Corrosion in sprinkler pipe – not one but many problems

The occurrence of corrosion is a potentially major problem for all sprinkler systems. It could cause a problem for the operational reliability as well as for the performance reliability. It is of course negative for the operational reliability if corrosion causes plugged piping, clogging of control valves or simply non-opening sprinkler heads. All of which may well be the effect of uncontrolled corrosion. But an even larger impact on the performance reliability will probably be the effects of discovered corrosion and the maintenance process following this discovery. A sprinkler system taken out of work will have a very poor performance record.

It is for these reasons of course very important to prevent corrosion from occurring in the first place. Equally important will be to have effective means of dealing with the corrosion that inevitably will occur in a normal sprinkler system.

Different aspects of sprinkler system reliability is to be found behind many of the requirements in the most commonly used sprinkler rules, codes and standards over the world. Viewing from these, corrosion does not constitute a reliability problem. Compared to all paragraphs written for obstructions, hazard classification, water supply, pumps etc, corrosion is seemingly a minor problem. Within the new European sprinkler standard, EN 12845, there are only two paragraphs on this subject. One being a very general requirement that piping used shall be corrosion resistant "in a suitable manner". And then there is a maintenance requirement for periodical interior pipe control in order to find out whether unacceptable corrosion exists or not.

In the American NFPA-standard for sprinkler installation, NFPA 13-2007, corrosion is mainly dealt with as something coming from the outside, from unusual environmental conditions or the water supply.

Interestingly enough there seems to be a cultural divide between the two sides of the Atlantic on the issue of the dominant corrosion problem. While the American side seems very pre-occupied with MIC, the Microbiologically Influenced Corrosion, this type of corrosion problem is generally not discussed on the European side of the ocean, and certainly not mentioned in the European standard. The reason for this could probably be of some interest (environmental, market economics, installation practices are some areas that might need to be evaluated) but is outside the scope of this paper.

However, this paper will instead focus on the complexity of the sprinkler corrosion that often will be the case, the reason for occurring corrosion not always being a single source. A real case will be used as the background but the conclusions have general effects. The importance of qualified inspection services as well as independent third party evaluations will be high-lighted, as well as the inadequacies of even very rigid qualification schemes.
The Swedish sprinkler market, although small in pure numbers of sprinklers installed (~300,000 sprinkler heads per year), is one of the largest per capita (at 33 heads per 1,000 inhabitants, making it number 4 or 5 in the world, behind the USA, Canada, Norway and maybe someone else). The tradition of insurance based national regulations for sprinkler installations is almost 100 years old. A system of only allowing approved installers, using only full time employed fitters with proven experience, has been the case since more than 50 years. All systems need to inspected by independent third party inspectors who themselves have to be approved, both individually as well as their inspection company. During the last ten years a certification systems has replaced the old system of approvals, on all levels.

A specific section of the sprinkler rules has been designed to make sure the welding practices of sprinkler fitters meet the standards needed. For regular steel pipe this requirement has been rather straight forward, the same level of performance as other pipe fitters, in other trades, need to meet (no obviously incorrect welds are accepted, minimum Level 3 on a 1-5 scale). For stainless steel pipe – not a normal pipe choice for most sprinkler systems – a higher standard has been set: approved welders and the right for the inspector to perform more than a visual inspection, i.e. X-raying the pipe to check for compliance.

Historically, sprinkler fitters have not enjoyed a reputation – at least not in Sweden – for being the most supreme welders of their trade. As a matter of fact, as late as 1989, before an amendment was made to the sprinkler installation rules, the only requirement given had been "to use a welding practice in accordance with normal standard for the [sprinkler] trade". And as the "normal practice" was to have a very low standard, this became the level one measured against. The introduction of a minimum welding level, as modest as Level 3, was seen as a major improvement. The requirement for stainless steel pipe, introduced at the same time and deliberately set on a higher level, was viewed by the sprinkler trade as almost impossible to achieve without the assistance of special welders, brought in for this very purpose.

