Commonly Missed Overpressure Scenarios
Today's Presenter

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Smith & Burgess

• Formed Smith & Burgess to have a company that provides the highest level of customer service.
• Founders have over 25+ years of Process Safety experience each.
• Over 250 years of combined Process Safety experience.
• Members of API & participants on the 520/521 Safety Committees.
• Saved our clients an estimated $100+ million in unnecessary costs.
Smith & Burgess

- Over 1500 completed national and international projects.
- 50+ process safety engineers on staff.
- Over 15 research papers published nationally.
- Created "Salus Solutions" - the ONLY customizable relief systems documentation tool.
- 2015 Houston Business Journal's "Best Places to Work - Top 20"
Today’s Topics

• Reverse Flow
• Vapor Breakthrough
• Partial Power Failures
Reverse Flow

- Historically, check valves were used to protect assets
  - Contamination
    - Reverse rotation – damage to bearings, seals
  - Not effective means of preventing overpressure
  - Check valves can leak or fail
Reverse Flow

<table>
<thead>
<tr>
<th></th>
<th>Double Disk</th>
<th>Lift</th>
<th>Stop-Check</th>
<th>Swing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Significant Failure Rate</strong>*</td>
<td>1/114 yrs</td>
<td>1/63 yrs</td>
<td>1/438 hrs</td>
<td>1/87 yrs</td>
</tr>
</tbody>
</table>

*Significant Failure Rate: Broken/Damaged, Restricted Motion, Stuck Open, Stuck Closed, Improper Seating

"Failure Modes and Causes for Swing and Lift Type Check Valves"
Nuclear Industry - Oak Ridge National Laboratory
Reverse Flow

Figure 3.3 Relative failure rate and population by size group

Oak Ridge National Laboratory (Nuclear Industry), Study of failures that occurred between 1984 and 1990
Figure 1. Relative Failure Rate and Extent of Degradation by Valve Type for All Failures 1991-1996.

Oak Ridge National Laboratory (Nuclear Industry)
# Reverse Flow

## RAGAGEP

<table>
<thead>
<tr>
<th></th>
<th>Single Check Valve</th>
<th>Dual Check Valves</th>
<th>Single Safety Critical Check Valve</th>
<th>Dual Safety Critical Check Valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Leakage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Severe Leakage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Complete Failure</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

*Normal leakage*: associated with normal wear  
*Severe leakage*: check valve seat damage or obstruction  
*Complete failure*: stuck wide open
## Reverse Flow

<table>
<thead>
<tr>
<th></th>
<th>Plant #1</th>
<th>Plant #2</th>
<th>Plant #3</th>
<th>Plant #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Type</td>
<td>West Coast Refinery</td>
<td>West Coast Refinery</td>
<td>Gulf Coast Refinery</td>
<td>Europe Refinery</td>
</tr>
<tr>
<td>Total PRV Systems Evaluated</td>
<td>1300</td>
<td>2200</td>
<td>600</td>
<td>600</td>
</tr>
<tr>
<td># of Systems with Applicable Reverse Flow Scenario</td>
<td>30</td>
<td>35</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td># of Systems w/ Inadequate Overpressure Protection</td>
<td>10</td>
<td>10</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>% Inadequate</td>
<td>33%</td>
<td>29%</td>
<td>73%</td>
<td>40%</td>
</tr>
<tr>
<td>Average Expected Accumulation</td>
<td>4 X MAWP</td>
<td>3 X MAWP</td>
<td>7 X MAWP</td>
<td>3 X MAWP</td>
</tr>
<tr>
<td>Range of Expected Accumulation</td>
<td>1.4 – 18 X MAWP</td>
<td>1.2 – 8 X MAWP</td>
<td>1.5 – 15 X MAWP</td>
<td>1.3 – 6 X MAWP</td>
</tr>
</tbody>
</table>
Reverse Flow

Common systems where check valve failure scenario is applicable:

• Feed Surge Drums
• Deaerators
• Compressor Suction Drums
• Wash Water Drums
Reverse Flow

