frequently more convenient and economic to provide a combined safety valve which will open in the case of excessive pressure or vacuum. The combined valve is simply a twin-ported valve with a single bifurcated inlet which requires a single nozzle on the vessel.

A special case of the pressure/vacuum relief valve is the breather valve described in Section 2.3.2 for low pressure storage tanks.

5.3 VACUUM BURSTING DISCS (Figure 5.1)

In some special circumstances, vacuum relief may be provided by a vacuum bursting disc device where the differential bursting pressure is created by the vacuum under the disc.

This is used when:

- the fluid is too toxic to permit any leakage past a vacuum safety valve;

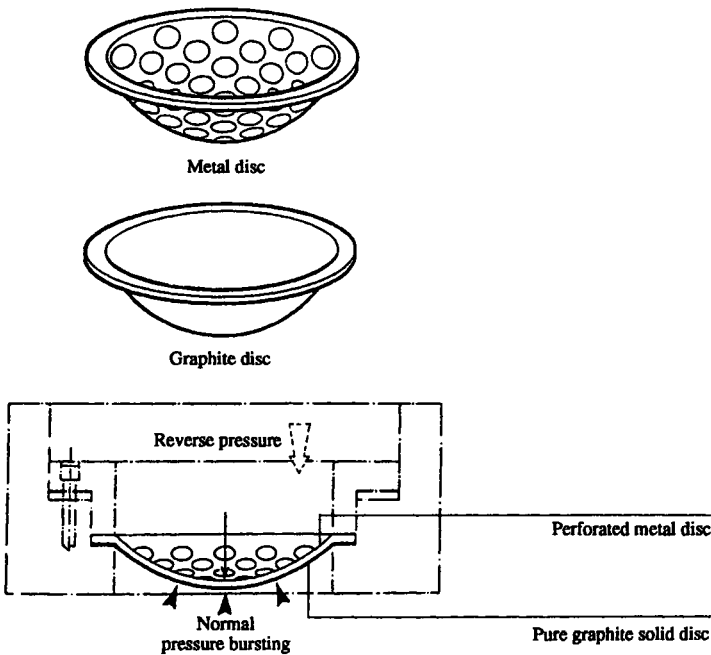


Figure 5.1 Vacuum bursting disc. (Courtesy of Marston Palmer Limited (Safety Systems Group).)

- the fluid is too corrosive to permit a reasonable life of a safety valve;
- the fluid forms solids or gums that may block the valve.

Like the pressure bursting disc described in Section 2.2, the vacuum bursting disc has the advantage of complete isolation of the operating fluid but the disadvantage of being a non-reclosing device.

It also has the added drawback of a small differential pressure, and so requires a large disc area to provide sufficient bursting force. A vacuum bursting disc which normally operates under pressure requires a pressure support on the outside. The reverse domed bursting disc (Section 2.2.2) with the concave side facing the vacuum is a good type of disc for this application.

5.4 OTHER DEVICES

Since vacuum relief is a comparatively unusual requirement, the alternative devices to safety valves and bursting discs are few in number.

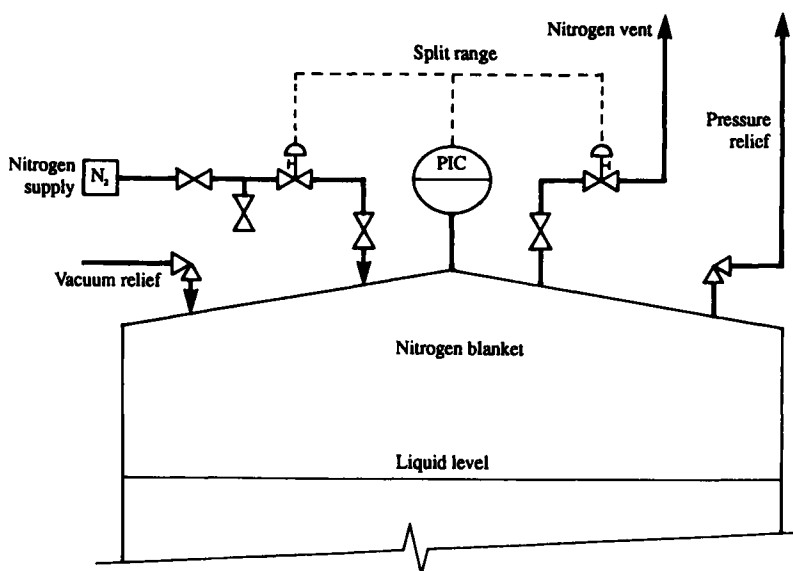


Figure 5.2 Nitrogen blanket protection.

5.4.1 LIQUID SEALS

The most important is the liquid seal device as described in Section 2.3.5. If the seal fluid can be sucked into the vessel when the set vacuum is exceeded, the seal fluid must be compatible with the vessel contents. A means of replenishing the fluid is required to maintain the seal during operation and to restore the seal after a break.

5.4.2 DEVICES FOR STORAGE TANKS

For low-pressure storage tanks containing innocuous fluids a simple pipe vent is sufficient protection against vacuum, providing that it is sized correctly to take account of the maximum combined rate of emptying and in-breathing (see API Std 2000).

For low pressure storage tanks that are provided with an inert gas blanket in the vapour phase (sometimes known as padding), special protection is required to avoid ingress of air into the blanket. The arrangement is shown in Figure 5.2.

6. THERMAL RELIEF

If any system is completely filled with a fluid and then heated, its internal pressure will rise. When the fluid is gas or vapour, the pressure rise is proportional to the temperature rise and can be predicted from Boyle's Law. When the fluid is liquid and there is no room for expansion or escape, very high pressures can be generated as the liquid tries to expand against fixed boundaries. The walls of the system will also tend to expand, but this increase in volume will be much smaller than that required by the liquid expansion.

Any liquid-containing system that is blocked in by valves or blinds and supplied with heat will be subject to this phenomenon and very careful judgement is required to decide whether pressure relief is required to protect the system. Although strictly speaking the subject should be referred to as 'pressure relief due to liquid expansion', it is almost universally known as 'thermal relief', and this description will be used here.

Since the number of recorded failures due to liquid expansion is small, there has been a tendency to ignore or forget the problem, particularly on short pipelines which are normally operating and only shut down infrequently. This is unacceptable and it is the responsibility of the process engineer to decide where thermal relief is required.

6.1 CRITERIA FOR INSTALLATION

When considering the requirement for thermal relief, look at:

- the source of heat and the rate of heat input;
- character of the liquid;
- volume of the system;
- tightness of the closure;
- likelihood of blocking-in;
- other means of thermal relief or liquid escape.

6.1.1 SOURCE OF HEAT

The source of the heat may be:

- (i) process heat from a heater or heat exchanger;

- (ii) heat tracing by steam, hot water or electricity;
- (iii) solar radiation;
- (iv) rise in ambient temperature.

In case (i) thermal relief must be provided when a liquid-filled system can be blocked in and simultaneously heated by the process. For example, if the cooling water side of a heat exchanger can be valved in with the hot side still in operation, then thermal relief of the cooling water side is essential.

In case (ii) thermal relief is strongly indicated unless the heat input to the tracing is controlled by the liquid temperature to prevent overheating, or switched off by a thermostat when the liquid temperature exceeds a predetermined level. Where these safeguards are provided, the source of heat may be regarded as case (iii).

In cases (iii) and (iv) the decision becomes more difficult. If the system can be buried, shielded, painted with white or metallic paint to reflect solar radiation, or efficiently insulated to minimise heat gain, the requirement for thermal relief can probably be eliminated.

6.1.2 CHARACTER OF THE LIQUID

For the purpose of thermal relief, liquids may conveniently be classified as follows (see Appendix 6.2 for definitions in this classification):

- (i) cryogenic liquids;
- (ii) low boiling point liquids;
- (iii) volatile liquids;
- (iv) flammable liquids;
- (v) toxic liquids;
- (vi) other liquids;
- (vii) water.

Categories (i)–(v) should generally be provided with thermal relief providing that a significant volume of liquid has been trapped and appreciable heat gain is possible. The reference to a significant volume is to avoid stipulating thermal relief where it would be impractical to install it, eg between valves installed face to face.

For other liquids (category (vi)) some judgement is required to avoid a proliferation of thermal relief valves. If the system is unlikely to be blocked in (see Section 6.1.5), or reliable operating procedures can prevent blocking-in, then thermal relief may not be required.

If blocking-in is still considered a definite risk, for example in transfer

systems which are regularly closed when not in use, then thermal relief is advisable. In borderline cases, take account of the volume of the system and the tightness of the closure.

If a vapour space in the system can be guaranteed, either by reliable level control or strict procedure, then thermal relief is not required.

In the case of water (category (vii)) the effect of solar radiation is unlikely to create a safety hazard, since the tightness of the closure is generally low and any water leakage will not constitute a serious danger.

6.1.3 TIGHTNESS OF THE CLOSURE

Since the actual increase in volume due to expansion is small, only a small amount of leakage is required to alleviate the pressure rise, and this leakage can occur through valves and flanges. In the case of valves the tightness depends on the construction of the valve, the character of the seal (metal seat or soft seat), and the amount of wear on the valve seat. This leakage can range from negligible, for a bubble-tight valve in toxic gas service, to measurable, for a worn metal valve in water service.

In the case of pipe flanges the tightness of the closure depends on the classification of the flange, the tightness of the bolts and the state of the gasket.

The following categories have been devised to characterise the tightness of the closure:

Construction	Valves		
	Bubble tight	Soft seated	Metal seated
All welded	A	A	B
Class 300 Flanges or higher	A	B	C
Class 150 Flanges	B	C	D

See Section 6.1.4 for the significance of these categories.

6.1.4 VOLUME OF THE SYSTEM

The pressure rise due to heat gain, and hence the chance of a leak, is independent of the system volume. However, in practice the hazard depends on the volume of the leak, which is greatest for systems of large volume. It is therefore quite possible to have a system of small volume without thermal relief, if it contains liquids in category (vi) (Note 6.1).

The following guidelines may be used to establish the maximum volume of trapped liquid in category (vi) without thermal relief:

Tightness category	Maximum volume, m³
A	0.1
B	1.0
C	5.0
D	10.0

6.1.5 LIKELIHOOD OF BLOCKING-IN

A system which is normally running and only occasionally closed for annual maintenance or breakdown is unlikely to be blocked in, since the procedure for closing down can incorporate measures to prevent isolation of liquid-filled sections. However, the procedure must be certificated so that the signature of a responsible supervisor is required to approve the correct closure of the system before it is left unattended.

On the other hand, systems which are frequently switched from running to stationary, due to batch operation or regular inventory movements, can easily be blocked in, and will require thermal relief if the other variables dictate it.

In between these extremes there are many different categories of closure and the process engineer must make a judgement of the likelihood of closure, the length of closure, and the necessity for thermal relief. The engineer must also be prepared to defend his or her judgement in a multi-disciplinary safety review.

6.1.6 OTHER MEANS OF THERMAL RELIEF

Alternative means of providing pressure relief due to liquid expansion may be available. For example, the system may already be provided with pressure relief for another contingency, or the valve that makes the final closure may be provided with a small bore by-pass, or a small hole in the valve plug, to prevent complete closure. If a suitable bellows material can be found to withstand the process conditions, a bellows branch is another method. The movement of the bellows must be sufficient to contain the liquid expansion.

6.1.7 SELECTION PROCEDURE

Figure 6.1 is a decision tree for establishing whether thermal relief is required.

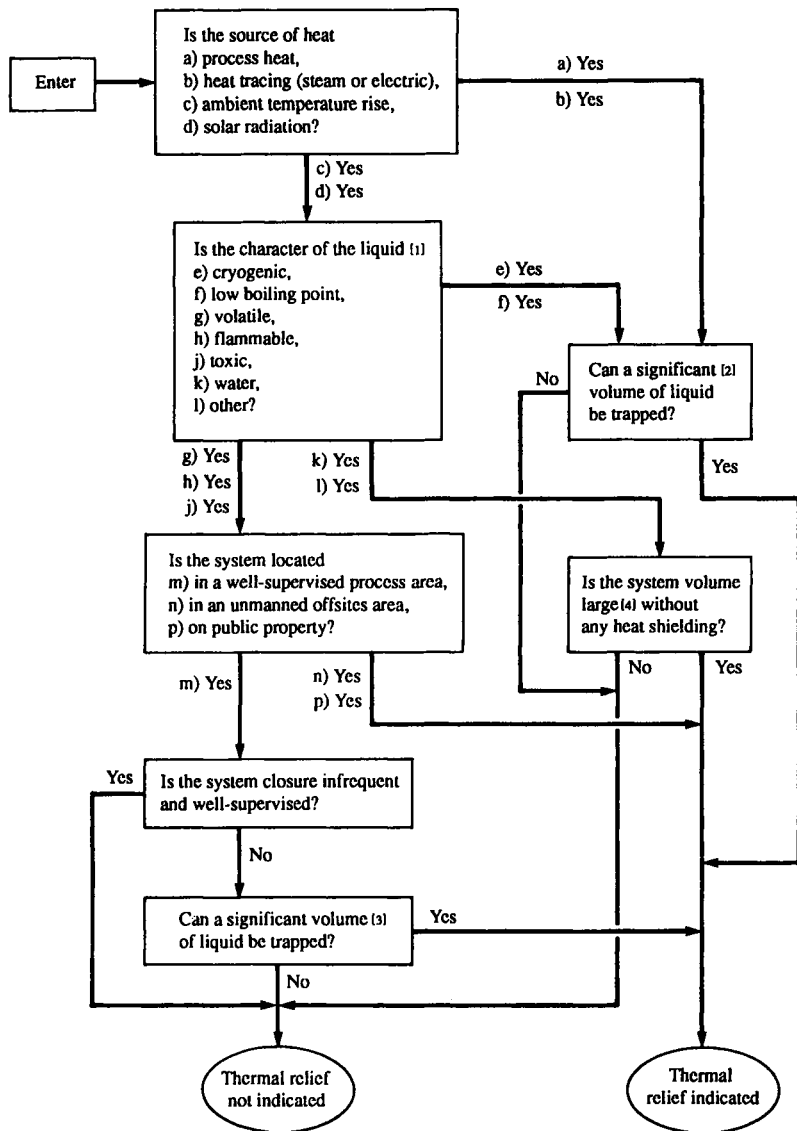


Figure 6.1 Criteria for thermal relief.

Notes: [1] See Appendix 6.2. [2][3] Greater than 0.01 m^3 . [4](k) Greater than 100 m^3 .
 [4](l) See table in text at Section 6.1.4 and notes therein.

6.2 SIZING THERMAL RELIEF VALVES

For the majority of cases where liquid expansion only is concerned, there is no flashing (or less than 1%) across the relief valve and the volume of the system is modest (less than 100 m³), the pressure relief due to liquid expansion may be accommodated with a 15 mm × 20 mm or 20 mm × 25 mm thermal relief valve.

However, with larger systems, or where extensive flashing of low-boiling liquids can occur, the discharge rate through the thermal relief valve must be calculated before sizing the valve.

The method for calculating the relief rate is described in Appendix 6.1 and the sizing of the relief valve in BS 6759.

6.2.1 SETTING THERMAL RELIEF VALVES

In general, the set pressure of a thermal relief valve should be determined by the design pressure of the system which it is protecting.

There is a temptation to set the valve at the maximum allowable working pressure (MAWP) of the pipe flanges at the operating temperature of the system. This could be acceptable if there is no other equipment in the system or the equipment and valves in the system were designed for the MAWP of the flanges. However, if any item in the system has a design pressure lower than the MAWP of the flanges, then the lowest design pressure in the system should determine the set pressure.

