Compression System Check Valve Failure Hazards

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Presentation Agenda

• Overview, Study Scope and Process System Review
• Assessment Process/Examples
• Risk Assessment Findings
  — Process Gas Compression Systems
  — Propylene Refrigeration Systems
  — Ethylene Refrigeration Systems
• Check Valve Hydraulics
• Check Valve Reliability Data
• Check Valve Maintenance and Selection
• Regulations and Guidelines
• Risk Mitigation Alternatives
Compressor System Check Valve Failure Scenarios and Consequences

• **Scenarios involve**
  – Compressor shutdown
  – Check valve failure (single and multiple)

• **Potential Consequences**
  – Catastrophic Vessel Failure
    • Overpressure > 300% of MAWP
  – Excess Flare System Loading/Back Pressure
  – Compressor Rotor Reverse Rotation
    • Mechanical Damage (bearings, seals, other)
    • Gas release (seal damage)
Study Scope

• Presentation content based on risk assessments performed on:
  – 23 different compression systems
  – 7 different ethylene plants
  – Representing 4 different technology licensors
    • Designed between 1968 and 1989.

• Highest magnitude of overpressure risk identified in:
  – The oldest plant’s ethylene refrigeration system.
  – The newest plant’s process gas compressor system.
Ethylene Plant (Hot Section)

Feedstock (e.g. Naphtha, Gas oil, Ethane)

Furnace

Oil Quench/Primary Fractionator

Water Quench

3-Stage Gas Compression

CO₂/H₂S Removal

4th-Stage Gas Compr.

Dehydration Unit:
- Activated alumina
- Molsieves
- TEG System

Chilling Train

to Cold Section, i.e. De-methanizer
Ethylene Plant (Cold Section)

- De-methanizer
- De-ethanizer
- C2 Splitter
- De-propanizer
- C3 Splitter
- De-butanizer

Acetylene Recovery catalytic hydrogenation

C2H2 Acetylene

CH4, H2

C2Hx

C2H4 Ethylene

C2H6 Ethane

C2H6 Recycle

C3H6 Propylene

C3Hx

C3H8 Propane

C5+
Typical Centrifugal Compressor Case
Typical Centrifugal Compressor Case and Internals
Process Gas Compressor Configuration #1

From Quench Tower → To Driers

1st Suction Drum → 1st

2nd Suction Drum → 2nd

3rd Suction Drum → 3rd

4th Suction Drum → 4th

5th Suction Drum → 5th

Check Valve

Min. Flow

1st Suction Drum → 1st

2nd Suction Drum → 2nd

3rd Suction Drum → 3rd

4th Suction Drum → 4th

5th Suction Drum → 5th

Potential Check Valve Location

To Flare

To Flare

Caustic Tower

MOV Valve

Check Valve

Min. Flow
Assessment Process

• Risk Assessment Screening Process
  — Static Analysis/Settle-Out Pressure Calculations
    • System dynamics ignored
    • Basis for determining need for further analysis
    • Flare loading & reverse rotation risks not addressed
  — Dynamic Simulation
    • Reverse flow rate – impacted by rotor coast-down, dP, and system resistance
    • Relief/vent capacity and continuing feed rate
    • Minimum flow valve capacity and response
  • ASME Pressure Vessel Code compliance considerations
## Static Pressure Analysis Summary Example

### Analysis - Process Gas Compressor - XYZ Chemical Company

<table>
<thead>
<tr>
<th>Process Data:</th>
<th>Disc CV+</th>
<th>Disc CV-</th>
<th>5th Suc</th>
<th>4th Suc</th>
<th>Between CVs</th>
<th>3rd Disc.</th>
<th>3rd Suc</th>
<th>2nd Suc</th>
<th>1st Suc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure (Psig)</td>
<td>540</td>
<td>540</td>
<td>290</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>80</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Density (Lbs/Ft³)</td>
<td>2.97</td>
<td>2.97</td>
<td>1.57</td>
<td>0.93</td>
<td>0.93</td>
<td>0.93</td>
<td>0.49</td>
<td>0.28</td>
<td>0.13</td>
</tr>
<tr>
<td>Volume (Ft³)</td>
<td>15,000</td>
<td>900</td>
<td>3,500</td>
<td>2,300</td>
<td>18,000</td>
<td>4,500</td>
<td>6,000</td>
<td>6,000</td>
<td>150,000</td>
</tr>
</tbody>
</table>

