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Ageing Processes in the Chemical Industry

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Many chemical companies in the Netherlands were built after the 2nd World War and put into operation, and nowadays many chemical installations have reached the (near-)end of their life. In 2017, to prevent ageing problems of all kinds, Seveso inspectors and specialists (Dutch: BRZO inspectors) started inspecting Lower-tier and Upper-tier establishments (250 respectively 170 establishments) on the ageing theme. Ageing, such as degradation of mechanisms which affect the vitality, reliability and safety of process installations, is an important inspection theme since Seveso III Directive 2012/18/EU. Companies are responsible for safe processes, and according to the law they should "take all measures to comply". When they don't comply, the government will protect the people and environment by enforcing compliance. But what exactly is compliance with respect to the ageing theme? This article introduces the current situation of ageing processes and makes recommendations on physical, obsolete and obsolescence and organizational ageing.

Introduction

Ageing equipment in large (petro) chemical companies is a large safety problem. The installations have reached the end of life and / or they are working with old techniques (Heel, 2017) (Ingenieur, 2014). Examples from the past of Major industrial accidents which have occurred that can be directly or indirectly linked to ageing are the Flixborough, UK in 1974 (Venart, 2004) (Hendershot, 2009) (Wilson & McCutcheon, 2003), the ConocoPhillips, UK in 2001 (Carter, et al., 2006). But even recently accidents occurred such as Chevron, US in 2012 (US-ChemicalBoard, 2015) Ludwigshafen, Germany in 2016 (Märker & Fielitz, 2017) and Chemelot Venlo, the Netherlands in 2017 (ANP, 2017). Those accidents show that ageing is still a disturbing phenomenon present in chemical process industries (Gyenes & Wood, 2016).
Less attention has been paid in the Netherlands to the ways in which Dutch BRZO inspectors and specialists are dealing with ageing issues. Internal interviews with Dutch inspectors and specialists in 2015 showed that older machines or installations do not always meet the current safety requirements. Inspectors also indicated that companies do not always have a good view of the degree to which ageing causes poorly managed risks. They also reported that companies and branch organizations do not always accept this message and that the supervision instruments do not fit well with checking for ageing-related risks. In the State of Security report to the House of Commons (Dutch: 2e Kamer) the inspection services, in particular the Inspectorate of the Ministry of Social Affairs and Employment (I-SZW), state that approximately 30 percent of the incidents of companies in the Netherlands that work with large quantities of hazardous substances have had to do with ageing phenomena and half of them suffer from signs of ageing (I&M, 2016) (Heel, 2017).
As a consequence of this in 2017 was ageing an important part for all Dutch BRZO inspection services (i.e.: I-SZW, environmental- and water inspectors) with emphasis on the safety whether the BRZO company and the extent to which BRZO companies are in control with respect to ageing (I-SZW, 2018). It seems that ageing is a serious problem in the chemical industry. But ageing is more than physical ageing of equipment. Several studies suggest that obsolete, obsolescence and organizational ageing are main bottlenecks in the chemical industry.
Definitions in the field of ageing (material degradation, obsolescence and organizational ageing included) could be: Properties, as well as the materials themselves, may and do deteriorate (Roberge, 2008). "Old…. is, one that is not fabricated to contemporary standards" (Hopkins, 2012). According to (Bierly III., H.E, &

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Christensen., 2000) an organization become unwise if the individual knowledge is not disseminated and transferred to others. A reservation is made that these definitions may seem arbitrary.

1. Three types of ageing

As shown above, ageing of equipment is only one aspect of the risks over the lifetime of a business. Everything related to a company and its processes can age, not only the above equipment but also technologies, procedures and organizations. Technical aspects are usually defined as material degradation, however, obsolete and obsolescence and ageing organizations can also affect equipment, processes and procedures (Table 1) (Gyenes & Wood, 2016), (Petterson, L; Simola, K, 2006). It is possible that organizations become obsolete if they can handle the results of checks in the areas of maintenance, inspections, supervision and operational problems due to insufficient knowledge. To clarify ageing equipment: equipment that are outdated or no longer in general use will soon be outdated (Pentland, W, 2018) (O'Keefe, E, 2018).