**Back-ground**

At one of the sprinkler systems installed at a pharmaceutical industry the local fire prevention personel – the only people really looking at sprinkler heads! – discovered a mysterious white powder-like substance on a couple of spray pendent sprinklers. The system was only 3-4 years old, having been installed in 1996. It covered a large building, 9 floors all in all, with most of floors occupied by laboratories of clean room nature. Due to the sensitive environment the sprinkler systems had been installed with stainless steel pipe, in order to make sure no leakage due to corrosion would ever occur. Any such leakage would contaminate the process in the area or floor concerned, making total close down and subsequent clean up of the facility a necessity. After completed clean up a new permit for the process had to be aquired from the authorities. Even a small leakage will thus have very large economical implications for the owner of the sprinkler system.
The system choice had been a wet alarm sprinkler system with a light water (AFFF ) addition to improve the extinguishing performance on the soluble components used for the production process.

The water supply was the industrial fire main,fed,via a water reservoir, from a nearby very large lake, pressurised by a sprinkler pump.

The sprinkler contractor was an approved installer with more than 20 years experience, with a reputation to be especially qualified for the particular case of welding stainless steel pipe. This was one of the very few contractors who claimed to have no problems in meeting the higher skill levels required for stainless steel pipe.

In accordance with older Swedish approval requirements the contractor had a licensing agreement with a specific sprinkler manufacturer for sprinkler heads and control valves, in this case a large American manufacturer. All sprinkler components had to be approved or certified by the Swedish certification organisation, SBSC. In order to obtain a certificate it was necessary to have a VdS- or LPCB-approval “or equivalent such as a UL and/or FM-listing”. The sprinkler heads in question were all UL-listed.

The systems within the facility had been commissioned in 1996 and had subsequently been third party approved as fulfilling both contractual as well as regulatory requirements. In the following years an annual inspection had been carried out, by the same inspector. No notes had been made of any residue on the sprinkler systems, or for that matter of any other problems of similar character.

An extension of the system was installed in 1999, with a third party inspection, subsequent approval and no notes of anything unusual found during neither inspection nor the regular maintenance. The same contractor had been used, with the same manufacturers sprinkler heads, albeit from a different year of production.

**First investigation**

The fire prevention office of the factory asked the contractor to investigate possible causes for the appearance of the white residue. The contractor sent samples of some sprinklers concerned as well as a sample of the water in the system to an independent laboratory. The laboratory in question had no prior knowledge of sprinkler systems as such. They had their primary focus on the water supply. The report presented declared that the “minor leakage ” that had nothing to do with the contractors installation but probably had a lot to do with the quality of the water supply. The residue was a corrosion by-product, being caused by minor leakage through the corrosion affected pin cap in the sprinkler head opening. It was also stated that the white residue mainly consisted of zinc. The water quality – being found to be of neutral pH-value - was discussed as the main suspect for this corrosion.
Major leakage

Not much else came out this first investigation. It was seen as a freak problem that was disturbing for the eye but did not seem to present a threat to the proper operation of the sprinkler system. And this was the primary concern for the fire prevention office.

Then there was a major leakage and this changed everything. The cost for the clean up operation made the facilities management department of the factory more than interested in avoiding a re-occurrence. A string of different investigations followed, each step seemingly only enlarging the amount of problems found, without finding a solution. During this period yet another major leakage occured, creating the need once again for a complete clean-up of the building floor concerned.

Each clean-up carried with it costs almost equal to the total installation cost for the original sprinkler systems.

A complete review of all sprinklers in the building was made and all sprinklers found to have either the white residue or the greenish signs of leakage on the head was replaced by new sprinkler heads. A new contractor was chosen was for this work, using their own sprinkler heads from another brand.

Less than a year later a new full review, a follow up to the replacements having been made the year before, showed an additional 200+ sprinklers to be affected – some of them sprinklers that had been replaced in the first place.
### TABLE 1

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2700</td>
<td>96</td>
<td>250</td>
</tr>
</tbody>
</table>

### New third party inspection

The facility management department brought in a new third party inspector to make a re-evaluation of the systems installed. This resulted in the discovery of many more problems, many of which were corrosional although not specifically concerning the sprinkler heads.