Feed Surge Drums

Feed Surge Drum

Feed Pumps

Feed / Product Exchanger

Reactors

Feed Heater

Separator

Level Valve

To Flare

Condenser

Off Gas

Overhead Product

Reboiler

Bottoms Product

Tankage

Next Unit Feed Surge

Unit Boundary
Reverse Flow

Feed may continue

50 - 100 psig

600 - 2000 psig Reverse Flow

Pressure Ratio could be 4X - 30X

Make-up H2

Feed Surge Drum

Feed Heater

Reactors

Separator
Reverse Flow

Rerate vessel

Dual Safety-Critical Check Valves

Feed Surge Drum

Pressure Ratio could be 4X - 30X

Make-up H2

Feed Heater

Reactors

Separator
Reverse Flow

Stops reverse flow

Feed Surge Drum

Pressure Ratio could be 4X - 30X
Make-up H2

Feed Heater

Reactors

Separator
Reverse Flow

Stops feed

Pressure Ratio could be 4X - 30X

Make-up H2
Reverse Flow

Relieves feed

Pressure Ratio could be 4X - 30X

Make-up H2
Reverse Flow

Summary

• Reverse flow can result in extremely high accumulation pressures if not properly mitigated

• Mitigate with:
  • Higher design pressures
  • Minimum dual safety critical check valves
  • Instrumentation may be required
Control valve is interface between HP and LP
Vapor Breakthrough

Liquid level drops

Liquid level rises

Control valve fails open
Vapor Breakthrough

If downstream level sufficiently low to allow vapor-liquid disengagement
Vapor Breakthrough

If downstream level reaches point where liquid is carried over with vapor

2-phase relief
Vapor Breakthrough

If downstream vessel overfills

Displaced liquid
Vapor Breakthrough

- Sophisticated methods should be used to determine relief phase
- Phase quality and flow rate depend on:
  - High and Low P/T
  - Compositions
  - Liquid levels
  - Vapor velocity
  - Vessel orientation
  - Inlet nozzle elevation
  - Location of relief device
- But...
- Generally, 14 inches of freeboard height between liquid level and outlet nozzle may be sufficient to minimize liquid carryover
• Liquid displacement often results in substantial relief requirements
• Design options:
  • Increase downstream MAWP
  • Increase downstream vessel size
• Existing installation mitigation options:
  • Size PSV for liquid displacement
  • Credit for liquid feed
  • Credit for flow resistance of piping
  • Restrict inlet flow
  • Modify liquid levels
  • HIPS
Reverse Flow

Summary

• Vapor breakthrough can result in high accumulation pressures if not properly mitigated

• Check effects of downstream liquid level on relief phase

• Prevent liquid displacement scenario
Partial Power Failures

- Power failures generally belong to three different categories:
  - Loss of individual equipment
  - Total Power Failure
  - Partial Power Failures

- Equipment affected from partial power failures are determined using one-line drawings

- Partial power failures often result in worst-case scenarios for relief device sizing and for flare system analysis
Partial Power Failures

Fractionator system

Feed

Heat input

Cooling

Steam
Partial Power Failures

Individual equipment failures
Partial Power Failures

Individual equipment failures
Partial Power Failures

Individual equipment failures
Partial Power Failures

Total Power Failure
Partial Power Failure
Partial Power Failures

PPF-1

Assume “A” pump is spare

All “A” pumps fail during PPF-1

All “B” pumps fail during PPF-2

Assume “B” pump is spare
### Partial Power Failures

<table>
<thead>
<tr>
<th></th>
<th>CW Failure</th>
<th>Steam Failure</th>
<th>Instrument Air Failure</th>
<th>TPF</th>
<th>PPF #1</th>
<th>PPF #2</th>
<th>PPF #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total load (lb/hr)</td>
<td>650,000</td>
<td>1.5 MM</td>
<td>2 MM</td>
<td>2.5 MM</td>
<td>3.5 MM</td>
<td>3.5 MM</td>
<td>4.5 MM</td>
</tr>
<tr>
<td># BP Concerns</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>13</td>
<td>17</td>
<td>21</td>
</tr>
</tbody>
</table>

Refinery example with ~2000 relief device systems
Partial Power Failures

Potential Impacts of Partial Power Failures

• Larger relief requirements
• Higher total flaring load
• Higher backpressures
• Higher header velocities
• Possibly significantly larger loads in certain subheaders
• Higher radiation
• Higher liquid flows
  • Higher liquid load to flare KO drum
  • Slug flow in flare header
Recap

- Reverse Flow
- Vapor Breakthrough
- Partial Power Failures
Questions & Answers

Thank you for attending today’s presentation:

Commonly Missed Overpressure Scenarios

Please reach out to either Waheed if you would like more information:

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