

INTRODUCTION

1.1 OBJECTIVE

Guidance for the design and selection of pressure relief devices for most applications can be found in documents provided by several organizations including: the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), the National Fire Protection Association (NFPA), the Compressed Gas Association (CGA), and the International Organization for Standardization (ISO). The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) regulation and the similar Environmental Protection Agency (EPA) Chemical Accident Prevention regulation (commonly referred to as Risk Management Plan (RMP)) and increased industry efforts to improve safety and environmental protection practices have led to much greater focus on reducing and controlling releases of materials from pressure relief systems to the atmosphere.

The guidance and sizing formulas provided by the above organizations are generally applicable only to single-phase flow. Research and studies by the Design Institute for Emergency Relief Systems (DIERS) resulted in a new body of technology on two-phase flow from relieving vessels and the effect of two-phase flow on pressure relief system design and on the performance of pressure relief valves under such conditions. These developments suggested a need for a presentation from a chemical industry perspective on the design and selection of pressure relief devices for single as well as multi-phase flow from pressure relief systems and for the treatment of the effluent from pressure relief systems. Preparation of this book by the CCPS was in response to this need.

This CCPS / DIERS book is directed toward experienced process engineers and specialists with a basic proficiency in fluid dynamics and process engineering fundamentals. The objective is to present information that will provide guidance for selecting and designing reliable emergency pressure relief and effluent handling systems. These systems should be designed to protect equipment from overpressure and to either contain or safely control hazardous materials discharged during an emergency.

This second edition presents updated information on several widely used national codes and standards to include those which have been adopted by regulatory authorities for inclusion in either federal or local regulations. These documents should be viewed by designers as representing industry practices with proven value in providing reliable process safety systems, not just as regulations requiring compliance.

1.2 SCOPE

General background information on pressure relief technology is presented along with guidance for selecting relief devices and effluent handling equipment. Calculation procedures for designing pressure relief and selected effluent handling equipment are also presented. Numerous example problems are used to illustrate calculation procedures. Computer programs are presented for handling flow calculations for compressible gases, for evaluating complex two-phase flow situations, and for sizing effluent handling equipment. The book includes:

- Discussions of national and international codes and regulatory impacts on pressure relief system design and operation.
- Reviews of causes of overpressure events and selection of the worst case scenario and the relief system design and design basis for the relief system including systems involving chemically reactive and highly viscous materials.
- Descriptions of a range of relief devices and operating performance characteristics including flow calculation methods for sizing pressure relief devices and associated piping systems.
- Characterization of fluid properties including sources of property information and handling of mixtures.
- Methods for calculation of reaction thrust forces from discharge of relief systems.
- Guidance in selecting effluent handling systems including equipment commonly used for pressure relief system applications. This includes gravity and cyclone separators, scrubbers, quench pools, flares, and atmospheric dispersion (for non-hazardous materials only).
- Calculation procedures for sizing the most widely used equipment for effluent handling, including gravity separators, cyclones, quench pools and spargers.

Maintenance, operations, and testing procedures and technology are not discussed in detail, but are covered briefly in selected cases. Prevention or mitigation of overpressure incidents and the essential components of a good process safety management system are beyond the scope of this book. Such procedures and technology include emergency control or shutdown systems, inherent safety concepts, safety layers of protection, prevention of explosive deflagrations and detonations, and other measures used to reduce the frequency or magnitude of emergency overpressure events. Guidance on these subjects can be found in other CCPS books, which are listed in the appropriate sections of this book.

If potentially hazardous materials might be discharged to the atmosphere, specialists on the health and environmental effects should be consulted to determine safe levels of discharge to the air, water, and land. In general the release of hazardous materials to the environment should be avoided if at all possible.

1.3 DESIGN CODES AND REGULATIONS, AND SOURCES OF INFORMATION

There are a number of organizations that provide information on pressure relief and handling of effluent from pressure relief systems. Some of these, with a brief summary of their role, are shown below (see Section 2.3.1 for a more extensive listing):

Federal and local governments. The federal government, through OSHA and EPA regulations, provides much information on requirements for process safety and environmental protection. Many states have implemented regulations that parallel or exceed federal regulations. Designers and operators of pressure relief systems should maintain a familiarity with these requirements. While the focus in this book is on practices, codes, and standards of U.S. origin, designers and operators of facilities in other countries are urged to become familiar with any practices or regulations that may apply. In many cases facilities designed to meet U.S. requirements will either meet or exceed requirements based on international regulations.

