

ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

Guide to life-cycle management of Pressure relief systems

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ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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Comments will be considered by the relevant EEMUA Technical Committee and may be incorporated in future editions of this Publication. New editions will be publicised on the EEMUA website.

Contents

Foreword	1
1. Introduction	3
2. Life-cycle Management Issues	5
2.1 Introduction	5
2.2 Relief System Design	6
2.3 Installation and Commissioning	6
2.4 Operation and Maintenance	7
2.5 Modifications	7
2.6 Documentation	7
3. Relief System Design and Specification	9
3.1 General	9
3.2 Pressure System Analysis	11
3.3 Relieving Devices	14
3.4 Sizing the Relieving Device	19
3.5 Specification and Selection of the Relieving Device	21
3.6 Location and Layout: Safety Valves	21
3.7 Disposal/Discharge Systems	22
4. Installation and Commissioning	25
4.1 Introduction	25
4.2 Contract Management	25
4.3 Pre-commissioning Checks and other Actions	25
4.4 Post-Overhaul Commissioning	29
4.5 Records	30
4.6 Establishing Initial Safe Operating Periods	30
5. Operation and Maintenance	31
5.1 Introduction	31
5.2 Operation	31
5.3 Maintenance and Inspection of Relief Devices	35
5.4 Maintenance Requirements for other Equipment and Devices	45
6. Definitions and Abbreviations	49
6.1 Definitions	49
6.2 Abbreviations	49
7. References	51
7.1 References	51
7.2 Related Documents	51
Appendix A Example Specifications	52
Appendix B Limiting the Relief Load	54
Appendix C Operation and Maintenance Checklists	56

Photographs

Photo 1 Safety valve isolation by using isolation valves along with a key operated interlock system	3
Photo 2 Safety valves showing local venting to atmosphere.....	11
Photo 3 Balanced bellows safety valve with local bonnet vent	16
Photo 4 Typical example of a bursting disc.....	18
Photo 5 Low pressure safety devices on refrigerated storage duty	19
Photo 6 Steam drum safety valve discharge pipework showing inlet route to silencers	23
Photo 7 Bursting disc and safety valve in series, with interspace vent and pressure gauge	28
Photo 8 Safety valve on steam duty showing vented bonnet, lift lever and discharge expansion chamber	31
Photo 9 Steam drum safety valves showing open bonnet style of construction. .	33
Photo 10 Steam safety valve showing butt welded inlet connection, and open bonnet construction	36
Photo 11 Safety valve on steam duty showing lift lever	41
Photo 12 Steam drum discharge silencers.....	47
Photo 13 Typical example of a storage tank vent	47

Foreword

The Publication provides advice on the full range of activities involved in the successful management of pressure relief systems. It also aims to fill the gaps in the current design guides and provide assistance in interpreting some of the standards and code issues and topics that are known to cause difficulties.

This Publication has been prepared as it is considered that there is currently no industry guide that addresses the primary aspects of pressure relief system management throughout the full life-cycle from design through construction, commissioning and operation.

It is applicable to any industry operating a pressure relief system and it is intended for use by those who have responsibility for any aspect of such systems. It provides an overall view of the management of pressure relief and links the design process with the operation and life-cycle issues which are the concern of plant management.

The Publication does not attempt to set out detailed design and operating methodologies. These are available in International and American standards and other industry documents, including EEMUA publications. In the absence of any specific company standards, the user is referred to the list of references in Chapter 7. These for the most part reflect industry best practice and provide some direction for addressing key areas of design and installation.

The intent of the Publication is to avoid repetition of advice that can be found in industry standards and codes. However, in important areas where guidance is lacking or does not exist, some suggested approaches are put forward based on the general practices of EEMUA members.

This Publication has been developed by the EEMUA Pressure Relieving Safety Systems Technical Committee from the experience and practices of its member companies in the petroleum, chemicals and power industries.

Note: The photographs included are for illustrative purposes and are not indicative of conformance with particular Codes and Standards.