More traditional rust was found on sprinkler pipes – even though it was supposedly "stainless steel". When corrosion was found on the outside of pipe, pieces of pipe was cut down to be investigated on the inside. Revealing even more advanced corrosion. All of these "pipe corrosion problems" had occurred in the direct vicinity of welds.

In order to avoid the next water damage incident, that seemed to be just a matter of time before it had to occur, a decision was made to alter the sprinkler installation from a wet pipe system into a double interlock pre-action system. However, this decision was later withdrawn when it was realised that the gridded pipe configuration and the amount of pendent sprinkler heads with vertical branch line pipe, would leave a lot of water, stagnant water at that, in the system after each activation. This would obviously create an environment for unavoidable internal corrosion with the interface of water/air. Also, the water remaining in the system would of course be sufficient to create a water damage problem if a sprinkler head leakage would again occur.

It was also discussed during this period to introduce a system of detailed visual inspection of every single sprinkler head, including very inaccessible sprinklers above false ceilings and inside closed shafts. This would make it possible to organise a replacement program of every sprinkler head found to be showing signs of being affected by the still unexplained corrosion process.
It was soon realised that such a maintenance program would be very costly, requiring the work of one person more than 2 weeks every year. Not counting the cost of replacing the sprinkler heads found to be deficient.

During a "test run" of the visual inspection program additional problems were discovered. One being a pipe plug of galvanised steel at the end of a stainless steel pipe – a plug of the same type had earlier caused one the water leakages....

During the test inspection it was also found that some of the replacement sprinklers, some not more than a couple of months old, already showed signs of corrosion.

Also, during the replacements of sprinklers, an unwanted change had been made from Quick Response sprinklers to Standard Response sprinklers. This constituted a probable violation of the original request to install sprinklers in the building.

It suddenly seemed that each new investigation and inspection only created more questions.

**Complete investigation**

Eventually a decision was taken to lift the question to another level. The Corrosion & Metals Research Institute, an internationally renowned institution for general corrosion research. They made a very thorough investigation and discovered the problem not to be one but at least three. The system was found to suffer from a severe case of zinc corrosion, also called de-zincification, caused by the physical properties of the brass used for the pin-cap in the sprinkler heads of the brands used. Also present was "regular" corrosion in supposedly stainless steel pipe that had been compromised by incorrect welding practices. Finally there were cases of galvanic corrosion caused by incorrect choice of mixed pipe materials (short parts of galvanised steel between regular runs of stainless steel pipe etc).

**Improper welding practices - and galvanised corrosion**

The last two problems were rather straight forward to deal with. The contractor had not followed the regulated requirements and this should have been detected during the third party inspections, had they been more detailed and/or qualified.

When welding stainless steel pipe it is important to understand the physical properties of the pipe – it is not a case of 100% stainless steel, from the outside to the inside. Instead the "stainless" should more be viewed as a rather thin protective layer, a coating. If this layer is damaged during the process of welding, i.e. the welder is not using the prescribed practices, a heat affected zone (HAZ) will occur. This zone, easily recognised by a streaked patch of pipe, will in effect have no more protection against corrosion than a standard steel pipe would have.

A third party inspection by an expert in sprinkler regulations may not know this, thus not understanding the signs even when they are obvious.
And the education of fitters must obviously include more information of the eventual consequences of not following standard procedures for welding.

The problem with galvanisation corrosion has to do with the differences in corrosion potential between metals. Galvanised steel will not cause a problem with stainless steel in an environment of air or even mild humidity. However, in the presence of water, corrosion will inevitably occur. In a sprinkler system, where water is an integral part, it is therefore not a good idea to install a galvanised steel plug at the end of a stainless steel pipe system.

To make the sometimes confusing relationships between different metals more obvious it would probably be a good idea to include tables with metal potentionals in the sprinkler standards. Doing so both fitters and inspectors could easily check the compatibility of different pipe materials.