American Society of Mechanical Engineers (ASME). The ASME publishes the Boiler and Pressure Vessel Code (ASME BPV Code), which contains basic requirements for overpressure protection of vessels covered by the Code. Section VIII covers Pressure Vessels, which are applicable to the petroleum and chemical process industries. Many governmental authorities have adopted the ASME BPV Code and made it part of their regulations. The ASME BPV Code therefore has the force of law in many states.

American Petroleum Institute (API). The API publishes a series of standards and recommended practices that cover the fundamentals and application of pressure relief technology including pressure relief of low pressure tanks and testing and maintenance of pressure relief valves. Many recommendations are presented that cover various aspects of pressure relief system design, including effluent handling.

National Fire Protection Association (NFPA). The NFPA publishes a number of documents that present pressure relief requirements for various specific fluid services. Their Flammable and Combustible Liquids Code (NFPA 30), Standard for Water Spray Fixed Systems for Fire Protection (NFPA 15), Standard on Explosion Protection by Deflagration Venting (NFPA 68) and Standard on Explosion Prevention Systems (NFPA 69) are of particular interest to the chemical and petroleum process industries.

National Board of Boiler and Pressure Vessel Inspectors (NB). The National Board publishes information on certified flow capacity of valves tested in accordance with ASME procedures and documents related to inspection and repair of pressure relief valves.

International Organization for Standardization (ISO). ISO publishes international standards. Some of these documents are cross-branded with API documents. Compliance with these standards is required by most European countries. The ISO 4126 standard for safety devices for protection against excessive pressure is divided into eleven separate parts applicable to safety valves, rupture disks, pilot operated valves and other topics.

DIERS. The Design Institute for Emergency Relief Systems (DIERS) was established in 1976 to develop a better understanding of pressure relief system technology including vapor-liquid disengagement in vessels and flow of two-phase fluids through pressure relief devices and piping. The results of the initial research have been published (DIERS 1992). Current developments are covered during DIERS biannual meetings and in associated reports where information on new research, practices and technology is presented and discussed.

Other sources of information that supplement the standards and codes indicated above are given as references and noted within the text of each chapter of the book.

1.4 ORGANIZATION OF THIS BOOK

Pressure relief technology is covered in the chapters of this book. The following is a brief summary of each chapter:

Chapter 1. Introduction

Chapter 2. Relief System Design Criteria and Strategy: Presents general information on pressure relief technology (including terminology and definitions) pressure relief design strategies, ASME BPV Code requirements, and descriptions and layout of relief systems. Also covered are causes of overpressure, review of worst credible relief scenarios, analysis of vapor-liquid phase behavior in vessels, determination of required flow capacity, fluid properties and system characterization, flow of fluids through relief systems, and relief system reliability.

Chapter 3. Requirements for Relief Systems Design: Covers vessel venting background to include vessel onset / disengagement dynamics for evaluating whether two-phase flow might occur, venting requirements for nonreacting cases, calorimetry for reactive emergency relief system design, and venting requirements for reactive cases.

Chapter 4. Methods for Relief Systems Design: Covers calculation methods for sizing and rating pressure relief devices and associated piping to include computerized and manual methods for safety relief valves and piping and rupture disks and associated piping for vapor, liquid, and two-phase flows.

Chapter 5. Additional Considerations for Relief Systems Design: Covers the mechanical forces involved during emergency venting. Methods for estimating reaction thrust from relief system discharge are covered.

Chapter 6. Handling Emergency Relief Effluents: Presents guides to selection of equipment and systems to treat the effluent from relief devices. The focus is on equipment and techniques that are more commonly used in pressure relief applications. Information is summarized in tables that list advantages, disadvantages, and areas of possible application for the various types of equipment.

Chapter 7. Design Methods for Handling Effluent from Emergency Relief Systems: Covers design methods and sizing calculation procedures for various types of equipment and processes that are commonly used to treat effluent in emergency relief situations. Methods are presented in detail for gravity separators, cyclone separators, and quench pools (including spargers for quench pools).