1. Introduction

The pressure relief system serving a process unit or utility is the ultimate safety system for protecting against overpressure when other means of protection have failed. In its simplest form, it may consist of a single relief device protecting a pressure system and independently discharging a non-hazardous fluid to atmosphere. Alternatively, it may be a complex, closed system into which a number of relief devices, each protecting a separate pressure system, discharge flammable or toxic fluids. These relief devices may discharge at varying rates and in different combinations in different overpressure scenarios.

Unlike most process systems, and irrespective of the degree of complexity, the performance of many relief systems cannot be fully proven in advance of a real event. Therefore, any deficiencies could go undetected for the life of the facility. It follows that the system should be designed, operated and maintained to ensure operational integrity appropriate to its critical role.

EEMUA members have extensive experience in all aspects of relief system design, operation and maintenance in a number of different environments, and recognise the importance of a structured, rather than a fragmented, approach to the subject.

This Publication is presented in a number of Chapters, each of which addresses key aspects of pressure relief system management. These are:

- Chapter 2 - management issues;
- Chapter 3 - design and specification;
- Chapter 4 - installing and commissioning;
- Chapter 5 - operation and maintenance.



Photo 1 Safety valve isolation by using isolation valves along with a key operated interlock system

2. Life-cycle Management Issues

2.1 Introduction

This Chapter deals with general issues with respect to life-cycle management of pressure relief devices, including training and competency, and the need to manage adequately any of the processes of, and interfaces between, design, installation, operation, maintenance and subsequent modification.

In order to ensure that the appropriate level of integrity is built into the system and sustained throughout its life, a visible management system is required which links and controls each of these activities. Design, operation and maintenance are interdependent aspects of the life-cycle and should not be treated as a series of fragmented, unrelated activities.

A number of different parties are involved in this process, making it particularly important to manage the resulting interfaces. Whilst a safety valve or pressure relieving safety system may only be part of a new plant or project, it is essential to ensure that the correct level of attention is paid to these critical systems, and that in the process of procurement appropriate provisions are made to clarify responsibilities and for the adequate transfer of information and records.

Organisations may adopt different strategies for:

- procurement;
- construction;
- operations;
- maintenance.

The parties involved may be wholly in-house or may involve contractors. It is incumbent on all such parties to ensure adequate records, communications and transfer of relevant information relating to such systems is maintained. This Publication highlights those issues that need to be addressed whatever the contractual arrangements adopted.

The management of pressure relief systems should be included as part of a formal overall management system, which defines the appropriate design and maintenance standards and operational procedures. Many relief-related incidents have been attributed to deficiencies in the design process. Managing the design process effectively is, therefore, an important area in ensuring the safety of the pressure system.

A range of standards, codes and practices are available to the user to follow. They differ in detail and approach, and it is important that those selected are compatible and appropriate to a particular process. A company needs to decide on the ones most appropriate to their application and whether they need to be supplemented by company standards and procedures.

To ensure a consistent approach, written procedures should be developed to control the important activities. The procedures should clearly define responsibilities for key activities and address the issues relating to the interfaces between different groups and between different parts of the process.

All information such as calculations, data sheets and records should be retained and available throughout the life-cycle. It is equally important that the personnel

involved in the process have the appropriate level of training and experience and can demonstrate an acceptable level of competency.

During the life-cycle of a pressure relief system, it is inevitable that changes are required. These may occur during initial design or at any other time during the life of the plant. Any such changes should be controlled by a formal management-of-change process appropriate to the level of risk. Examples that would be regarded as a change in this context include changes/modifications to operating procedures, process fluid, operating parameters (including changes to plant capacity and/or throughput), plant/equipment hardware, maintenance and testing practices, and legislation. Temporary changes should be treated in the same manner as permanent changes.

If risk-based approaches are adopted in the design, operation or maintenance activities, the criteria to be applied should be clearly defined in formal procedures to ensure auditability and consistency in their application.

2.2 Relief System Design

The main contributors to poor relief system design include:

- limited awareness of the designer; and
- lack of comprehensive design guidance currently available within industry.

In the design of even the simplest relief system, input is typically provided from a number of sources which often work independently within their own areas of functional expertise. During the early stages of the design, assumptions are generally made and therefore a definite design basis is usually not available until near the end of the design phase of the project.

