Introduction to Overpressure Protection

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Agenda

Background

Codes and Standards

Sizing Basis

Fire Scenario

Relief Effluent

Types of Relief Devices

System Design

Summary

Questions
Major process safety incidents have resulted from overpressure and associated relief effluent:

- Bhopal (1984)
- Mexico City LPG tank (1984)
- Piper Alpha (1988)
- BP Texas City (2005)
- T2 Laboratories (2007)*
- Bayer Institute (2008)
- Williams Geismar (2013)*
- Shell Moerdijk (2014)

* Chemical Safety Board investigation concluded event could have been prevented with a properly designed relief system
BP Texas City

Column overfilled during start-up (blocked outlet). Flammables overflowed from the relief blowdown drum which ignited and resulted in a vapor cloud explosion.

Photo courtesy of the Chemical Safety Board
Reactor ruptured from a runaway reaction due to inadequate cooling (improper scale up).
Pressure vessel ruptured due to runaway reaction during a start-up (outside safe operating limits).
Column reboiler ruptured due to overheating from steam during a start-up (blocked-in).
Hazards

Hazards associated with overpressure and relief effluent:

- Vessel rupture
- Building explosion
- Flash Fire
- Vapor cloud explosion
- On site toxic exposure
- Off site toxic exposure
- Toxic exposure to buildings
- Environmental risks (e.g. contamination of waterways)
What equipment must be protected from overpressure?

Chemical plants contain a broad range of different types of process equipment.

- Pressure vessels
- Low-pressure storage tanks
- Piping
- Machinery (Pumps, Compressors, etc.)

All equipment must be protected from overpressure - that’s essential for safe risk management.

We have a wide range of discretion.

Different rules are applied for different equipment.
Which Rules Apply?

Pressure protection designs are influenced by a broad range of rules (codes, standards, and local governmental requirements).

The applicable rules depend on the equipment type (pressure vessel, storage tank, pipe) and the geographic location.

**Pressure Vessels**
- Designed for > 15 psig
- Strong construction

**Storage Tanks (“API Tanks”)**
- Designed for ≤ 15 psig
- Relatively weak
Pressure Vessel Codes & Standards

In the US, the “final straw’ was a boiler explosion that leveled a Brockton Ma. shoe factory, killing 58 and injuring 150.

ASME Sec I Steam Boiler Code
- Issued in 1914
- Avoided a patch-work of rules by individual states

ASME Sec VIII Unfired Pressure Vessels
- Issued in 1925
Requirements for Vacuum Protection

✓ Requirements for protection against internal pressure and external pressure (vacuum) are different.

✓ There are no prescriptive requirements for vacuum protection.

• Pressure vessels need to be protected from excessive vacuum (external pressure), but there are no prescriptive rules for how this must be done.
• It’s up to the user to assess what is needed, on a case-by-case basis.

ASME Sec VIII is silent on vacuum protection.

✓ Consequences of vacuum failures are generally less severe than failures caused by internal pressure.

✓ Standard practice is to design the vessel for the worst case vacuum exposure.

✓ Protective measures (instrumentation, operating discipline, vacuum relief devices) are used when inherently safe design is not practical.
Sizing Basis for Relief Devices

- It’s ultimately up to the user to define which scenarios are “credible”
- Requires judgment decision – Need to consider consequence and likelihood (risk)
- Avoid “cookbook” approach
- Refer to API 521 for industry-standard guidance/checklist

ASME Sec VIII

OVERPRESSURE PROTECTION
UG-125 GENERAL

(a) Other than unfired steam boilers, all pressure vessels within the scope of this Division, irrespective of size or pressure, shall be provided with overpressure protection in accordance with the requirements of UG-125 through UG-138, or with overpressure protection by system design in accordance with the requirements of UG-140, or a combination of the two. Unfired steam boilers shall be provided with overpressure protection in accordance with the requirements of UG-125 through UG-138. In addition, the following shall apply:

(1) It is the user’s or his/her designated agent’s responsibility to identify all potential overpressure scenarios and the method of overpressure protection used to mitigate each scenario.
Sizing Basis for Relief Devices

The need for careful case-by-case assessment is best illustrated by analysis of whether to include fire exposure as a sizing scenario.

✓ The decision to size a PSV for fire exposure is often an over-simplified decision, based solely on whether or not the vessel can be exposed to fire.
✓ The question of whether or not a PSV can actually provide any meaningful protection from fire exposure is often overlooked.

In many cases a PSV can’t provide any meaningful protection from fire exposure, but the users proceeds as though it can - taking credit for a layer of protection that doesn’t actually exist.