6.3 CONTAINMENT OF THERMAL RELIEF

Although the volume of discharge through a thermal relief valve is small, a safe containment system is still required if the discharge is dangerous, ie flammable, toxic, corrosive or high-temperature, and it cannot be safely released to the atmosphere.

If the discharge is not dangerous it can be directed to grade or sewer providing that care is taken to avoid directing it onto people or equipment.

If the discharge is dangerous then there are one or two special arrangements that can be made in addition to the containments described in Section 4.5.

6.3.1 DISCHARGE TO PROCESS

Since the final closure that creates the potential of thermal relief is almost always a valve, consider the possibility of routing the discharge to the other side of the valve. When the other side of the valve is connected to a storage tank or low-pressure vessel, this route is a prime candidate. When the other side of the

valve is another part of the process which may also be blocked in, great care must be taken not to impose a high back pressure on the thermal relief valve.

When this method of containment is chosen, regular maintenance of the relief valve is essential (see Section 11.3).

6.3.2 DISCHARGE TO A CLOSED RECEIVER

Since the volume of discharge is small, a good arrangement for containment is a small closed blowdown chamber, filled with air if permissible, or otherwise filled with inert gas at atmospheric pressure. Providing that the volume of discharge is small compared with the volume of the chamber, (say a container of 0.1 m^3 for a $20 \text{ mm} \times 25 \text{ mm}$ relief valve), the effect of the discharge on the chamber back pressure is correspondingly small. The pressure in the chamber should be monitored with a remote pressure indicator and a pressure alarm in case the thermal relief valve malfunctions and fails to close after a pressure relief. The design pressure of the chamber should be at least equal to the design pressure of the system it is connected to.

This option should only be used for liquid expansion without flashing.

NOTE

6.1 In doubtful or borderline cases a more rigorous approach may be preferred by calculation of pressure rise (Reference 6.1). This approach is particularly recommended in the case of cast piping where brittle fracture may occur.

7. FIRE RELIEF

Although this handbook does not deal with the calculation of relief rates, except by reference in Section 1.6, fire relief is unusual in that the calculations are very dependent on the judgement of the engineer. The calculated relief rate in a fire is frequently the ruling contingency for the sizing of the relief device, and the inconsistency of some relevant codes of practice gives rise to some confusion.

For these reasons, the calculation of relief rates in a fire emergency will be examined in some detail. This chapter will attempt to clarify the relevant Codes of Practice and provide some guidelines for the chemical engineer faced with the calculation of fire relief.

The approach will lean heavily on the Recommended Practices of the American Petroleum Institute, notably API RP 520 Part 1 and API Std 2000. The API has addressed the problem of fire relief over many years, starting in 1928, and has refined the heat flow formulae several times in response to experimental data and communications from the users of relief devices.

The method assumes that only vapour is discharged through the relief device. Although it can be shown that in certain circumstances liquid may also be discharged (Reference 7.1) the assumption of a vapour discharge may still be safely used for sizing the relief device.

The API method will be treated as the recommended method and will then be compared with the other relevant codes on the subject. The only reservation applying to the API method is the use of the environmental factor F mentioned in Section 7.3.2.

7.1 CODES OF PRACTICE

The relevant codes for calculating fire relief rates are:

API RP 520 Part 1	(1990)
API 2000	(1982)
NFPA - 30	(1981)
OSHA 1910.106	(1981)
CI 5.3.3.	(1977)
CGA S-1.3	(1980)

where the authorities' names in full are as follows:

API	American Petroleum Institute
NFPA	National Fire Protection Association
OSHA	Occupational Safety & Health Administration
CI	Chlorine Institute
CGA	Compressed Gas Associations

The NFPA and OSHA codes are virtually identical in this context and will be treated as such. Similarly the CI has adopted the criteria of CGA on this topic.

Where the Code of Practice is mandatory the designer has no choice but to follow its regulations. However, where the designer has some freedom of choice, a comparison of methods is helpful.

7.2 DESIGN METHODS

The basic formula given by API 520 for the heat absorbed by a vessel engulfed in fire is:

$$Q = 21000 FA^{0.82} \text{ in Imperial units (Note 7.5)}$$

or

$$Q = 43.2 FA^{0.82} \text{ in SI units}$$

where

Q is the heat absorbed expressed in BTU/h or kW

A is the effective wetted surface area of the vessel in ft^2 or m^2

F is an environment factor (see Section 7.3).

The effective wetted area of the vessel is defined as the surface area of the vessel in contact with liquid up to a height of 25 ft or 7.62 m above ground level, or above any floor or surface that could sustain a fire. For a vertical cylindrical vessel at ground level it does not include the area of the base of the cylinder.

This definition is applied to all vessel shapes except spheres and spheroids when the effective elevation above ground level is taken to the equator of the vessel if it exceeds 25 ft.

A vertical storage vessel with a variable inventory is assumed to be half full. The wetted area is thus half the cylindrical surface area within 25 ft of ground level.

In the case of a plate distillation column, the wetted area is calculated from the normal level of liquid in the base of the column plus the normal level on each tray. For a packed column, the wetted area is calculated from the level

in the base plus the height of liquid between distributors. In each case the effective area is the area within 25 ft of ground level.

The philosophy of limiting the effective elevation to 25 ft is based on observations that wind effects and shape effects limit the contact of the fire with the vessel as the elevation increases. However some companies prefer to use larger values (Note 7.4) for the effective elevation. Check whether there is a company standard taking priority over API 520.

The philosophy of wetted area is that heat transfer to the liquid will eventually boil it and produce much more vapour than heat transfer to the vapour phase, which produces only vapour expansion.

If the vessel does not contain any liquid the calculation of relief rate must be radically different (see Section 7.2.4).

The environment factor F is an attempt to correct the heat flow for the effect of insulation, water drenching and earth covering, and is dealt with in Section 7.3. The numerical values of F and the limitations on application give rise to most of the conflict between codes.

7.2.1 RELIEF RATE

The conversion of the heat flow into a vapour relief rate uses the latent heat of the liquid under relieving conditions.

$$W = \frac{Q}{L}$$

where W = relief rate in lb/h or kg/s

and L = latent heat in BTU/lb or kJ/kg.

It is essential to use values at the actual pressure and temperature of the relief rather than at normal working conditions.

7.2.2 LOW PRESSURE STORAGE TANKS

API 520 applies to pressure vessels and storage tanks with a design pressure greater than 70 mbar g.

For low-pressure storage tanks API 2000 provides a table of venting (relieving) requirements in ft³/h against wetted surface area in ft².

The rules for calculating effective wetted area are quite different to API 520. For horizontal storage tanks, the effective wetted area is 75% of the total surface area. For vertical storage tanks, the effective wetted area is the total cylindrical surface area of the shell up to an effective elevation of 30 ft or 9.14 m.

For spheres and spheroids the effective wetted area is 55% of the total surface area or the surface area up to an elevation of 30 ft, whichever is the greater.

The justification for this larger view of the effective wetted area is that storage tanks are more likely to stand in banded areas which would tend to hold the flammable material in the vicinity of the tanks. In contrast, the area beneath process vessels is less likely to be banded, and hence flammables are more likely to drain away.

Providing that it is quite clear which Code of Practice applies to the vessel in question there is no need for conflict between these codes.

In the case of a process vessel sited in a storage area the design engineer can apply judgement and increase the effective height to 30 ft if the surrounding area is likely to confine the flames.

7.2.3 OTHER CODES OF PRACTICE

The calculation of effective wetted surface area for the NFPA and OSHA codes are identical to API 2000, so that there is no conflict between NFPA/OSHA and API for low pressure storage tanks.

For pressure vessels with wetted areas in the range 10–2000 ft² the NFPA/OSHA codes appear to give heat flows about twice those of API 520. Between 2000 and 2800 ft² the ratio drops steadily from 2 to 1 (see Figure 7.1 on page 88), and for wetted areas above 2800 ft² the NFPA/OSHA codes are identical to API 520.

However, the NFPA/OSHA codes also allow an environmental factor of 0.5 for good ground drainage beneath the vessel. This applies if a pool of liquid sustaining the fire would quickly run off to a containing sump out of range of the affected vessel. The effect of this environment factor is to make the heat flow almost equal to that predicted by API 520, for effective wetted areas in the range 10–2000 ft², as shown in Figure 7.2 on page 88. A good case can therefore be made for using API 520 in this context as the preferred code.

The CI/CGA codes use a heat flow of $Q = 34500 A^{0.82}$ where Q is in BTU/h and A is the total surface area of the vessel in ft². In the context of portable gas containers, which are the main concern of CI and CGA, this concept of flame exposure to the total surface area of the container seems plausible. The high value of the heat flux can also be justified on the grounds that gas containers are more likely to be stored indoors or in well shielded locations where higher heat fluxes can be experienced. But for process vessels and storage tanks the concept is considered unlikely and is not recommended.

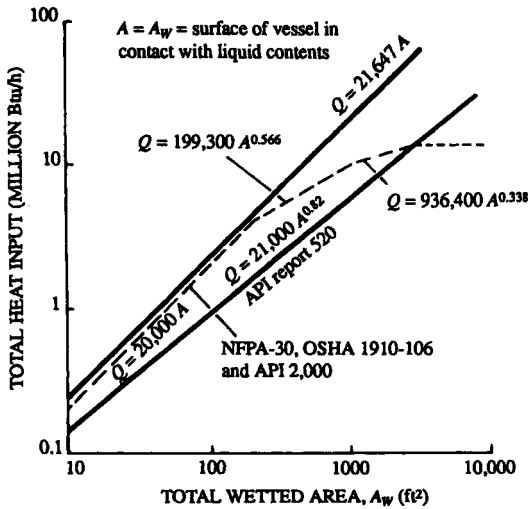


Figure 7.1 Comparison of NFPA/OSHA and API Codes.
Source: R.A. Crozier (Reference 7.3).

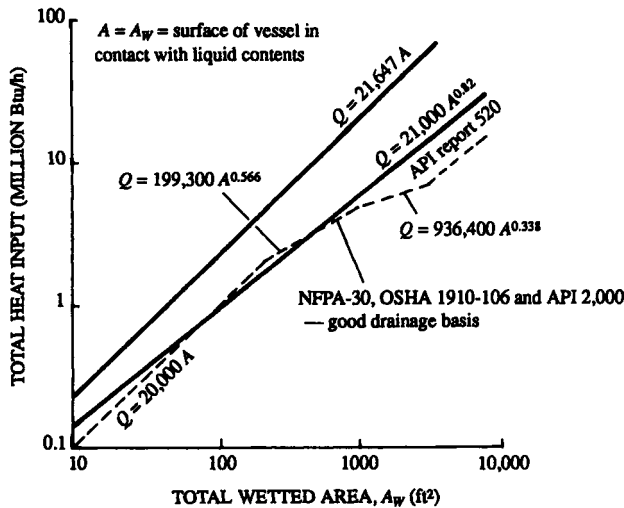


Figure 7.2 Modified comparison of NPFA/OSHA and API Codes.
Source: R.A. Crozier (Reference 7.3).

7.2.4 GAS FILLED VESSELS

For a gas-filled vessel, the relief rate in a fire situation depends entirely on the thermal expansion of the gas.

API 520 gives a method for calculating the effective discharge area of the safety valve as follows:

$$A = \frac{FA_e}{\sqrt{P}}$$

where

A is the required discharge area (in²)

F is a relief valve factor which can be calculated (Formula D-4 of API 520)

P is the relieving pressure (Section 3.4) (psi a)

A_e is the exposed surface area of the vessel (ft²).

This method has a number of defects, notably:

- no allowance for insulation;
- no restriction on effective area;
- the relief rate is proportional to the exposed area rather than $A^{0.82}$ as used for a liquid-filled vessel.

Calculations using this method can produce results where the relief rate for a gas-filled vessel is higher than a liquid-filled vessel which from previous considerations seems anomalous. On the other hand, the consequences of overheating the unwetted wall of a pressure vessel can be disastrous (see Section 7.4.3).

Reference 7.2 looks at these defects in detail and offers an alternative computer-based method.

7.3 FIRE PROTECTION

Certain measures can be adopted to reduce the heat absorbed during a fire. These measures can then be accounted for in the environmental factor F . For bare vessels with no specific fire protection the F factor is unity.

7.3.1 GOOD DRAINAGE

As mentioned in Section 7.2.3 the NFPA/OSHA codes permit an F factor of 0.5 for good drainage (Note 7.3) of the ground beneath the vessel. This is not permitted by API but it is worth noting that the API formulae assume good drainage and fire-fighting equipment in their derivation. (See Section D.5 of API 520).

7.3.2 INSULATION

All the Codes permit factors for insulation providing that it is correctly specified and applied and impervious to the impact of fire hose streams (Note 7.1). Although not explicit in the codes, insulation should cover the whole vessel and not just the lowest 30 ft.

The NFPA/OSHA codes give $F = 0.3$ for adequate insulation whereas API gives reduced F values as the thickness increases:

Insulation thickness	1"	2"	3"	4"
F	0.3	0.15	0.1	0.075

In the CI/CGA codes the F factor is calculated as the thermal conductivity (Imperial units) of the insulating material divided by the thickness (ins).

On balance the conservative approach of NFPA/OSHA is recommended, bearing in mind the inevitable deterioration of insulation in time and the notorious difficulty of ensuring 100% protection during application (see Section 11.5).

In the case of a large refrigerated storage tank where a high standard of insulation is essential for maintaining the normal operating temperature of the contents, F factors lower than 0.3 may be permitted by company standards.

7.3.3 EARTH COVERING

All codes concur that F factors can safely be applied for earth covering as follows:

	F
Underground storage	0
Earth-covered above ground, eg for LPG and LNG storage tanks	0.03

7.3.4 WATER APPLICATION

Although sprinkler systems and water drenches are highly recommended for flammable inventories, the temptation to quantify their effect should be treated with caution.

The API code takes the view that these systems are not fool-proof and therefore should not qualify for an environment factor. This approach is preferred to that of the other codes, which permit an F factor of 0.3 for adequate (Note 7.2) automatic water sprays.

7.3.5 DEPRESSURING AND EMPTYING FACILITIES (see 12.2)

Depressuring and emptying facilities are highly desirable for pressure vessels and storage tanks containing flammable or dangerous materials. Exercise caution with emptying facilities, as noted in the final paragraph of Section 12.2.

However, in a fire the prompt functioning of these facilities cannot be guaranteed and consequently they should not be allocated an F factor.

7.3.6 RECOMMENDED ENVIRONMENT FACTORS

In conclusion, the effect of fire protection on the calculation of fire relief should be treated conservatively. The API Code is recommended in this application, modified by the restriction on the F factor for insulation as described in Section 7.3.2.

It is worth re-emphasising that the insulation must be fire-resistant (Note 7.1) and well-maintained (see Section 11.5).

7.4 EFFECT OF FIRE ON RELIEF DEVICES

The effect of fire on relief devices has not been well documented, although there have been many opportunities to inspect relief devices after a fire.

The following theoretical considerations may be noted:

7.4.1 SAFETY VALVES

Fire produces thermal expansion and distortion. The thermal expansion of a helical spring above its normal operating temperature will tend to reduce its tension and hence lower the set pressure, so the effect tends to be in a safe direction.

On the other hand, unequal thermal expansion can distort the valve spindle leading to jamming of the valve and a possible reduction in discharge capacity. Fortunately the small size of a safety valve in comparison with the size of a serious fire will tend to equalise temperature throughout the valve and minimise distortion.

7.4.2 BURSTING DISCS

Similarly the effect of high temperature on a bursting disc is to lower the bursting pressure or destroy it altogether, and hence the tendency is in a safe direction.

