Corrosion-related accidents in petroleum refineries: Lessons Learned from Accidents in EU and OECD countries, JRC-MAHB, 2013

Accident 1
Crude distillation unit

(Continued from cover page.)

Lessons Learned

Crude distillation units are generally at risk for elevated corrosion rates due to the high presence of a variety of corrosive substances present, or that may be formed from, the crude oil. Numerous corrosion mechanisms, including sulphidation, are associated with the presence of sulphur compounds in crude feedstock, as well as ammonia and hydrogen, and derivatives of these substances formed by chemical reactions facilitated by process conditions. Hazard assessments of these units should therefore evaluate the corrosion vulnerabilities associated with the process, including the composition of the crude feedstock, extremes and fluctuations in temperature and flow, and production intensity. For these processes there should be established procedures that make involvement of relevant experts routine in the process risk assessment and the associated risk management strategy.

• The risk assessment should identify sections of a pipeline as a critical area of the equipment on the basis of potential accident risk. Inspection frequencies should be calculated accordingly. Likewise, maintenance and inspection procedures should be established with particular attention to age-associated weaknesses in processes over 20 years old in petroleum refineries (as well as other similar high hazard industry sectors).
• Any documentation associated with the original specifications of equipment, or any subsequent modifications to equipment, should be made accessible explicitly for establishing an appropriate mechanical integrity programme. If complete records are not available, conservative strategies to manage mechanical integrity should be applied to areas of the equipment of critical relevance to risk potential such information is missing and until more precise estimates of the risk can be established from testing and monitoring over time.

[Chevron Intern Investigation Report, US Chemical Safety Board]
[Chevron Investigation Report, Chevron USA]

Similar accidents:
• eMARS Accident 26G062004 Petrochemical/Oil Industries

To understand better failure associated with corrosion in refineries, the Major Accident Hazard Bureau conducted a study of corrosion-related accidents in OECD and EU refineries over the past 50 years, looking at lessons learned from past corrosion-related accidents at refinery sites. The study was based on 59 reports of important refinery accidents in which corrosion of an equipment part was identified as being the key failure leading to the event. For this study, the main sources of accident information were eMARS and the other open sources cited in the accident cases selected for this bulletin (ARIA, ZEMA, the CSB and the JST Failure Knowledge Database). The lessons learned and the summary of corrosion risk in refineries in this report are derived from study findings as well as analyses in the individual accident reports cited.

Available soon

Corrosion-Related Accidents in Petroleum Refineries: Lessons Learned from Accidents in EU and OECD countries, JRC-MAHB, 2013

This is the fourth issue of the JRC-MAHB Lessons Learned Bulletin for chemical accident prevention and preparedness.

Each issue of the Bulletin focuses on a particular theme. The theme of this issue is Corrosion-Related Accidents in Petroleum Oil Refineries. The case studies are drawn from a JRC study of nearly 100 accident reports available in eMARS and other open sources of information on accidents occurring in EU and OECD countries.

The accident descriptions and lessons learned are reconstructed from accident reports submitted to the EU’s Major Accident Reporting System (eMARS) and other open sources. As a result of the accident, the refinery’s crude unit remained out of commission for more than eight months.

Causes

Contractors: The underlying cause of the pipe rupture in this case appears to be poor operating procedure in regard to mechanical integrity. The operator appears to have overlooked a number of factors that should have been incorporated into the maintenance strategy for this particular process unit, including the following:

• Subsequent testing demonstrated that the rupture was due to pipe wall thinning caused by sulphidation corrosion. In fact, over a period of nearly 35 years, the 52-inch piping component had lost on average 90 percent of its original wall thickness in the area near the rupture.

• Although the operator employed experts in sulphidation corrosion, their opinion was not consulted on any key decisions associated with potential sulphidation risk of the crude distillation unit. The crude distillation unit is one of the processes most associated with sulphidation corrosion in petroleum refineries. Yet the process hazard analysis of the crude unit did not consider the potential for sulphidation corrosion.