Table 1: Ageing with multiple meanings

	Technical aspects Material degradation (physical ageing) **Indicators:** Wear / damage by age	Technical aspects Material degradation (physical ageing) **Indicators:** Wear / damage by age and manner of use	Technical and non-technical aspects *Technology ageing / non-physical ageing)* *Obsolete / Obsolescence*	Technical and non-technical aspects *Organizational*
Ageing concerns material properties, operating conditions (operating limits), and environmental conditions and maintenance practices. 'Inspect' a site and rust is possible all over the place. Due to physical, mechanical, thermal, electrical, chemical, irradiation and/or biological processes **(Jarvis & Goddard, 2016)**.	x			
Ageing becoming out-of-date, concerns spare parts management, processes and procedures, design changes due to new technologies **(CNSC, 2011)**, **(Kletz, 2010)** **(Simola, 1999)**	x	x	x	
Ageing concerns expertise, ageing of facility personnel, contractors and third party personnel, transfer of knowledge, loss of knowledge and expertise of plant personnel (management level; high- mid- and lower-level), knowledge and competence, document changes or the revision of documents, corporate memory, maintenance policy, performance metrics for items of plant **(Slack, Chambers, & Johnston, 2010)** **(Wintle, Johnston, & Mc Grath, 2012)** **(Hopkins, 2012)**.	x	x	x	x

2. Analysis of incidents involving hazardous substances at large companies

In 2016, a study was published as part of a Dutch post-secondary vocational training in Safety. The data were collected using a questionnaire in a semi-structured interview. The publication (Nulkes, 2016) shows that in the 1960s, ten large BRZO companies were built and put into use in the Rijnmond area. The publication shows that eight companies in the context of ageing, comply with Seveso and Dutch legislation and regulations. Nevertheless there have been four incidents at three companies as a result of ageing. All these incidents were investigated by the company's own experts and led to the conclusion that they were related to corrosion, pipe thickness and pipe wall rupture and material degradation (pipe and compressor degradation). Two companies are scoring poorly in terms of the organizational corporate memory. Organizational corporate memory is defined as undocumented acquired insights, work experience, skills and knowledge of employees. The absence of ageing knowledge in companies will be solved by recruiting external staff and by training in-house personnel. Results of the post-secondary vocational training in the safety study of 10 Dutch companies can be found in (Figure 1). It should be noted that no percentages are used in the study described above. Some companies reported that they did not struggle with ageing, which means that they did not need any knowledge and they did not hire external personnel.

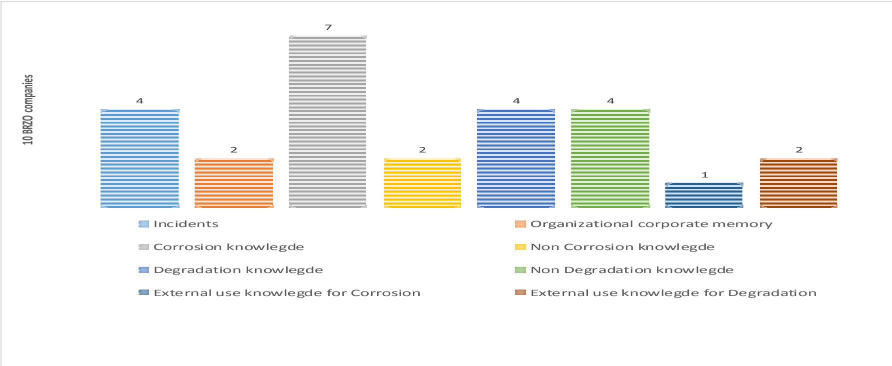

Figure 1: Results from 10 Dutch companies for a post-secondary vocational training in Safety

A research using data from the Ministry of Social Affairs and Employment shows that between 2016-2017 direct causes lead to a loss of containment (LOC) (i.e.: 13 incidents resulted in hazardous substances being released). The thirteen incidents were caused by various shortcomings in safe operations. In eleven incidents, the underlying working procedures were not in order or were not properly applied. In three cases a fire broke out and in eight cases, gases or vapors were released into the environment. It has been shown to be related to material degradation (1x by corrosion, 1x by creep and 1x by degradation of material) and organizational ageing (4x by human error) (Kooi, et al., 2017). During this period, the companies were not in control.
Another research shows that twelve incidents took place between 2017-2018, including one fire and two explosions. Other incidents concerned the release of hazardous substances and incidents in which three people were injured. The twelve incidents involved problems with various elements, such as weakening of materials or chemical reactions that were not properly controlled. The resulting deviations were not detected in time and remedied by insufficient monitoring and inspection. Six incidents could have been prevented if appropriate emergency protection measures had been taken. These emergency protection measures, such as protecting the installation against overpressure, were not or insufficiently implemented or not properly maintained. At nine incidents the underlying working procedures were not properly applied. In addition, staff members were sometimes not competent and alert enough and sometimes do not work safe due to insufficient equipment. The two incidents causes are: temperature, creep, fatigue and fragility" (Kooi, et al., 2018). The final results shows that it is related to material degradation, obsolete and organizational ageing.
Based on incidents reported by the United Kingdom Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR), ageing in chemical and process industries is a real problem (Gyenes & Wood, 2016). Between 1996 and 2008, there were 173 LOC incidents (13 per year on average) attributable to the ageing of an installation and these incidents represent 5.5% of all containment incident losses. An important conclusion from another study: "An analysis….” (Horrocks, et al., 2010) showed that between 1980 and 2006, an estimated 96 LOC incidents (i.e. an average of 4 per year) were reported throughout Europe in the EU Major Accident Reporting System (MARS) (European Environment Agency, 2018), mainly due to ageing mechanisms. 30% of major incidents reported, resulted in the release of LOC and 50% concerned to technical integrity of installations, process control and instrumentation. During this period