7.4.3 OTHER EFFECTS

More serious than the effect of fire on the relief device is the effect of high temperature on the strength of the vessel walls.

All carbon steels used for vessel fabrication rapidly lose their ultimate strength at the high temperatures created by fire. One example given in Appendix D3 of API 520 predicts a failure by rupture in about 20 minutes for 1" thick carbon steel. It is worth noting that vessels designed to BS 5500 are at greater risk in this respect than ASME Code Section VIII due to the lower metal thickness permitted by BS 5500.

This research work emphasises the importance of insulation and water drenching as a safety system to reduce the rise in temperature of the vessel walls during a fire.

7.4.4 FIRE AT THE VENT

Another serious effect is ignition at an atmospheric vent containing flammable vapours. This ignition is almost certain to occur during a larger fire and the radiation from the flame could be quantified and added to the heat input to the vessel being relieved.

This emphasises the importance of the safe routing of atmospheric vents as discussed in Section 4.2.1.

NOTES

7.1 The requirements for fire-resistant insulation are searching and specific:

- the insulating materials and metallic cladding must withstand a fire temperature as defined in BS 476 (1987);
- the cladding system must be designed to resist the impact of water from the fire hoses;
- the total insulating system must be part of a scheduled maintenance procedure under management supervision (see Section 11.5).

7.2 Adequate water sprays may be defined as follows:

- a water flow rate of at least $0.5\text{m}^3/\text{h}$ per m^2 of surface area;
- sufficient water manifolds and spray nozzles to drench the whole surface;
- water pressure at the highest point of the system displayed in the control room, with a low pressure alarm;
- facilities for testing and flushing the whole spray system;
- adequate materials of construction, filters and dirt traps to preserve the integrity of the system;

- water sprays initiated automatically by fire detectors or by remote manual operation;
- in cryogenic service, the water sprays must not be able to block any vents in the event of freezing.

7.3 Good drainage may be defined as a ground slope of at least 1 in 40 to an underground sewer inlet.

7.4 Figures of 50 ft have been quoted for large pool fires in storage areas. An effective elevation (E) related to the base diameter (D) has also been suggested with a relationship $E/D = 2.5$ to 3.0 .

7.5 This formula assumes prompt fire fighting and good drainage beneath the vessel. If these conditions do not exist, the constant 21000 is increased to 34500.

8. RELIABILITY OF RELIEF SYSTEMS

The definition of reliability in this context needs careful consideration. A failure under test is obviously less serious than a failure in operation and a failure in a safe condition is less serious than a failure in a dangerous condition.

The approach in this chapter will be to consider the various possible failure modes of relief devices and then to survey the available reliability data.

The failure rate of devices in operation, F_1 , is:

$$F_1 = \frac{\text{number of failures}}{\text{number of operating years}}$$

and the percentage of failures under test, F_2 , is:

$$F_2 = \frac{\text{number of failures}}{\text{total number of tests}} \times 100\%$$

The reliability in each case can then be expressed by a formula incorporating the corresponding failure rate.

$$R_1 = \frac{1}{F_1} \text{ years}$$

where R_1 is reliability in operation

and $R_2 = 100 - F_2$

where R_2 is the percentage reliability under test.

Comparison of reliabilities between different devices and between different users is fraught with difficulty since the accuracy of recorded data varies enormously. Some users are reluctant to report failures which may reflect on their competence and some manufacturers are reluctant to report failures which may reflect on their reputation. And even when the resources are available, accurate recording requires vigilance on the part of the operator and expertise on the part of the records clerk.

In view of these reporting difficulties, some judgement and experience is required to draw conclusions from the published data.

8.1 RELIEF DEVICES

Generally speaking, relief devices are robust in design with no rotating parts subject to continuous wear. At first sight they would seem to be reliable devices; however, their performance on test does show some unreliability, and since the consequences of a single failure can be catastrophic, we should expect total reliability. The failure modes of safety valves and bursting discs are sufficiently different to warrant separate treatment.

8.1.1 SAFETY VALVES

As the design of safety valves has been developed and refined over many years, their reliability has improved steadily. For example, bottom guided valves have shown lower reliability than top guided valves and consequently have fallen out of favour. On the other hand, as the valves become more sophisticated in the search for greater precision and improved tightness, so the number of parts increases and the reliability can suffer.

The failure modes of safety valves are:

- (a) Failure to open at the set pressure.
- (b) Failure to open fully at the relieving pressure.
- (c) Premature opening below the set pressure.
- (d) Failure to reseal after opening.
- (e) Valve simmer and chatter, ie rapid opening and closing (Note 8.4).
- (f) Leakage through the valve seat (Note 8.5).
- (g) Leakage through the valve body.
- (h) Rupture of the valve body.

And each failure mode can be subdivided into failure in operation and failure under test.

Failure to open (categories (a) and (b)) is the crucial failure mode and the reliability of the valve in these categories is sometimes referred to as the primary reliability (Reference 8.1).

Unfortunately most reliability data is recorded in the workshop, where the main concern is the condition of the valve and the accuracy of the cold set pressure when the valve returns to the workshop for routine overhaul and maintenance. Depending on the process duty, statutory and company requirements, this can be after one, two or more years service, so that more variability can enter the investigation. Fortunately some work by Aird (Reference 8.3) indicates that the reliability under test after service is independent of the length of service.

In this context we must distinguish between failure to open at the required set pressure, and inaccurate adjustment or measurement during the cold set procedure. Safety valves operating at modest temperatures (say below 100°C) are comparatively easy to adjust since this can be done at ambient temperature under standard workshop conditions. As the operating temperature increases, the adjustment becomes more difficult owing to the reduction of set pressure between ambient and operating temperature (Note 8.2). The operator must either accept the manufacturer's correction factor or attempt to adjust the set pressure under working conditions.

This can be done in some circumstances, eg with steam safety valves where spare equipment is available, but for most high-temperature process duties adjustment *in situ* is too difficult to accomplish and the manufacturer's temperature correction must be accepted.

If the cold set adjustment in the workshop is faulty or the correction factor is invalid, the safety valve cannot be expected to lift precisely at the set pressure. To allow for this variability, a margin of tolerance about the set pressure is usually accepted before a failure is recorded. This tolerance is specified in BS 6759 (Note 11.1) and should always be reported with reliability data.

8.1.1.1 RELIABILITY DATA

Failure rates for safety valves under test in the workshop have been reported by Pearce (Reference 8.2) and Aird (Reference 8.3). Failure rates listed in the Reliability Data Bank of the NCSR (Note 8.3) are reported in Appendix 8.1.

With a sample of 1062 valves and a tolerance of $\pm 10\%$ on set pressure, Pearce reported a failure rate of 17%, of which 7% lifted heavy (category (a)) and 10% lifted light (category (c)). This was reported as a reliability of 83%. When the sample was subdivided into clean, average and dirty duties the corresponding reliabilities were 95%, 84% and 73%. In the clean group only one valve out of 165 lifted heavy so that the primary reliability was over 99%. In contrast the primary reliabilities in the average and dirty groups were 90% and 86%.

The overwhelming reason for lifting heavy in these latter categories was the tendency of the valves to stick due to process deposits in the valves, which suggests that a judicious use of bursting discs upstream of the safety valves would make a major improvement (see Section 2.5).

It may well be that some safety valves that stick in the workshop under ambient conditions operate satisfactorily under process conditions, when the

valve surfaces are hot.

In contrast to Pearce's results, with a sample of 746 valves Aird reported a reliability of only 55% using a tolerance of $\pm 10\%$ on set pressure. Aird does not distinguish in this reference (Reference 8.3) between heavy and light lifting so that a comparison of primary reliability is not possible.

8.1.1.2 CAUSE OF FAILURE

Apart from the problem of sticking, other causes of lifting heavy were reported:

- (a) Damage to the sliding surfaces (spindle and guides) caused by excessive vibration, chatter or corrosion (Reference 8.1).
- (b) Foreign material in the bonnet preventing the valve from moving.

In the cases of valves lifting light the noteworthy causes were:

- (c) Spring relaxation (or loss of tension).
- (d) Spring failure.
- (e) Loose adjustment nut.

Cause (c) is by far the most common and deserves some close attention during the valve specification and selection stage. Relaxation of a spring occurs in two stages: an initial relaxation immediately after cold setting, followed by a gradual time-dependent relaxation which proceeds exponentially to an eventual limit. The rate of relaxation is a function of spring material, spring tension and operating temperature. At modest temperatures and pressures the relaxation is negligible if the spring material is sound. At high operating temperatures, some relaxation of the spring seems inevitable and the set pressure will tend to drop. The relaxation can be minimised by careful selection of the spring material to suit the operating temperature and also by a technique of hot setting (Reference 8.1). In this technique the valve spring is heated in the workshop to a temperature above its normal operating temperature and then compressed above its normal tension for a period of at least two hours.

Apart from failing to lift at the set pressure, the most commonly reported failures are in categories (d) and (e), ie failure to reseal after lifting and the phenomenon of chattering.

Failure to reseal is a mechanical problem which can be caused by either a temporary misalignment of the valve disc in the seat or, more seriously, permanent damage to the valve seat caused by erosion or chattering. A temporary misalignment can usually be cured by lifting the valve and then restoring the reseating pressure. Occasionally a further temporary reduction in pressure is required to make the valve tight. Any permanent reduction in reseating pressure

indicates a loss of adjustment of the blowdown rings or permanent damage to the valve seat. In either case the valve must be removed and overhauled.

Valve simmering or chattering (Note 8.4) occurs when the operating pressure is too close to the set pressure and pressure transients are experienced. Chattering, rather than simmering, predominates when the pressure drop in the inlet piping is too large (see Section 4.1) or the back pressure is too high. Since valve chatter can permanently damage the valve seat, it is important to adjust the pressure regime at the first opportunity.

8.1.2 BURSTING DISCS

As the design of bursting discs has developed, the number of types and materials have proliferated. Improvements in convenience and economy are not, however, always compatible with greater reliability.

The failure modes of bursting discs are, in order of importance but not of probability:

- (a) Failure to rupture at maximum bursting pressure.
- (b) Failure to open fully at maximum bursting pressure.
- (c) Premature rupture below minimum bursting pressure.
- (d) Leakage through the disc to the vent (via cracks or pinholes).
- (e) Leakage through the holder to atmosphere.

Categories (a) and (b) are the critical failure modes for protection of equipment and the reliability of the disc in these modes can be referred to as the primary reliability. Category (c) is inconvenient and sometimes costly but is not usually dangerous unless the containment or disposal system for the discharge is inadequate. Categories (d) and (e) are comparatively rare and less noteworthy.

Bursting discs should be removed from service at predetermined intervals for visual inspection and then, depending on condition and manufacturers' recommendations, either returned to service or replaced.

Consequently there is no great incentive to test the bursting discs after they have completed their service. The wealth of statistical data examined for safety valves in Section 8.1.1 is much more difficult to assemble.

However, a review of the case studies in Section 8.3 indicates that category (c), premature rupture below the minimum bursting pressure, is the commonest failure mode. An analysis of the causes of failure shows that this can be caused by:

- (a) Incorrect specification of the disc, eg overlooking intermittent vacuum conditions and other pressure/temperature transients, failure to predict corro-

sion, or operating at a pressure too close to the bursting pressure, resulting in fatigue failure.

- (b) Damage to the disc by faulty handling before installation or during maintenance.
- (c) Incorrect installation of the disc — particularly by faulty fitting.
- (d) Damaged or flawed disc undetected during installation.
- (e) Disc left in service beyond its recommended service life.
- (f) Incorrect disc fitted.

In a review of bursting disc reliability by the Vinyl Chloride Safety Association, 20 out of the 38 respondents reported incidents of premature rupture during one operating year (1984) whilst five respondents each reported one incident of failure to rupture in the previous five years.

In explanation of the premature ruptures, causes (a), (b), (c) and (d) were all quoted, with (b) and (c) the most prevalent.

In the cases of failure to rupture, the following explanations were offered:

- blunt knife blades failing to pierce the disc (Note 8.1);
- fouling of the disc preventing rupture;
- faulty disc housing;
- pressure accumulation between disc and safety valve.

Unfortunately the statistics are not specific in the number of discs in the sample and the operating hours per disc, so the reliability is indeterminate.

8.2 CONTAINMENT OR DISPOSAL SYSTEMS

Where containment or disposal systems are concerned, we are dealing with system reliability rather than equipment reliability.

There are so many systems working in a multitude of situations that an enormous amount of data would be required to quantify system reliability.

We can only touch upon the factors affecting system reliability. It is immediately apparent that three categories can be identified:

- (a) Systems that operate continuously and hence are always available when a relief discharge occurs.
- (b) Systems that are normally operating at less than full capacity, which is then run up to full capacity when a relief discharge occurs.
- (c) Systems that only start up on demand from any relief discharge.

Examples of these categories taken from Chapter 4 are:

- (a) Elevated flares (Section 4.9).
- (b) Absorber/scrubber (Section 4.5.7).
- (c) A standby incinerator (Section 4.5.8).

In category (a) the theoretical reliability of the continuous system can be developed from the reliability of its individual pieces of equipment. With essential items of rotating machinery, the reliability of the system may be improved by duplication of equipment and automatic start of the standby equipment following a signal of failure from the operating item. With essential items of instrumentation, the reliability may be improved by duplicating or even triplicating sensors and transmitters, with two-out-of-three voting in the case of triplication. The reliability may also be improved by periodic testing and inspection.

The reliability of category (b) is slightly lower in that a sensor must reliably detect a discharge or a change in operating conditions caused by the discharge; and then a control valve must respond to a change in signal from the controller.

The reliability of category (c) is appreciably lower in that machinery must start, or burners ignite, in response to a discharge, with all the possible malfunctions that could occur.

8.3 CASE STUDIES

Examples may be found in the literature describing failures of relief devices in service and the consequences of these failures.

The following section contains a brief description of each case together with some literature references for further information and any lessons to be learnt from studying the cause of failure.

Cases 1–7 concern safety valves, Cases 8–12 bursting discs and 13–18 containment or disposal systems.

8.3.1 SAFETY VALVE FAILURES

CASE 1 — British Columbia, September 1983 (Reference 8.4).

During a transfer of borol from a rail tank car, the safety valve on the padding gas supply ruptured. Following a pressure rise, the flexible transfer hose blew off spilling 10,000 gallons of borol (Note 8.6).

CASE 2 — Tennessee, December 1983 (Reference 8.5).

A safety valve on an acid vessel opened prematurely releasing a cloud of HCl

vapour. 3200 kgs of acid were released but no environmental damage was caused.

CASE 3 — New Jersey, June 1978 (Reference 8.6).

A relief valve on an ether distillation column ruptured and vented an ether vapour cloud to atmosphere. A subsequent explosion and fire damaged property and injured seven people.

CASE 4 — USA, September 1977 (Reference 8.7).

An LPG storage vessel was overfilled due to instrument failure. The relief valve failed to open and the vessel ruptured at the seam. The resulting explosion and fire destroyed six other LPG vessels, causing two deaths and damage costing \$2 million.

CASE 5 — Quebec, January 1970 (Reference 8.8).

A safety valve on a liquid ethylene storage tank failed due to icing up. The aluminium inner shell ruptured, followed by the steel outer shell, releasing 70 tonnes of liquid ethylene. The subsequent fire destroyed the storage tank.

CASE 6 — Brazil, March 1972 (Reference 8.9).

Hot product transferred into an LPG storage tank causes a rapid pressure rise, but the safety valve failed to open. To reduce pressure the operator opened the drain valve, which froze open. The consequent vapour cloud exploded causing 39 deaths, 51 injuries and damage costing \$4.8 million.

CASE 7 — UK, November 1967 (Reference 8.10).

