Analysis of accidents and good inspection practices for the management of ageing of industrial plants

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As part of the implementation of the SMS-PMA, The Italian implementation of the Seveso III directive imposes an obligation to provide a plan for monitoring and control of risks related to ageing of equipment and systems.

Starting from some industrial accidents, the main results of the analysis are provided, based on the results of SMS inspections, where ageing mechanisms have been identified as a significant cause.

An overview is presented about the national legislation, the technical standards of the sector and guidelines concerning the issue of "asset integrity", focusing attention on the role of the Public Administration in addressing the control of risks associated with aging.

Brief descriptions of the processes and methodologies implemented are proposed, starting from some practical cases relating to how companies manage these issues, through specific "asset integrity management" procedures, with relative focus on good practices about the methods used for the evaluation of the response, by the industry, to the question of aging.

The main findings of the inspections on the SMS are described, conducted in the last three years in Italy, with particular reference to the critical issues that emerged regarding the aging and asset integrity problems of industrial installations.

It is important to understand that the correct implementation of the SMS plays a considerable role, which requires each equipment to be subject to control programs, planned in order to ensure safe operational continuity.

Keywords

Seveso, SMS, hazardous, accidents, ageing, integrity, practices, inspections

1. Introduction

The D.Lgs. 105/2015 (the Italian implementation of the Seveso III directive “2012/18/EU”) is aimed at the prevention of major accidents involving dangerous substances. The Decree covers establishments where dangerous substances may be present (e.g. during processing or storage) in quantities exceeding certain threshold. Operators of the establishments are obliged to take all necessary measures to prevent major accidents and to limit their consequences for human health and the environment. Depending on the amount of dangerous substances present, establishments are categorised in lower and upper tier, with different obligations in agreement with the 2012/18/EU directive.

As part of the implementation of the Safety Management System for Prevention of Major Accident (SMS-PMA), the D.Lgs. 105/2015 imposes an obligation to provide a plan for monitoring and control of risks related to ageing of equipment and systems that can lead to loss of containment of hazardous substances, including the necessary corrective and preventive measures.

2. Report

2.1 Industrial accidents and plant aging: some national cases

In order to frame the problem under discussion, the main outcomes of the analysis of some industrial accidents, which recently occurred at Italian chemical and petrochemical establishments, are presented, based on the results of inspections, where ageing mechanisms have been identified as a significant cause. The analysis of technical and organizational factors of such events highlights problems of asset integrity of hazardous installations. They are mainly connected to deterioration/degradation caused by corrosion, erosion, fatigue. The corrective actions taken by the authorities and site managers concerned the Internal Emergency Plan, investigation and risk analysis, checks on installations and plants (pipeline, tanks, basins, pumps, etc.). Among the methods used to assess industry’s response to ageing it is possible to identify activities of remediation and maintenance, updating management procedures and operational instructions, specific planning for critical technical systems.

The events are:

- Site: Refinery plant. Date: 30/04/2006. Title: Fire and explosions in piping (see Fig. 1). Synthetic description: Release of crude oil from transfer pipe in the underpass of the road that crosses the plant, which developed a fire by accidental triggering which subsequently involved the adjacent piping belonging to different operators and then a series of explosions (Domino Effect). Causes: Age (over 25 years) and state of preservation of the pipe in relation to the progressive corrosion phenomena, which led to the pipe drilling. Actions taken: Visual inspection and basic design of corrective actions. Necessary reconstruction activities. Expected/Planned actions: Specific risk analysis. Planned and/or required compliances following Competent Authorities examination. Check of the pipeline inspection plan.

Fig. 2. The pipeline rack after the event

- Site: Refinery plant. Date: 01/05/2006. Title: Leakage through the tank bottom (see Fig. 2). Synthetic description: Leakage of oil through a large lesion at the bottom of a floating roof tank and subsequent release of the total amount of oil inside the containment basin. Causes: High corrosion and deteriorated area. Actions taken: Tank insulation. Transferring the product to another tank with temporary pipes. Expected/Planned actions: Tank out of service. Carrying out the remediation and maintenance of the basin and the tank. Double bottom insertion.

