8

FLUID TRANSFER EQUIPMENT

8.1 INTRODUCTION

This chapter presents potential failure mechanisms for fluid transfer systems and suggests design alternatives for reducing the risks associated with such failures. The types of fluid transfer equipment covered in this chapter include:

- Blowers
- Pumps
- Compressors

This chapter presents only those failure modes that are unique to fluid transfer systems. Some of the generic failure scenarios pertaining to vessels may also be applicable to fluid transfer systems. Consequently, this chapter should be used in conjunction with Chapter 3, Vessels. Unless specifically noted, the failure scenarios apply to more than one class of fluid transfer systems.

8.2 PAST INCIDENTS

This section provides several case histories of incidents involving failure of fluid transfer systems to reinforce the need for the safe design practices presented in this chapter.

8.2.1 Reciprocating Pump Leak

A high-pressure reciprocating pump, originally used for pumping heavy hydrocarbons, was put into service to pump propylene in an unventilated building. A leak occurred from the gland due to failure by fatigue of the studs holding the gland in position. The escaping liquid vaporized and was ignited.
by a furnace 76 meters away. Four men were badly burned and the glass windows on the buildings were broken. The failure was attributed to the fact that plant management had not implemented effective management of change procedures. As a result of the deflagration, gas detectors and remote isolation capability were provided. Also, the pump was moved to an open building where small leaks would be dispersed by natural ventilation.

8.2.2 Pump Leak Fire

In November 1990 a fire occurred at a flammable liquid tank farm supporting Denver’s Stapleton international airport. Eight of the farm’s twelve storage tanks contained jet fuel, totaling almost 4.2 million gallons. The fire burned for 55 hours, destroying seven tanks.

Investigators concluded that a damaged pump in a valve pit near the storage tanks may have caused the initial leak and also may have ignited the fuel. In addition, the investigators concluded that a pipe simultaneously cracked, thus releasing fuel into the fire area. The subsequent fire fed on the fuel collecting in the pit and spewing from the two leaks, and impinged on piping and related equipment in the valve pit. As this fire continued to burn, flange gaskets deteriorated, causing more leaks and allowing more fuel to flow out of the storage tanks. The growing fire encroached on two storage tanks adjacent to the valve pit. Approximately 12 hours into the incident, a friction coupling parted, allowing fuel from one storage tank to suddenly increase the fire size. The fire spread to an impounding area and involved two more fuel tanks.

The following changes to the tank farm site would have mitigated the outcome of this incident:

- Increased distance between the tanks and the pumping/valve area
- Increased tank-to-tank separation
- Installation of internal excess flow or fail-safe remotely operated valves for tanks at locations where piping connects
- Provisions for the removal of fuel in the event the storage tanks’ primary discharge means becomes inoperable
- Simple and recognizable means for fire fighters to shut off fuel flow into the facility
- Increased structural support for piping

8.2.3 Compressor Fire and Explosion

An ethylene leak occurred in a high-pressure pipe joint in an enclosed, unventilated ground floor area underneath a compressor house. The escaping ethylene ignited and four men were killed. The source of ignition was never
established with certainty, but may have been faulty or misapplied electrical equipment. The welding on the joint that leaked was also faulty.

After the incident, the following recommendations were made:

• Surround the compressors and associated equipment with a steam curtain to hinder leaks from reaching a source of ignition
• Install flammable gas detectors to detect leaks promptly
• Install remotely operated valves so that leaking compressors can be isolated and depressured from a safe distance
• Locate the compressors in an open-sided building so that small leaks can be dispersed by natural ventilation

8.2.4 Start-up of Parallel Centrifugal Pumps

Parallel high-head centrifugal pumps were used to transfer an organic acid stream approximately 1.5 miles from a distillation facility to another manufacturing unit in the same complex. Because both the distillation unit and the destination manufacturing unit had significant inventory capacity, switching from primary to spare pump was not automated since timing was not critical and short breaks in service were tolerable. After one such changeover, the pump taken off-line was not properly isolated and drained. Consequently, when the spare pump was started, the off-line pump immediately saw full discharge pressure on its seal which caused the off-line pump seal to fail, spilling about 500 gallons of material into a contained area until the pump could be shut off.

Ed. Note: (1) Adding a check valve in the discharge line of each pump might have prevented the problem from occurring. (2) The seal should have been suitable for pump maximum discharge pressure.

8.3 FAILURE SCENARIOS AND DESIGN SOLUTIONS

Table 8 presents information on equipment failure scenarios and associated design solutions specific to fluid transfer equipment. The table heading definitions are provided in Chapter 3, section 3.3.

8.4 DISCUSSION

8.4.1 Use of Potential Design Solutions Table

To arrive at the optimal design solution for a given application, use Table 8 in conjunction with the design basis selection methodology presented in Chapter
2. Use of the design solutions presented in the table should be combined with sound engineering judgment and consideration of all relevant factors.