Chapter 3 covers, in detail, important aspects that need to be considered to ensure the adequate design of pressure relief systems.

2.3 Installation and Commissioning

Effective management of the installation and commissioning phases of the relief system life-cycle is essential for ensuring that the design philosophy has been correctly interpreted. These activities should be considered an integral part of the entire life-cycle.

During the commissioning phase, a newly installed relief system may be required to perform its pressure relieving function for the first time. Hence it is important to ensure that the actual installation of the relief system fully meets the design intent, recognising the criticality of the system and the reliance to be placed upon it as an essential safety system.

Chapter 4 provides guidance on the aspects of the installation and commissioning process of relief systems.

It may be useful to use a commissioning check sheet to formalise the process, reduce the potential for omissions and provide a permanent record. Where these checks are performed as part of a post-overhaul commissioning process, it should be ensured that the activities are part of maintenance/overhaul procedures.

2.4 Operation and Maintenance

The management system should address the training of operations and maintenance personnel to ensure that the original design intent is fully understood. Operations and maintenance procedures should be an integral part of the plant management system; the procedures and practices should be subject to audit and review to ensure they reflect good practice.

Operations and maintenance issues are often addressed as being specific to individual relief devices. As a result, common problems can be overlooked and opportunities to improve reliability and reduce costs missed. The approach should be holistic and documented. This allows for cross-referencing of common failures and the development of a comprehensive history of all relief devices. This information can be invaluable both in arriving at a common philosophy towards operations and maintenance, and in setting inspection frequencies based on risk.

Regardless of how well designed and constructed, a pressure relief system cannot function effectively unless it is operated and maintained correctly. Chapter 5 of this guide highlights the essential aspects of successful operation, inspection and maintenance of relief systems.

2.5 Modifications

Changes required to a relief system can arise at any stage in the life-cycle (e.g. during the design process, the installation and commissioning phases, or the operational phase of the plant). Such changes should be managed appropriately to ensure safety requirements are met. All changes should be assessed and a formal change/modification management process used. Consideration should be given to any differences between the current editions of the relevant codes and standards and those applicable at the time of the design. The process should ensure that the changes are documented, risk assessed, evaluated and approved, and that the results are communicated to all relevant parties. Documentation and records should be updated, see below (Section 2.6).

2.6 Documentation

Documentation should be maintained covering all stages from design through to disposal. Throughout the life of the plant and equipment, records should cover:

- design details and assumptions, including data sheets;
- drawings;
- operational documentation (including operating instructions and training requirements);
- commissioning procedures;
- written schemes of examination;
- maintenance instructions;
- spares requirements;
- inspection and maintenance reports.

3. Relief System Design and Specification

3.1 General

3.1.1 Introduction

This Chapter provides a basic framework that enables the engineer to approach the design and selection of overpressure protection and relief systems in a logical and consistent manner. It covers, in some detail, all the important aspects that need to be considered to ensure the adequate design of pressure relief systems. It offers guidance on recommended practices, identification of hazards and the evaluation of risk, along with the factors to be considered when selecting an appropriate relief device.

However, the detailed methodologies that support this framework to achieve the final design are, generally, beyond the scope of this Publication. These may be derived from design standards, industry or company practices. Some are specific to a particular industry and the hazardous nature of the fluid being handled.

Project specification usually requires the design of the relief system to meet the requirements of a particular design code. Specific requirements of the design code should be followed and the advice contained in this Publication adopted where appropriate.

Chapter 2 recognises that organisations may have different strategies for procurement of safety valves or pressure relieving safety systems. Irrespective of the strategy adopted, this Chapter details some of the important considerations that need to be made for the successful design of a relief system.

The design of relief systems has, for the most part, remained unchanged for many years. Generally, designs are simple and robust and do not rely on intervention from either instrumentation or operating personnel in order to perform their function in preventing overpressure or vacuum (underpressure).