### Check valve status:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Density Lbs/Ft³</th>
<th>Pressure Psig</th>
<th>% of MAWP</th>
<th>Brittle Frac.</th>
<th>Failure Risk ?</th>
</tr>
</thead>
<tbody>
<tr>
<td>5th suction</td>
<td>2.5</td>
<td>476</td>
<td>153%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4th suction</td>
<td>1.5</td>
<td>284</td>
<td>162%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>4th suction</td>
<td>2.5</td>
<td>476</td>
<td>272%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Caustic Tower</td>
<td>1.1</td>
<td>197</td>
<td>113%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Caustic Tower</td>
<td>1.8</td>
<td>335</td>
<td>191%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>3rd suction</td>
<td>0.2</td>
<td>32</td>
<td>28%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>3rd suction</td>
<td>0.4</td>
<td>72</td>
<td>63%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>2nd suction</td>
<td>0.2</td>
<td>32</td>
<td>43%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>2nd suction</td>
<td>0.4</td>
<td>72</td>
<td>96%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>1st suction</td>
<td>0.2</td>
<td>32</td>
<td>75%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>1st suction</td>
<td>0.4</td>
<td>72</td>
<td>167%</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Note: Caustic Tower between 4th suction check valve and 3rd discharge check valve.
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<tr>
<td>Volume Ft3</td>
<td>15,000</td>
<td>900</td>
<td>3,500</td>
<td>2,300</td>
<td>18,000</td>
</tr>
</tbody>
</table>

### Check valve status:

- **5th Disc**
  - Fails

- **4th Suc**
  - Holds

- **3rd Disc**
  - Holds

### Evaluation:

- **Stage**
  - 5th suction
  - 4th suction
  - Caustic Tower
# Static Pressure Analysis Summary Example

<table>
<thead>
<tr>
<th>Evaluation:</th>
<th>Density Lbs/ft³</th>
<th>Pres., Psig</th>
<th>% of MAWP</th>
<th>Brittle Frac. Failure Risk ?</th>
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<td>272%</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>4th suction</td>
<td>0.5 79</td>
<td>45%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Caustic Tower</td>
<td>1.1 197</td>
<td>113%</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Caustic Tower</td>
<td>1.8 335</td>
<td>191%</td>
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<td>167%</td>
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Dynamic Analysis Methodology – Flow Sources

• Rate and magnitude of overpressure is impacted by multiple flow sources:
  — Continuing feed flow into the system (in-flow)
  — Discharge system depressurization (in-flow)
  — Compressor stage reverse flow
    • In-flow only for refrigeration compressors
    • In-flow and/or out-flow for process gas compressors dependent on equipment location
  — Minimum flow piping (in-flow or out-flow)
  — Relief valves and flare vent valves (out-flow)
Dynamic Analysis Methodology – Impacting Factors

• Factors impacting flow source and rate
  – Check valve functionality
  – Differential pressures
  – Flow resistance created by compressor internals, interstage piping and equipment.
    • Represented as equivalent piping lengths
  – Flow resistance created by decelerating rotor during coast-down
  – Trip/isolation valve response timing.
  – Impact of flare system back pressure on relieving capacity
Dynamic Analysis Methodology – Simulation Tool

• Simulations created within MS Excel:
  – Pressure drop calculated using standard compressible flow equations.
  – Mass balance calculations determined discharge, interstage and suction system inventory.
  – System pressures are calculated based on system mass inventory and temperature.
  – Solver adjusts reverse flow rates until system pressures determined by pressure-drop calculations and system pressures determined by mass balance are equivalent.
  – Calculation iteration time increment specified as between ~1 second and 1 minute dependent on application and time elapsed since compressor trip.
Process Gas Compressor Overpressure Risks – Configuration #1