8.4.2 Special Considerations

This section contains additional information on selected design solutions. The information is organized and cross-referenced by the Operational Deviation Number in the table.

**Deadheading (1)**
Pump and compressor systems should be designed to minimize the probability of deadheading. Deadheading a pump may result in high temperature, high pressure, or both. This situation is especially dangerous if the fluid being transferred is shock sensitive, or prone to exothermic decomposition. Because deadheading of a positive displacement pump or compressor can lead to a buildup of very high pressures, a means must be provided to protect against overpressure.

**Cavitation/Surging (8, 9)**
Cavitation in pumps can cause severe damage to the pump impeller and seals, resulting in loss of containment. Cavitation problems usually can be avoided by designing the pump so that the net positive suction head (NPSH) requirement is met.

Compressor surge may lead to excessive vibration, high bearing temperatures, and extensive mechanical damage. This risk can be managed by providing automatic anti-surge systems and vibration monitoring systems.

**Reverse Flow through Pumps/Compressors (10, 11)**
There are various pump/compressor configurations that may result in the backflow of fluid through the machine. In a parallel configuration, where two or more machines discharge fluid to a common line, the fluid may backflow through the machine that is not in operation. Procedures for isolating standby machines help to prevent this problem. In addition, check valves placed on the discharge will reduce the probability of backflow through idle or tripped machines. Additional backflow protection via automatic isolation valves may be warranted in fouling service or where the consequence of backflow is severe (API RP 521 1990).

**Loss of Containment—Seal Leaks (13)**
Seal leaks are a major source of concern, especially when handling toxic or flammable materials. Centrifugal pumps with double mechanical seals, dia-
phragm pumps, and various types of sealless pumps may be used for highly hazardous duty. For a review of the advantages and disadvantages of various types of sealless pumps, refer to Newby and Forth 1991. Consideration should be given to eliminating pumps and compressors, and transferring fluid via gravity flow or differential pressure, where possible. See Grossel 1990 for more details.