Fig. 2. Leakage following a rupture in the tank bottom

- Site: Chemical plant. Date: 25/05/2017. Title: Spill of sulphuric acid from a supply pipe in an underground channel. Synthetic description: Because of the accidental damage of a sulphuric acid (H2SO4) pipe, connecting the storage tanks (6 tanks above ground) with the buried tank in front of it, a spill occurred in the buried channel housing the pipeline itself. This spill of H2SO4 in the subsoil caused the structural failure of one tank and the relative rotation of the base of the containment basin. Causes: Spill of H2SO4 in the subsoil, following a leak from a connecting pipeline, caused by advanced corrosion in a section of this pipeline not accessible to the controls. It has been supposed a duration of the spill in the subsoil of about 40 days, for a total of H2SO4 spilled from the pipe equal to about 45 t. Actions taken: H2SO4 tank immediately emptied of the product. Supply lines promptly intercepted and further tank subsequently isolated. Monitoring and verification of the deformation of structures. The perimeter wall of the containment basin has been reinforced, in order to ensure the seal of the basin itself. Expected/Planned actions: Scheduled maintenance on H2SO4 tanks and monitoring of corrosion of these tanks and of the loading pipes, for the calculation of the corrosion rate in the short and long term and of the residual life (new procedure).

- Site: Refinery plant. Date: 07/03/2018. Title: Presence of diesel in piezometers near a storage tank. Synthetic description: Following the sampling at 2 piezometers, located near a storage tank containing diesel, the presence of a supernatant hydrocarbon product of the same type in the tank was found. Causes: Spill of about 1000 cubic meters of diesel in the subsoil, following a leak from a storage tank, caused probably by corrosion in the single bottom of the tank, although this had been subject to maintenance work on the bottom in the previous 2 years (application and welding of overlapping sheets on the existing bottom). Actions taken: Construction of a draining trench north of the tank and commissioning of new piezometers. Update of the operational protocol for the hydro-chemical and piezometric monitoring of groundwater. Expected/Planned actions: Implementation of the double bottom on all tanks of hydrocarbon products, with viscosity lower than 12 ° E at 50 ° C, with a single bottom. Review of the aging management program of the tanks (Method for the evaluation of the adequacy of the asset integrity management).

2.2 Italian law, national standards and guideline concerning ageing

In the following an overview is presented about the national legislation, the technical standards of the sector and guidelines concerning the issue of "asset integrity", focusing attention on the role of the Public Administration in addressing the control of risks associated with aging.

The D.Lgs. 105/2015 requirements related to the control of ageing and asset integrity are:

- Annex 3 (information on the SMS-PMA). Operational control is among the elements to be taken into account for the implementation of a SMS; in this frame, management and control of the risks associated with ageing equipment installed in the establishment and corrosion have to be taken in consideration.
- Annex B (guidelines for SMS-PMA implementation) requires that plans for monitoring and controlling risks related to ageing (corrosion, erosion, fatigue, creep), of equipment and installations that can lead to loss of containment of dangerous substances, including necessary corrective and preventive measures, must be provided.
- Annex H (Criteria for conducting inspections). A checklist is provided for SMS-PMA inspections and, among elements to inspect, the "ageing" item is specifically considered.

The national standards, present in Italy since the 90s and written to provide users specific tools for the implementation of an effective SMS, are specifically mentioned in the D.Lgs.105/2015 as "state of the art" in the field and are developed to meet both the requirements of the law, and the structure of the other ISO standards. They are:

- UNI 10617. Major accident process plants: Safety Management System essential requirement.
- UNI 10616. Major accident process plants: Guidelines for the implementation of the UNI 10617.
- UNI 10672. Major accident process plants: Safety assurance procedures for design.
- UNI 11226. Major accident process plants: Procedures and requirements for safety audits.

There are also technical standards:

- Specific for pressure equipment: UNI/TS 11325-8. Pressure equipment - Commissioning and use of pressure equipment and assemblies. Part 8 "Planning of pressure equipment maintenance using risk based methodologies (RBI)"; UNI/TS 11325-9. Pressure equipment - Commissioning and use of pressure equipment and assemblies. Part 9 "FFS (Fitness For Service)".
- Specific for the Risk Based Maintenance (RBM): UNI EN 16991. European Framework for risk-based inspections; API RP 581 "Risk-Based Inspection Technology"; API 579 1/ASME FFS-1 "Fitness for service assessment standard"; EEMUA 159 "Above ground flat bottomed storage tanks. A guide to inspection, maintenance and repair". These last sector technical regulations are the basis for the Risk Based Inspection (RBI) and Fitness For Service (FFS) evaluation methods. The RBI methodology provides inspection criteria according to the actual operating conditions of the equipment, for a targeted planning of maintenance operations. The FFS methodology allows to keep in operation, with accurate monitoring, the equipment that has defects/flaws.

