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RÉPUBLIQUE FRANÇAISE
Ministère de l'Environnement, de l'Énergie et de la Mer

Accidentology associated with the ageing of industrial installations

The ageing of industrial installations is a normal phenomenon, and its mechanisms are often well known. However, the process may be accelerated due to defects in design, sizing or construction, but also as the result of under-estimated stresses in the event of insufficient monitoring or maintenance.
A site containing older equipment, or on which ageing is not properly managed, is more prone to accidents. Even though it is not the primary cause of an accident, deteriorated equipment can significantly amplify the consequences of the event. Anticipating and managing the ageing of facilities are key elements in the risk prevention!

SPOTLIGHT ON "AGEING OF INDUSTRIAL INSTALLATIONS"

Signs of ageing

Ageing can appear in many ways depending on the type of equipment and its operating context.

- The most frequently observed indicator of the effects of ageing is the **deterioration of materials**, which can result in:
  - perforation of equipment which can lead to leaks into the environment or result in the accidental introduction of disrupting substances into the process,
  - the weakening of critical structural elements, such as anchors or supports,
  - the sudden rupture of tanks,
  - parts and structural elements falling off, and
  - the collapse of large equipment elements, such as silos or furnaces.
- Another common symptom of ageing is the **malfunction** of electrical installations, process equipment (treatment, protection or intervention).

This document focuses on the two main mechanisms of ageing: corrosion and fatigue.

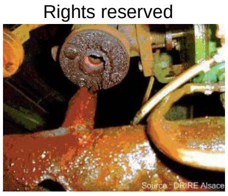
In France, **since the creation of the ARIA database (1992), more than 700 accidents have occurred in which ageing was involved**:

→ More than 500 of these accidents took place in Classified Facilities (ICPE, Installation Classified for the Protection of the Environment)

→ Approximately 100 involving pipelines (hazardous substances, gas, steam, etc.)

→ Approximately 30 involving the transport of hazardous materials by road, rail, sea ...

In more than 90% of the cases, the accidents lead to the release of hazardous or polluting substances into the environment.



Corrosion: the leading cause of ageing-related accidents

Corrosion mechanisms are determined by the environment, operating conditions and the layout of the installations:

- Marine, wet or acidic environments are particularly prone to this phenomenon.
- The change of coating or environment, special points, and the contact between different metals promote corrosion.

The **industrial sectors most affected** by these types of accidents are:

- Chemical industry
- Transportation of hazardous materials
- Refining
- Food
- Storage of flammable liquids
- Manufacture of gas

Accidents often involve large chemical or petroleum platforms or transport pipelines.

Of the 200 corrosion-related accidents which occurred in France over the last 10 years, **more than half involve pipelines and piping.**

The probability of occurrence of these accidents is increased by:

→ frequent **difficulties in accessing the pipes for inspection purposes** (pipes that are buried or in sleeves, pipes located overhead on racks, insulated pipes, etc.);

→ their **extensive length** (on or between sites), which **makes monitoring difficult**.

Example of an accident involving corrosion on piping

ARIA 34351 - 13/03/2008 - 44 - DONGES

A leak on a refinery's transfer line while loading 31,000 m³ of bunker fuel into a ship, resulting in a major spillage into the Loire estuary. More than 750 people were mobilised for 3.5 months to clean up 90 km of soiled river banks.
An examination of the pipeline revealed a **longitudinal break caused by localised corrosion under the insulation. The origin of the corrosion was linked water leaking onto the pipeline from above**. The water penetrated beneath the heat insulation and caused corrosion which then perforated the fuel pipe. **Despite several anomalies detected in the previous months on this same rack, the operator did not review its inspection program in order to take into account the specific risks facing this line owning to its proximity to the river banks**.

The operator was asked to undertake several actions and additional measures, including:

- Inspection operations extended to other piping on the site with thickness measurements at sensitive locations (supports, branch connections, etc.) ;
- Displacement of the routing of the service water line to prevent it from being located directly above insulated piping;
- Continuous monitoring with a leak detection system and alarm reporting in the control room for piping located near the river;
- Modification of the ground under the rack to drain off any accidental spillage to a suitable collection network;
- The installation of a device that measures the quantities of products leaving a tank and those received at the end of the corresponding transfer pipe.