11 people died and 183 people were injured. The average loss per ageing incident (96 incidents) was 1.8 million euros per event. Based on the average loss per event, it is concluded that ageing incidents involve relatively high costs in euros per event.Figure 2, the high level categorization of MARS incidents, illustrates the proportion of analyzed incidents, (i.e.: 294 incidents) that can be divided into categories as a result of problems in the areas of technical integrity, electrical control and instrumentation (EC&I) or other (human, procedural) issues. This indicates that more than 60% of MARS incidents are related to technical integrity issues and 50% of those are associated with ageing of one type or another. Please note: This information is an indication of ageing incidents, errors may occur due to different insights.

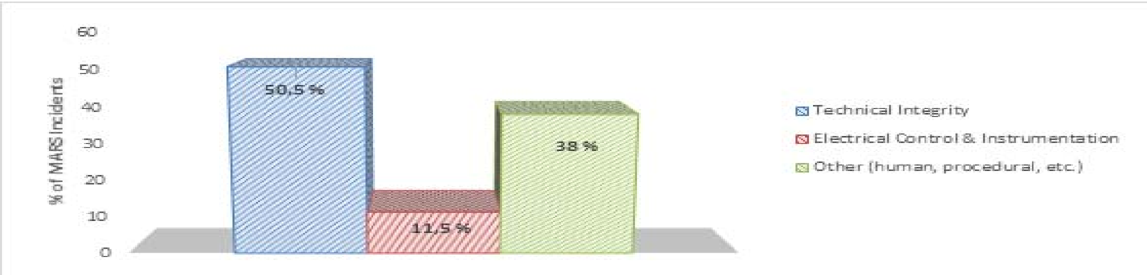

Figure 2: The high level categorization of MARS Incidents.

In this study, the category technical integrity has a special meaning, because it represents physical ageing (36%), EC&I (21.7%), maintenance (13.4%) and other issues (10.8%). The causes of technical integrity incidents is shown in Figure 3. Please note: the information below is an indication of ageing incidents, errors may have been made as a result of different insights.

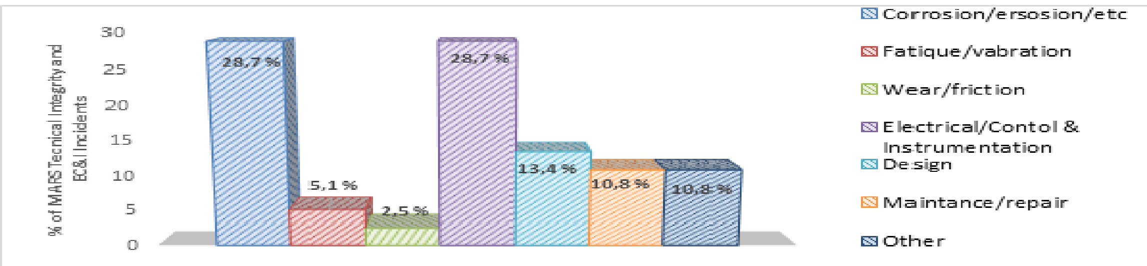

Figure 3: The causes of technical integrity incidents in MARS data

If all ageing causes of technical integrity incidents, ageing containment (32%), ageing EC&I (11.8%) and ageing others (10.1%), are combined, this leads to Figure 4. It is noted that 48.9% has no ageing cause, but no further study has been done on this issue. Pleas note: This information is an indication of ageing incidents, errors may occur due to different insights.