The pressure rose in a liquid ethylene storage tank. The safety valve iced up and failed to open. The tank shell subsequently collapsed releasing 204 tonnes of liquid ethylene. The spillage was contained in the bunded area and evaporated without incident.

8.3.2 BURSTING DISC FAILURES

CASE 8

A graphite bursting disc protecting a 4500 litre batch reactor failed prematurely at 18 psig compared with the specified bursting pressure of 30 psig. 800 litres of dyestuff were released to atmosphere and sprayed over adjacent property. A manufacturing defect in the bursting disc was diagnosed.

CASE 9

A 400 kg pressurised dye vessel was operating at 105°C and 3 bar g when its bursting disc ruptured prematurely, releasing hot water into the working area.

Investigations revealed that the disc had been weakened by the slight vacuum condition experienced at the rundown of each vessel batch. The original specification had overlooked this intermittent vacuum and hence an unsuitable bursting disc had been fitted.

CASE 10

A bromine header tank at a pharmaceutical facility was operating at 1.9 bar g when the bursting disc designed for 4.5 bar g failed. 10 kgs of bromine vapour were released to atmosphere but dispersed safely in windy conditions.

It was found that the bursting disc was not protected by a PTFE coating as specified and additionally the disc had not been changed after the recommended 12 months' service.

CASE 11

A bursting disc on a drying vessel failed to open fully following rupture. The drying vessel subsequently ruptured due to overpressure, propelling the major part of the vessel through the roof of the process building and causing considerable damage.

The bursting disc was a reverse domed type with knife blades. Examination of the disc after the accident revealed that the disc had only opened partially with the intact portion supported on one of the knives.

CASE 12

A graphite bursting disc at a phosgene plant cracked in normal operation, releasing phosgene vapour to atmosphere. Two operators were overcome and hospitalised but without any permanent damage to their health.

It was found that the disc had been subjected to excessive mechanical stress by misalignment of the connecting pipework. A more robust disc holder was subsequently fitted and the pipework realigned.

8.3.3 FAILURE OF CONTAINMENT SYSTEMS

CASE 13

A bursting disc on a phosgene reactor ruptured during a pressure surge, releasing phosgene vapour into the scrubber system. The scrubber system became over-

loaded and subsequently released phosgene vapour to atmosphere. The phosgene vapour travelled downwind affecting operators on an adjacent plant.

Investigations revealed that the scrubber system had not been designed for the contingency that occurred.

CASE 14

A bursting disc on a phenol formaldehyde (PF) reactor ruptured due to overpressure and released a two phase mixture of reactor contents to a dump tank. The PF vapour was vented to atmosphere and drifted downwind for half a mile where it affected members of the public.

The design of the dump tank system had not considered the containment or disposal of the vapour release.

CASE 15

A bursting disc on an acid pressure vessel ruptured released HCl vapour to a scrubber system. The line to the scrubber was fitted with an atmospheric vent protected by a low pressure bursting disc which subsequently ruptured releasing acid fumes to atmosphere.

The design of the LP bursting disc had not considered the back pressure of the scrubber system.

CASE 16

Following a tube failure in a water cooled condenser, cooling water entered a xylene reactor working at 180°C. The rapid generation of steam overpressurised the reactor and ruptured the bursting disc.

A mixture of xylene and steam vented into the reactor building where it subsequently exploded and destroyed the roof of the building.

The system design had not provided a safe location for the discharge from the bursting disc.

CASE 17 — Seveso, Italy, July 1976 (Reference 8.11)

Due to overheating, a runaway reaction occurred in a batch reactor manufacturing 2,4,5 trichlorophenol, a herbicide intermediary. The pressure rise ruptured the bursting disc, releasing six tonnes of reaction mixture including 1 kg of poisonous dioxin. No catchpot or blowdown vessel was provided on the vent side of the bursting disc. Two hundred and fifty people were injured and a large area of land was contaminated.

CASE 18 — Bhopal, India, December 1984 (Reference 8.12).

A tank containing 25 tonnes of methyl isocyanate (MIC) was contaminated with water, creating a runaway reaction. The safety valve lifted, releasing a cloud of MIC vapour into the atmosphere. The scrubbing system downstream of the safety valve was not in full working order and the flare system was disconnected for repair. The vapour cloud killed 1754 people living close to the plant site.

NOTES

8.1 This mode of failure only applies to the reversed-domed bursting disc with knife blades described in Section 2.2.2.

8.2 Strictly speaking the adjustment should be made to the relieving temperature, ie the temperature at the relief valve when it commences to lift.

8.3 The National Centre for Systems Reliability, UKAEA, Wigshaw Lane, Culcheth, Warrington WA3 4NE.

8.4 Valve simmer and chatter are really subsets of Section 8.1.1.(d). Valve simmer (or flutter) is rapid reciprocating motion of the moving parts without contact between disc and seat. Valve chatter is the same motion with intermittent contact between disc and seat.

8.5 Leakage through the valve seat is really a subset of Section 8.1.1.(c).

8.6 Borol is a solution of 40% sodium hydroxide and 10% sodium borohydride.

9. PERFORMANCE OF RELIEF DEVICES

Relief devices are required to operate in a wide range of service conditions from clean conditions at ambient temperature to fouling conditions at high or low temperature.

In the latter circumstances the performance of the relief devices can be impaired unless special care is taken at the design and selection stage. This chapter considers some examples of arduous conditions and the steps that can be taken to improve performance for:

- high pressure;
- high temperature;
- low temperature;
- corrosive environment;
- fouling service;
- two phase flow.

9.1 HIGH PRESSURE

In high-pressure applications the tightness of the safety valve seat and the precision of the lift are important.

The tightness can be improved by assisting the closure with a supplementary loading as described in Section 2.1.3.

The precision of the lift becomes critical when operating close to the design pressure, which is frequently the case in high-pressure service to minimise the design thickness of metal. The precision can be improved by selecting a pilot-operated valve (Section 2.1.4) providing the service is clean, eg in steam and air service. If the service is dirty then the pilot-assisted valve is an alternative with some loss of precision (Section 2.1.5).

The bursting disc in high-pressure service has the advantage of a perfect seal providing that the disc is correctly installed. In general, the precision of the bursting pressure is not as accurate as the set pressure of a pilot-operated safety valve owing to the required tolerance (see Section 3.9), although certain types

of bursting disc can be made with a tolerance of $\pm 2\%$.

The sizing of relief devices discharging compressible fluids at high pressure also needs special attention since assumptions of ideal fluid behaviour are frequently untenable (Reference 9.1).

9.2 HIGH TEMPERATURE

The performance of a safety valve at high temperature is affected by:

- the correct selection of the valve materials to withstand the temperature;
- the precise adjustment of the hot set pressure compared with the cold set at ambient temperature;
- any relaxation of the spring at prolonged exposure to high temperature.

The accurate specification of the safety valve operating and relieving temperature at the design stage is essential, particularly the assessment of any appreciable margin below the vessel operating temperature if the valve is not directly mounted (see Section 3.8).

For the adjustment of the hot set pressure, the manufacturer's guidance must be sought, augmented by any users' experience.

The relaxation of the valve spring can be minimised by the hot set procedure described in Reference 8.1.

For a bursting disc operating at high temperature, the most important consideration is the correct selection of disc type and material. High temperature materials are, for example, stainless steel, nickel and inconel in order of increasing temperature (Note 9.2).

As an alternative to making the disc in high temperature material, the disc may be protected by a temperature shield.

9.3 LOW TEMPERATURE

The performance of the safety valve at low temperatures is affected by:

- the correct selection of valve materials to preserve impact strength;
- the precise adjustment of the low temperature set pressure compared with the ambient temperature setting;
- the arrangement of the valve, which may permit icing in adverse circumstances (Note 9.3).

The accurate specification of the safety valve operating temperature and relieving temperature is essential. This includes the calculation of the auto-refrigeration effect during discharge.

Although the low-temperature setting can be obtained from the ambient set pressure using a correction factor, the valve is often adjusted at operating temperature *in situ*.

The bursting disc is well suited to low temperature service, although a premature disc failure may cause a large loss of product and hence duplication of relief devices is advisable (see Section 10.1). The choice of material for low temperature service would be aluminium, stainless steel or nickel, in order of decreasing temperature.

9.4 CORROSIVE ENVIRONMENT

The performance of a safety valve in corrosive service can be severely impaired. All parts of the valve are likely to experience the corrosive environment so that each part must be manufactured in corrosion-resistant material.

Where the selection of corrosion-resistant materials is impracticable, the recommended solution is to fit a bursting disc upstream of the safety valve. The material of the bursting disc must either be corrosion-resistant itself or protected by a corrosion-resistant membrane.

For highly corrosive conditions, two bursting discs in series may be necessary to ensure the integrity of the relief device.

It is essential that the space between disc and safety valve or between discs is monitored as described in Section 2.4.2.

9.5 FOULING SERVICE (Note 9.1)

When a safety valve is used for a fluid containing solid matter in the form of dirt, solidified or sublimated product, there is the danger of particles penetrating the valve passages during a lift. Any particulate or sticky matter adhering to the seat can then prejudice the future operation of the safety valve.

To protect the valve it is good practice to install a bursting disc upstream, as described in Section 2.4.2. The bursting disc is almost unaffected by particulate matter unless the particles adhere to the disc and upset the bursting pressure.

The following methods have been suggested to prevent fouling of the disc:

- PTFE coating of the pressure side of the disc;
- application of proprietary anti-fouling compounds;
- installation of water sprays to wash the disc, when process conditions permit;

- steam or electric heating of the disc holder to prevent condensation;
- purging the dead space immediately upstream of the disc with inert gas.

If none of these methods is appropriate, then frequent inspections of the pressure side of the disc are essential.

In fouling conditions, a further precaution is recommended for the interspace monitoring between disc and valve (see Section 2.4.2). The pressure sensors should be of the diaphragm type to prevent blockage of the impulse piping.

9.6 TWO-PHASE FLOW

A relief discharge from a vessel containing a liquid near its saturation point may be a single-phase or more frequently a two-phase mixture, depending on the liquid level and the discharge mechanism.

Even when the fluid at the valve inlet is predominantly liquid, the drop in pressure through the valve can produce rapid vaporisation so that the discharge at the valve outlet is two-phase.

The passage of the two-phase mixture through the valve is unlikely to cause any damage to the valve although prolonged exposure to flashing may eventually wear the seat.

The sizing of the safety valve for two-phase flow is more complex and several methods have been cited in the literature (Reference 9.2 and ISO 4126).

The performance of the containment or disposal system during a two-phase discharge becomes more arduous since slugs of liquid or high velocity droplets can cause mechanical shock. The first requirement of the containment or disposal system should be to separate the phases and then treat the phases by different methods (see Section 4.5.3).

9.7 LIQUIDS CONTAINING SOLIDS

A special case of two-phase flow is a liquid containing solids, eg in a slurry transport system.

The presence of solids can interfere with the operation of a safety valve, as discussed in Section 9.5. A bursting disc upstream of the safety valve is recommended if the liquid/solid mixture is present at the safety valve inlet, ie if there is no guaranteed vapour space.

The sizing of the relief device should take account of the solids content, which will affect the physical properties of the liquid — notably the density and viscosity.

The inlet and outlet connections should also be designed to handle the solids, particularly if they are erosive. If the final disposal system is sensitive to the presence of solids, the design of the system should include a solids separation stage by settling and/or filtration.

If the bursting disc ruptures, the safety valve should be cleaned and re-tested when the bursting disc is replaced.

NOTES

9.1 Fouling service implies the following undesirable components in the process fluid:

- particulate matter, eg dust, rust or dirt;
- viscous or sticky material;
- fluids with a tendency to coke, polymerise, sublimate or form gums.

9.2 When designing for high temperatures, check that the bursting pressure at lower temperatures is still below the vessel design pressure.

9.3 In some low-temperature applications this will involve insulating and possibly heat tracing the safety valve. In cryogenic service, however, the safety valve is deliberately installed outside the cold box to keep it at ambient temperature.

10. INSTALLATION OF RELIEF DEVICES

In Chapter 4 we considered installation of relief devices; the inlet connections in Section 4.1 and the discharge arrangements in Sections 4.2 and 4.3.

This chapter is concerned with the process and mechanical requirements of the installation:

- duplication;
- valving;
- instrumentation;
- access;
- noise;
- process conditions;
- mechanical design.

Other related topics such as the drainage of discharge piping and weather protection have been treated in Section 4.6 under the heading of vent side protection.

10.1 DUPLICATION OF RELIEF DEVICES

Duplication of relief devices is recommended when any interruption to the process for maintenance or replacement of the relief device would be costly or unsafe. With large continuous processes which are designed to run for two or three years without scheduled interruption, the decision to duplicate relief devices is straightforward and can be written into the design philosophy. With smaller units that can be shut down and restarted comparatively quickly, the decision to duplicate requires more judgement.

In this context duplication means the use of two identical devices in parallel, either of which can provide the total relief requirement, or in more complicated installations the use of at least one spare relief device. Duplication is not the same as using a multiplicity of devices to achieve the required relief area, or the provision of multiple relief devices to meet different contingencies, which is a separate subject dealt with in Section 2.4.

10.2 VALVING OF DUPLICATED RELIEF DEVICES

Duplicating relief devices to provide process continuity implies the use of valves to isolate one device while putting the other on-line.

It must be impossible to isolate both relief devices simultaneously. This can be achieved in several ways:

- (i) Mechanically interlocked valves where one valve opens as the other valve closes.
- (ii) Three-way valves which are ported in such a way that the full cross-sectional area is always available and partial closure is impossible (Note 10.2).
- (iii) Locked and sealed valves which require a formal procedure and the drawing of keys before the valves can be operated.
- (iv) Electrically operated valves, with electrical interlocks to prevent simultaneous closure and a non-interruptible power supply.

The first two methods are the most reliable because they exclude human errors and electrical malfunction. However, method (iii) may be necessary where very large isolating valves are concerned.

Where venting is to atmosphere, the duplex valving can be confined to the inlet of the relief devices. Where venting is to a disposal or containment system, duplex valving is required on both sides of the relief devices as shown in Figure 10.1.

The pressure drop through the valves is important, so fullway plug, ball or butterfly valves are preferable with the valve size at least equal to the inlet size of the device.

The connecting pipework must also be designed for minimum pressure drop consistent with the requirement of Sections 4.1 and 4.14.

Vent branches and valves should be provided between the isolating valves and the relief device for depressuring the device before removal (see Figure 10.1 on page 112). These branches can also be used for purging of toxic and flammable vapours.

10.2.1 VALVING NOT PERMISSIBLE

In certain applications valving of the relief device is forbidden by statute:

- steam boilers;
- steam receivers/accumulators;
- steam economizers;
- steam superheaters.

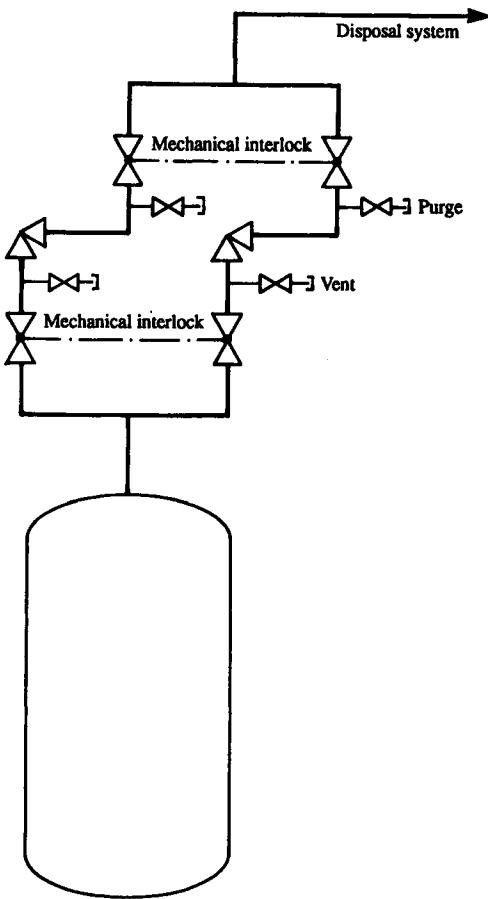


Figure 10.1 Duplex valving for relief devices.