In the example above, the cause of pipe corrosion is external (dripping from another pipe). Other examples of deterioration of **external origin** include: corrosion on pipeline elements (flanges, valves, etc.), corrosion by a defect on the passive protection in the case of buried piping, corrosion due to stresses related to improper supporting elements...
However, the origin of the pipe corrosion can also **be internal**, particularly if the protective coating is absent or damaged, due to erosion at an elbow or a deposit at a low point, etc.

Apart from piping, a significant proportion of corrosion-related accidents involve **vats and tanks**.

- The most commonly identified cause is **internal corrosion due to an internal coating being absent or defective.**
- Tank failures most often concern **crude oil** and **diesel fuel** storage containers.
- At chemical sites, the tanks concerned primarily contain **acid.**

Example of an accident involving corrosion on a storage tank

ARIA 42401 - 05/07/2012 - 33 - BIGANOS

At a paper manufacturing plant located 5 km to the east of the Bay of Arcachon, a 5,000 m³ tank of black liquor ruptured during a filling operation at 2:30 pm. […]
The tank showed signs of obsolescence, and corrosion. Additional inspections were scheduled to take place on tank in late July 2012 to ensure its ability to remain in service. […]
Production losses exceeded 10 million euros and the environmental clean-up costs were evaluated at more than 1 million euros. Property damage was estimated between 2 and 10 million euros.

Common failures leading to equipment corrosion

Inappropriate technical choices:

- Absence of protective coating
- Incompatibility of products/materials
- Inadequate ergonomics (equipment inaccessible for inspection)
- Potentially hazardous design (water pipe located above a heat-insulated pipe)

Inadequate maintenance:

- Insufficient interventions
- Inadequate non-destructive testing

Human errors:

- Faulty assembly of heat insulation
- Shock resulting in damage to a protective coating

Examples of corrective actions to combat corrosion

Improved monitoring

- Updating of pipe networks, inventory of sensitive points
- Inspection hatches to inspect insulated pipes

Improvement of inspection procedures

- Regular thickness measurements at critical points
- Hydraulic tests
- Intensification of inspection programs

Modification of facilities

- Use of stronger alloys (hastelloy, stainless steel)
- Modification of protective coating materials
- Removal of branch connections at risk
- Servo-controlled operation of safety equipment

Modification of processes

- Changes in temperature, pH, flow rate, etc.
- Reduction of equipment service pressure

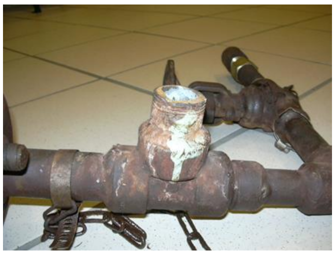
Another recurring cause of accidents: fatigue ageing

Over the last 10 years, approximately 30 accidents involving **fatigue phenomena (primarily excessive vibrations)** have been recorded in France. The main equipment concerned are indicated below, along with a few examples of the failures encountered:

- **tanks:**
  - fatigue cracking on a sulphuric acid tank (not corrosion-related)
  - fatigue of a tank following successive filling/emptying cycles resulting in cracking
  - delayed rupture (by static fatigue) of a reservoir as a result of embrittlement of the steel under the influence of hydrogen

- **pipes:**
  - rupture of a branch connection due to vibration following non-reinforcement of the weld on a pump discharge line
  - rupture of a 1" branch connection on a compressor discharge tank as a result of progressive vibration-induced cracking
  - slight fatigue cracking at the edge of a weld bead in an area of stress concentrations (presence of vibrations in particular)

- **security devices:**
  - premature opening of rupture discs (before the opening pressure is reached) on reactors due to fatigue ageing
  - rupture of a safety pin on generating sets



