Safety practice

Lessons learned from corrosion-related accidents in petroleum refineries

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Summary

Corrosion represents a particularly relevant risk to petroleum refineries because refineries typically have several high risk factors due to the type of substances and processes involved in its 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.

Keywords: Corrosion, refinery

Introduction

The cases demonstrated below are drawn from a study[1] that analysed corrosion-related accidents in refineries within the European Union (EU) and the Organisation for Economic Co-operation and Development (OECD). The aim of the study was to analyse accident reports in terms of known corrosion risks associated with oil refineries and determine to what extent a failure to recognise or control various known factors, technical and/or managerial, may have contributed to the accident. The accidents reviewed in the study consisted of several cases where typical conditions conducive to a significant corrosion failure were somehow overlooked, or if recognised, sufficient measures were not applied to avoid an accident.

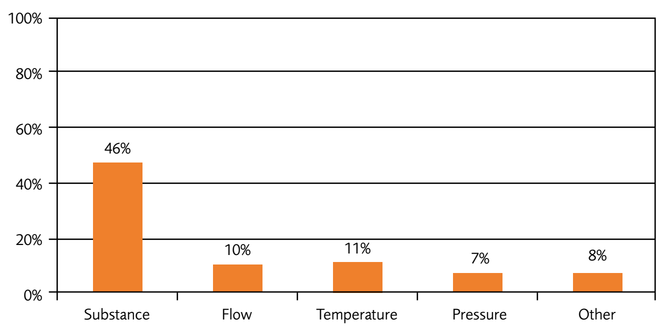

Figure 1 – Process conditions cited as contributing to corrosive conditions accidents studied (53 cases in total)

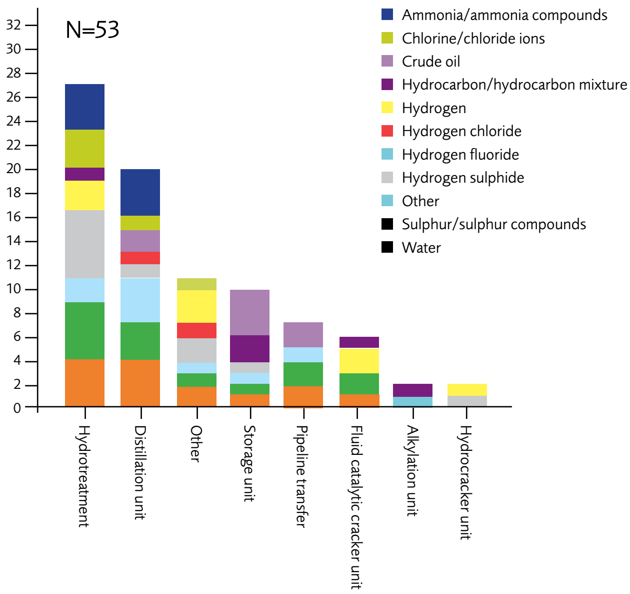

Figure 2 – Process-related substances cited as contributing to corrosion failures in association with the process unit of origin[2]

As shown in Figure 1, process conditions were identified as contributing to the corrosive conditions preceding the accident in 53 cases. The most commonly cited contributor was the substance (46). Flow (either high, low, turbulent or unequal) was cited in ten cases, and temperature (mostly high, but in a few cases, low) and pressure (mostly high) were cited as contributors in 11 and 7 cases respectively. In eight cases other exacerbating process conditions were present, including operation outside design parameters and variation across process cycles.

Figure 2 shows which process units were identified as the origin of the accident in relation to process substances indicated as contributing to the corrosion failure. Although some substances are cited slightly more frequently than others, the frequency is not high enough in any one unit to indicate dominance of a particular substance. Rather, this figure illustrates the wide diversity of substances throughout refinery production that can accelerate corrosion rates.

Case studies

The cases represent a small subset of the nearly 100 accident reports selected for this study from the EC Joint Research Centre eMARS database and other open sources of information on accidents occurring in EU and OECD countries[3-7].

Case 1

An 8" (200mm) pipe 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 gases, essentially butane and propane, from different units (reforming gasoline, atmospheric distillation). According to the witnesses in the control room, the unit was functioning normally and the pipe suddenly burst. The violence of the rupture caused the entire control room to shake. A black cloud was observed as well as the odour of H_2S. The internal emergency plan was activated. Control measures stopped any further release and remaining gases were vented to the flare. The rupture zone was located near an elbow, not far from the compressor discharge. After examination, it was noted that the pipeline had signs of internal corrosion, notably in the lower generator. The rupture occurred in a zone affected thermally by welding. Measurements of thickness at various points revealed that certain areas were less than specified. The site has a preventive inspection and maintenance programme but the particular sensitivity of this area at the discharge point had not been identified previously. In addition, the poor accessibility of this particular section may have also caused this section to be overlooked in past inspections.