Computer Programs. Several useful computer programs are provided at the CCPS website listed in the front of the book. These programs are provided to aid in making flow calculations for relief devices and piping and for sizing selected effluent handling equipment. The computer programs include the SuperChems™ family of new programs and the CCFlow and TPHEM legacy programs provided in the first edition of this guideline.

SuperChems™ for DIERS Lite includes steady state methods for evaluation of relief requirements and contains a visual interface for the construction of piping isometrics with a variety of pressure relief devices components such as rupture disks and safety relief valves. SuperChems™ for DIERS includes methods for modeling the dynamics of relief from vessels with and/or without chemical reactions.

The CCFlow family of programs includes the following:

- TPHEM, a DOS program for two-phase flow through piping and nozzles,
- COMFLOW, a DOS program for gas/vapor flow through piping and nozzles,
- CCFlow, a Windows® program for two-phase and gas/vapor flow through piping and nozzles for sizing and evaluating relief valves and for sizing gravity separators, cyclone separators, and spargers.
- CCFlow Utilities, a program to calculate Antoine coefficients, compressibility factors, and isentropic expansion coefficients. Multicomponent systems can be handled for the latter two items.

Instructions for use of The CCFlow program are included in the CCFlow Help files. The uses of the programs are illustrated in the Appendices. These programs do not address determination of required relieving capacity or composition of the effluent.

1.5 GENERAL PRESSURE AND RELIEF SYSTEM DESIGN CRITERIA

Anyone with responsibility for designing, operating, and maintaining pressure relief systems and other process equipment should be familiar with: the provisions of the OSHA Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119) PSM standard; the EPA Risk Management Program (40 CFR 68.130) RMP rule; and the requirements of States that have their own State Plan. Guidance on the implementation of the principles embodied in the Federal and State standards are discussed in general in CCPS (1989c and 1992) and in API Standard 750. More specific guidance on each of the required elements is provided in numerous CCPS books.

While compliance with all applicable regulations is important, the basic objective is the safety of people and preventing damage to facilities and the environment. Compliance with regulations alone may not provide an acceptable level of protection. Compliance with the Federal and State Plan regulations is required if a listed chemical is present in the process in an amount equal to or in excess of a threshold quantity. The engineering practices provided in this book are applicable to all processes and may be considered to represent the current best thinking of the DIERS working group.

Company standards and practices are also an important source of information on design requirements for pressure relief systems. They are usually based on process safety management principles that have been developed from many years of experience. Many regulations use industry best-practices as a reference. These practices have been proven to represent good business practices as well as good process safety management and have been incorporated into the culture of many organizations.

Some important process safety management techniques related to pressure relief system design, which are not covered in detail in this book, are discussed briefly below. OSHA published a standard in 1992, Process Safety Management of Highly Hazardous Chemicals (29 CFR 1910.119) to control chemical hazards in the workplace. That standard covers basic requirements for implementing a good process safety management program which involves applying generally recognized and accepted good engineering practices to ensure process safety in new and existing plant facilities. Two components of a process safety management program referred to in 29 CFR 1910.119 are particularly relevant to the design, operation, and maintenance of pressure relief systems; these are Process Hazards Analysis and Process Safety Information, which are discussed briefly in the following sections.

1.5.1 Process Hazard Analysis

A chemical process and plant facility should be analyzed for all possible causes of overpressure to determine the worst credible scenario. The worst credible scenario establishes the design basis for the pressure relief and for the effluent handling system. Methods for conducting such a hazards analysis and evaluation are presented in CCPS (2003 and 2008a). The hazard analysis should be revalidated on a regular basis to review the current process conditions, any possible mechanical changes in the facility since the original construction or last hazard analysis, and maintenance and operating records for any signs of problems. The pressure relief system should then be verified to ensure that it is still adequate to protect the equipment. Guidance on how to revalidate a hazard analysis is provided in CCPS (2001) and by Chadwell (1997).