From Quench Tower

1st Suction Drum

2nd Suction Drum

3rd Suction Drum

3rd Disc. Drum

Caustic Tower

To Driers

To Flare

Min. Flow

Check Valve

Potential Check Valve Location

MOV Valve

Check Valve
Process Gas Compressor Overpressure Risks – Configuration #2

From Quench Tower

Min. Flow

1st Suction Drum
Check Valve

2nd Suction Drum
Check Valve

3rd Suction Drum
Check Valve

3rd Disc. Drum

Check Valve

Min. Flow

4th Suction Drum
Check Valve

Potential Check Valve Location

Caustic Tower

From Hydrocarbon Stripper

Check Valve

5th Disc. Drum

Check Valve

To Driers
Dynamic Analysis Example – Configuration #1 with no caustic tower outlet check valve

Process Gas Compressor Trip Dynamics
Pressure as a % of MAWP

System Pressure as a % of MAWP

0% 20% 40% 60% 80% 100% 120% 140%

Time, Seconds Since Trip
0 25 50 75 75 100 125 150

Compressor Speed RPM
0 1000 2000 3000 4000 5000

5th Stage Suction 4th Stage Suction 3rd Stage Suction 2nd Stage Suction 1st Stage Suction RPM
Dynamic Analysis Example – Configuration #1 with a functional caustic tower outlet check valve

Process Gas Compressor Trip Dynamics
Pressure as a % of MAWP

System Pressure as a % of MAWP

Time, Seconds Since Trip

Compressor Speed RPM

5th Stage Suction
4th Stage Suction
3rd Stage Suction
2nd Stage Suction
1st Stage Suction
RPM
Dynamic Analysis Example – Flare Loading

Process Gas Compressor Trip Dynamics
Flare Loading - Relief Valve Flow, Vent Valves Closed

![Graph showing flow to flare, MPPH vs. time, seconds since trip, and compressor speed, RPM. The graph includes lines for 1st Stage Suction PSV, 1st Stage Suction PCV, 4th Stage Suction PCV, 4th Stage Suction PSV, and RPM.]}
Dynamic Analysis Example – Flare Loading

Process Gas Compressor Trip Dynamics
Flare Loading - Flare Vent Valves Functional

- Flow to Flare, MPPH
- Time, Seconds Since Trip
- Compressor Speed RPM

- 1st Stage Suction PSV
- 1st Stage Suction PCV
- 4th Stage Suction PCV
- 4th Stage Suction PSV
- RPM
Dynamic Analysis – System DP – Rotor Rotation Reversal Risk Assessment

Process Gas Compressor Trip Dynamics
Stage to Stage Differential Pressure

- 5th Discharge vs 4th Suction DP
- 5th Suction - 4th Suction DP
- 3rd Discharge - 1st Suction
- RPM
Process Gas Compressor Risk Summary
- Overpressure Hazards

• Overpressure risks identified in excess of 300% of equipment design pressure. Typical scenarios:
  – Final discharge check failure allows process dryers/chilling train to depressure back to PGC interstage equipment with pressures approach equalization between one and three minutes.
  – Failure of the check valve upstream of the caustic tower allows the tower inventory to depressure back to low pressure interstage equipment.
  – PGC configurations with check valves segregating each stage can pose a significant hazard.

• Potential for caustic cracking must be considered when evaluating integrity of vessels above MAWP.
  – Catastrophic vessel failure may occur below hydrotest pressure.

• Brittle fracture failure risks need to be considered.
  – Conditions can cross minimum allowable temperature (MAT) curve at normal operating temperature with limited overpressure.
Process Gas Compressor Risk Summary
- Other Hazards

• Flare Loading and Backpressure
  – Check valve failure scenarios can result in flare flows from the Process Gas Compression System 2 to 3 times higher than quench tower overhead flow.
  – Risks of first-stage suction overpressure due to:
    • High relieving flow requirements (3 sources)
    • High flare system back pressure.

