Primatech White Paper - How to Address Damage Mechanisms in PHA

Damage Mechanism Reviews are now considered an essential precursor to PHA studies. The use of DMR results in PHA is described in the white paper, How to Address Damage Mechanisms in PHA .

View other Primatech white papers by clicking here .

PRIMATECH WHITE PAPER

HOW TO ADDRESS DAMAGE MECHANISMS IN PHA

Introduction

A damage mechanism is a mechanical, chemical, physical or other process that results in equipment or material degradation. Damage mechanisms result in flaws and defects that affect the integrity of process piping, vessels, and other equipment. For example, virtually all crude oil feeds contain sulfur compounds and, as a result, sulfidation corrosion is a damage mechanism present at refineries that process crude oil. Sulfidation corrosion can cause thinning to the point of pipe failure when not properly monitored and controlled. Many different damage mechanisms exist [1]. Table 1 provides examples of different types of damage mechanisms.

On October 1, 2017 , the Division of Occupational Safety and Health within the California Department of Industrial Relations amended its process safety management (PSM) regulations for petroleum refineries in California to include requirements for conducting damage mechanism reviews (DMRs), preparing DMR reports, and addressing DMR reports during process hazard analysis (PHA) studies [2]. A damage mechanism review (DMR) identifies

potential process damage mechanisms, and the consequences of failures that may result from them, to help ensure that hazards they cause are properly identified and analyzed and effective safeguards are in place to control the hazards and/or new systems are implemented to control or eliminate the hazards. The California regulation does not provide or reference any guidance for performing DMRs or addressing DMR reports in PHA. A separate Primatech white paper addresses how to perform DMRs. This white paper addresses how to use DMR reports, and the information they contain on damage mechanisms, in PHA studies. A knowledge of equipment damage mechanisms is essential when performing PHA studies.

Damage Mechanisms

Damage mechanisms may cause the failure of process equipment resulting in loss of containment or impaired operability of equipment. They may cause damage to equipment that contains hazardous materials, such as tanks and reactors, or through which hazardous materials flow, such as piping, valves and pumps. Damage mechanisms also may affect equipment safeguards that protect against process incidents, such as fireproofing, dikes, and deluge systems. Some safeguards may be in contact with process fluids, such as flame arresters, while other are not, such as barriers and fireproofing. Damage mechanisms can exist for either case. Damage mechanisms also may affect equipment in utilities and support systems whose failure may impact on or result in a process safety incident.

Damage mechanisms can arise internally or externally, such as from internal or external corrosion. They can affect not only equipment or materials made from metals, including alloys, but also others, such as polymers, including plastics; ceramics, including refractories; composites, including concrete; and glasses.

Damage mechanisms may apply to a particular part of a process or throughout a process, that is, they may be local or global. For example, one particular vessel may be susceptible to low temperature embrittlement but piping throughout a process may be susceptible to corrosion. Damage mechanisms can be considered to include failures due to causes such as liquid hammer and vibration.

The susceptibility of equipment to damage mechanisms depends on materials of construction; chemicals present, including contaminants; process operating conditions; environmental conditions; and process history.

Damage Mechanism Reviews

DMRs are performed prior to the performance of PHA studies to identify those damage mechanisms that are believed possible for a process. DMR reports are reference documents for PHA studies. The DMR report for a facility or process must be provided to the PHA team for consideration during a study.

A DMR may be performed for an entire facility or each process within it may be studied separately depending on the types of damage mechanisms

present. Damage mechanisms may affect particular or all parts of a process. Consequently, processes are subdivided into sections for analysis in a similar manner to performing PHA studies where, for example, Hazard and Operability (HAZOP) studies use nodes, defined as pipe sections and vessels. There does not need to be a one-to-one correspondence between the sections used in the DMR and PHA. Certainly, it is possible that damage mechanisms may be possible only for some process sections or that the same mechanism(s) may be present in multiple sections. Of course, the possible presence of damage mechanisms must be considered for all parts of a process.

DMRs must consider all materials of construction that may be subject to damage mechanisms, for example, not just piping but also fittings, connectors, and welds.

DMRs should address all modes of process operation. They should be revalidated on the same schedule as PHAs.

DMR and PHA

PHA is used to identify hazard scenarios for processes [3]. PHA teams brainstorm initiating events (causes) for hazard scenarios. They may be equipment failures, human failures, or external events. Historically, reliance has been placed on PHA teams to identify initiating events using their process knowledge and experience. However, it has become apparent that some equipment damage mechanisms may be overlooked in the performance of PHA

studies. This is not surprising in that current process safety management (PSM) regulations establish only minimal requirements for the qualifications and composition of PHA teams [4]. Table 2 provides examples of process safety incidents that resulted from such causes. The occurrence of such incidents demonstrates that damage mechanisms can be overlooked.

Some PHA practitioners consider only immediate causes of equipment failure, such as leaks and ruptures, and do not address underlying failure mechanisms. Lack of recognition of possible damage mechanisms may result in some equipment failures being missed or judged not credible. In turn, this will result in the omission of needed safeguards and the occurrence of process safety incidents.

Damage mechanisms contribute to the failure of equipment that is part of the primary containment envelope. Such failures result in loss of containment. Damage mechanisms can also contribute to the failure of process safeguards, either when a demand is placed upon them or prior to the initiation of a scenario when a latent condition results. Damage mechanisms also may affect equipment in utilities and support systems whose failure may impact on or result in a process safety incident.

Thus, PHA studies must consider damage mechanisms when identifying initiating events; considering the reliability, availability, and effectiveness of safeguards; determining if enabling conditions are present; and when considering the failure of utilities and support systems.