Inherent safety concepts should be applied during the process design on the hazards of the process. Refer to CCPS (2009) for guidance on this topic. This can include changing process chemistry to use less hazardous materials, avoiding extreme temperatures and pressures, and designing for total containment by increasing vessel design pressure.

Operating and maintenance personnel should be trained. Operating and maintenance procedures must be written for start-up, shutdown, upset, and normal operating conditions. These written procedures must be updated and must be part of the periodic hazard review and analysis program. Proper supervisory controls must be instituted and training and refresher courses provided for operating and maintenance personnel. Refer to CCPS (1989c, 1995e and 1996b) for guidance on this topic.

Process safety audits should be conducted. An independent audit and verification of the design can provide additional assurance that the emergency relief system will adequately protect the vessel. An audit of the initial design can include a review of overpressure events that were considered in selecting the design basis. A check of the final mechanical design and specifications for the pressure relief system should also be reviewed. For existing process units, a periodic audit can include a review of current process conditions, any possible mechanical changes in the facility since the original construction, maintenance and operating records for any signs of problems, and verification that the pressure relief system is still adequate to protect the vessel. See CCPS (2008).

Robust and redundant process control and emergency shutdown systems should be installed. In recent years there has been increased interest in application of instrumentation to reduce either the frequency or the consequence of overpressure events. Overall protection system reliability can be improved by using high integrity instrumentation to supplement the mechanical pressure relief devices normally used. Instrumented systems can also be used effectively to deinventory and depressure a vessel to either prevent the pressure relief device from opening or to mitigate the magnitude of the release. Such instrumentation should be independent of normal process control instrumentation, of high reliability, and provided with a high degree of redundancy and diversity to avoid common cause failures. Refer to CCPS (2007a) for additional information. Instrument protection systems should be supported by a detailed hazard analysis to identify the causes, frequencies, and consequences and of overpressure events. A periodic operational testing program under close supervisory control is also required.

If the frequency of a particular event can be reduced to an extremely low level, that event might be considered not credible. Under such circumstances the event would not be considered further in determining the design basis for the pressure relief system. The ASME BPV Code provides guidance on the analysis and instrumentation required to determine if a scenario can be considered not credible. Such system design is based on a detailed analysis to examine all credible scenarios which could result in an overpressure condition. The user must ensure that the Maximum Allowable Working Pressure (MAWP) of the vessel is greater than the highest pressure that can reasonably be expected to be achieved by the system. The system is likely to include a highly reliable instrumentation and control system which is used to limit the system pressure under all scenarios along with a reliability evaluation of the overall safety system. Documentation must be available to regulatory and enforcement authorities where the vessel will be installed.

1.5.2 Process Safety Information

The design basis and description of all pressure relief systems must be retained and available for review. The design basis should be kept up-to-date with current process conditions and reviewed periodically when process hazards analyses are conducted. Such documentation should include: identification and description of the design basis overpressure event and the equipment being protected to include required flow capacity; the description and specification of relief devices; important operating parameters such as flow capacity, set pressures, materials handled; and

inspection, testing, and maintenance history. Information is also needed about the equipment in the process that is being protected by the pressure relief systems and includes all of the information required by the ASME BPV Code for the design, construction, testing and application of the nameplate on the vessel. See CCPS (1995d) and Howell (2009) for additional guidance on what should be included in process safety information.

The following paragraphs summarize some of the important general requirements of the OSHA PSM standard and EPA RMP regulation:

- Process safety information - should include a complete compilation of process safety information before conducting any required process hazard analysis - information pertaining to the hazards of highly hazardous chemicals, process technology, and process equipment
- Hazards of highly hazardous chemicals - should include data on physical properties, reactivity, corrosivity, chemical and thermal stability, and hazardous effects of inadvertent mixing of different materials that could foreseeably occur. Material Safety Data Sheets meeting the requirements of 29 CFR 1910.1200(g) may be used to comply with these requirements to the extent that they contain the information needed
- Process Equipment - should include documentation on the following:
 - ◇ Relief system design and design basis
 - ◇ Design codes, standards and recommended practices employed
 - ◇ Safety systems (interlocks, detection or suppression systems)
 - ◇ Documentation that the equipment complies with Recognized And Generally Accepted Good Engineering Practice (RAGAGEP). Codes, standards, and technical publications of various engineering societies constitute good engineering practices. Documents from the DIERS Users Group and CCPS are examples of such published good engineering practices
 - ◇ For equipment designed and constructed in accordance with codes, standards, or practices that are no longer in general use, documentation that such equipment is designed, maintained, inspected, tested, and operated in a safe manner, and that such equipment is still suitable for its intended use. Where the process technology requires a design that departs from the applicable codes and standards, documentation that the design and construction are suitable for the intended purpose