• Compressor Rotor Reverse Rotation
  – Reverse rotation up to critical speeds possible (demonstrated).
  – Due to large rotor mass/inertia, reverse rotation to overspeed limits considered improbable.
Propylene Refrigeration System Overpressure Risks - Typical System Configuration

1st Stage Users

2nd Stage Users

3rd Stage Users

4th Stage Users

FLARE

Check Valve

Check Valve

Check Valve or Interlocked Isolation Valve

Check Valve

1st

2nd

3rd

4th

Minimum Flow to Suction Drums

Refrigerant Users and Drums

Refrigerant Receiver
Propylene Refrigeration System Risk Summary

• Overpressure Risks
  – Magnitude of overpressure typically limited (<150% of MAWP) due to relative volume of suction systems vs. discharge system volume.
  – Overpressure dependent on dual check valve failure in combination with minimum flow valves remaining closed or delayed opening.
  – Although overpressure is limited, brittle fracture failure risks are frequently present on propylene refrigeration systems @<135% of MAWP.

• Compressor Rotor Reverse Rotation
  – Limited risk of low RPM rotor rotation reversal in the event of combined failures.
  – Damage, if any, limited to dry gas seals.
Ethylene Refrigeration System Overpressure Risks - Typical System Configuration
Ethylene Refrigeration System Risk Summary - Overpressure Hazards

• Overpressure risks identified in excess of 300% of equipment design pressure.
  – Volume of first and second-stage suction equipment typically small versus volume of discharge system.
  – Older plant systems frequently designed at relatively low pressures.
  – Low relief capacity, particularly on first and second-stage suction.
  – Rotor coast down duration is frequently less than 10 seconds and thus provides very little reverse flow resistance.

• Brittle fracture failure risks need to be considered.
  – If carbon steel alloy materials of construction used rather than stainless steel, brittle fracture failure risks exist on first-stage equipment and possibly other stages.
Compressor Rotor Reverse Rotation

- Rotor reversal risks, up to operating speed (demonstrated) and potentially beyond overspeed limits, are feasible.
- Low rotor mass/inertia results in rapid coast down (typically around 10 seconds or less).
- Consequently, system differential pressures remain high when rotor speed reaches 0 RPM.
- In the event of check valve failures, high energy (differential pressure) combined with low rotor mass allows for rapid acceleration of the rotor in the reverse direction.
- Major mechanical damage and gross seal failure is viable (demonstrated).
Check Valve Hydraulics

- Significant reverse flow occurs with only limited check valve opening.
- Process Gas Compressor examples:

<table>
<thead>
<tr>
<th>Check Valve Flow Area % of maximum</th>
<th>Equipment MAWP %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>140</td>
</tr>
<tr>
<td>33</td>
<td>138</td>
</tr>
<tr>
<td>10</td>
<td>130</td>
</tr>
<tr>
<td>5</td>
<td>111</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Check Valve Flow Area % of maximum</th>
<th>Equipment MAWP %</th>
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<tbody>
<tr>
<td>100</td>
<td>164</td>
</tr>
<tr>
<td>33</td>
<td>163</td>
</tr>
<tr>
<td>10</td>
<td>155</td>
</tr>
<tr>
<td>5</td>
<td>141</td>
</tr>
</tbody>
</table>

- Ethylene Refrigeration Application

<table>
<thead>
<tr>
<th>Check Valve Flow Area % of maximum</th>
<th>3rd Suction MAWP %</th>
<th>2nd Suction MAWP %</th>
<th>1st Suction MAWP %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>209</td>
<td>166</td>
<td>127</td>
</tr>
<tr>
<td>50</td>
<td>207</td>
<td>163</td>
<td>124</td>
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<tr>
<td>33</td>
<td>204</td>
<td>158</td>
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</tr>
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<td>20</td>
<td>199</td>
<td>146</td>
<td>112</td>
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<td>15</td>
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<td>10</td>
<td>169</td>
<td>124</td>
<td>101</td>
</tr>
<tr>
<td>5</td>
<td>119</td>
<td>111</td>
<td>101</td>
</tr>
</tbody>
</table>
Check Valve Reliability Factors