At last, a first approach for the support to SMS inspectors and Seveso site managers has been the development of a method suited for a base evaluation of the adequacy of ageing consideration in the frame of the asset integrity management [MATTM. 2018; Bragatto, P. et al. 2016; Milazzo, M.F. et al. 2019]. The method was drafted by a specific working group, nominated by the National Coordination Table for the application in Italy of the Seveso Directive (art. 11 of D.Lgs. 105/2015), with the participation of representatives from Competent Authorities.

The method developed provide site managers with criteria useful to address a qualitative assessment of their equipment and SMS inspectors with a methodology to evaluate the adequacy of the implementation of ageing management programs. In its essence, the method uses indexes and is based on a fishbone analysis approach. The method is mainly aimed at identifying factors that have an accelerating effect on ageing and the factors that have the effect of slowing or reversing the natural trend to degradation. As in the other index methods, the accelerating factors and the braking factors are identified as penalties and compensations and the general evaluation of the system is given by the comparison of the algebraic sums obtained for the two factors.

2.3 An approach to good practices: the example of the primary containment system

Brief descriptions of the processes and methodologies implemented are now proposed, with relative focus on good practices about the methods used for the evaluation of the response, by the industry, to the question of aging through specific "asset integrity management" procedures.

The integrity plan of critical systems and components for the prevention of major accidents shall ensure both the containment of hazardous substances, within critical equipment and/or lines, and the operation of active and passive dedicated safety systems. The different assets subject to ageing can be traced back to four basic types [HSE. 2010]: Primary containment systems; Control & Mitigation Measures, i.e. safeguards; EC&I (electrical control and instrumentation) systems; Structures.

Operational control of a plant from production, handling, storage and distribution of hazardous substances that may lead to a major accident (in case of accidental release and/or process anomalies) shall be carried out with specific procedures and/or operating instructions. The identification of equipment and critical lines shall be a part of the risk analysis in the safety report and it shall form the basis of a specific inspection/control plan. Preventive, scheduled, or corrective maintenance of critical equipment or lines may be performed in accordance with the RBM Policies or Best Practices. Such maintenance shall minimize the risk of loss of containment of hazardous substances and the functionality of equipment that are critical for the prevention of major accidents (i.e. pumps, compressors and heat exchangers).

It is important to understand that ageing is not strictly related to the age of the equipment, but to its changes over time, in terms of deterioration and/or damage degree. These factors are more likely to cause failures in the lifetime of the equipment, but are not necessarily associated with it. In the case of equipment or installations, ageing can lead to significant deterioration and/or damage to initial conditions, which may compromise functionality, availability, reliability and safety [OECD. 2017].

The following figures show the influence of aging on the life times and operating times of equipment and systems [HSE. 2010], and in particular how the accumulated damage varies during the service (see Fig. 3).

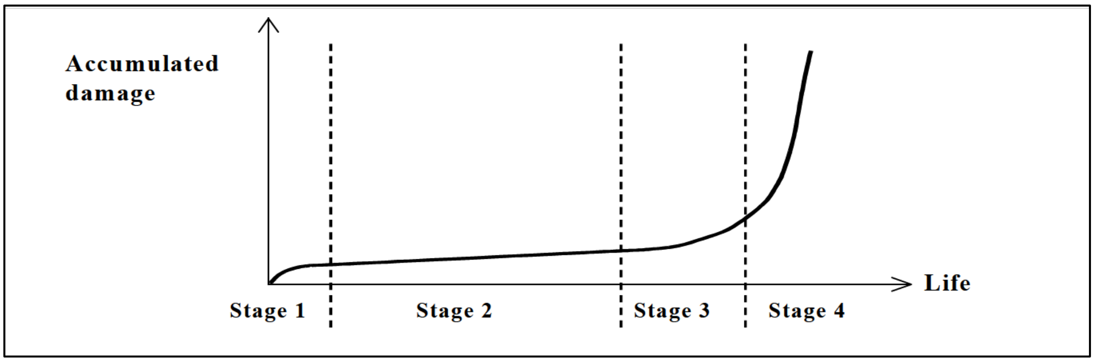

Fig. 3. Variation of accumulated damage

It is important to note the effect of periodic maintenance, inspection and repair on the risk of failure for a piece of equipment, varying between tolerable risk and operating risk. As you can see in the next figure, each saw-tooth represents an inspection being carried out, varying between a maximum and a minimum operating risk (see Fig. 4).