**Dezincification**

The problem of the material used in parts of the sprinkler heads was more problematic. All sprinklers installed had been of the "approved" type. But only "during recent years" had there been introduced a dezincification test included in the standards used by UL for approving sprinkler heads (NFPA Journal March/April 2004). Such a test will most probably fail sprinklers with less than 65-70% copper in the brass (less copper equals more zinc, to simplify matters a bit).

The process can in layman terms be described as streaks or lines of zinc moving out of the metal, leaving channels through which water and moisture may then travel, through the pin-cap and on the outside. Contact with the copper will then cause the greenish residue. The white residue is the zinc that has gone from the inside to the outside of the metal.
In the case discussed here most sprinklers had been installed during the period from 1996-2001. The composition of the brass was found to be almost impossible to obtain from the manufacturers (many of whom were no longer companies of their own, due to mergers and other market changes). Instead laboratory test had to be performed. They showed very large variations:

**TABLE 2**

<table>
<thead>
<tr>
<th>BRAND</th>
<th>Cu</th>
<th>Zn</th>
<th>Pb</th>
<th>As</th>
<th>Fe</th>
<th>Ni</th>
<th>Mn</th>
<th>Si</th>
<th>Sb</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (new)</td>
<td>61.9</td>
<td>34.5</td>
<td>2.01</td>
<td>0.17</td>
<td>0.25</td>
<td>0.07</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>A (old)</td>
<td>62.9</td>
<td>33.4</td>
<td>2.25</td>
<td>0.08</td>
<td>0.31</td>
<td>0.19</td>
<td>0.08</td>
<td>0.17</td>
<td>0.02</td>
<td>0.49</td>
</tr>
<tr>
<td>B (replacement)</td>
<td>66.1</td>
<td>28.5</td>
<td>2.26</td>
<td>0.02</td>
<td>0.30</td>
<td>0.36</td>
<td>0.45</td>
<td>0.69</td>
<td>0.08</td>
<td>0.53</td>
</tr>
<tr>
<td>C</td>
<td>85.4</td>
<td>6.10</td>
<td>5.41</td>
<td>0.01</td>
<td>0.20</td>
<td>0.21</td>
<td>-</td>
<td>-</td>
<td>0.04</td>
<td>2.53</td>
</tr>
</tbody>
</table>

**Note:** Sprinkler A(new) were the originally installed. A(new) had been installed during extension work some years later. B (replacement) were installed when corroded sprinklers initially were replaced. C was eventually used as the final replacement (and has not been shown to suffer from de-zincification during the period after this).

The leakage that had occurred was identified by the Corrosion Institute as having a direct connection with the unsuitable physical properties of brass. A recommendation was made to replace all sprinkler heads to new heads, of type C (or of equal material quality if this could be proven).

**Operational reliability**

The de-zincification was generally not found to affect the safe performance of sprinkler heads in case of fire. Tests performed by a laboratory (SP i Borås) with extensive experience of sprinkler testing, on 12 samples from the facility in question, gave the results to be seen in the table 3 below.

The sampling tests performed in this case happened to be the first tests ever of this kind in Sweden. The at the time newly introduced European standard for the installation of fixed fire fighting systems, EN 12845, has an annex for 25 year interval test of sprinkler head samples. The standard specifies what to test for but does not go into detail of how these tests shall be performed. In order to meet a probably market demand for sample tests, the SP laboratory had prepared a test program of its own and this program was then used to evaluate the sprinkler heads from the corrosion problem site. This meant that a test of RTI-values was also included, regardless of the fact that this had most probably not been affected by the corrosion witnessed.