PSVs are very imperfect, and often completely inadequate, at defending from fire exposure.
Basis for Fire Exposure Scenarios

Fire relief scenarios are based on exposure to heat from a pool fire.

**Pool Fire**: A fire burning above a pool of liquid fuel.

The spill may originate from a vessel or from piping.

Which liquid pose a risk of fire and which don’t?

What criteria are used to assess combustibility of a specific liquid (risk of causing a pool fire)?

- For pressure vessels, combustibility criteria are left to the user to decide.
- For low pressure tanks, combustibility criteria stated in OSHA 1910.106.
How PSVs Protect from Fire

A rough heat equilibrium is established.

Fire heat in ≈ Heat out (H_{vap}) through PSV.

Q_1 \approx Q_2

H_{vap} removes a significant amount of heat, helping to cool the vessel walls.

The vapor that is generated causes the PSV to open, purging heat from the vessel.

If no vapor is being generated (no H_{vap}) then there is insignificant cooling of the vessel walls and an insignificant heat exiting the vessel through the PSV.

If this equilibrium can’t be established, the wall temperature rises unabated, and the vessel will fail.

A PSV, regardless of its size, won’t have any noticeable effect on this outcome.

Equilibrium necessary to protect from fire.
Protecting from Fire Exposure

For the cases below, PSVs are ineffective at protecting from fire exposure.

✓ This should be recognized and acknowledged, so that other (effective) layers of protection are considered.

- Water spray
- Fire-resistant insulation
- Automatic de-pressurization
Using PSVs to Defend from Fire Exposure

Recognize that there is a spectrum of risk mitigation.

A flowsheet (decision-tree) approach to decision making is an inadequate risk-management methodology in this case.
Relief Effluent Risks

Does the relief system inadvertently create other risks?

✓ A hazard analysis is needed for relief devices that discharge to the atmosphere.

✓ Consider the effluent risks associated with each credible scenario.
  - Toxicity risks
  - Flammability risks
  - Corrosivity to skin & eyes
  - Thermal risks
  - Environmental risks (e.g. contamination of waterways)
Common Misunderstandings

Avoid mischaracterizing the risks

Does the relief effluent pose a significant risk of a vapor cloud explosion (VCE)?

Propylene

Control valve failure

Req’d flowrate: 150000 lb/hr
Common Misunderstandings

The risk of VCE is actually very low when the gas is released vertically into an open (non-confined) area.

A high volume of air is naturally induced into high-velocity exit streams.

High velocity vapor releases from PSVs have a flammable envelope that has a characteristic shape – like that shown in this diagram.
Flammable Vapor Releases

Flammable vapor should not be released into a confined area!
### Effluent Analysis: Understanding the Risks

<table>
<thead>
<tr>
<th>Type Release</th>
<th>Ease of Mitigating the Hazard</th>
<th>Risk of Large VCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammable Vapor</td>
<td>Very High</td>
<td>Very Low</td>
</tr>
<tr>
<td>Flammable Liquid</td>
<td>Very Low</td>
<td>Very High</td>
</tr>
</tbody>
</table>

**BP Texas City, 2005**
2-Phase release from blowdown drum.

What if the BP incident had been an all-vapor release?

**Ground-level explosive cloud**

Huge difference in likely consequences.
Types of Relief Devices

Pressure Relief Valves
✓ Reclosing devices

Minimizes risk
Maximizes plant reliability

Rupture Disks
✓ Non-reclosing

Buckling Pin Devices
✓ Non-reclosing
✓ Can change pin while continue to operate
Types of Relief Devices

Low Pressure Tank Relief Devices

✓ Reclosing devices
Types of Relief Devices

“API 526 PSVs”

- Flanged steel construction
- Standard dimensions
- Easily repaired

But there are many other types of valves which are also ASME certified.

✓ A common mistake is to think that API 526 valves are the only ones that can be used.
Types of Relief Devices

ASME Sec VIII Certified Valves

All of the valves shown here are ASME Sec VIII certified relief valves.

✓ A common mistake is to think that API 526 valve are the only ones that can be used.

✓ One can’t look at a valve and determine whether it is an ASME Sec VIII certified PSV.
Types of Relief Valves

Why are there three different types of pressure relief valves?

Why don’t we use conventional PSVs in all applications?