Sequence of events

A pipe in the crude distillation unit ruptured releasing flammable hydrocarbon process fluid that partially vaporized into a large vapor cloud engulfing nineteen employees. Approximately two minutes after the release, the flammable portion of the vapor cloud ignited. All of the employees escaped, narrowly avoiding serious injury. The ignition and subsequent continued burning of the hydrogen process fluid resulted in a large plume of unknown and unquantified particulates and vapour that went offsite in the direction of a nearby city (approximately 2 km from the site). In the week following the incident, approximately 15,000 people from the surrounding area sought medical treatment due to the release and as of this writing, 20 were hospitalized for treatment. As a result of the accident, the refinery’s crude unit remained out of commission for more than eight months.

Keywords

Corrosion, embrittlement, sulphidation, distillation, refinery, pipeline, management of change.
Corrosion-related accidents in petroleum oil refineries

**Accident 1**

**Crude distillation unit**

Sequence of events

An 8” pipeline was located in an overhead rack (pressure = 31 bars, thickness specification = 5 mm). It was installed when the unit was constructed in 1992 to collect gaseous, esentially butane and propane, from different points that were to be removed from the vacuum distillation of asphaltic distillation. According to the witnesses in the control room, the unit was functioning normally and the pipe suddenly burst. The evidence of the rupture caused the entire control room to shake. A black cloud was observed as well as the odor of H2S. The rupture zone was located near an elbow, not far from the compressor discharge.

Causes

After examination, it was noted that the pipeline had signs of internal corrosion, notably in the lower generator. The hole occurred in a zone affected thermally by welding. Measurements of thickness at various points revealed that certain areas were less than specified. The wall thicknesses of the pipeline were estimated at approximately 25% of the specified wall thicknesses. The wall thickness is critical to the integrity of the pipeline and to the integrity of the system.

Lessons learned

- Hazard awareness should be paid to the potential for accelerated corrosion in particular localized areas.
- Piping should be periodically inspected in accordance with established norms.

**Accident 2**

**Hydrocracker unit**

Sequence of events

Due to a leakage at a T-connection in the high pressure side of an air cooler of the hydrocracker, a rapid pressure drop occurred. The emergency pressure release valve was therefore not activated. A little water and released gas ignited due to unknown ignition source resulting in a vapour cloud explosion that was followed by a fire. The products present in the unit at the time were estimated to be 301 of hydrogen, 151 of light hydrocarbons (C1-C4), 5.5 of pentane, and 25 of butane. A substantial part of the plant was destroyed by the explosion and subsequent fire. The workers neglected the piping insulation (cotton and rock wool) in the corresponding pipe section, nevertheless, the piping was designed in such a way that a leak would not have remained unnoticed. The impact of this incident, the hydrocracker unit was shut down for approximately 2 months. 24 persons working on the site suffered injuries.

Causes

The leakage was caused by the failure of the air cooler due to erosion/corrosion resulting from a productivity increase of the unit. The effects on the design plant of a productivity increase were not adequately analyzed because of a wrong attitude of management towards safety.

Lessons learned

- Hazard awareness should also be paid particular attention to the potential for accelerated corrosion in particular localized areas, notably, within equipment and corrosion expected.

**Accident 3**

**External pipeline**

Sequence of events

A leak was detected on an exposed pipeline section 2 meters from the refinery's topping plant. The pipeline was connected to a tank in the crude oil tank-farm associated with the refinery’s topping plant. The pipeline was installed as a part of the crude oil tank-farm associated with the refinery’s topping plant. The pipeline was connected to a tank in the crude oil tank-farm associated with the refinery’s topping plant. The pipeline was connected to a tank in the crude oil tank-farm associated with the refinery’s topping plant. The pipeline was connected to a tank in the crude oil tank-farm associated with the refinery’s topping plant. The pipeline was connected to a tank in the crude oil tank-farm associated with the refinery’s topping plant.

Causes

An investigation determined that the pipe was perforated due to corrosion processes occurring externally on the pipe surface. The investigation report speculated that the fissure occurred at that location due to one or more of the following factors:

- Localized corrosion on the original pipe coating
- Material defect in the original pipe coating
- Critical operational condition of the pipe section in which the fissure occurred
- Environmental conditions

The operator declared that the pipe was periodically inspected in accordance with established norms. The last inspection of the pipeline had been performed approximately a year prior to the accident. The report also indicated that it was not possible to affirm that the maintenance of the pipe in question was insufficient. It pointed out that the pipeline had been replaced by a new pipeline more than 40 years ago. Moreover, the pipe had been bought from another entity 4 years prior without any technical documentation on maintenance operation associated with piping bundle prior to the sale.