8.5 REFERENCES


Suggested Additional Reading

<table>
<thead>
<tr>
<th>No.</th>
<th>Operational Deviations</th>
<th>Failure Scenarios</th>
<th>Inherently Safer/Passive</th>
<th>Active</th>
<th>Procedural</th>
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<tbody>
<tr>
<td>1</td>
<td>Overpressure</td>
<td>Failure of control or closure of downstream block valve, or failure to remove blind, or plugged outlet which deadheads pump/compressor resulting in possible overpressure and/or excessive temperature</td>
<td>Minimum flow recirculation line to ensure a minimum flow through the machine (flow controlled by orifice)</td>
<td>High temperature shutdown interlock&lt;br&gt;High pressure shutdown interlock&lt;br&gt;Low flow or power shutdown interlock&lt;br&gt;Emergency relief device&lt;br&gt;Automatic pump/compressor shutdown on high discharge pressure detection</td>
<td>Operator action in response to high temperature, pressure and/or low flow indication&lt;br&gt;Procedural controls to avoid deadheading pump/compressor</td>
</tr>
<tr>
<td>2</td>
<td>Overpressure</td>
<td>Pump/compressor used for higher than design density fluid service especially during startup and upset conditions</td>
<td>Design for maximum expected pressure</td>
<td>Emergency relief device&lt;br&gt;Automatic pump/compressor shutdown on high discharge pressure detection</td>
<td>Operator action in response to high pressure indication</td>
</tr>
<tr>
<td>3</td>
<td>Overpressure (blower or compressor)</td>
<td>Leakage on suction side of blower/compressor pulls air into system creating a flammable atmosphere</td>
<td>Positive pressure throughout system</td>
<td>Automatic oxygen monitoring interlocked to blower and/or isolation valves on high oxygen measurement&lt;br&gt;Inerting or gas enrichment system&lt;br&gt;Automatic pressure control which limits rate of oxygen infiltration or negative pressure&lt;br&gt;Flame arresters&lt;br&gt;Explosion suppression systems</td>
<td>Leak test suction system prior to start-up</td>
</tr>
</tbody>
</table>
|   | Overpressure | Exothermic decomposition of pumped/compressed fluid (e.g., acetylene) leading to overpressure | • Design casing to contain decomposition overpressure  
• Limit individual stage compression ratio to avoid high temperature  
• Eliminate dead legs and other stagnant regions | • High temperature/pressure shutdown interlock  
• Emergency relief device | • Operator action in response to high temperature indication |
|---|---------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 5 | High Temperature (bearing) | Failure of lubrication system resulting in bearing failure due to overheating | • High bearing temperature shutdown interlock  
• Low lubrication pressure/level shutdown interlock | | • Operator action in response to high temperature indication/alarm on lube oil reservoir  
• Operator action in response to low pressure alarm on the discharge of lube-oil pump |
| 6 | High Temperature (compressor) | Loss of upstream/interstage cooling resulting in high enough inlet temperature in subsequent stages of the compressor to cause compressor damage | • Choice of materials and design to maximum temperature conditions | • High temperature shutdown interlock  
• Low coolant flow shutdown interlock | • Operator action in response to high inlet temperature and/or low coolant flow indication/alarms |
| 7 | High Temperature | Operation on total recycle without adequate cooling | • Choice of materials and design to maximum temperature conditions | • High temperature shutdown interlock  
• Cooler in recycle loop | • Operator action in response to high temperature indication |
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</thead>
<tbody>
<tr>
<td>8 (T)</td>
<td>Low Flow (centrifugal pump)</td>
<td>Reduced flow to the inlet of a centrifugal pump causing cavitation, excessive vibration and damage to pump seal</td>
<td>• Eliminate suction system restrictions</td>
<td>• Low flow shutdown interlock</td>
<td>• Operator action in response to low flow indication and/or high vibration</td>
</tr>
<tr>
<td>9 (T)</td>
<td>Low Flow (centrifugal compressor)</td>
<td>Reduced flow through a centrifugal compressor causing surge leading to high vibrations and compressor damage</td>
<td>• Use compressor design other than centrifugal</td>
<td>• Automatic anti-surge system</td>
<td></td>
</tr>
<tr>
<td>10 (T)</td>
<td>Reverse Flow</td>
<td>High pressure on discharge side of pump/compressor causes backflow leading to seal failure and loss of containment</td>
<td>• Use seal-less pumps • Eliminate parallel machine</td>
<td>• Check valve placed at the discharge side • Automatic isolation valve on discharge activated on machine trip or high pressure • Emergency relief device</td>
<td></td>
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<tr>
<td>11 (T)</td>
<td>Reverse Flow (centrifugal compressor)</td>
<td>Backflow via recycle loop due to control system failure resulting in overpressure of low pressure stages and loss of containment</td>
<td>• Design low pressure stages for higher pressure</td>
<td>• Check valve or automatic isolation valve to protect against backflow from downstream side • Restriction to limit back flow • Emergency relief valve for protection of low pressure stages sized for maximum backflow</td>
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<td><strong>12</strong></td>
<td><strong>Overspeed (Compressor)</strong></td>
<td>Compressor overspeed leading to equipment damage due to speed control system failure and loss of containment</td>
<td>• Use solid versus built-up rotor</td>
<td>• High speed alarm and compressor overspeed shutdown system</td>
<td></td>
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<tr>
<td><strong>13 (T)</strong></td>
<td><strong>Loss of Containment</strong></td>
<td>Particulate matter in pump feed leading to seal damage and loss of containment</td>
<td>• Double or tandem seals</td>
<td>• Automatic pump trip on detection of loss of seal fluid</td>
<td>• Provide a strainer or filter in pump or compressor inlet with manual cleaning</td>
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<td></td>
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<td></td>
<td>• Use pump design that can accommodate solids (e.g., diaphragm)</td>
<td>• Provide seal leak detection system with alarm</td>
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<td></td>
<td>• Automatic back-flushing strainer</td>
<td>• Provide remotely operated isolation valves at inlet and outlet with manual activation</td>
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<td>• Periodic inspection of shaft seals</td>
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<td><strong>14</strong></td>
<td><strong>Loss of Containment</strong></td>
<td>Pump operated at a fraction of capacity resulting in excessive internal recirculation, frequent seal and bearing failure</td>
<td>• Use a pump size matched to the service</td>
<td>• Minimum flow recirculation line (flow automatically controlled)</td>
<td>• Procedural controls to avoid operating at too low a flow</td>
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<td></td>
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<td>• Minimum flow recirculation line to ensure a minimum flow through the pump (flow controlled by orifice)</td>
<td>• Pump trip on minimum flow</td>
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<td>15</td>
<td>Loss of Containment</td>
<td>Improper shaft aligntment causing bearing and/or mechanical seal problems leading to seal leakage or hot-spot, resulting in ignition</td>
<td>• Alternative pump or compressor design without shaft alignment needs (e.g., diaphragm/piston)</td>
<td>• On-line vibration monitoring with automatic shutdown</td>
<td>• Operator action on alarm from axial displacement sensors&lt;br&gt;• Periodic audible/visual inspection of machine</td>
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<tr>
<td>16</td>
<td>Wrong Composition/Phase (compressor)</td>
<td>Liquid in compressor suction leading to damage of compressor rotor</td>
<td>• Use liquid-tolerant design (e.g., liquid ring compressor)</td>
<td>• Provide a Knock Out (KO) drum with automatic liquid removal and high level switch to trip the compressor&lt;br&gt;• Heat trace the line between the KO drum and the compressor&lt;br&gt;• On-line vibration monitoring with automatic shutdown</td>
<td>• Operator action in response to high level alarm in the KO drum</td>
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