10.2.2 VALVING OF A SINGLE RELIEF DEVICE

In some rare circumstances a single relief device may be valved for maintenance purposes, providing that no unacceptable pressure can occur in the system when the device is isolated. Typical examples are thermal relief valves and surge relief valves on pipelines in intermittent service, where maintenance may be carried

out when the pipeline is out of service. A valve on the discharge side of a relief device venting into a header is another example.

In these rare cases the valves should normally be locked open, with the keys held in a safe place and their use covered by a mandatory standard procedure.

10.3 INSTRUMENTATION

The instrumentation of relief devices has been mentioned briefly in earlier sections and will be summarised here. Instrumentation is recommended but not mandatory.

10.3.1 PRESSURE INSTRUMENTS

Each pressure vessel or pressure system protected by its own relief device requires a pressure gauge. In the case of thermal relief or surge relief of a pipeline system a local pressure tapping will suffice. Where the pressure system is part of a process which is remotely controlled from a control room, the pressure gauge should be supplemented by a pressure indicator with optional recording facility and a high pressure alarm.

Similar instruments should be provided downstream of the relief device if it discharges into a containment or disposal system. If several relief devices discharge into a common header, the pressure instrumentation can be conveniently sited at the header.

With two relief devices in series the intervening space should be monitored for pressure and vented as described in Section 2.4.2.

10.3.2 TEMPERATURE INSTRUMENTS

In high-temperature and low-temperature applications, the relief device should be provided with a local temperature well so that the true temperature at the relief device can be checked with an accurate portable temperature indicator during normal operation. If the temperature at the device is known, this temperature well may be omitted.

The provision of temperature instrumentation for containment and disposal systems cannot be generalised but is obviously essential for quench systems, incinerators and flares (see Sections 4.5.5 to 4.5.9).

10.3.3 FLOW INSTRUMENTS

Flow through relief devices is usually too intermittent and too variable to justify a flowmeter. However, in the special case of flare headers, flow measurement

in the main header is recommended for control of diluent steam at the flare tip, assessment of the economic value of the gas being flared and monitoring the purge velocity through the header. As a less expensive alternative, the sensing element can be installed with pressure tappings for a portable instrument.

A low pressure drop sensor such as a pitot tube is recommended.

10.3.4 LEVEL INSTRUMENTS

Most containment and disposal systems use liquid separators or seal drums, and level instrumentation of these vessels is recommended. For knock-out drums normally running empty but occasionally receiving liquid, level measurement with level switches and alarms for the pumpout system are required (Section 4.12). For seal drums with a continuous liquid level controlled by a weir, level alarms to detect maloperation are sufficient.

10.4 SAFE ACCESS

Access to relief devices for testing and maintenance is important. An adequately-sized platform with safety handrails, kerb plate and ladder or stair access is the usual requirement. The platform should be large enough to accommodate the working crew, their maintenance tools and a laydown area for the device itself. With large devices, a swing davit may be preferable for lowering the device to ground level.

The platform should be arranged to give access to the adjacent instrumentation as well. The choice of ladder or stairway depends on the access frequency and the method of conveying the relief device to the workshop. If the device requires frequent access for monitoring or must be lifted down by hand then stairs are preferable.

The care and attention required for the safe removal of relief devices cannot be over-emphasised. The work should be supervised by a competent technician following written instructions. Permission for work to start should be sanctioned by a written certificate signed by an authorised operating supervisor (see Section 11.3.7). In some cases where access is only required infrequently, a temporary access platform may be cheaper. The above safety advice applies with equal force to temporary access.

10.5 NOISE

The noise and vibration caused by relief discharges can be a serious nuisance. Noise and vibration in the discharge pipes is a function of the vapour velocity

and the arrangement of the pipework. As recommended in Section 4.3.2, the velocity should be kept within the range Mach 0.25–0.65 to minimise noise and pressure drop, and the pipework should be securely anchored to prevent vibration.

In the case of atmospheric venting, the noise of the jet as it leaves the final discharge exit can be very difficult to eliminate, despite the use of one of the proprietary silencers which are available. How often the discharge occurs, the proximity of the public and the cost of effective silencing are matters of judgement. The silencer may foul, in which case a back-pressure monitor will be required at the silencer inlet, with routine inspections of the silencer to detect any build-up of deposits.

10.6 PROCESS CONDITIONS

The sizing of the inlet and outlet pipework has been considered in Sections 4.1 and 4.3 based on velocity and pressure drop.

The pressure and temperature conditions in this pipework must also be specified by the process engineer. The pressure regime does not present any difficulty since the inlet pipework is at the same pressures as the system it is protecting, and the outlet pipework will be subjected to the back-pressure of the containment or disposal system. The pressure rating of the discharge flange of a safety valve needs checking against the maximum back-pressure.

The temperature of the inlet pipework needs more careful thought since the temperature may be different to the prevailing temperature in the system, as discussed in Section 3.8, and the relieving temperature may be significantly higher or lower than the normal operating temperature. The design temperature margin should be sufficient to cover these excursions.

The temperature of the outlet pipework at discharge also needs careful thought since it can differ significantly from the inlet temperature. For example, if flashing takes place, the temperature on the discharge side will usually be lower due to autorefrigeration; the temperature drop could be sufficient to demand a low-temperature material and heat tracing to prevent icing.

For high-temperature applications, the temperature of the discharge pipework up to the main header can usually be equated with the inlet temperature without serious penalty. However, with a large lengthy header (eg at a refinery or petrochemical complex) the temperature regime in the header will repay more detailed analysis to avoid over-specification of the metallurgy and proliferation of expansion bends.

If a discharge is of short duration the heat capacity of the header may mean that the pipework temperature does not reach that of the fluid. Other factors are the Joule-Thomson effect, the temperature drop by atmospheric cooling and also the cooling effect of any simultaneous discharges or purges. The calculations are arduous by manual methods but can easily be handled by a programmable calculator.

The objective is to arrive at the true maximum operating and design conditions so that mechanical design of the pipework is both economic and reliable.

10.7 MECHANICAL DESIGN

The mechanical design of the connecting pipework can be subdivided into three main activities:

- specifying the metallurgy, the wall thickness, the flanges, valves and gaskets;
- providing expansion bends or bellows to cope with expansion or contraction of the pipework where necessary;
- installing pipe supports and anchors to cope with the reaction forces of the relief discharges and the movement of the expansion bends or bellows.

10.7.1 PIPE SPECIFICATION

The information is usually taken from a database, the selection being governed by the character of the fluid and the design pressure and temperature. The data may be available in-house or may be obtained from a piping contractor.

10.7.2 EXPANSION CONTRACTION FACILITIES

The pipe movement due to expansion or contraction depends on the length, the metallurgy and the maximum/minimum operating temperatures. With long headers, the specification of the maximum operating temperature becomes so important that the temperature analysis recommended in Section 10.6 is justified by the cost of the expansion facilities.

In those cases where the temperature is falling along the header, the mathematical analysis of the temperature profile can be extended to calculate the total linear expansion.

The detailed design of the expansion/contraction facilities is a specialised activity for the piping designer.

10.7.3 PIPE SUPPORTS AND ANCHORS

The normal techniques of pipework design will provide the necessary supports and anchors for the pipework at ambient temperature.

These supports and anchors must also withstand the reaction forces that are generated during a discharge. The piping designer will need to know the maximum discharge velocity and density at each change of direction in the system, on both the inlet and outlet sides of the relief device (Note 10.1).

This is particularly necessary where valves are installed for duplicate relief devices, because the lifting or bursting of the relief device can generate very high asymmetric forces on the assembly.

Similarly, the entry of a discharge pipe into a header can generate sufficient force to require additional or heavier pipe supports or anchors.

The pipe supports and anchors must also be capable of withstanding any liquid slugs projected along the pipework. Where slugs are expected, line enlargements and separators should be provided at bends and loops.

10.7.4 VENT-SIDE PROTECTION

The mechanical design of the pipework includes the vent-side protection described in Section 4.6.

NOTES

10.1 API RP 520 Part II Section 2.4 gives a formula for calculating the reaction forces assuming that critical flow is reached at the outlet of the relief device. For sub-critical flow the reaction forces are lower, so that the formula gives a conservative result. See Appendix 10.1.

10.2 The pressure drop through the three-way valves must be assessed to comply with the pressure drop limitation of 3% inlet losses.

11. OPERATION AND MAINTENANCE

Once the relief devices have been correctly designed and installed, their operation does not require any lengthy procedures or instructions. Their role is passive until they are required to respond instantaneously to overpressure.

However, the integrity of the relief devices depends on good maintenance and meticulous recording of any modification or replacement of parts. This chapter looks at:

- commissioning;
- testing;
- inspection and maintenance;
- replacements;
- modifications;
- recording;
- responsibilities.

Maintenance of containment and disposal systems should be done whenever the relief devices are serviced. Operators should also check containment systems visually at regular intervals — weekly, daily or every shift depending on the complexity of the system and its distance from the control room. Inspections are particularly necessary following a pressure excursion.

The operators should be trained and encouraged to report defects such as leakage, vibration, instrument malfunction and external corrosion. The operating pressures of safety valves and bursting discs should also be reported where local pressure gauges are provided. Depending on the type of control system, certain variables may be routinely observed, eg interspace pressures and blow-down vessel levels. Routine inspection of the instrumentation can also be included in the operating instructions.

11.1 COMMISSIONING RELIEF DEVICES

Commissioning a relief device involves a careful sequence of activities between completion of the mechanical installation and handing over to the appointed operators.

The sequence is:

- (a) Verify the installation.
- (b) Check the tag and locks.
- (c) Check that the relief data is in place.
- (d) Verify the test procedure.
- (e) Confirm satisfactory operation.
- (f) Check the inspection and maintenance procedure.

11.1.1 CORRECT INSTALLATION

Check that the correct device with the correct tag has been installed in the position shown on the engineering flow diagram, and that it is connected the right way round. All blanks and plugs should be removed and counted at this stage.

Check also that plant commissioning and pressure testing will not jeopardise the relief devices by overpressure or high temperature. This procedure takes time and patience but is vital.

11.1.2 TAG DATA

The information on the tag plate should be checked with the data sheet for correctness and legibility. The quality of the tag material and impressions must obviously be good enough to withstand the environment and the tag must be securely and permanently attached.

In the case of a safety valve, check the lock and seal that prevent unauthorised interference.

11.1.3 DATA IN PLACE

Check that the complete audited data for the relief device has been received from the contractor or vendor. This data comprises the process design basis, process specification sheet, mechanical requisition, calculation of relief discharge area and vendor's data — drawings and instructions. This data should be carefully filed in the plant archives or the plant database where it can be retrieved in cases of dispute or modification.

11.1.4 TESTING PROCEDURE

In the case of safety valves, testing requires that the set pressure and valve tightness have been verified on site by a competent technician and authorised engineer before plant start-up (see Section 11.2). Check also that the instruments have been tested and calibrated.

11.1.5 SATISFACTORY OPERATION

As the plant comes up to operating pressure and temperature, monitor the relief device for leaks, vibration or chattering.

Satisfactory operation should be recorded in the commissioning log. Correct any defects before handing over to the operators. The operating instructions should include guidance on any acceptable deviations from normal.

Note and record in the log the position of any isolating valves on the inlet and outlet side. If the valves are lockable, visually check the integrity of the locks and seals. It is recommended that pressure testing is completed before the safety valves are installed. However, if this is not possible and if a gagging device has been fitted to the safety valve to facilitate pressure testing, this device should be removed and any gagging holes plugged off.

11.1.6 INSPECTION AND MAINTENANCE PROCEDURE

Following the contractor's and vendor's recommendations, verify the timing and procedure for the routine inspection and maintenance of the relief device in the written scheme of examination as required by the Regulations described in Section 1.4.5. This scheme should then be entered in the plant database, so that the operators and maintenance staff can be reminded when an inspection is due.

11.2 TESTING OF RELIEF DEVICES

Since safety valves and bursting discs are fundamentally different with respect to testing, this section is divided accordingly.

11.2.1 TESTING OF SAFETY VALVES

All safety valves require testing before installation and then at predetermined intervals during service. As recommended in Section 11.3.3, the valves should be tested before and after overhaul.

The testing is normally carried out by an authorised technician on a dedicated test rig in a properly equipped workshop. The test rig should be provided with an accurate calibrated pressure gauge, a pressure source (Note 11.2) and a regulating valve to raise the pressure gradually to the expected set pressure. The set pressure, overpressure and reseating pressure can then be observed in sequence (see Sections 3.4–3.6). If the measured set pressure is significantly different (Note 11.1) to the specified set pressure, the difference should be recorded in the test report. The setting should then be adjusted to the correct value.

Whilst the valve is being tested it should also be checked for any fluid leakage past the valve seat. This can conveniently be done by soap testing or bubble testing after the valve has reseated. API 526 and BS 6759 Part 3 Section 10.5 give details. The precise leakage limits should be established in the test procedure.

If an easing mechanism is fitted to the valve, this should also be tested for ease of movement at the specified pressure.

Mark the valve tag with the test date and the precise value of the set pressure. Then lock and seal the valve ready for installation.

11.2.2 TESTING *IN SITU*

In some cases the safety valve can be tested *in situ*. Before doing this, an accurate calibrated pressure gauge must be fitted and the test procedure approved by a competent authority. Also consider the disposal of the test fluid — is it compatible with the disposal system, or can it be safely disposed of to atmosphere?

- If an isolating valve is fitted on the inlet side, the safety valve can be pressurised through vent branch between the closed isolating valve and the relief valve.
- If a reverse-domed bursting disc is installed upstream of the safety valve, the valve can be pressurised through the interspace vent. Check that the bursting disc can safely handle this back-pressure and vent the interspace before returning the system to service.
- In the case of steam boilers, steam receivers, air receivers, etc, the safety valve may be tested with the working fluid provided that sufficient pressure can be generated to reach the set pressure.
- Another possible *in situ* test is the Trevitest method, which uses an external hydraulic force to open the valve. The required opening force can then be divided by the nozzle area to calculate the set pressure.

11.2.3 TESTING OF BURSTING DISCS

The bursting disc may be tested at maximum working pressure to verify that this pressure is below the minimum bursting pressure.

Since the bursting pressure of a bursting disc can only be tested by destruction, the motivation for testing on site is solely for the investigation of incidents and the creation of reliability statistics. The batch testing of bursting discs prior to delivery to site is carried out by the manufacturer in accordance with the provisions of BS 2915.

If the disc has been routinely replaced at a scheduled servicing, its bursting pressure should be tested and recorded. The testing is best carried out on the vendor's rig (possibly witnessed by the owner) followed by a test report with comments by the vendor on the reliability.

11.3 MAINTENANCE

The routine scheduled maintenance of relief devices should be based initially on the contractor's or manufacturer's maintenance instructions which at a minimum should cover:

- service intervals;
- visual inspection;
- overhaul;
- recording.

11.3.1 SERVICING INTERVALS

Frequency of scheduled services depends on statutory obligations, code requirements and company operating policy, and, in the case of bursting discs, the manufacturer's recommendations.