Lessons learned

- Inspection should be performed to ensure that the inspection was in accordance with established norms.

**Accident 4**

**Vacuum distillation unit**

Sequence of events

The discharge piping of a furnace recirculates a vacuum distillation unit, was corroded by a sulphur compound contained in a residue under high-temperature conditions. An opening was formed from which fuel oil leaked. The leaked vacuum residue ignited, and a fire occurred. The piping was used for recycling from the bottom of the vacuum distillation column to the feed furnace, and joined with a fresh feed liquid, which was bottom oil of the top, at just downstream the accident position. The section of the piping that failed was composed of ordinary carbon steel.

As a consequence of the accident, piping around a recycling pump of a heating furnace. Peripheral electrical equipment and instrumentation were also damaged by fire. Peripheral electrical equipment and instrumentation were also damaged by fire.

Causes

One of the causes is considered to be the fact that changes in piping materials are often made after an accident. The designer of the piping selected carbon steel to cut cost because there were no suitable flanges downstream from the check valve. Originally, a material above SCI-0.5 Mo steel should have been chosen as the piping material around the condenser for the fresh feed side. High-grade material of above SCI-0.5 Mo steel is necessary for recycling piping considering the temperature and fluid properties, which ordinary carbon steel can be used for the fresh feed side. The location of the accident was upstream from the condenser, material above SCI-0.5 Mo steel should have been used. However, the piping material was changed at the position of the check valve downstream flange, which was upstream from the location of the accident, and carbon steel had been used at the location of the accident.

Lessons learned

This accident is particular noted as a failure in management of change. Apparently, there was an error in selection and design of material with high-temperature conditions. The plating of the pipe. The location of the accident was the heaviest part of the crude oil distillation system. There were a lot of solids and corrosive mediums present, and the temperature was high. A management of change process should have been activated resulting in an assessment of the risk associated with different options for the material in the replacement pipe.

**Accident 5**

**Vacuum distillation unit**

Sequence of events

The discharge piping of a furnace recirculates a vacuum distillation unit, was corroded by a sulphur compound contained in a residue under high-temperature conditions. An opening was formed from which fuel oil leaked. The leaked vacuum residue ignited, and a fire occurred. The piping was used for recycling from the bottom of the vacuum distillation column to the feed furnace, and joined with a fresh feed liquid, which was bottom oil of the top, at just downstream the accident position. The section of the piping that failed was composed of ordinary carbon steel.

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**Similar accidents**

- AISI 407:2013 (Also confirmed but not yet Online in eMARS)
- AISI 20356
Uncontrolled corrosion can cause release of hazardous substances and components or can reduce both the performance and reliability of equipment until their failure. This latter situation can put at risk the safety and well-being of both plant employees and the general public as well as lead to severe damage of process units, and in some cases shutdown of refinery operations. Notably, of the 137 major refinery accidents reported by EU countries to the EU's eMARS database since 1984, around 20% indicated corrosion failure as an important contributing factor. Moreover, this remains the average percentage of the total accidents reported even in recent years.

Corrosion represents a particularly relevant risk to petroleum refineries because refineries typically have several high risk factors because of the type of substances and processes involved in refinery operations. Other local conditions may also contribute to an acceleration in the corrosion rate, including physical location of equipment and the climate. Moreover, certain operating conditions in a refinery, both normal and abnormal, by their nature are particularly likely to present favourable opportunities for a corrosion failure to initiate a chain of events leading to a major accident.

Types of Corrosion

Corrosion can appear as either uniform corrosion or localized corrosion. The American Petroleum Institute Recommended Practice 571 (API 571) lists over 25 common corrosion damage mechanisms to industrial activity plus 11 addition types that are specific to refineries. In addition, studies of aging facilities may classify corrosion effects into different groupings on the basis of characteristics such as failure mechanisms (e.g., wall thinning, cracking and fracture, physical deformation), common causal factors (e.g., stress-driven damage, metallurgical/ environmental damage) or other commonalities.