Lessons learned:

- Hazard assessments should pay particular attention to the potential for accelerated corrosion in particular localised areas of equipment, such as elbow joints, T-intersections and welded sections. Elbow joints and T-joints exhibit particular vulnerability to certain types of stresses, notably vibration and external pressure from natural forces such as wind and floods, and additionally for elbow joints, erosion/corrosion and low or uneven flow. The process of welding is invasive and errors in miscalculation in procedure can increase corrosion vulnerability of welded areas.
- Inspection routines should be based on the risk estimates resulting from the hazard assessments and be adjusted as necessary when changes to metal thickness exceed predicted rates.
- Inaccessible equipment cannot benefit from even the occasional visual check and routine monitoring can be neglected. For this reason, pipes that are less accessible are often not monitored as frequently as required in relation to their actual risk potential. When documentation is limited, the composition and status of inaccessible areas cannot be assumed on the basis of nearby, more accessible pipework. Rather, inspection intervals should be based on conservative assumptions specific to the pipe function, composition and prior inspections.

Case 2

Due to a leakage at a T-junction in the high pressure side of an air cooler of the hydrocracker, a rapid pressure drop occurred. The emergency pressure release was therefore not activated. A little later, the released gas ignited due to an 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 30 tonnes of hydrogen, 150 tonnes of light hydrocarbons (C1-C4), 5.5 tonnes of pentane, as well as hydrogen sulphide. A substantial part of this plant was destroyed by the explosion and subsequent fire. Because of this incident, the hydrocracker unit was shut down for approximately seven months. Twenty-four people working on the site suffered light injuries. 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 the management's attitude towards safety.

Lessons learned:

- The effect of a significant departure from design conditions, such as increased production rates, should trigger a management of change process. The management of change process in refineries should automatically include an analysis of potential increased corrosion risk for areas of known elevated corrosion risk.
- In this particular case, the site of the accident had elevated risk of corrosion due to the presence of hydrogen and hydrogen sulphide, the T-joint configuration of the pipeline and location in cooling equipment. Moreover, the intensity of temperatures and temperature fluctuations in heating and cooling elements, such as air coolers and heat exchangers, are a factor that can accelerate the corrosion process in the presence of certain corrosive agents. The operator should take this circumstance into consideration in the hazards assessment.
- In addition to the crude distillation unit, there are several units in a refinery that normally exhibit vulnerability to accelerated corrosion rates, including cracking units. The refinery should systematically identify these units and ensure that their process hazard assessments are thorough in accounting for this phenomenon on equipment critical to safety. The challenge to operators is in continuously maintaining a systematic approach amidst ongoing business pressures and competing demands for resources. It is important that refinery staff performing the hazard assessments are actively aware of this concern and the typical causes. An emphasis on reviewing and discussing past cases and lessons learned can help maintain this awareness. This case concerns hydrotreatment, which is a typical refinery process with exposure to a number of corrosion phenomena. It consists of a catalytic reaction occurring in the presence of hydrogen at elevated temperature and pressure. It removes objectionable materials (e.g., sulphur, nitrogen, olefins, and aromatics) from petroleum fractions by selectively reacting these materials with hydrogen in a reactor at relatively high temperatures at moderate pressures. There are a number of hydrotreating processes used in refineries, one of the most common being desulphurisation and denitrogenation.

Case 3

The discharge piping of a furnace recycle pump of a vacuum distillation unit was corroded by a sulphur compound contained in a residue under high-temperature conditions.

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An opening 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 topper, at just downstream to the accident position. The section of the piping that failed was composed of ordinary carbon steel. Peripheral electrical equipment and instrumentation were damaged by the fire. The damage was estimated at approximately €400,000. There were no injuries or other consequences reported. One of the causes is considered to be the fact that changes in piping material selection often set flanges as a boundary. It seems that the designer of this piping selected carbon steel to cut cost because there were no suitable flanges downstream from the check valve. Originally, a material above 5Cr-0.5 Mo steel should have been chosen as the piping material around the confluence at the fresh feed side. High-grade material of above 5Cr-0.5 Mo steel is necessary for recycling piping considering the temperature and fluid properties, while ordinary carbon steel can be used for the fresh feed. As the location of the accident was upstream from the confluence, material above 5Cr-0.5 Mo steel should have been used. However, the piping material was changed at the position of a 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 particularly notable as a failure in management of change. Apparently, there was an error in selection and design of material when it was decided to replace this section 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.