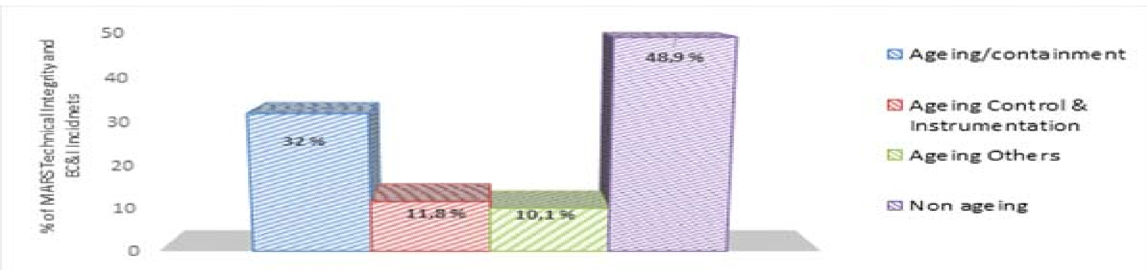

Figure 4: Proportion of MARS technical integrity incidents, ageing containment, EC&I incidents and ageing others

This analysis shows that about 50% of technical integrity and EC&I-related incidents are age-related. Due to the uncertainties in the analysis, a broad estimate of the extent of the ageing problem can be made. It indicates that 60% of 'potential major accidents' incidents are related to technical integrity or control and

instrumentation and 50% of the incidents are related to ageing of one type or another. This proves that ageing mechanisms are a key factor in the cause of major accidents.
The MARS database contains reports of chemical accidents and near misses and provides a more detailed and complete insight into the incidents and causal factors and is specifically related to potential major accidents and dangerous events. This is a more realistic indication of the size and severity of an ageing plant and its contribution to major accidents, but please note: not all incidents are reported to MARS; near misses are not classified as major accidents and major accidents with Lower-tier and Upper-tier establishments, and new, existing or other companies not exist until the early 2000s. In practice, there are no new and different companies. The following ageing keywords have been used to perform this analysis (Table 2).

Table 2: Ageing keywords identified by the research

Physical ageing	Technology ageing	Organizational ageing
Corrosion	Obsolete	Loss of knowledge/ competence/ memory
Creep	Obsolescence	Policy/compliance/legislation (Brzo, Rrzo, NTA-8620, PGS-6)
Fatigue	Fit for purpose	Wrong documentation
Fragile	Overaged (old)	Safety studies
Temperature	Age	Modifications and Management of Change
Degradation	Ageing	Major incidents /accidents
Pipe thickness/rupture		Failure mechanisms

3. Conclusions

The objective was to try to draw general conclusions from a large amount of data from HSE-data, and information from its own (I-SZW) organization. Ageing processes in the chemical and process industry is a major problem. Besides physical ageing, obsolete, obsolescence and organizational ageing are also bottlenecks in the chemical industry. Companies in the chemical and process industries covered by the Seveso III Directive 2012/18/EU, are obliged to have a clear picture of the safety risks associated in general terms with ageing and in particular terms with corrosion in their installations and they are obliged to control these risks. The evidence and studies outlined above shows that ten BRZO companies were built in the 1960s and put into operation in the Rijnmond area. It shows also that eight companies in the context of ageing comply with Seveso and Dutch legislation and regulations. However, 4 ageing incidents have been reported in 5 companies. All these incidents were investigated by the company's own experts and led to the conclusion that they were related to corrosion, pipe thickness and pipe wall rupture and material degradation. The concerning companies draw lessons about it and they pay now more specific attention to ageing. The majority of the 10 BRZO companies have their own knowledge of corrosion and/or degradation, whether or not using external sources. The database of the I-SZW shows that in the period 2016-2017 there have been 13 incidents with dangerous substances reported, which can be related to material degradation, obsolescence and organizational ageing. Between 2017 and 2018, twelve incidents took place which can be related to material degradation, obsolete, obsolescence and organizational ageing. During this period, the companies were not in control. Based on incidents between 1996 and 2008 reported by RIDDOR, there were 173 LOC incidents (13 per year on average) attributable to the ageing of an installation. Based on incidents between 1980 and 2006 reported by MARS, there were 96 LOC incidents mainly due to ageing mechanisms and the average loss per ageing incident is 1.8 million euros per event. Between 1980 and 2006 eleven people died and one hundred eighty three were injured as a result of an ageing population.
A point of attention is that it was difficult to positively assign the issues identified in the reports, and there is a possibility that some ageing incidents before the early 2000s, have been left out of attention.
The above data leads to final conclusions that ageing and deadly incidents have been reported by chemical companies and that they have the obligation to prevent LOC's and fatal incidents. Yet there have been ageing incidents. Companies need to focus more on the risks of technology- and organizational ageing as well as physical ageing. In order to be able to manage ageing processes:

- pay more attention for the identification about possible risks as a result of obsolete and obsolescence;
- pay more attention for the identification about possible risks as a result of organizational ageing.

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