Uniform corrosion is also known as general corrosion and is the classic form of corrosion in which the entire surface area, or a large fraction of the total area, is affected by a general thinning of the metal. In chemical processing uniform corrosion is considered the least dangerous form because it is easily visible long before it is degraded enough to fail. Nonetheless, uniform corrosion may sometimes be a cause of accidents, for example, in pipelines that are in remote locations, underground, or otherwise, not viewed frequently, general corrosion may continue for a long time undetected.

Conversely, there are numerous types of localized corrosion that are far more difficult to detect without targeted effort. Thus, consequences of localized corrosion can be more severe than uniform corrosion as failure occurs without warning and often after only a short period of use or exposure. Typically, localized corrosion occurs between joints (crevice corrosion) or under a paint coating or insulation. Stress corrosion cracking and hydrogen-assisted stress corrosion are also forms of localized corrosion. They are often grouped together with hydrogen embrittlement and stress embrittlement, even though these are not corrosion phenomena, because the conditions and the resulting failure mechanism (cracks in the metal) are remarkably similar. As such, it is not necessarily easy to determine which phenomenon caused such a failure following an accident; hence, by necessity, analyses of accidents involving corrosion-related failures may refer to both phenomena.

Process Conditions

A fundamental ingredient of corrosion is exposure to a corrosive agent via a refinery process, that is, a substance that under certain processing conditions acts upon the metal and weakens it. These corrosive agents are in effect oxidizing substances, which may include water, a variety of acid compounds introduced or generated in the process as well as the crude oil and final and interim products, such as coke and kerosene. Some substances have unique corrosion “signatures”, that is, the corrosion produced is characterized by a particular specific visual or textural pattern, reacts with specific metal compounds, and frequently occurs in the same types of locations. As noted in Figure 1, substances cited most commonly in relation to corrosion failures were sulphur and sulphur compounds and water (14 cases each) followed by hydrogen sulphide (11 cases). The substances identified in Figure 1 are normally present in the highest volumes and in a variety of processes throughout a typical refinery site.

The Importance of Implementing Safety Management Systems to Address Corrosion Risks

Neglecting to identify or manage corrosion hazards also continues to be a problem on some refinery sites. Accident reports studied by JRC-MAHB were quite clear that the lesson learned was less about the technical challenge of managing corrosion but simply about having an effective risk management program. In fact, many of the reports studied by JRC-MAHB contained detail that suggested that a risk assessment should have occurred at a particular point in the life cycle, and that at the time it was either not performed or it was insufficient in identifying the corrosion hazard and/or its associated risk potential.
The study found that these inadequacies could be grouped into four different categories according to their occurrence in the safety management process, as follows:

- Inadequate risk analysis at design and construction stage
- Inadequate risk analysis prior to change, which is essentially a lack of or failure in the management of change process
- Failure to identify or address process risks in planning inspections
- Inadequate identification of hazards and risks for other purposes, such as safe performance of repairs and establishment of detection and mitigation systems

In addition, one of the most important challenges in managing refinery corrosion is the element of change. Already changes to process design and equipment pose a challenge and need a certain competency to identify if a new corrosion risk has been introduced.

However, other changes that can affect corrosion rates may go unrecognized and thus not be evaluated for an elevated risk. Particular changes of this nature could be a change in the source of crude oil or an increase in production rate, particularly if they are considered to be somewhat temporary. Inconspicuous changes can also create risk and in this regard, the refinery’s greatest risk may be change over time. Loss of experienced personnel, lack of knowledge of the original process and equipment design (sometimes decades ago), and aging equipment all fall in this category. Strategies such as risk-based inspections, life-cycle management, and safety performance indicators, to name a few, are all good practices that can support risk management for this somewhat insidious changes that can greatly influence the level of risk. Corporate leadership and safety culture, areas of renewed emphasis following the accident at BP Texas City in March 2005, also offer promising conceptual frameworks for organizations to reinforce and sustain efforts at the operational level.

Figure 1:
Process-related substances cited as contributing to corrosion failures in association with the process unit of origin
(Source: Corrosion-Related Accidents in Petroleum Refineries: Lessons Learned from Accidents in EU and OECD countries, JRC-MAHB, 2013)