*Answer: Backpressure*

<table>
<thead>
<tr>
<th>Type of Valve</th>
<th>Effects of Backpressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Opening pressure is affected by any amount of backpressure</td>
</tr>
<tr>
<td>Balanced</td>
<td>Opening pressure is unaffected by moderate amounts of backpressure</td>
</tr>
<tr>
<td>Pilot Operated</td>
<td>Opening pressure is unaffected by high amounts of backpressure</td>
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</table>
Rupture Disks

Advantages

• Immediate opening
• Available in very large sizes
• Less costly if very large size is needed

Disadvantages

• Not re-closing
• High risk of nuisance failures in liquid services
• Subject to metal fatigue failure (cycling services or frequent SU/SD)
• Burst pressure is sensitive to temperature
Rupture Disk Metallurgy

Consider temperature sensitivity when selecting a disk material.

Unlike PSVs, the opening pressure of a rupture disk is sensitive to pressure and temperature.

This sensitivity varies, depending on the specific metallurgy.
System Design

Conventional pressure relief devices provide highly reliable and cost-effective protection for most pressure containing equipment.

There are scenarios where conventional relief devices are not practical, not reliable, or the risk from the associated effluent scenarios are not acceptable.

**System design** is then used to mitigate the overpressure scenario or reduce the size of the relief device.

Requirements for use of system design to mitigate overpressure scenarios is described in ASME VIII UG-140 and PED Guideline 1/43
When to use system design?

1. A conventional relief system is not possible/practical
   - Relief system impractical (e.g. deflagration, reactive),
   - Protection against excessive temperatures

2. A conventional relief system is not reliable
   - Plugging services

3. The risk from the relief effluent is unacceptable
   - Costly effluent treatment systems are required
System Design Options

Design the equipment for containment

➢ Impractical for gas generating reactions

Mitigate by fully instrumented interlocks

➢ System design that utilizes a fully instrumented loop is referred to as High Integrity Protection Systems (HIPS)

Mitigate by operating discipline and safety related protection systems (e.g. passive protection systems)
Example 1: Distillation Tower and Reboiler

**Impractical Relief – Decomposition:**

The heating media supply temperature (e.g. steam) for distillation towers may be greater than the temperature of no return (TNR).

**Scenarios:**

- Loss of Power
- Loss of cooling (e.g. cooling pump failure)

**Problem:**

Due to the low vapor pressure of the bottoms material, the bottoms temperature may exceed the Maximum Allowable Working Temperature (MAWT) of the equipment and lead to decomposition reactions which are difficult to relieve.
Example 1: Distillation Tower and Reboiler

Solution:

Use HIPS to mitigate both scenarios

HIPS: Shut off steam supply upon high reboiler temperature.
Example 2: Low Pressure Fixed Roof Monomer Storage Tank

Impractical Relief – Fire:

Fire results in an exothermic runaway polymerization and decomposition reaction in a nearby monomer storage tank.

Scenarios:

- Fire with Reaction
- Filling and Thermal Breathing

Problem:

Required relief size for the fire with reaction scenario is impractical.
Example 2: Low Pressure Fixed Roof Monomer Storage Tank

Solution:
- Size the relief for the filling and thermal breathing scenario
- Use system design to mitigate the fire with reaction scenario with fire protection systems

Fire Protection Systems include:
- Drainage to remote containment
- Direct water spray
- Area water deluge if vapors are suppressed (e.g. miscible or higher specific gravity than water)
- Foam suppression systems

*Note for improved reliability, heat activated water and foam deluge systems are recommended.*
Summary

Major process safety incidents have occurred due to overpressure events.

Relief design scenarios and associated mitigation strategy must be carefully evaluated as part of the risk assessment.

Need to mitigate the risks for the associated effluent scenarios.

Reclosing relief devices are preferred over non-reclosing devices.

Relief devices may not provide adequate overpressure protection. Use system design when a relief device is impractical, unreliable, or the risk from the effluent is not acceptable.
Questions?
Common Acronyms

API = American Petroleum Institute
ASME = American Society of Mechanical Engineers
BLEVE = Boiling Liquid Expanding Vapor Explosion
CGA = Compressed Gas Association
ERV = Emergency Relief Valve
HIPS = High Integrity Protection Systems
ISO = International Organization for Standardization
PRD = Pressure Relief Device
PRV = Pressure Relief Valve
PVRV = Pressure and Vacuum Relief Valve
PSV = Pressure Safety Valve
OSHA = Occupational Safety & Health Administration
RD = Rupture Disk
NFPA = National Fire Protection Association
MAWP = Maximum Allowable Working Pressure
MAWT = Maximum Allowable Working Temperature
PED = Pressure Equipment Directive
PSE = Process Safety Event
SU/SD = Start Up and Shut Down
TNR = Temperature of no Return
VCE = Vapor Cloud Explosion
VRV = Vacuum Relief Valve