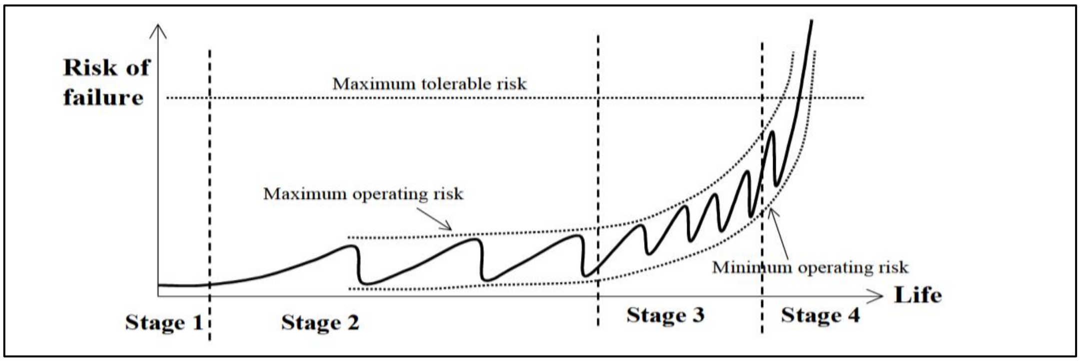

Fig. 4. Effect of periodic maintenance on the risk of failure

Finally, the classical representation of the variation of a failure rate for an equipment is the "bathtub curve", that shows the typical four stages of the progressive ageing of an equipment: the increase in the failure rate, from deterioration and degradation, and the reduction of the lifetime (see Fig. 5).

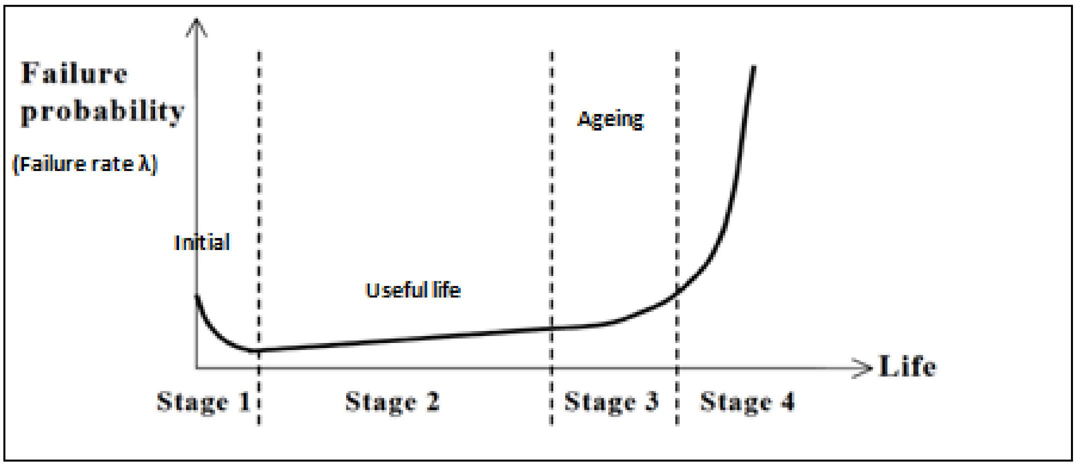

Fig. 5. Model for the probability of failure of a population of equipment

A possible approach is proposed to define the main steps of good practices for maintenance activities in case of primary containment systems, in order to ensure sufficient mechanical integrity:

- Defining the degradation mechanisms. They depend on the type of tanks, on the nature of the stored fluids, which are the basis of the organization of the inspection activities. For example, you can make the following classifications: Corrosion (internal or external, localized or generalized); Mechanisms not related to corrosion (deformations, mechanical breaks, cracks on weld, yielding).
- Defining and personalizing inspection technologies. In addition to internal or external visual inspection, the degradation mechanisms affecting both atmospheric tanks and pressure vessels can be identified by the NDT common techniques. For example: Liquid penetrant testing; Magneto-scope test; Vacuum box test; Ultrasonic (long range); Spark test; Acoustic Emissions.
- Determining the frequency of inspections. The factors that need to be considered: Construction features; Repair techniques and materials; Nature of stored product; Conditions found at the previous inspection; Corrosion rates; Presence of corrosion prevention systems; Potential contamination of soil, water, air; Presence of double bottoms or other systems to prevent losses of containment; Leak detection systems with operating tanks.