The intervals are typically:

12 months $\pm$ 1 months for fired steam generators;

24 months $\pm$ 2 months for steam receivers, air and arduous process duties;

36 months $\pm$ 3 months for storage tanks and normal process duty.

The inspection date for each relief device should be entered in the plant database with an automatic reminder to the operating staff say three months beforehand. The service interval should be reviewed at the time of the first service in the light of operating experience.

11.3.2 VISUAL INSPECTION

The visual inspection and report on the condition of a relief device is an important discipline for the maintenance department. The inspection should be made as formal as possible with a published procedure and a witnessed report for the archives. It should cover inspection during operation, in addition to inspection during servicing.

A typical visual inspection report would consist of the following elements as a minimum:

IN-SITU

- general condition of the device and its tag;
- integrity and condition of any locks and seals;
- signs of external corrosion or erosion;
- any deposits or foreign matter;
- any sign of tampering or unauthorised interference;
- general condition of the connecting pipework with respect to deposits or corrosion.

IN THE WORKSHOP

- any internal corrosion or erosion;
- any deposits or dirt inside the device;
- any wear or damage to parts of the device;
- measurement of any wear or damage;
- any signs of leakage.

11.3.3 OVERHAUL

In this context, the overhaul refers to a safety valve and any associated pilot valves or instrumentation (bursting discs are covered by visual inspection (see Section 11.3.2) and replacement where necessary (see Section 11.4)). Before the overhaul, the safety valve should be tested “as found” for set pressure and seat leakage and the data recorded in the maintenance log.

The overhaul consists of the following stages:

DISMANTLING

Prior to dismantling the valve should be washed thoroughly, particularly valves in toxic, hydrocarbon or dirty service. The valve should be carefully dismantled in accordance with the manufacturer’s instructions. All the component parts should be meticulously laid down and segregated for cleaning and inspection.

CLEANING AND INSPECTION

Clean the valve parts with proprietary cleaning fluids, brushes and scrapers. Inspect all the parts for wear, pitting, cracking, scoring or warping. Check the seating surfaces of the disc and nozzle for flatness with the appropriate seat gauges or optical flats. Check the clearance between spindle and guides with feeler gauges. Enter results of this stage in the visual report of Section 11.3.2.

REPLACEMENT OF PARTS

Replace any damaged parts with authorised spare parts — either supplied directly by the valve manufacturer or by an approved and certified parts supplier. Record any replacement of parts in the log and re-order the appropriate parts for stock.

RECONDITIONING OF PARTS

Repair of parts is not recommended, with the exception of the seating surfaces of the disc and nozzle. If these surfaces show signs of wear they may be machined or lapped following the manufacturer's instructions. In particular, do not repair parts such as springs and bellows.

REASSEMBLY

Once every part has been inspected and replaced where necessary, re-assemble the valve in the order and manner prescribed by the manufacturer. Check clearances and settings and make the valve ready for pressure testing. The setting of the blowdown ring is particularly important.

11.3.4 MAINTENANCE *IN SITU*

Maintenance *in situ* without disturbing the main pipe flanges and gaskets is possible with some designs of safety valve — those with a top-entry design and drop-in trim (Figure 11.1). Isolating valves, venting valves and *in situ* test facilities (see Section 11.2.2) are essential for this task.

The advantages of maintenance *in situ* — speed and convenience — must be weighed carefully against those of workshop servicing — better conditions and supervision. On balance, maintenance *in situ* is only recommended for isolated sites and short unscheduled shutdowns.

11.3.5 RECORDING LOG

Record and witness all the maintenance steps on the maintenance report. Then file the report in the plant archives so that it can be retrieved at the next service. Where a computerised maintenance system is in place, the essential parts of the report can be logged into it.

Figure 11.2 (see pages 126–127) shows a typical maintenance report.

11.3.6 HANDLING RELIEF DEVICES

During maintenance relief, devices should be handled with great care and the movement from plant to workshop supervised by an authorised technician.

Protect the flange faces from accidental damage and seal the connecting pipe-work with metal blanks or full-face gaskets.

11.3.7 REMOVAL OF RELIEF DEVICES

The removal of any relief device from a process plant requires a written safety procedure and a formal permit-to-work before the work commences.

If the device can be isolated from the process and the disposal system, then a safe isolation and depressuring procedure is required. If isolation is not possible, then the pressure system must be depressurised, drained and purged.

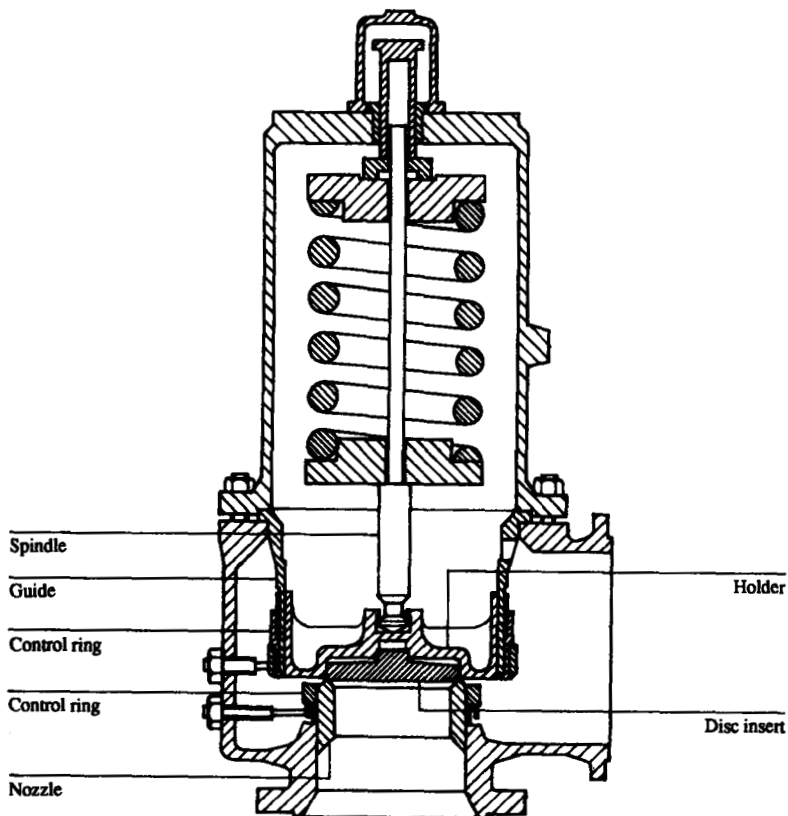


Figure 11.1 Top entry design of safety valve. (Courtesy of Crosby Valve & Eng. Co. Limited.)

RELIEF VALVE OVERHAUL REPORT		Registration no.	
1. Valve details			
Make			
Maker's serial no.			
Size			
Type			
Cold set pressure		psig	
Body test pressure inlet		psig	
Body test pressure outlet		psig	
Orifice size			
Valve discharge rate			
Bellows test pressure			
Location: Plant			
Equipment protected			
Equipment reg. no.			
Process fluid			
Process temp.		°C	
Operating pressure		psig	
Back pressure		psig	
Reason for removal from plant:			
Routine	☐	Failed to reseat	☐
Leak	☐	Other reason	☐
Chatter	☐		

Figure 11.2 Typical maintenance report. (Courtesy of Harcros Chemicals UK Ltd.)

RELIEF VALVE OVERHAUL REPORT (Continued)				
2. Pre-inspection test and overhaul required (tick below)				
Before dismantling				
Leak test	☐	Complete overhaul	☐	
Blow off test	☐	Check orifice size	☐	
Body test inlet/outlet	☐ ☐	RESET SET PRESSURE TO	psig*	
* Separate authority required if different from set pressure in Section 1.				
Foreman's order no.	Signed		Date	
Date	Maintenance supervisor			
3. Overhaul/test results (to be completed by workshops)				
Leak test	Bubbles/min	Pre-inspection blow off pressure		psig
Valve part	Defect/condition	Action taken		
		Lap	M/c regrind	Replace
Body				
Spindle				
Spring				
Nozzle				
Seat				
Bellows				
Orifice dia.	FINAL SET PRESSURE			psig
Other remarks				

Figure 11.2 Typical maintenance report (continued).

11.4 REPLACEMENTS

Bursting discs may be replaced on a routine basis after one, two or three years' operation. The frequency of replacement will depend on the material of the disc and the operating conditions (see BS 2915 Appendix B3).

It is essential that the replacement disc and the holder are provided by the same manufacturer and are replicas of the originals. To this end, the replacement must be witnessed and approved by a competent person who has complete access to the records of the installation.

The same considerations apply to replacing a safety valve that is judged beyond repair. The replacement valve must be identical in all respects, particularly the size of the valve trim and the set pressure.

Do not be tempted to replace a relief device with one from stock or from another plant, unless a competent engineer has checked that the two devices are exactly the same.

The receipt, handling and storage of relief devices requires a careful written procedure to avoid damage and recording errors. Each disc or valve should be inspected by a competent technician on receipt from the manufacturer to check its integrity and tagging. The accompanying paperwork and test certificate should also be checked and filed correctly in the archives.

11.5 MAINTENANCE OF FIRE INSULATION

The inspection and maintenance of fire insulation are emphasised in Section 7.3.

The integrity of the cladding is essential and this should be inspected at least as frequently as the associated relief device.

Any damage or defects in the cladding, particularly near vulnerable joints and overlaps, should be repaired immediately. The cladding should also be carefully inspected after any maintenance or modifications which have interfered with the insulation.

Any repairs to the insulation and cladding should be carried out to the original specification. This work should be entrusted to insulating specialists and not undertaken by a convenient maintenance crew who may be willing but inexperienced.

Every five years (or more frequently in aggressive environments) remove some of the cladding and inspect the underlying insulation for defects. This removal can be confined to areas where problems might be expected due to weathering, spillage or the difficult geometry of the vessel. The insulation of nozzles and adjacent pipework may be examined at the same time.

11.6 MODIFICATIONS

During the course of its service life, a production plant or utility is subject to modification and retrofitting to improve its performance or eradicate operating problems.

It is the duty of the engineering manager to ensure that any change is subject to a safety analysis, which should include the effect on the pressure relief facilities. Any increase in throughput may need a bigger relief device. Even apparently small changes, such as the replacement of a control valve trim, can have big implications for the relief system. This is why it is important to have access to the original design calculations.

A change in the set pressure of a relief device is a frequent request by a production department. If the new pressure does not exceed the design pressure (changes of up to 5% of the set pressure are usually acceptable — see Section 3.5), it can be accommodated in a safety valve by adjusting the spring tension. Otherwise a replacement spring or a replacement bursting disc is required.

In either case the full consequences of the change must be assessed and approved by a properly appointed safety audit.

11.7 RECORDS

The importance of plant records in relation to relief devices cannot be over-emphasised. Every relief device should have its own unique tag number and record in the plant archives. The complete record should consist of:

- original data sheets and drawings;
- original calculations (including design basis);
- record of pressure tests;
- servicing records;
- replacements;
- modifications.

Figure 11.3 (see page 130) gives an example.

11.8 RESPONSIBILITIES

Although inspection and maintenance are closely related, the responsibilities and manning of the two functions should be clearly differentiated.

The inspection department should be responsible for the activities described in Sections 11.3.1, 11.3.2, 11.3.5 and the witnessing of tests described in Section 11.2, whilst the maintenance department should be responsible for

REGISTRATION OF PROTECTIVE DEVICES		Registration no.
1. Location		Process fluid
Plant		Process temperature
Equipment protected		Operating pressure
Equipment reg. no.		Back pressure
2. Relief valve details		
Make		Materials of construction
Maker's serial no.		Body
Order no.		Valve trim
Size		Spring
Type		
Orifice size		Test pressure
Discharge rate		Inlet side
Cold set pressure		Outlet side
Blow off pressure at op. temp.		Bellows
Flange size inlet outlet		
Lifting lever fitted Yes/No.		
3. Bursting disc details		Vacuum support fitted Yes/No
Maker		Material of vacuum support
Order no.		Bursting pressure at 20°C
Material of disc		Bursting pressure at operating temp.
Material of holder		Manufacturing tolerance on disc bursting pressure
4. Instrument/electrical device		
Description		

Figure 11.3 Typical plant record. (Courtesy of Harcros Chemicals UK Ltd.)

the activities in Section 11.3.3 and the mechanics of the test programme in Section 11.2.

This demarcation of responsibilities is made more obvious if the inspection department is part of the technical group whilst maintenance is part of the operations group.

NOTES

11.1 The recommended tolerances for set pressure are given in BS 6759:

Set pressure	Tolerance
Less than 5 bar	0.14 bar
5–20 bar	3%
20–100 bar	2%
Over 100 bar	1.5%

11.2 The pressure source is normally an air compressor with an air receiver or receivers rated for the required pressure. The size of the air receivers depends on the capacity of the safety valve, ranging from 0.1 m³ for the smallest valves up to 1.5 m³ for the largest. The advice of the valve manufacturer should be sought on the adequate sizing of the compressed air equipment.

12. CURRENT AND FUTURE DEVELOPMENT

Conventional pressure relief devices have been used for some time with varying degrees of success and reliability.

As chemical plants have become larger, conventional relief devices have grown in size to the point where they are often very expensive. At the same time, the requirements of occupational safety and environmental protection have received greater emphasis, so that it has become more difficult to achieve acceptable means of disposing of or containing relief discharges.

The question arises — can we design the system to eliminate the causes of overpressure or increase the design pressure to accommodate the overpressure? These are inherently safe solutions. If this is not possible, can we protect systems against overpressure by methods other than conventional relief devices that afford equal or greater reliability but require smaller pieces of hardware and less complicated disposal systems?

To meet this situation we have seen the development of instrumented protective systems (IPS). It must be remembered that any protective system must comply with the relevant legislation and the codes and standards described in Chapter 1. In particular, any unvented system must satisfy the requirements of the new Pressurised System Regulations and the associated Approved Code of Practice and Guidance Note.

12.1 INSTRUMENTED PROTECTIVE SYSTEMS (IPS)

These systems are used to reduce the frequency of pressure relief discharges and in some rare cases to replace or reduce the size of conventional pressure relief devices. All such systems should be independent of the normal process control system to avoid common mode failure. The system should be considered as a whole unit rather than individual components.

12.1.1 IPS USED TO REDUCE RELIEF FREQUENCY

These systems can be defined as a combination of instrumentation, including computer control, and trips designed to limit the frequency of relief discharges.

In general, these systems are not designed to replace conventional relief

devices but to complement them. The sizing of the relief devices and disposal systems does not take credit for the presence of the IPS. The IPS will improve the reliability of overpressure protection over that of a conventional relief device alone. There may be some penalty in terms of plant downtime to test the IPS and downtime due to spurious operation of the trips (which may be far more frequent than spurious operation of a conventional relief device). The design of the IPS is beyond the scope of this handbook. The following descriptions of typical components of IPS are intended for guidance only.

PRESSURE MEASUREMENT

The pressure transmitter should preferably be completely independent of other instrumentation, with a dedicated pressure connection positioned for rapid response to pressure changes. For fluids with any tendency to block the pressure tapping, the tapping should be continuously purged (Note 12.1) or a pad-type transmitter used. A single pressure transmitter will usually suffice, providing that the connection is well engineered.

The IPS pressure measurement should be displayed and recorded as required in the control room.

Although we are primarily concerned with overpressure, the IPS may be triggered by other variables such as temperature or liquid level.

TRIP SETTING

The trip setting for the IPS will depend on the accuracy and repeatability of the measurement and the response time of the trip system in the event of overpressure. The setting must lie between the maximum operating pressure and the set (or minimum bursting) pressure of the conventional relief device. The initial setting should be halfway between these limits; during commissioning the setting can be lowered if the response of the trip system is slower than expected and vice versa. A pre-alarm signal can be taken from the pressure transmitter to warn the operator of impending trip action.