Case 4

A leak was detected on an exposed pipeline section 2 metres from the subway. The pipeline was connected to a tank in the crude oil tank farm associated with the refinery's topping plant. The pipeline was part of a bundle of 102 pipes belonging to three different companies used for one-way transfer of raw materials, intermediates and/or finished products (liquid hydrocarbons and gas) and including also service lines (nitrogen, high pressure water steam at different temperatures, etc). The company decided to seal the leak by installing a sealing collar on the located rupture point. The workers dismantled the piping insulation (latten and rock wool) in the corresponding pipe section. After the insulation had been dismantled the spill increased with hot hydrocarbons (60°C) spraying downwards towards the subway. An approximately 30 mm long fissure was revealed on the pipe axis. A liquid hydrocarbon pool formed and spread some 60 m from the leakage point in the pipe due to the incline of the slope inclination.

A vapour cloud subsequently formed and was ignited from an ignition source downhill from the subway where the first fire was detected. Ten people were injured and hospitalised as a result of the fire. The rail line and the shipping area of the port were closed for up to 48 hours and one public road was closed for 53 days. Production loss from the temporary shutdown of refinery operations was estimated at approximately €110,000,000. 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:

- localised damage in the original pipe coating;
- material defect in the original pipe coating;
- critical operative conditions (of the pipe section in which the fissure occurred) linked to the placement of the pipe near the ground and its exposition to atmospheric events (sea air).

The operator declared that the pipe was periodically inspected in compliance 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 examined had been built more than 40 years ago. Moreover, the pipeline had been bought from another entity four years prior without any technical documentation on maintenance operations on the piping bundle prior to the sale.

Lessons learned:

- Inspections should be designed not only to be consistent with the relevant industry standard for the equipment but also take into account specific circumstances associated with the equipment in question. The pipe that failed in this case was very old. It was in contact with the ground below, and potentially abrasive substances on the surface, as well as a marine (salty) atmosphere. Although the technical documentation for the pipeline was not available, it should already have been obvious that the minimum standard inspection would not be adequate.
- Moreover, pipelines in remote locations or external to the site are often at risk of accelerated corrosion rates due to atmospheric conditions as well as neglect. The condition of the anti-corrosion protection associated with this refinery equipment should be systematically verified during routine inspections scheduled at a frequency established on the basis of a hazard assessment.
- In addition, it should be common practice that a prospective buyer performs due diligence when taking over assets from a different company, including a full assessment of the integrity of the assets. Due diligence allows the new owner to make risk-informed decisions about all aspects of the business, including its safe operation.

Conclusions

Corrosion of equipment continues to be an important source of accident risk potential at EU and OECD refineries[1]. The important conclusions from the four cases in this article are as follows:

- **Inspecting to the relevant standard is not enough.** Common sense should also be applied to address specific

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stressors associated with age, environment and working conditions.

- **Missing documentation can elevate risk.** Having complete documentation, in particular for older equipment, is a problem common to older sites, especially where process hazards are numerous. All documentation limitations associated with equipment critical to safety should be identified along with associated risks of not having precise information on composition, functionality, design parameters, etc.
- **Choosing to perform management of change should not be an ad hoc decision.** Sites cannot leave this up to random decisions of staff involved. They need to establish and follow criteria for when a management of change procedure is necessary. The management of change in refineries should automatically include an analysis of potential increased corrosion risk for areas of known elevated corrosion risk.
- **Refineries cannot take focus off their high risk processes.** Many processes in refineries are associated with high risk of corrosion, including atmospheric and vacuum distillation, hydrotreatment, and alkylation. Moreover, the intensity of temperatures and temperature fluctuations in heating and cooling elements, such as air coolers and heat exchangers, are a factor that can accelerate the corrosion process in the presence of certain corrosive agents.
- **Equipment configuration matters.** Hazard assessments should pay particular attention to the potential for accelerated corrosion in particular localised areas of equipment, such as elbow joints, T-intersections and welded sections. Elbow joints and T-joints exhibit particular vulnerability to certain types of stresses, notably, vibration, and external pressure from natural forces such as wind and floods and additionally for elbow joints, erosion/corrosion and low or uneven flow.
- **Welded areas can be a source of corrosion.** The process of welding is invasive and errors in miscalculation in procedure can increase corrosion vulnerability of welded areas. Welding is an entire field of study in itself and should be entrusted to qualified experts.
- **Inaccessible equipment is not incidental to the inspection routine.** Pipes that are less accessible need to be inspected with the same rigour as accessible pipes. Without documentation, their condition and status cannot be assumed from nearby, more accessible pipe sections.

Generally, significant corrosion failures occur either because the hazard was not properly identified or the hazard was substantially ignored. There is an enormous variety of corrosion phenomena that can occur, yet the list of factors that may contribute to any corrosion failure, whatever type, is relatively short. The factors mainly involve the presence of various known corrosive agents, exposure to certain conditions, and equipment composition and configuration. Still it requires a certain level of competency, particular in regard to production processes (versus storage and transfer), to recognise that all the conditions are present to create a significant corrosion hazard.

One of the most important challenges in managing refinery corrosion is also 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 unrecognised 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.

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