It is possible to schedule a targeted maintenance-planning, based on the RBI method, which consists of specific inspection activities according to the actual operating conditions of the equipment; while through the FFS method you can continue to maintain in operation, with accurate monitoring, equipment that has a structural degradation. It is important to highlight that the setting of these methodologies is well suited and integrated in the structure of a SMS already implemented.

In addition, the SMS element of "Management of Changes" is crucial, considering the difficulty of identifying new corrosion risks for process and plant design changes and the possibility that other modifications may also have a lesser impact on corrosion risk and therefore not recognized (i.e. changes in the source of crude oil supply or an increase in production, especially temporary). Typical examples of such modifications are: Installing an additional nozzle (or enlarging an existing nozzle); Installing an agitator to an existing vessel; Altering the tank/vessel to make it larger/smaller; Change of process conditions; Retro-fitting steam coils to heat the contents; Installing or removing insulation to/from the exterior of a tank/vessel.

It is important to keep records of the operating history and problems encountered during the life. For example, running hours, duty cycles, operational excursions and changes in duty or process. This means that to ensure the integrity of all plant containing hazardous substances, it is necessary to evaluate all the compliance requested (occupational safety, environmental safety, PMA, etc.).

2.4 The analysis of inspections

Finally, the main findings of the inspections on the Safety Management System are described, conducted in the last three years in Italy, with particular reference to the critical issues that emerged regarding the aging and asset integrity problems of industrial installations.

It is in particular possible to highlight the results, lessons learned and return of experience of this analysis. About 160 inspection reports were examined: in 20% of the cases, problems and with the correct management of mechanical integrity were found. In particular, weaknesses emerged with reference to ageing and asset integrity of the hazardous installations inspected (deterioration and degradation caused by corrosion, erosion, stress, fatigue).

In the following, some examples of non-compliances found are given:

- Need to consider and analyse the problems of ageing (corrosion, erosion, fatigue) of equipment and installations that can lead to losses of dangerous substances, including, where relevant, a specific monitoring plan and control, and the subsequent corrective and preventive measures.
- No evidence of a plan for monitoring the risks associated with the ageing of equipment, unless it is in accordance with law obligations.
- Developed a well-structured Asset Integrity Management procedure, but partially implemented (no evidences).
- Lack of a specific procedure for monitoring and control of ageing. The procedure shall contain: an analysis of existing or potential degradation mechanisms, a lifetime consumed assessment due to the identified damage mechanism; a fixed-term monitoring plan or, alternatively, a time-tracking plan and the techniques to use; a reference to preventative actions and any corrective actions.

3. Conclusions

Industrial plants are subject to degradation phenomena based on the level of accumulation of static/dynamic stresses and the effect of changes of operating conditions. Knowing performance decay rates is useful for adequate scheduling maintenance interventions.

The site managers must consider the equipment changes over time in terms of deterioration and/or damage degree and understand damage mechanisms. This would allow to identify the best “non-destructive control method and test (NDT)” to apply in order to assess the equipment damage state.

It is important to control and maintain risk at acceptable levels through management of equipment maintenance activities. These activities are aimed at ensuring operational continuity and the stability conditions to prevent losses of containment of hazardous substances.

The safety management system should provide that each equipment and utility is subject to a program of inspections, testing and maintenance properly scheduled overtime to ensure that these components continue to meet safety requirements as long as they are in service. The organization should establish and formalize specific criteria for the determination of the defined maintenance regimes (preventive maintenance, condition-based maintenance, predictive maintenance).

It is important to establish a clear strategy, not just for periodic examination, but also for the whole plant lifecycle. This is especially relevant on sites storing and processing hazardous substances, where the consequences of integrity failure can be major. The RBI and FFS methodologies, meeting the criteria of a SMS adequately implemented, can constitute a valid response to the asset integrity management and the related problem of ageing.

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