3.1.2 Design Considerations

Every item of pressure equipment, either individually or as part of a pressure system, should be capable of withstanding the maximum pressure or vacuum it might experience in service. Otherwise, it should be protected by a suitable relieving device (or an acceptable alternative) against all potential sources of overpressure. The preferred and often simplest approach to addressing potential overpressure is to eliminate it by providing inherent safety in the process design. This may be achieved with little or no additional cost, provided the need is recognised sufficiently early in the project's design stage. For example, it is often possible to increase design pressures by a relatively small amount to ensure that all equipment can withstand the maximum pressure that it may experience.

If overpressure (or vacuum) protection is required, the size (capacity) of the required relieving device should be based on a thorough analysis of all sources of possible overpressure, both internal and external to the process, and relief loads for each device calculated. The design of the disposal or flare system should be based on the calculated relief loads and, where appropriate, should take account of any coincident discharges from other relieving devices during a site-wide or plant-wide failure scenario.

Selection of the relieving device (e.g. spring-loaded versus pilot-operated safety valve, or safety valve versus bursting disc) should take into account the conditions prevailing upstream and downstream of the device during all envisaged overpressure scenarios, and this decision may require input from the manufacturer of the relieving device.

In order to achieve the necessary reliability and integrity for the relief system, the following approach should normally be adopted when evaluating overpressure scenarios:

- allowance should not be given to the predicted response of instrumentation for the purpose of reducing the required capacity of a relieving device;
- where appropriate, it should be recognised that the response of instrumentation may be to increase the potential for overpressure and hence, the required capacity of the relieving device; this is particularly so with 'advanced control' systems installed to maximise plant performance;
- allowance should not be given to any operator response expected to limit a relief load to a specific duration. Industry guidance suggests a time of 30 minutes, but each case should be addressed on its merits and the approach agreed with those responsible for the process design or operation of the plant.

Allowance may be made, however, for changes in operating parameters which are governed solely by the thermodynamics of the pressure system and which are not dependent upon the response of a protective system (e.g. a higher process temperature resulting in reduced heat input at the system relieving pressure).

Traditionally, overpressure protection is provided by pressure relieving devices which discharge excess material to the atmosphere or to a closed disposal system, depending on the nature of the fluid. As facilities have expanded and environmental requirements increased, greater reliance has been placed on instrumented protection systems (see Appendix B). These systems protect against overpressure by reducing the pressure at source and thereby avoid the discharge of additional material to the relief system. The final overpressure protection is, normally, still provided by a conventional mechanical relief system.

3.1.3 Standards and Recommended Practices

To further safeguard the integrity of the design and provide some degree of guidance, many countries publish requirements for the protection of pressure vessels against overpressure within a national pressure vessel design code or standard. In certain countries compliance with particular codes or standards is mandatory; in other countries there is flexibility, provided specific safety requirements are satisfied. It is, however, essential to comply with local statutory legislation or regulations in force at the location of the plant. For instance, in the UK, the use of mechanical equipment in explosive atmospheres is legislated by 'The Dangerous Substances and Explosive Atmospheres Regulations 2002', commonly referred to as the DSEAR Regulations ⁽¹⁾.

In addition to pressure vessel codes and standards, there are a number of standards and guidance documents which are recognised within the industry as representing best practice for the design of overpressure protection and relief systems. The most widely-accepted of these for the design of pressure relief systems in refineries and petrochemical installations are API RP 520 Parts I

and II ^(2, 3) and ISO 23251 (ANSI/API Std 521) ⁽⁴⁾. These documents are applicable to any pressure vessel with a maximum allowable working pressure of 15 psig (1 bar) or greater. For atmospheric storage vessels, guidance on overpressure protection requirements is provided in API Std 2000 ⁽⁵⁾.

These standards or recommended practices are not prescriptive and they make no attempt to address every overpressure scenario which might be encountered. Sound engineering judgement needs to be applied in each particular case.



Photo 2 Safety valves showing local venting to atmosphere

3.1.4 Limiting the Relief Load

The traditional and proven, simple approach to overpressure protection, relying on a recognised relief device and a suitable disposal system, remains the preferred design option. However, with the installation of new plant, the demand on available disposal system capacity tends to increase and the cost of providing additional header capacity can be prohibitive. As an alternative to the modification of an existing relief system, increasing use is being made of more sophisticated analytic techniques and, in some situations, the provision of extremely reliable and more cost-effective instrumentation systems, which either eliminate or reduce the size of any discharge to the disposal system. See Appendix B for further information.