• Check valve failure frequencies typically no better than 1/100 years and may approach 1/10 years depending on:
  – Check valve design (swing, dual plate, axial, etc.)
  – Maintenance practices (scope and frequency)
  – Installation
  – Application

• Influencing application factors include:
  – Fouling service (Process Gas Compressor applications)
  – Corrosive service (Caustic, entrainment impact)
  – Compressor applications:
    • Compressor surge can damage check valves and provides a common mode failure mechanism that can result in multiple valve failures.
Check Valve Failure Experience - Internal

- Check Valve Failure Experience – Internal
  - PGC Service - Failure of three individual check valves results in compressor rotor rotation reversal sustained in the critical region for 3 minutes. Primary failure factor = maintenance. Fouling and material incompatibility are secondary failure factors. A fourth check valve also failed.
  - C2R Service – Check valve(s) failure results in rotor reverse rotation with speeds beyond 10,000 RPM resulting fire and mechanical damage.
  - C3R Service – Surge event results in check valve internal component fracture and compressor damage – 11 day shutdown.
Check Valve Failure Experience - Internal

• Check Valve Failure Experience – Internal
  – FCUU Compressor – Check valve failure preceded by a surge event results in rotor reverse rotation. Speeds exceed 4500 RPM with resulting mechanical damage and fire.
  – C2R Service – Multiple rotor reverse rotation events occur on two separate compressors with speeds up to 6000 RPM. Specific cause not identified. No mechanical damage occurred.
  – Cooling Water Pump – Discharge check valve failure results in reverse rotation, causing driver overspeed and subsequent catastrophic failure of the turbine. Steam header damage resulted in plant shutdown.
Check Valve Failure Experience - External

• Check Valve Failure Experience – External
  – PGC Service - Check valve failure reportedly resulted in overpressure incident. No details available.
  – Refinery Hydrotreater Charge Pump * – Failure of multiple back flow prevention devices (series check valves and SIL 3 isolation interlock) results in rotor rotation reversal, mechanical damage and fire. Operator intervention prevented catastrophic vessel failure.

* Mary Kay O’Connor Process Safety Center Centerline periodical, Vol. 8, No 2, Summer 2004
Check Valve Reliability References

• ility Engineering (http://www.saunalahti.fi/~ility/)
  – Failure to check average 1/52 years (range of 1/394 to 1/17 years) for unassisted check valves
  – No differentiation by valve type or service

• Oak Ridge National Laboratory (Nuclear Industry)
  – Average significant failure frequencies between 1/63 years and 1/438 years dependent on check valve type.
  – Swing type check valve significant failure frequency ~1/80 years
  – Dual plate check valve significant failures ~1/100 years
  Significant failures: detached/broken, restricted motion, stuck closed, stuck open
Check Valve Maintenance and Selection Considerations

- Check valve reliability is a function of design, application/service, installation, maintenance and operation (surge event frequency).
- Minimally, check valves in critical service should be removed for shop inspection, refurbishing and testing during every major turnaround.
- Compressor surge represents a common mode failure risk potentially impacting multiple check valves.
- Non-slam designs such as dual plate (wafer) and axial (nozzle) should be considered in compressor applications.
- However, impact of fouling, corrosion and erosion need to be considered when evaluating check valve design alternatives, particularly in PGC applications.
- Additionally, in low-pressure applications in which low-pressure drop is critical, valve selection and installation warrants additional caution.
Codes and Standards

• ASME Boiler & Pressure Vessel Code Sec VIII Div. 1 & 2
  – Allowable Overpressure – Limited to 110% of MAWP with a single relief valve and 116% of MAWP with dual relief valves for scenarios other than fire exposure.
  – Viable Overpressure Scenarios - UG-125 merely states that it is the user’s responsibility to identify all potential overpressure scenarios and the overpressure protection methodology to be used.
  – Overpressure Protection by System Design (Interlocks) – Addressed by UG-140. UG-140 & Code Case 2211, outline methodology for defining viable over-pressure scenarios which are consistent with industry risk classification methodologies.
    • UG-140 references API Recommended Practice 521 for guidance in defining viable overpressure scenarios.
    • UG-140 refers the User to WRC-498, Guidance for Application of Overpressure Protection by System Design for application and risk reduction.
Guidelines - Industry