All tests were made with a water pressure of 0.5 bar. This equals the minimum pressure for the systems installed.
TABLE 3

<table>
<thead>
<tr>
<th>Type of sprinkler</th>
<th>Number of samples</th>
<th>Spraypattern OK</th>
<th>RTI-value OK</th>
<th>Lodgement OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – old (Cu/p)</td>
<td>1</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
</tr>
<tr>
<td>A – new (Cu/p)</td>
<td>1*</td>
<td>1/1</td>
<td>0/1</td>
<td>0/1</td>
</tr>
<tr>
<td>A – old (SSP)</td>
<td>1</td>
<td>1/1</td>
<td>0/1</td>
<td>1/1</td>
</tr>
<tr>
<td>A - new (SSP)</td>
<td>2</td>
<td>2/2</td>
<td>1/2</td>
<td>2/2</td>
</tr>
<tr>
<td>B (Cu/p)</td>
<td>3</td>
<td>3/3</td>
<td>3/3</td>
<td>3/3</td>
</tr>
<tr>
<td>B (SSP)</td>
<td>2</td>
<td>2/2</td>
<td>0/2</td>
<td>2/2</td>
</tr>
<tr>
<td>D (HSW)</td>
<td>1</td>
<td>1/1</td>
<td>1/1</td>
<td>1/1</td>
</tr>
</tbody>
</table>

*1 One of the sprinklers had been damaged during transport, no bulb liquid was present and the test was not valid because of this.

*2 The RTI value of the sprinklers installed was measured against an unused sprinkler with the same 3 mm thermal bulb, having a RTI value of 36. A deviation of less than 10% has been regarded as OK.

As can be noticed, the acceptable tolerance of the RTI-values was not fulfilled for a number of the tested sprinklers. It shall be taken into consideration that the tolerance used, ± 10%, had been picked more or less randomly, this being a new test program for the SP laboratory in Borås. Given the fact that all sprinklers tested were of the glass bulb type it was also seen as probable that the deviation in RTI-values had nothing, or at least very little to do with the dezincification. It should more likely be viewed as an example of the production tolerance being different from the test program tolerance..

The only aspect thus not completely satisfactory was the lodgement problem with one of the sprinklers of type A. Lodgement is the technical term used to describe a situation when, after the activation of the thermal bulb and subsequent release of the pin-cap due to the water pressure of the sprinkler system, the pin-cap "sits" on the sprinkler deflector. This will transform the back-side of the pin-cap to a de facto deflector for the water flowing through the sprinkler orifice, creating an unwanted spray-pattern.

A correct pin-cap will be irregular in its shape, tipping over from the pressure of the water flow. However, a pin-cap with a non-irregular back could be balanced by the steady flow, keeping it in place on top of the deflector.

This could have been caused by the zinc corrosion, as an effect of an altered pin-cap structure.
Conclusion:

It is obvious that more knowledge is needed on the subject of corrosional problems within sprinkler systems. Both European as well as national Swedish sprinkler installation standards need to address in more detail how to minimise corrosion of all types.

Experience from incidents such as the one described in this paper must be included in future routines for commissioning and inspection of sprinkler systems.

No national routines were present to implement any kind of sprinkler head replacement program. It was found that the market had to rely on an individual contractor to fulfill such a program – and this did not happen.

Component standards must include provisions for de-zincification tests. Failures of sprinkler heads can not be tolerated, even under non-fire conditions.

It has been reported that UL-standards now incorporate this test. Verbal communication with representatives for the major European laboratories, VdS in Cologne, Germany and LPCB in the UK, have given the information that "dezincification test have been part of the standrad for many years ". This information needs to be verified and at the same time it is important that current work within CEN as well as ISO Sprinkler Component Groups take this important requirement into account.
The down time for replacing malfunctioning sprinkler heads is an obvious negative for the total system reliability and must be avoided. Routines for inspections need to be improved in order to discover occurring problems of potential replacement needs at an early stage. Certification schemes for both contractors and inspection companies need to include more qualification requirements for issues of welding practices and failure investigation.

Bo Hjorth is the principal of AlbaCon AB, a Swedish fire protection engineering and inspection company with business in more than ten European countries, including Denmark, Norway, Russia, Poland and Germany. Bo Hjorth is a certified engineer in the field of fire detection, sprinklers and gas extinguishing systems and has more than 25 years of experience as an inspection engineer for automatic fire prevention systems. Mr Hjorth serves on numerous national and international code writing committees, including CEN WG5 and NFPA 13 (Discharge Criteria). He is also the author of the Sprinkler Handbook published by the Swedish Fire Protection Association.