TRIP SYSTEM

The response of the IPS to an overpressure signal depends on the source of pressure and the possibility of depressuring the system. Typical responses would be:

- trip a process feed pump;
- trip a recycle compressor;

- shut the fuel supply to a heater;
- shut the steam supply to a reboiler;
- open a vent valve to a low-pressure system;
- start an emergency cooling system.

In each case the operation of the trip and the pre-alarm should be displayed in the control room.

TRIP VALVES

In those cases where the trip response is to close a valve, a tight shut-off valve may be required depending on reliability and the consequences of leakage. Although a dedicated trip valve is preferable, it is not essential if a convenient control valve is already available. The IPS trip signals may be routed through the normal electrical control circuits or highways.

SYSTEM TESTING

Adequate test facilities and a comprehensive test procedure are a vital part of the system. The frequency of testing will be specified in the operating procedure and will normally coincide with scheduled plant shutdowns. If more frequent testing is specified, this can be done during plant operation by simulating an overpressure and noting the initial movement of the trip valve.

12.1.2 IPS USED AS AN ALTERNATIVE TO RELIEF

In certain cases, an IPS may be used either to replace a conventional relief device or to eliminate some potential causes of overpressure and so reduce the size of a conventional relief device and its disposal system. Such systems are commonly used in the gas industry to protect equipment downstream of a pressure let-down valve. They are used in rare and carefully controlled cases within the chemical industry, for example:

- where no practicable means of containing or disposing of the relief discharge can be designed, eg with a highly toxic discharge;
- in some cases where the overpressure would be associated with an internal explosion which cannot be handled by explosion relief or suppression;
- where the overpressure would be the precursor of a runaway chemical reaction for which relief cannot be provided.

In all these cases a full hazard analysis is essential.

The reliability of an IPS used as an alternative to relief needs to be

significantly higher than one used to reduce relief frequency. Pay careful attention to the reliability of the trip systems and the process controller/computer. The analysis of the safety performance of the latter needs particular care and some valuable guidance is given in documents published by HMSO and EEMUA (Note 12.2).

The required reliability of the IPS depends on two factors: the frequency at which a demand would be put on it (ie the frequency at which the equipment could potentially otherwise be overpressurised), and how low a frequency of overpressure needs to be achieved (which depends on the consequences of overpressure). IPS design needs considerable expertise, particularly if the IPS reliability target is very stringent.

The consequences of overpressure require assessment:

- size and duration of the release;
- toxicity and flammability of the release;
- effect on people and environment.

12.2 EMERGENCY DEPRESSURING AND EMPTYING

As mentioned in Section 7.3.5, emergency depressuring facilities are becoming increasingly adopted as additional safeguards against overpressure, particularly in the fire situations described in Section 7.4.3. It is anticipated that eventually these facilities will be recognised by statutory authorities for onshore installations as they are already recognised offshore.

The objective is to provide dedicated piping and valves with the capacity to depressure the system to 50% of design pressure within 15–45 minutes of opening. The valving is remotely operated, either automatically as part of the IPS System, or manually from the control room in response to an overpressure or other emergency alarm.

The vent side of the depressuring valves may be connected to the disposal or containment system downstream of the pressure relief devices. If so, it is essential to check the capacity of the downstream system to handle the initial depressuring load, which may be higher than the relief rate of the pressure relief devices. This check is particularly relevant when flashing occurs during depressuring.

It is possible to design liquid emptying facilities that will act simultaneously with depressuring, providing that a suitable destination for the liquid contents can be arranged. Make sure that liquid emptying does not exacerbate the danger from fire by removing cooling of the vessel walls (see Section 7.4.3).

12.3 OTHER DEVELOPMENTS

Apart from the growth of pressure limiting instrumentation, the main progress in the manufacture of conventional pressure relief devices has been the improvement in quality control and quality assurance of materials and manufacturing procedures.

Quality assurance means that each part of a pressure relief device can be traced back to its parent material and each step in the manufacturing procedure is witnessed and approved. This must increase the confidence of the user in the final product and improve the reliability of the relief device.

There are also some interesting developments in the accessories for bursting discs and safety valves.

12.3.1 BURSTING DISC INDICATORS

An important development in the application of bursting discs is an indication that the disc has ruptured either prematurely or due to overpressure.

The vent side of the disc is connected to a wire loop forming part of an electrical circuit. Rupture of the disc interrupts the circuit and triggers a relay. The signal can be used to trip an alarm or shut down the process (see Figure 12.1).

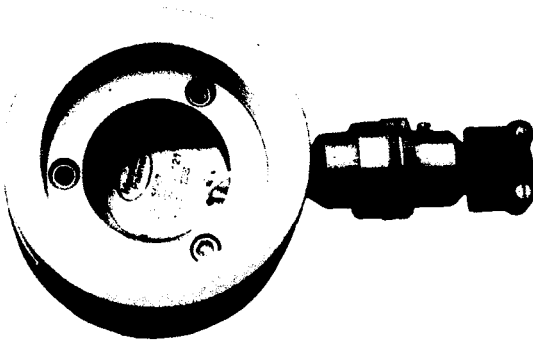
12.3.2 PILOT-OPERATED SAFETY VALVES

Pilot-operated safety valves have been improved by the development of the 'non-flowing' pilot valve (see Figure 12.2 on page 138).

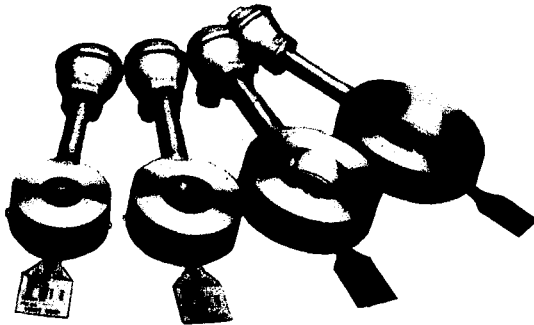
With a conventional pilot valve, when the set pressure is exceeded the process fluid continues to flow through the pilot valve to the vent, and the presence of dirt or foreign matter in the process fluid jeopardises the operation of the pilot valve.

With a non-flowing pilot valve, the flow through the pilot valve ceases immediately the main valve opens. This means that much less process fluid passes through the pilot valve, so minimising the chance that foreign matter will be drawn into the valve.

This development radically increases the reliability of the pilot valve in process duties and also introduces the possibility of filtering the pilot flow, thus further increasing the reliability. The advantages of the pilot-operated safety valve discussed in Section 2.1.4 can be applied to more process duties without insisting on clean service.



(a)



(b)

Figure 12.1 Bursting disc indicators. (a) Low pressure reverse buckling 'Maxivent' assembly fitted with indicator and BS 4568 connection. (b) Composite slotted assemblies fitted with indicators and DIN standard connection heads. (Courtesy of Marston Palmer Limited (Safety Systems Group).)

12.4 OTHER WORK

The results of two relevant investigations in progress at the same time as this work have now been published:

- *Emergency Relief Design Using DIERS Technology* (ISBN 0 8169 0568 1), published in 1992 by the Design Institute for Emergency Relief Systems (DIERS) of the American Institute of Chemical Engineers.

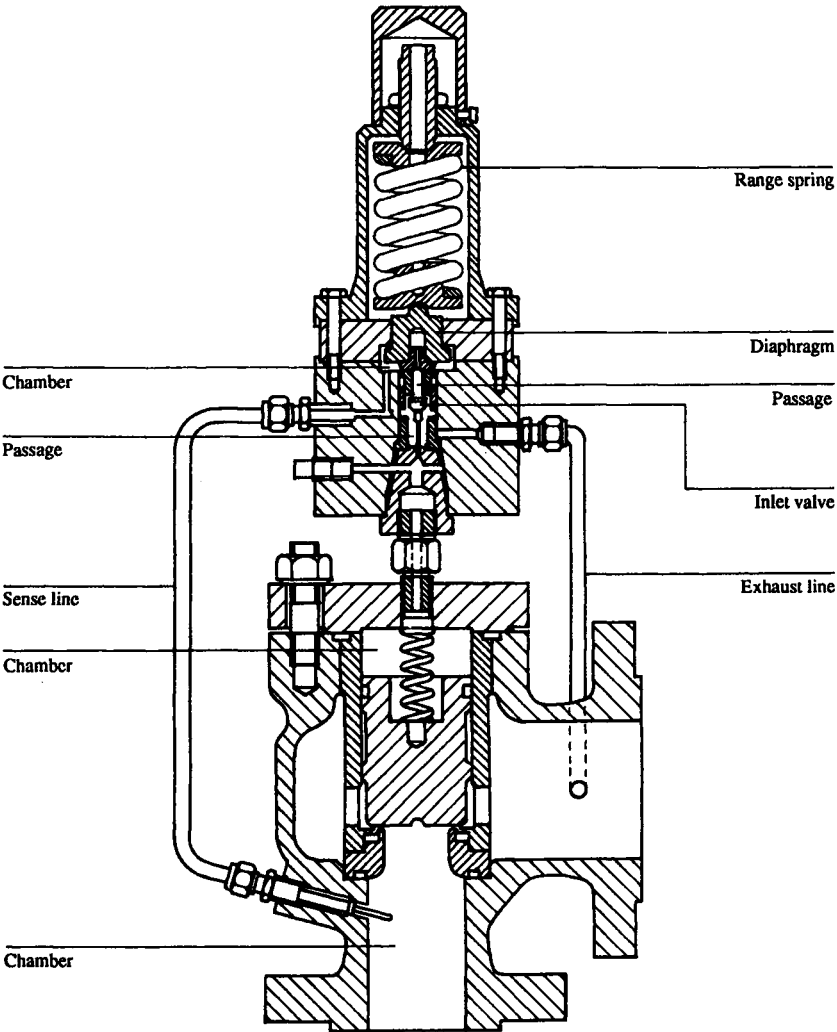


Figure 12.2 Non-flowing type of pilot-operated safety valve. (Courtesy of Crosby Valve & Eng. Co. Limited.)

- *Chemical Reaction Hazards* (ISBN 0 85295 284 8), published in 1993 by the Institution of Chemical Engineers. Appendix 12.1 contains a list of the contents of this guide.

NOTES

12.1 The selection of purging fluid will depend on cost and compatibility with the process fluid. In the case of process gases, the purging fluid may be inert gas or fuel gas. In the case of process liquids, the purging fluid may be kerosene, gas oil or lube oil.

12.2 *Programmable Electronic Systems in Safety Related Applications Parts 1 & 2* (HMSO).

Safety Related Instrument Systems for the Process Industries (Engineering Equipment and Materials Users Association, 14–15 Belgrave Square, London SW1X 8PS).

13. CONCLUDING REMARKS

The following remarks arise from the text and would repay further study by the appropriate authorities:

13.1 Process designers should be more aware of the advantages of combinations of relief devices (see Section 3.10).

13.2 The reliability of conventional safety valves, particularly under test in the workshop, is lower than should be expected (see Section 8.1.1.1).

13.3 Users of pressure relief devices should make positive efforts to collect reliability data and transmit the results back to designers and manufacturers (see Section 8.1).

13.4 The use of safety valves alone in difficult process applications is a contributor to the lack of reliability (see Section 8.1.1.1).

13.5 The criteria for thermal relief due to liquid expansion in pipelines lack authority (see Section 6.1).

13.6 The calculation of relief discharge rates for fire exposure show some conflict between codes, particularly in the environment factor contributed by insulation (see Section 7.2.3).

13.7 The application of instrumented protective systems (IPS) to pressure relief should be encouraged in suitable cases and the legislators of engineering codes should be more aware of the benefits (see Section 12.1).

GLOSSARY

1. TERMS RELATING TO THE PRESSURISED SYSTEM

ACCUMULATION

Pressure increase over the design pressure of the equipment during discharge through the pressure relieving system. The term refers to the equipment to be protected and not to the pressure relieving device. Maximum permitted accumulation is stated in the equipment or systems design/application code.

PRESSURE RELIEVING DEVICE

A generic term to describe any device which automatically discharges a fluid when a predetermined pressure is reached.

PRESSURE RELIEVING SYSTEM

An arrangement of the pressure relieving device(s) and piping intended for the safe relief of fluids. A complex pressure relieving system may involve many pressure relieving devices with discharges manifolded into a common header and vent stack or flare.

REQUIRED RELIEF RATE

The calculated flowrate of fluid discharging under relieving conditions required to maintain the pressure in the protected equipment at or below the permitted accumulation.

OPERATING PRESSURE

The system pressure during normal operation.

DESIGN PRESSURE

The pressure used in calculating the thickness of a vessel or pipe system.

MAXIMUM ALLOWABLE ACCUMULATED PRESSURE

The sum of the design pressure and the maximum permitted accumulation.

2. TERMS RELATING TO SAFETY VALVES

SAFETY VALVE

A valve which automatically, without the assistance of any energy other than that of the fluid concerned, discharges fluid so as to prevent a predetermined safe pressure being exceeded and which is designed to re-close and prevent the further flow of fluid after normal pressure conditions of service have been restored.

DIRECT-LOADED SAFETY VALVE

A safety valve in which the loading due to the fluid pressure underneath the valve disc is opposed only by direct mechanical loading such as a weight, a lever and weight, or a spring.

ASSISTED-OPENING SAFETY VALVE

A direct-loaded safety valve which, by means of a powered assistance mechanism, is lifted at a pressure below the set pressure and will, even in the event of failure of the assistance mechanism, comply with all the relevant requirements for a safety valve.

SUPPLEMENTARY-LOADED SAFETY VALVE

A safety valve which:

- has, until the pressure at the inlet of the safety valve reaches set pressure, an additional force (supplementary load) to increase the sealing force, which may be provided by means of an extraneous power source which is reliably released when the pressure at the inlet of the safety valve reaches the set pressure; and
- attains its certified discharge capacity in the event of the supplementary loading not being released at an overpressure not exceeding 15% of the set pressure.

PILOT-OPERATED SAFETY VALVE (indirect-loaded safety valve)

A safety valve, the operation of which is initiated and controlled by the fluid discharged from a pilot valve which is itself a direct-loaded safety valve.

BALANCED BELLOWS SAFETY VALVE

A safety valve incorporating a bellows which has an effective area equal to that of the valve seat to eliminate the effect of back pressure on the set pressure of

the valve and which effectively prevents the discharging fluid entering the bonnet space.

BALANCED BELLOWS SAFETY VALVE WITH AUXILIARY PISTON

A balanced bellows safety valve incorporating an auxiliary piston which has an effective area equal to the safety valve seat which becomes effective in the event of a bellows failure.

BALANCED PISTON SAFETY VALVE

A safety valve incorporating a piston which has an area equal to that of the safety valve seat to eliminate the effect of back pressure on the set pressure of the safety valve.

BELLOWS SEAL SAFETY VALVE

A safety valve incorporating a bellows which prevents discharging fluid from entering the bonnet space.

CONVENTIONAL SAFETY VALVE

A safety valve of the direct loaded type, the set pressure of which will be affected by changes in the superimposed back pressure.

BLOWDOWN OF A SAFETY VALVE

The difference between the set pressure and the reseating pressure, normally stated as a percentage of set pressure, except for very low set pressure when the blowdown is then expressed in bar.

BACK PRESSURE

The pressure existing at the outlet of a safety valve.

BUILT-UP BACK PRESSURE

The back pressure caused by flow from the safety valve through the discharge system.

SUPERIMPOSED BACK PRESSURE

The back pressure caused by flow from other sources into the discharge system.