In order to address damage mechanisms in PHA, DMR reports must be available to PHA teams and teams must understand their contents. DMR reports provide PHA teams with the following information:

• Identification of potential damage mechanisms for the process

• Operating parameters that affect the damage mechanisms

This information allows the PHA team to recognize circumstances in which process conditions may accelerate or worsen damage. Also, it allows recommendations to be made to modify process conditions to minimize or eliminate damage.

• The consequences of equipment failure resulting from each damage mechanism

• Safeguards that are in place to protect against the occurrence or the effects of each of the damage mechanisms

• Methods to prevent the occurrence of damage mechanisms or mitigate damage that may occur

This information helps when making recommendations for additional safeguards.

• Previous experience with damage mechanisms for the process, including the inspection history

• Industry Information on damage mechanisms for the process

• Applicable standards, codes and best industry practices for addressing damage mechanisms

They provide information on ways to address damage mechanisms.

PHA teams must review DMR reports at the outset of studies to familiarize themselves with the damage mechanisms that are possible for the process. During PHA studies, teams must consult the DMR reports to identify damage mechanisms that may produce or contribute to initiating events for hazard scenarios or influence the reliability of process safeguards, utilities and support systems. The team must determine whether existing safeguards adequately protect against the possible damage mechanisms and whether safeguards, utilities, and support systems are sufficiently resistant to the damage mechanisms that may affect them. A checklist of questions that should be posed to PHA teams is provided in Table 3.

The actual occurrence of particular damage mechanisms depends on the conditions that occur within a process over time. The DMR team certainly will be aware of the anticipated normal operating conditions for a process but they will not be fully aware of possible deviations that may occur. Such deviations are identified during PHA studies. In particular, PHA teams need to determine if deviations from design intent may exacerbate damage mechanisms, for example, unusually low temperatures in a process may induce low temperature

embrittlement of equipment. Also, it is possible that deviations in process operation may be identified during a PHA study that result in damage mechanisms not anticipated by the DMR team. Consequently, DMR specialists may need to be consulted during the performance of PHA studies and management of change (MOC) reviews. Note, however, that DMRs should not be performed as part of PHA studies. Of course, PHA teams and MOC reviewers must be capable of recognizing when consultation with DMR specialists is advisable.

PHA teams must make recommendations for any additional safeguards that are deemed appropriate to protect against damage mechanisms.

Conclusions

The results of DMRs help to provide more comprehensive identification of hazard scenarios in PHA studies. DMRs are valuable not only for petroleum refineries but also for any facility where equipment failures may result in catastrophic accidents.

References

1. API 571: *Damage Mechanisms Affecting Fixed Equipment in the Refining Industry* , 2nd Edition, April 2011.

2. General Industry Safety Order (GISO) §5189.1 *Process Safety Management for Petroleum Refineries* , State of California, Department of Industrial Relations, Division of Occupational Safety and Health, October 1, 2017 .

3. Process Hazards Analysis, in Handbook of Loss Prevention Engineering, Wiley-VCH, 2013.

4. Occupational Safety and Health Administration, *Process safety management of highly hazardous chemicals* , CFR 1910.119.

Table 1. Examples of Incidents Involving Damage Mechanisms .

Incident	Consequences	Damage Mechanism
Esso Gas Plant, Longford, Australia, 1998	Explosion and fire. 2 fatalities, 8 injuries. Destruction of one plant and shutdown of two others. Loss of gas supplies to businesses.	Low temperature metal embrittlement
Bethune Point Wastewater Treatment Plant, City of Daytona Beach, FL, 2006	Explosion and fire. 2 fatalities, 1 critical injury. The aluminum flame arrester on a methanol tank had corroded to the point that it no longer functioned.	Corrosion of aluminum by methanol
Silver Eagle Refinery, Woods Cross, UT, 2009	Explosion that damaged nearby homes.	Sulfidation corrosion
NDK Crystal, Inc., Belvidere, IL, 2009	High-pressure vessel rupture. One public fatality, one public injury.	Stress corrosion cracking. Temper embrittlement, or some other form of heat treatment embrittlement, may have been a contributing factor .
Tesoro Petroleum Refinery, Anacortes, WA, 2010	Explosion and fire. 7 fatalities.	High temperature hydrogen attack
Millard Refrigerated Services, Theodore, AL, 2010.	One employee and 152 offsite workers sustained injuries. 32 workers were admitted to the hospital, and four were placed in intensive care.	Hydraulic shock
Chevron	15,000 members of the public sought treatment for various	

Refinery, Richmond, CA, 2012	ailments including breathing problems. Approximately 20 people were admitted to local hospitals as inpatients for treatment.	Sulfidation corrosion

Table 2. Damage Mechanisms.

Type	Examples
Mechanical loading failures	Ductile fracture, brittle fracture, mechanical fatigue and buckling
Erosion	Abrasive wear, adhesive wear and fretting
Corrosion	Uniform corrosion, localized corrosion and pitting, sulfidation corrosion
Thermal-related failures	Creep, metallurgical transformation and thermal fatigue
Cracking	Stress-corrosion cracking
Embrittlement	High-temperature hydrogen attack, low temperature metal embrittlement

Table 3. Checklist of Damage Mechanism Questions for PHA.

For the process operating modes addressed, is there equipment in the node / system / subsystem that is susceptible to one or more damage mechanisms?
Has all equipment been considered including equipment that contains process fluids; other equipment such as fireproofing, safeguards, utilities, support systems; and fittings, connectors, welds, etc.?
If so, what is the impact on the equipment failure rates?
Are there aggravating conditions that accelerate the rate of degradation?
Do process deviations exacerbate damage mechanisms?
Can process deviations trigger damage mechanisms not addressed in the DMR report?
Are there sufficient measures in place to address to protect against the damage mechanisms?
If not, what additional measures are recommended?