3.2 Pressure System Analysis

This Section describes the approach to identifying and quantifying potential causes of equipment overpressure.

3.2.1 Identification of Hazards

In order to establish the scenarios which could result in the overpressure of equipment and for which overpressure protection should be provided, it is necessary to undertake some form of relief study.

During normal operation, a hazardous situation may arise for many reasons and it may directly or indirectly lead to overpressure. Examples include:

- operating excursions (exceeding the prescribed pressure/temperature operating envelope);
- human error;
- system failures (process and utility);
- external fire;
- unreliability, due to inadequate maintenance;
- the physical and chemical properties of the fluid;
- mechanical factors (e.g. corrosion, vibration).

Depending upon the risk associated with each of the hazards identified, it may be deemed necessary to provide protection against overpressure. This decision needs to be based on an assessment of the consequences of overpressure, policy as to the acceptability of risk, and the requirements of the applicable design standard. The hazard identification process should be comprehensively documented in order to provide an audit trail and agreed with the relevant parties.

3.2.2 Consideration of Risk

An appreciation of the risk associated with a hazardous event may be obtained by means of risk assessment. Risk assessment comprises:

- risk analysis;
- risk evaluation.

Risk analysis involves:

- determination of the boundaries of the pressure equipment or system, definition of its intended use, and identification of potential operating excursions;
- identification of the potential hazards and an estimation of the associated risk.

Risk evaluation is the process in which, on the basis of the risk analysis, judgement is made as to what measures (if any) are required in order to achieve an acceptable risk.

If a risk is judged to be unacceptable, it may be possible to make changes to the pressure system design to achieve an acceptable reduction. If this is not feasible, the risk needs to be reduced to an acceptable level by means of appropriate protection. This would typically be a pressure relieving device, but it may be more appropriate to provide an alternative option which eliminates the primary hazard.

3.2.3 Pressure Systems Review

The most common cause of overpressure in a pressure system is an internal process upset or failure. In order to determine the relief loads which should be considered when sizing the relieving device, it is first necessary to carry out a review of the process and instrumentation diagrams for the facility to identify every possible internal source of overpressure for each item of pressure equipment in the plant.

The following list of scenarios represents the most commonly encountered process failure cases and may be used as a check list in the pressure systems analysis:

- power failure;
- cooling water failure;
- power plus cooling water failure (if appropriate);
- steam failure;
- instrument air failure;
- fire;
- blocked outlet;
- blocked inlet;
- flow stoppage;
- liquid overfill;
- open inlet;
- thermal expansion;
- control valve failure;
- exchanger tube rupture;
- rotating equipment failure;
- back flow;
- abnormal heat input;
- distributed control system failure;
- runaway reaction;
- emergency depressuring;
- atmospheric tank venting;
- explosion;
- underpressure/vacuum formation.

Note: The above list should not be regarded as exhaustive and the potential for other sources specific to the type of plant in question should be considered.

A detailed discussion of these scenarios is beyond the scope of this document.

It is important that the exercise be carried out in an open and systematic manner. In addition to normal operation, start up and shutdown procedures and operations carried out under defined and infrequent circumstances should also be considered. The exact purpose of every line and cross-over in the plant should be established and ways in which each of these systems may fail or be incorrectly operated should be considered. A small and seemingly insignificant connection between two pressure systems may provide the source of significant overpressure. Some input would normally be required from operating personnel and the final analysis should have management support.

Although allowance is not normally given for the response of instrumentation, this response may have an impact on downstream systems and needs to be addressed. For example, a pressure control valve may become fully open in response to increasing pressure and cause overpressure in downstream equipment.

A record should be made of each overpressure scenario considered and the conclusions reached, even if that conclusion is that there is no case to address.