- ◇ Mechanical integrity application - should include documentation on piping systems (including piping components such as valves), relief vent systems and devices, and emergency shutdown systems
 - ◇ In addition to the OSHA standard discussed above, the EPA has issued rules on Chemical Accident Prevention Requirements: Risk Management Programs (RMP) (40 CFR Part 68). These rules parallel those of the OSHA process safety management standard. The focus of the OSHA standard is the safety and health of workers at the facility. The EPA focus is off-site protection of public health and the environment. The basic purposes of the RMP rules are to prevent accidental releases of regulated substances and other extremely hazardous substances and to minimize the consequences of releases by focusing on preventive measures for those chemicals that pose the greatest risk.

The EPA standard further impacts the design, operation, and maintenance of pressure relief and effluent handling systems.

1.5.3 Problems Inherent in Pressure Relief and Effluent Handling Systems

There are many uncertainties involved in designing pressure relief and effluent handling systems to attain system reliability. Many pressure relief and effluent handling systems have been constructed on the basis of available information and technology. These have performed satisfactorily with few reported problems. Designers of pressure relief and effluent handling systems should be aware of the uncertainties involved and provide for back-up measures in preparation for contingencies in applications that involve highly hazardous materials. Specialists in the design of effluent handling equipment should be consulted. Experimental validation or testing the design on a large scale should be considered for critical applications.

The design of pressure relief and effluent handling facilities is complicated by the conditions inherent in relieving overpressure events because a process involves variable flow rates and fluid conditions. The flow rate, temperature, pressure, vapor-liquid ratio, physical properties, and material composition commonly vary widely during the discharge from the relieving vessel. Computer-based dynamic process simulation is often the preferred approach to sizing pressure relief and effluent handling

systems, particularly those involving reactive materials and runaway reactions. The AIChE offers one such simulation program, SuperChems™ for DIERS, that can handle vessel dynamics to estimate effluent rate and composition as well as flow through relief devices and piping for chemically reacting and multicomponent nonideal systems. The capabilities of this software include a wide-ranging physical and thermodynamic property database. Simulation programs are very powerful, but do require training for effective use by the typical process engineer.

The technological and experimental foundation for designing and predicting the performance of effluent handling equipment under emergency relief conditions is sometimes limited. High inlet velocity of flashing vapor-liquid mixtures can generate hard-to-separate small liquid droplets which may not be collected by a cyclone or gravity separator. If the effluent from the separator is going to a flare or some other treatment device, the discharge of smaller droplets may be of little consequence. If the effluent from the separator is hazardous, additional treatment will be required before discharge to the atmosphere.

There is uncertainty also in designing quench pools handling vapor containing large quantities of noncondensable gas where it is hard to accurately predict the approach to vapor-liquid equilibrium in the effluent from the quench pool. The consequence of this should be evaluated and provisions made for a secondary treatment such as a flare, stack, or scrubber if the discharge from the quench pool might present a hazardous condition.

Spargers that handle mixtures of condensable vapor and liquid can generate vibration and large shock loadings that are difficult to predict and control. There were a number of sparger failures in the early years of the nuclear power industry due to steam-water hammer. Performance was improved following the application of sophisticated mechanical design methods, the use of more rugged designs, attention to details of the structural supports, rigorous quality control in sparger fabrication, and better distribution of incoming vapor. Sometimes highly specialized mechanical analysis may be required; however, the usual approach within the chemical and petroleum industries is to rely on general mechanical design methods with emphasis on rugged design and inspection of the sparger before operation and after any overpressure incident.

The flow of fluids through pipes and relief valves generates vibrations that can destroy the piping system under certain conditions. Analysis of all forces due to fluid flow derived vibrations must be considered.