WHITE PAPER

Design of Emergency Pressure Relief Systems

An emergency pressure relief system is the most frequently employed Basis of Safety or layer of protection option for overpressure safeguarding in the chemical, pharmaceutical and allied industries. It can provide protection to reactors, storage tanks, columns, dryers and other process equipment. When designed and operated properly such a system can be both cost-effective and reliable.

Correct specification, operation, maintenance and inspection of the emergency pressure relief system is critical for the safety of staff and the environment. However, we continue to see incidents that put some focus on the common failures along the lifecycle of the system.

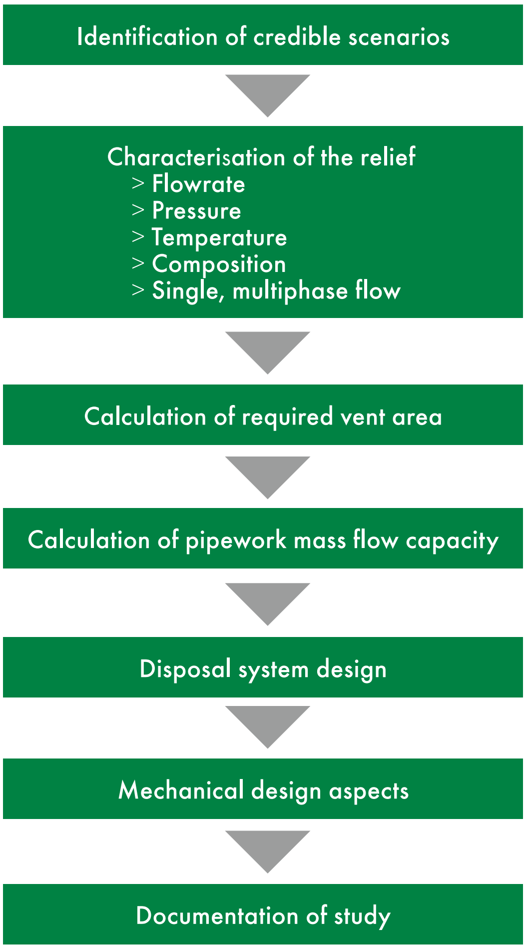
1. Initial Considerations

The emergency relief system must be designed specifically for an individual process and installation; a "standard" size undertaken by an engineering contractor or equipment supplier will often be inadequate, unless all of the aspects of the process have been fully assessed. The design must consider all credible failure conditions, including runaway reactions, chemical decomposition and fire engulfment, as well as physical overpressure events (blocked outlet, failure of control loops, utility failure, thermal expansion of liquids blocked in…). The sizing calculations will frequently have to be performed for a two-phase flashing fluid discharging from the relief device, with downstream treatment facilities being required to provide environmental protection. Mechanical construction of the vessel and pressure relief vent will need to take into consideration the large reaction forces associated with emergency venting. This whole design procedure requires a structured approach in order to reliably assess the system requirements and generate a comprehensive design dossier.

Most companies have their own imperatives for safety of the workforce, environmental impact and protection against capital loss. In other words, most companies have corporate criteria on what level of risk is deemed tolerable. Additionally, the protection of vessels against possible overpressure is enshrined in legislation and in engineering standards, and regulators generally require evidence to demonstrate that although other protection options may be employed, (e.g instrumented safety systems to IEC61508/11) emergency pressure relief systems will generally be installed to provide the ultimate level of protection.

2. Design Procedure

The state-of-the-art design methods for relief systems are based upon the work of DIERS (Design Institute for Emergency Relief Systems) and subsequent supporting research. The principal steps in a procedure for the design of an emergency relief system follow an established flow chart:

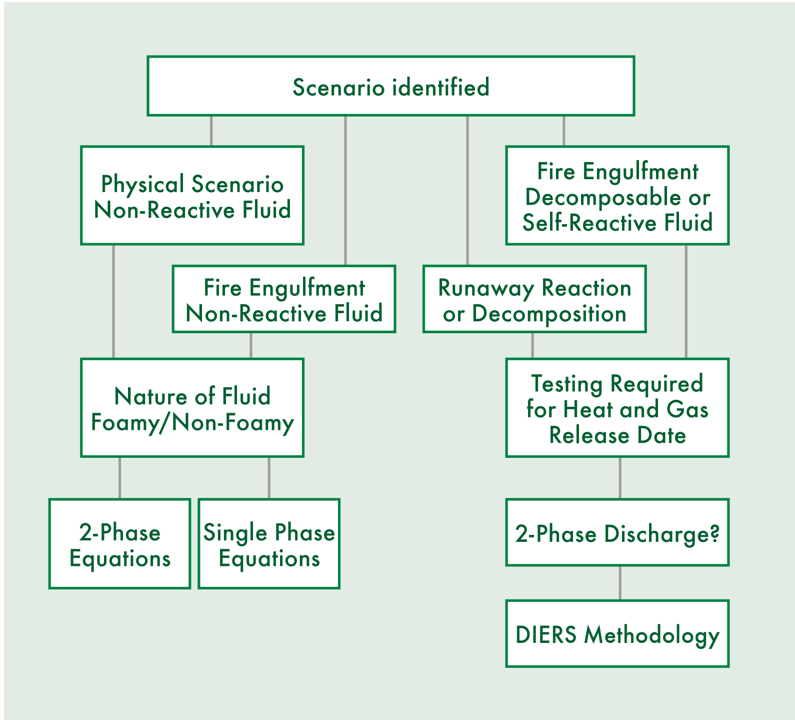


2.1. Identification of Credible Scenarios

Some general relief scenarios (e.g. fire engulfment) can be identified straight away, by simple inspection of process diagrams or using checklists provided in engineering standards, such as API 521 or ISO 4126-10. However, these standard approaches may miss some scenarios (especially those related to process deviations, runaway reactions….) or may lead to overengineering by protecting extremely unlikely events. In a most cases, therefore, identification of the worst credible scenario requires a formal risk analysis using any of the methods available: HAZID, HAZOP…

2.2. Characterization of the Scenario and Calculation of Vent Area

The following chart summarizes the workflow to characterize the scenario and calculate required relief area for every scenario identified:



In reactive systems it is often the case that only the worst scenario (that is, the one with the highest flowrate) needs to be characterized. However, if there are other scenarios with significantly lower flowrates, and the system will be protected with a safety valve, all scenarios need to be considered. Dimensioning a safety valve for the worst can lead to chattering (and fast damage) of the valve in the smaller cases. It is often the case that we need to design two different devices: one (say, a rupture disc) for the ultimate worst scenario and another (a safety valve) for the less demanding cases; with the opening pressures being set to give a progressive operation. In any event, it is essential to identify and document every scenario in a pressure relief dossier for future reference and management of change.

2.2.1 Reactive Systems

Characterisation of the scenario is particularly important when a chemical reaction is at play. In the case of exothermic reactions or thermal decompositions, loss of control often results in a self-accelerating reaction and consequent exponential rise in heat release rate.

If one of the products of the reaction is a gas, as often happens with decomposition, the pressure in a closed vessel will rise; equally, as the temperature rises, the solvent vapour pressure will increase. For calculations to be performed, it is important to be able to distinguish the dominant mode of pressure generation and assess its rate. Once the emergency relief vent opens, the discharge is generally a multi-phase fluid, with a high proportion of liquid accompanying the vapour or gas, and possibly solids as well. Some systems will continue to disengage vapour during relief, whilst naturally foamy materials will discharge two-phase throughout the venting period often completely emptying the vessel. These characteristics must be known in order to apply the appropriate calculation method. As the pressure falls along the vent line, the gas phase will expand and the saturated liquid phase will flash to vapour, often leading to multiple choking that reduces the relieving capacity. The calculation procedure must recognise and account for this behaviour.

In addition to the straightforward approach of the 'standard' DIERS methodology, a number of more complex cases are occasionally encountered in industrial situations. These include systems where the fluids increase in viscosity during reaction (e.g. polymerisations), fluids containing a high proportion of solids, fluids with immiscible liquid phases, systems having a significant degree of dissolved gas and those close to the thermodynamic critical condition of the solvent. These cases are more complex and will require more detailed consideration and additional data.

2.2.2. Non-Reactive Systems

If there is no chemical reaction involved, we need still to determine whether the discharge will be single or two-phase, and apply appropriate calculation methods. Standards-based approaches can be very conservative and based on risk tolerability criteria that may not coincide with corporate standards. Occasionally, the simplified approach within a standard does not reveal the more complex behavior of the equipment during the overpressure incident. The use of advanced calculation methods such as dynamic process simulation can allow the calculation of scenarios based on sound technical and scientific principles, and on risk tolerability criteria that can be explicitly stated. Needless to say, this type of approach is invaluable when re-calculating existing valves during revamping or debottlenecking projects. Quite often the precise calculation of the scenario can justify not replacing a large valve, with all the associated savings in cost and time.

2.3. Provision of Data

Clearly any emergency relief system designed to accommodate an exothermic event will require a certain minimum data set to permit design calculations. This data will describe the overall kinetics, thermochemistry and physical property characteristics under the relief conditions. This is achieved by conducting adiabatic calorimetry to simulate the failure condition and studying the following parameters:

- The self-heating rate and gas formation during runaway reaction, decomposition or fire induced exotherm – an expression of the kinetics and thermochemistry – obtained from closed cell studies.
- The pressurisation behaviour – vapour pressure or gassy – obtained from tempering cell studies.
- The foaming characteristics – obtained from top discharge blowdown tests.
- The fluid viscosity – obtained from bottom discharge blowdown tests.
- The potential for hybrid behaviour and the measurement of vapour/gas proportions throughout the venting duration.

Not every test will always be required, with the choice of data being determined by the nature of the chemistry, the fluids, and the vessel conditions.