CERTIFIED DISCHARGE CAPACITY

That portion of the actual flow rate of discharge on test permitted to be used as a basis for the application of a safety valve.

Note: The certified discharge capacity is derived from measured flow rate $\times$ derating factor, or theoretical flow rate $\times$ coefficient of discharge $\times$ derating factor, or theoretical flow rate $\times$ derated coefficient of discharge.

COEFFICIENT OF DISCHARGE OF A SAFETY VALVE

Ratio of the actual flowing capacity (from test) to the theoretical capacity based on the orifice area.

COLD DIFFERENTIAL TEST PRESSURE

The inlet static pressure at which a safety valve commences to lift on the test stand (the back pressure being atmospheric). The required test pressure is based on the set pressure corrected for service conditions of back pressure and/or temperature.

COMMENCEMENT OF LIFT

Initial lift such as would cause the first indication of movement on a linear transducer or equivalent.

DERATED COEFFICIENT OF DISCHARGE

The coefficient of discharge multiplied by the derating factor.

DISCHARGE AREA OF A SAFETY VALVE

The minimum cross-sectional area between inlet and seat, or the curtain area if less, which controls the flow of fluid through the safety valve when it is discharging its certified discharge capacity.

EASING GEAR

A device for manually opening a safety valve by the application of external force to lessen the spring load which holds the safety valve closed.

EQUIVALENT CALCULATED CAPACITY

The calculated capacity of the safety valve for conditions of pressure, temperature or nature of the fluid which differs from those for which the certified capacities are available.

LIFT

The travel of the disc away from the closed position.

MEASURED CAPACITY

Actual flowrate of discharge on test.

FLOW AREA

The minimum cross-sectional flow area (but not the curtain area) between inlet and seat which is used to calculate the theoretical flow rate, with no deduction for any obstruction.

OVERPRESSURE OF A SAFETY VALVE

A pressure increase over the set pressure of a safety valve, usually expressed as a percentage of set pressure.

RELIEVING PRESSURE OF A SAFETY VALVE

Set pressure plus overpressure during relief.

RESEATING PRESSURE OF A SAFETY VALVE

The value of inlet static pressure at which the disc re-establishes contact with the seat or at which lift becomes zero.

SET PRESSURE

The predetermined gauge pressure at which a safety valve under operating conditions should commence to lift. It is the pressure measured at the valve inlet at which the pressure forces tending to open the valve for the specified conditions are in equilibrium with the forces retaining the valve disc on its seat.

THEORETICAL FLOWING (DISCHARGE) CAPACITY

The calculated capacity expressed in gravimetric or volumetric units of a theoretically perfect nozzle having a cross-sectional flow area equal to the flow area of a safety valve.

VACUUM SAFETY VALVE

A vacuum safety valve is a pressure relief device designed to admit fluid to prevent an excessive internal vacuum; it is designed to reclose and prevent further flow of fluid after normal conditions have been restored.

3. TERMS RELATING TO PARTS OF SAFETY VALVES

DISC

The pressure-containing movable element of a safety valve which effects closure.

NOZZLE

A pressure-containing element which constitutes the inlet flow passage and includes the fixed portion of the seat closure.

PILOT VALVE

An auxiliary valve which actuates a major relieving device.

SEAT

The pressure-containing contact between the fixed and moving portions of the pressure-containing elements of a valve.

SEAT ANGLE

The angle between the axis of a valve and the seating surface. A flat seated valve has a seat angle of 90 degrees.

CHATTER

Abnormal rapid reciprocating motion of the movable parts of a safety valve in which the disc contacts the seat.

FLUTTER

Abnormal, rapid reciprocating motion of the movable parts of a safety valve in which the disc does not contact the seat.

SIMMER

The audible or visible escape of fluid between the seat and disc at an inlet static pressure below the set pressure and at no measurable capacity. It applies to safety valves on compressible fluid service.

4. TERMS RELATING TO BURSTING DISCS

BACK PRESSURE

The static pressure existing at the outlet of a bursting disc device at the time the device is required to operate.

BAFFLE PLATE

A plate attached to the vent side of a bursting disc device or system to redirect discharge and/or reduce recoil.

BATCH

A quantity of bursting discs made as a single group of the same type, size, maximum and minimum specified limits of pressure (q.v.) and coincident temperature, manufactured from material of the same identity and properties.

BURSTING DISC

The pressure-containing and pressure-sensitive elements of a bursting disc device.

BURSTING DISC ASSEMBLY

The complete assembly of components which are installed into the holder to perform the desired function.

BURSTING DISC DEVICE

A non-reclosing pressure relief device actuated by differential pressure and designed to function by the bursting or venting of the bursting disc.

BURSTING DISC DEVICE DISCHARGE AREA

The area specified by the manufacturer which is the minimum discharge area of the bursting disc device after bursting or venting of the bursting disc assembly.

BURSTING DISC DEVICE THEORETICAL DISCHARGE CAPACITY

The maximum rate at which a bursting disc device discharges a fluid after bursting or venting of the bursting disc assembly.

BURSTING PRESSURE

The value of the pressure differential across the bursting disc at which a bursting disc device functions.

COATING

A layer of metallic or non-metallic material applied by brush, spray, dipping, fluidized bed or other similar method, to components of a bursting disc device.

COINCIDENT TEMPERATURE

The temperature used in conjunction with a bursting pressure.

CONVENTIONAL DOMED BURSTING DISC

A bursting disc which is domed in the direction of the bursting pressure, and is designed to fail in tension.

EXCESS FLOW VALVE

A device which permits limited flow and which closes when the limit is exceeded.

FOIL

The sheet or strip used for the manufacture of metallic bursting discs.

HOLDER

That component of a bursting disc device into which the bursting disc assembly is fitted and which influences the bursting pressure and correct operation of the bursting disc assembly.

LINING

An additional sheet or sheets of material forming part of the bursting disc assembly or holder.

MAXIMUM SPECIFIED BURSTING PRESSURE

The maximum pressure quoted by the user or the manufacturer with a coincident temperature when specifying the bursting disc performance.

MINIMUM SPECIFIED BURSTING PRESSURE

The minimum pressure quoted by the user or the manufacturer with a coincident temperature when specifying the bursting disc performance.

MUFFLED OUTLET

A component of a bursting disc device which disperses the discharge.

OPERATING PRESSURE

The pressure to which the bursting disc is exposed during normal operation.

PERFORMANCE TOLERANCE

The difference between the maximum and minimum specified bursting pressure at a coincident temperature.

PLATING

A metal layer applied by a plating process to components of a bursting disc device.

REVERSE DOMED BURSTING DISC

A bursting disc which is domed against the direction of the bursting pressure and designed to fail by buckling, bending or shearing forces.

REVERSE PRESSURE SUPPORT

That component of a bursting disc device which prevents the failure of the bursting disc due to pressure differential in a reverse direction.

A reverse pressure support which is intended to prevent the failure of a bursting disc when the system pressure falls below atmospheric pressure is sometimes referred to as a vacuum support.

SERVICE LIFE

The time period beginning at the installation of a bursting disc assembly and ending at either replacement or burst.

SLOTTED LINED BURSTING DISC

A conventional domed bursting disc made up of two or more layers, one of which is slit or slotted so as to reduce its strength and to control the bursting pressure of the bursting disc.

This type of bursting disc may also be referred to as a composite slotted bursting disc.

STIFFENING RING

An integral component of the bursting disc assembly used primarily for the stiffening of fragile discs.

TEMPERATURE SHIELD

A component of a bursting disc device which protects a bursting disc from excessive temperature.

5. TERMS RELATING TO OTHER PRESSURE RELIEVING DEVICES

BREAKING PIN DEVICE

A non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the breakage of a load-carrying section of a pin which supports a pressure-containing member.

SHEAR PIN DEVICE

A non-reclosing pressure relief device actuated by inlet static pressure and designed to function by the shearing of a load-carrying pin which supports a pressure-containing member.

FUSIBLE PLUG DEVICE

A non-reclosing pressure relief device designed to function by the yielding or melting of a plug of suitable melting temperature material.

6. TERMS USED BY API FOR SAFETY VALVES

PRESSURE RELIEF VALVE

A generic term applied to relief valves, safety valves and safety relief valves.

SAFETY RELIEF VALVE

An automatic pressure relieving device suitable for use as either a safety or a relief valve, depending on the application.

SAFETY VALVE

An automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by rapid full opening or pop action.

RELIEF VALVE

An automatic pressure relieving device actuated by the static pressure upstream of the valve, which opens in proportion to the increase in pressure over the opening pressure. A relief valve is used primarily for liquid service.

REFERENCES

- 1.1 Schofield, C., 1984, *Guide to dust explosion prevention and protection, Part 1 — Venting*, Institution of Chemical Engineers, Rugby, UK, 25.
- Harris, R.J., 1983, *Gas explosions in buildings and heating plant*, E & F Spon, London.
- 1.2 Duxbury, H.A. and Wilday, A.J., 1987, *IChemE Symposium Series No. 102*, Institution of Chemical Engineers, Rugby, UK, 175.
- 1.3 Case, R.C., 1970, *API Proceedings*, 50: 1082.
- 1.4 Acton, A. and Meerbeke, R.C., 1986, *LNG Congress VIII*.
- 2.1 *Design and Installation of Pressure Relieving Systems API RP 520 Pt 1*, 1976, 7.
- 4.1 Speechly, D., Thornton, R.E. and Woods, W.A., 1979, Principles of total containment system design, *IChemE NW Branch Symposium No. 2*, Paper 7.
- 4.2 Grossel, S.S., 1986, *Plant/Operations Progress*, 5: 129.
- 4.3 Scheiman, A.D., 1964, *Hydrocarbon Processing*, 43 (5): 155.
- 4.4 Watkins, R.N., 1967, *Ibid*, 46 (11): 253.
- 4.5 Gifford, F.A., 1960, *Nuclear safety*, U.S. Department of Energy, 56.
- 4.6 Miller, P.D., Hibshman, H.J. and Connell, J.R., 1958, *Petroleum Refiner*, 37: 5.
- 4.7 Tan, S.H., 1967, *Hydrocarbon Processing*, 46 (1): 172.
- 4.8 *Manual on disposal of refinery wastes API 931*, 1977.
- 4.9 Brzustowski, T.A. and Sommer, E.C., 1973, *API Proceedings*, 53: 865.
- 4.10 Taylor, J.F., Grimmett, H.L. and Comings, E.C., 1951, *Chem Eng Prog*, 47: 175.
- 4.11 Hajek, J.D. and Ludwig, E.E., 1960, *Petrochem Engineer*, 32 (6): 31.
- 4.12 Perry, R.H. and Chilton, C.H., 1973, *Chemical engineers' handbook*, 5th edition, McGraw-Hill, 5-61.
- 4.13 Husa, H.W., 1964, *Hydrocarbon Processing*, 43 (5): 179.
- 6.1 Valdes, E.C. and Svoboda, K.J., 1985, *Chem Eng*, 92 (18): 77.
- 7.1 Wilday, A.J., 1988, *IBC/HSE European Seminar*.
- 7.2 Heitner, I., Trautmanis, T. and Morrissey, M., 1983, *Hydrocarbon Processing*, 62 (11): 263.
- 7.3 Crozier, R.A., 1985, *Chem Eng*, 92 (22): 49.
- 8.1 Weighell, S.C., 1980, *IChemE Symposium Series No. 60*, 1.
- 8.2 Pearce, I.D., 1985, *Reliability 85 5B/R/1*.
- 8.3 Aird, R.J., 1982, *Trans IChemE*, 60: 314.

- 8.4 *Hazardous Materials Intelligence Report*, 2.9.1983.
- 8.5 *Ibid* 16.12.1983.
- 8.6 ICI Petrochemicals Division, 1978, *Fires and explosions in the oil and chemical industries*, 12.
- 8.7 Vervalin, C.H. (ed.), 1980, *Fire protection manual: for hydrocarbon processing plants*, Gulf Publishing, 181.
- 8.8 Lewis, D. 1980, *Major hazards*, Cambridge University, 3.
- 8.9 *Fire Prevention*, No. 19: 39.
- 8.10 Davis, L.N., 1979, *Frozen fire — Where will it happen next?*, Friends of the Earth, 25.
- 8.11 Bretherick, L., 1983, *ICHEME Loss Prevention Bulletin*, 054: 38.
- 8.12 Varadarajan, S., December 1985, *Report on Bhopal toxic gas leakage*, Indian Planning Commission.
- 9.1 Kent, G.R., 1966, *Control Engineering*, 13 (5): 87.
Kent, G.R., 1966, *Ibid*, 13 (6): 69.
- 9.2 Leung, J.C., 1986, *AIChE Journal*, 32: 1743.
Leung, J.C. and Grolmes, M.A., 1988, *Ibid*, 34: 688.
Fauske, H.K., 1985, *Plant/Operations Progress*, 4: 132.
Leung, J.C. and Fauske, H.K., 1987, *Ibid*, 6: 77.

The Library and Information Service of the Institution of Chemical Engineers in Rugby, UK, offers a worldwide service for the supply of these references.

BIBLIOGRAPHY

LEGISLATION

See listing in Section 1.4.

CODES AND STANDARDS

See listing in Section 1.5.

SOURCE MATERIAL

Addison, H., 1964, *Applied hydraulics*, 5th edition, Chapman & Hall.

Rodger, C.D., 1987, *Protection of pressurised systems against excessive pressure*, IMechE, Process Industries Division, North West Centre.

Thornton, B., *et al*, 1979, *Pressure relief devices*, IMechE Symposium.

Zappe, R.W., 1987, *Valve selection handbook*, 2nd edition, Gulf Publishing, Houston, Texas.

Kern, D.Q., 1950, *Process heat transfer*, McGraw-Hill, New York.

Perry, R.H. and Chilton, C.H., 1984, *Chemical engineers' handbook*, 6th edition, McGraw-Hill, New York.

Kletz, T.A., 1988, *Learning from accidents*, Butterworths, London.

APPENDIX 1.1 — THE PRESSURE SYSTEMS AND TRANSPORTABLE GAS CONTAINERS REGULATIONS 1989

The following regulations should be read in conjunction with Section 1.4.5 of the text:

Part II General

Regulation 4 — Design, construction, repair and modification

- (1) Any person who designs, manufactures, imports or supplies any pressure system or transportable gas container, or any article which is intended to be a component part of any pressure system or transportable gas container, shall ensure that paragraphs (2) to (5) are complied with.
- (2) The pressure system, transportable gas container, or article, as the case may be, shall be properly designed and properly constructed from suitable material, so as to prevent damage.
- (3) The pressure system, transportable gas container or article, as the case may be, shall be so designed and constructed that all necessary examinations for preventing danger can be carried out.
- (4) Where the pressure system has any means of access to its interior, it shall be so designed and constructed as to ensure, so far as practicable, that access can be gained without danger.
- (5) The pressure system and transportable gas container shall be provided with such protective devices as may be necessary for preventing danger; and any such device designed to release contents shall do so safely, so far as is practicable.
- (6) The employer of a person who modifies or repairs a pressure system or transportable gas container at work shall ensure that nothing about the way in which it is modified or repaired gives rise to danger or otherwise impairs the operation of any protective device or inspection facility.

Part III Pressure Systems

Regulation 5	Provision of Information and Marking
Regulation 6	Installation
Regulation 7	Safe Operating Limits
Regulation 8	Written Scheme of Examination
Regulation 9	Examination in accordance with the Written Scheme

Regulation 10	Action in case of Imminent Danger
Regulation 11	Operation
Regulation 12	Maintenance
Regulation 13	Keeping of Records

Note: The Regulations in Part III may be found in the full legislation or summarised in HS(R) 30, *A guide to the Pressure Systems Regulations (1989)*, published by HMSO.

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