In addition to internal sources of overpressure, external sources should be considered. These are normally only solar radiation and fire. It is usually not necessary to consider overpressure due to fire if it can be demonstrated that there is no potential for the spillage of flammable liquid in the area surrounding

the vessel, or if the vessel is at an elevation or in a location where it could not be subjected to the effects of a fire. However, although ISO 23251 (ANSI/API Std 521) ⁽⁴⁾ considers 7.62 metres (25 feet) to be a safe elevation, it should be recognised that pool fires resulting from the combustion of some fluids (e.g. LPG) can create flame lengths much greater than this.

3.2.4 Site Utilities

The failure of a site utility system can cause overpressure. A review should be made of each of the main utility systems (i.e. power, cooling water, steam and instrument air) to determine possible modes of failure and any impact that failure of one facility may have on another (e.g. the effect of loss of power on steam production). The interdependence of utility services may have a significant impact on the outcome of the pressure systems review. In the case of power, consideration should be given to partial failures of a level of supply in which cooling capacity is lost but heat input is maintained.

3.3 Relieving Devices

3.3.1 Types of Device

The primary element of protection against overpressure or underpressure in a relief system is the relieving device located on the pressure vessel or in the pressure system.

Common types of relieving device used to protect against overpressure include:

- safety valves;
- bursting discs;
- buckling pin relief devices;
- pressure/vacuum valves;
- vacuum breakers;
- vents, overflows and lutes.

These are discussed in the following Sections.

Additionally, in recent years, various types of instrumented protective device have been adopted as a means of eliminating a source of overpressure and preventing a relief load from being generated. These are special, custom-designed devices and systems and are discussed in Appendix B.

3.3.2 Safety Valves

3.3.2.1 General

A safety valve is a relieving device which is designed to open and relieve excess pressure and thereafter re-close to prevent the further flow of fluid once normal conditions have been restored.

Safety valves fall into one of three main classifications:

- conventional valves;
- balanced valves;
- pilot-operated valves.

A summary of the differences between each type of valve is given below.

The performance of a safety valve is influenced by the back-pressure in the downstream disposal system. In order to have confidence that the safety valve opens at the pressure specified and provides the required capacity, it is important to select the appropriate type of valve.

3.3.2.2 Conventional Valves

A conventional valve is a spring-loaded pressure safety valve whose operational characteristics are directly affected by changes in back-pressure. It is generally the most reliable type of safety valve and also the cheapest. It can operate in systems containing hazardous fluids with no release of fluid to the atmosphere. Use of the valves is typically limited to applications where neither the superimposed nor the variable built-up back-pressure exceeds 10 percent (%) of the set pressure.

A higher superimposed back-pressure can result in the valve not lifting until the required set pressure has been exceeded, whilst a higher built-up back-pressure can result in valve instability during operation.

Conventional valves may, however, be used in applications where the superimposed back-pressure exceeds 10 percent of set pressure, provided it is constant. In this case, the spring setting should be adjusted to take account of the superimposed back-pressure. A common example of this is on a pump system where a safety valve downstream of the pump discharges to pump suction.

3.3.2.3 Balanced Valves

A balanced safety valve is a spring-loaded pressure safety valve which is designed to minimise the effects of back-pressure on the operating characteristics of the valve. In its commonest form, the valve employs a flexible bellows to prevent the back-pressure acting on the discharge side of the disc, so that the valve can be used in applications where the back-pressure exceeds 10 percent of set pressure.

The use of balanced valves typically allows the size of the downstream disposal system to be significantly reduced. This type of valve can be used satisfactorily in applications where the superimposed and/or built-up back-pressure is variable, and the total back-pressure does not exceed approximately 50 percent of the set pressure.

It should be noted that increasing back-pressure does reduce the capacity of the valve and this needs to be taken into account in sizing. For most makes of valve, the capacity reduction below a back-pressure of 30 percent of set pressure is not significant and it is common practice to design header systems to limit back-pressure to this level. The performance of balanced valves remains stable until the back-pressure exceeds 50 percent of set pressure. Installing balanced valves, therefore, leaves some system capacity for future expansion.

It should also be noted that the bellows have a maximum allowable pressure limitation which the total back-pressure should not exceed, to avoid risk of bellows failure. For some balanced valves (particularly those in high pressure systems), this may be significantly less than 50 percent of set pressure and may