2.4. Disposal System Design

The release of a single or multi-phase stream from the vessel relief device is not the end of the design study. For safety and environmental protection reasons, the discharge of this material must be carefully considered. The risk of a secondary incident cannot be casually disregarded. Downstream treatment systems may include liquid/vapour separators, flares, scrubbers or quench tanks. The design of these units is important, both for their individual effectiveness and for the influence that they may have on the performance of the whole relief system. Quite often atmospheric dispersion calculations are required to prove that, even under adverse dispersion conditions, hazardous concentrations of substances will not reach locations where people might be present.

Where relief vents from a number of vessels are manifolded into common headers feeding common treatment, these too will require close scrutiny and careful design to ensure correct functioning of all protection devices can occur under all credible upset conditions.

Equally, the pipe work and the vessels must be of adequate mechanical design to withstand the substantial reaction forces that will occur during venting. In this case it is important to define criteria which more than one venting device may be triggered either simultaneously or overlapping. Once again, this requires an in-depth understanding of the process. The use of an over-simplified approach can lead systems that are either, over-engineered (thus, unnecessarily costly) and inefficient, or, conversely, inadequate.

2.5. Documentation

Compiling an emergency relief system dossier may seem a purely administrative task. However, such a document is an important part of the process safety information of the plant. It is necessary to keep track of hypotheses, scenario identification, process and experimental data, calculations and conclusions. Any changes to the facilities will rely on this information to prevent re-calculation of existing devices, or designing new equipment with different criteria. Additionally, in certain jurisdictions, it is a legal requirement to archive such studies. These days a relief device database often is the choice to replace legacy paper reports.

2.6. Inspection and Maintenance

From the above description it is quite obvious that the emergency pressure relief system of a plant will be one of its safety critical elements (SCE). As such, it will need to be properly maintained and inspected throughout its lifecycle. Historically equipment suppliers have provided guidelines on frequency of inspection and maintenance, but they are unlikely to be fully aware of the specific demands of the process conditions. But then again, these might not be fully aligned with corporate risk tolerability criteria. In recent years risk based maintenance (RBM) and risk based inspection (RBI) have provided an adequate answer. In very simple terms, the maintenance and inspection programs for equipment are correlated with the operational experience and the posed risk by the equipment: the higher the risk, to more demanding the process conditions; the stricter will be the maintenance and inspection and operational experience.

3. How can DEKRA Process Safety Help?

At DEKRA Process Safety we have a team of specialists with significant expertise in performing emergency pressure relief vent sizing studies. Indeed, the DEKRA Process Safety design for a pressure relief system covering multiple vessels in a plant manufacturing a pyrophoric product, including a quench tank for containment of relieved material, won the 2001 Safety and Environmental Award of the Institution of Chemical Engineers. We are able to conduct or offer advice on all aspects of emergency pressure relief design. Notably, we can integrate the initial hazard assessment and choice of design scenarios with the generation of the necessary data in our specialist laboratories.

This means that we are particularly well placed to interpret the results in the context of their influence on the relief system design. Further, we can undertake the design of appropriate secondary treatment facilities, provide data to enable mechanical engineering calculations to be performed, and can provide the full specification for the whole emergency relief vent system. We can also use RBI and RBM principles to design maintenance and inspection programs.

Finally, we can provide in-company training courses on emergency pressure relief design tailored to your specific requirements. Our training courses span all levels of depth, from awareness to competency building in engineering, maintenance and inspection teams.

Being an independent third-party, DEKRA is not linked to any supplier. Our advice is therefore based solely on technical principles and best practice.

DEKRA Process Safety

The breadth and depth of expertise in process safety makes us globally recognized specialists and trusted advisors. We help our clients to understand and evaluate their risks, and work together to develop pragmatic solutions. Our value-adding and practical approach integrates specialist process safety management, engineering and testing. We seek to educate and grow client competence to provide sustainable performance improvement. Partnering with our clients we combine technical expertise with a passion for life preservation, harm reduction and asset protection. As a part of the world's leading expert organization DEKRA, we are the global partner for a safe world.

Process Safety Management (PSM) Programs

- Design and creation of relevant PSM programmes
- Support the implementation, monitoring, and sustainability of PSM programmes
- Audit existing PSM programmes, comparing with best practices around the world
- Correct and improve deficient programmes

Process Safety Information/Data (Laboratory Testing)

- Flammability/combustibility properties of dusts, gases, vapours, mists, and hybrid atmospheres
- Chemical reaction hazards and chemical process optimisation (reaction and adiabatic calorimetry RC1, ARC, VSP, Dewar)
- Thermal instability (DSC, DTA, and powder specific tests)
- Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
- Regulatory testing: REACH, UN, CLP, ADR, OSHA, DOT
- Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

Specialist Consulting (Technical/Engineering)

- Dust, gas, and vapour flash fire and explosion hazards
- Electrostatic hazards, problems, and applications
- Reactive chemical, self-heating, and thermal instability hazards
- Hazardous area classification
- Mechanical equipment ignition risk assessment
- Transport & classification of dangerous goods

We have offices throughout North America, Europe, and Asia.
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