Example of a fatigue-related accident on piping

ARIA 32611 - 28/10/2006 - 76 - GONFREVILLE-L'ORCHER

In a plastics manufacturing plant, a 1" branch connection ruptured on a discharge cylinder of a propylene gas compressor resulted in the release of a gas cloud. Subsequent examination of the ruptured branch connection determined the cause to be mechanical fatigue, i.e. progressive cracking. There had already been an initial phase of cracking several years ago. Progressive cracking then continued until the branch connection ruptured completely. The purge piping generated constant mechanical vibration, the boss on the equipment had played the role of a recess resulting in a zone of local stress. **The piping's design was not suited to a vibrating environment.** The inspection procedure regarding the piping was not appropriate: The inspection plans did not take into account the type of fatigue cracking at the thread root, specific to a screw-mounted assembly. The thread roots had not been verified.
Following this incident, the threaded branch connection was replaced by a fitted-welded assembly. All branch connections subject to vibrations are identified; whenever possible, screw-type assemblies are replaced by a fitted-welded type assembly. The assemblies installed on the equipment subject to the modernisation plan are monitored in the inspection plans; the other equipment is monitored in the maintenance plans. Moreover, the operator plans to reinforce this assembly on this compressor and a neighbouring compressor with an additional weld bead on the cylinder, and to connect it to the flare network using hose isolated on the compressor side and the flare network side so as to do away with a fixed point that is prejudicial in vibrating environments.

Examples of corrective actions to combat fatigue phenomena

- **Improvement of inspection procedures**
  - Increase in the inspection frequency
  - Identification of equipment subject to the same risks as those involved in an accident and implementation of large-scale corrective measures
  - Modification of inspection plans to take the fatigue vulnerability of certain equipment into account (e.g.: risk of fatigue fracture of certain screwed assemblies)
  - Increase in the replacement frequency of critical equipment (e.g.: rupture discs)

- **Modifications in facilities and processes**
  - Changes in the design of the equipment to make them more able to withstand exposure to vibrations (elimination of fixed points, replacement of screwed assemblies by fitted-welded assemblies)
  - Modification of operating procedures to reduce stresses (e.g.: modification of the boiler start-up procedure to limit expansion stresses and pressure surges)
  - Modification of operating parameters (calibration values, etc.)

- **Training**
  - Training of maintenance crews regarding the precautions to be observed for safe handling of equipment.

Lessons drawn from accident studies

The analysis of accidents shows that:

- In many cases, the **symptoms of ageing have not been detected in a timely manner** or anticipated, despite sometimes many “alerts”.
- **Inspections** can also be **unsuitable** or fail to properly evaluate the progression of alterations by material defect or misinterpretation.
- The **implementation** of the conclusions arising from findings or inspections is sometimes **too late** or **temporary or insufficient** repairs are made.
- Major **platforms remain even more exposed to** the risk due to the large number of equipment and piping involved.
- One must **remain aware of all the possibilities of deterioration** and identify the factors likely to lead to their acceleration.
- A certain number of **sensitive points** deserve close attention: protective coatings, structures, welds, supports, seals, tank bottoms, etc.
- The inspection and maintenance of **areas that are hard to access or see**, under thermal insulation or buried, and which are conducive to accelerated deterioration, must not be overlooked due to their complexity or the constraints they impose.

The prevention of ageing must be part of a comprehensive approach that takes the following into account:

- the management of a potential accident with **early detection of the anomaly** (visible equipment, frequent rounds, detectors, cameras, alarms, etc.) and preparation of the **organisation** to be implemented in the event an **intervention is necessary;**
- the **limitation of potential effects** (retention, capture of effluents from the entire surface area of the site, water curtains, etc.) the **evaluation of possible consequences and the definition of remedial measures;**
- the **integration lessons drawn from past events.**

The issues in a few words

- In addition to the damage and operating losses generated by a possible accident, **ageing represents a significant cost for industry.**
- Protecting against the effects of ageing makes it possible **to extend the service life of installations** and, above all, to **limit the occurrence of accidents** with consequences that are sometimes catastrophic.
- As the European industrial landscape ages in certain major activity sectors, **it is now crucial that the problem of ageing**, as old as it is, **be taken into account.**

For further information on ageing: consult our publications at the following address https://www.aria.developpement-durable.gouv.fr/accidentologie/ageing-and-degradation-mechanisms/?lang=en