• ANSI/API Standard 521
  – Single check valve not always effective
    • For single check valve, relief sizing based on full open flow
    • Even if check valve failure considered unlikely, relief protection required if high pressure system > low pressure hydrotest
  – Series check valves sufficient to eliminate significant reverse flow
    • Back-flow quantity dependent on check valve type, fouling nature, etc.
      – “Etc.” would include compressor surge related failure risks.
    • Responsibility of the user to determine appropriate technique for estimating reverse flow rate.
    • Where no specific experience or company guideline exist, one may estimate flow as the flow through a diameter equal to 1/10th the largest check valve’s nominal flow diameter.
Guidelines – Industry (continued)

• ANSI/API Standard 521
  – Excludes “double jeopardy” overpressure scenarios
    • Latent failures not considered double jeopardy failures
    • Latent failures include check valve failures
  – By excluding “double jeopardy” scenarios, this guideline is essentially designed only to mitigate risks occurring more often than 1/100 years.
  – Typical industry risk management standards requires mitigating hazards on existing plants to < 1/10,000 years or < 1/100,000 years.
  – Compliance to ANSI/API Standard 521 does not necessarily mitigate catastrophic vessel failure in compliance with corporate risk mitigation standards.
Risk Mitigation Alternatives - Benefits and Disadvantages

• Series Check Valves
  — Pro -
    • Low cost alternative
    • Mitigates overpressure, flare loading, and rotor reverse rotation hazards.
  — Con -
    • Projected catastrophic failure frequency higher than allowed by industry risk mitigation standards
    • Check valve failures are often covert (latent)
    • Common mode failure risks due to compressor surge
      — Need to consider operating history
      — Improvements to, or installation of anti-surge controls may be warranted
      — Since failures are covert (latent), may operate for years with a single functional check valve.
Risk Mitigation Alternatives
- Benefits and Disadvantages (continued)

• Equipment Replacement
  — Pro -
    • Eliminates overpressure risks
  — Con -
    • Cost
    • Doesn’t address rotor reverse rotation risks

• Increased Relief Capacity
  — Pro -
    • Can be lowest cost solution
  — Con -
    • Determining adequate relief capacity subject to significant calculation uncertainty.
    • Can create flare loading hazards
Risk Mitigation Alternatives  
- Benefits and Disadvantages (continued)

• Isolation Interlock
  — Pro -
  • Typically reduced cost versus equipment replacement
  • Mitigates flare loading risks
  • Mitigates rotor reverse rotation risks
  • Trip valve closure timing requirements subject to uncertainty. Rapid closure frequently required.
Risk Mitigation Alternatives
- Benefits and Disadvantages (continued)

• Isolation Interlock
  — Con -
  • Risk of inadvertent isolation valve closure while compressor is running (process upset consequences, compressor surge risks, may necessitate compressor trip on closure detection)
  • Achieving “Code” compliance can be challenging
  • Can necessitate additional costs to upgrade minimum flow controls/valves and trip detection instrumentation.
  • Larger, SIL 3 applications are costly (installation and maintenance) if required.
Risk Mitigation Summary

• Mitigation Alternative Summary
  – Series Check Valves
  – Equipment Replacement
  – Increased Relief Capacity
  – Isolation Interlocks

• An effective solution frequently involves a combination of the above in order to:
  – Mitigate all hazards in compliance with internal risk mitigation standards
  – Achieve Code compliance
  – Minimize cost
Conclusions

• Industry data supports expected check valve failure frequencies between 1/10 and 1/100 years.

• Fouling, corrosion and surge negatively impact check valve reliability in compressor applications. Failures can go undetected for years.

• Check valve failure scenarios can result in overpressure magnitudes in excess of 300% as well as flare loading hazards and rotor reverse rotation hazards.

• A comprehensive and effective check valve maintenance program is critical to maintaining check valve integrity.

• Additional reverse flow prevention measures are often required to reduce risk probabilities within compliance with both corporate risk mitigation standards and with Code.
Thank you for your attention
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