



**A European Fire Safety Coalition**

## Corrosion in Sprinkler Systems

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## Introduction

Sprinkler systems are highly reliable, with analyses finding they control or extinguish well over 90% of fires. In countries with requirements for third party inspections and third party installer accreditations reliability is 98% or higher. Yet one acknowledged challenge to sprinkler system reliability is the vulnerability of steel pipes to internal corrosion. The above reliability figures achieved in real fires put that risk in perspective. Nevertheless some of the small numbers of failures may have been due to corrosion. There have also been some high profile leaks caused by internal corrosion. These damage the reputation of sprinkler systems.

This paper aims to give an objective view of the issue and to provide a summary of measures to ensure corrosion does not prevent a sprinkler system from performing as intended or cause it to leak. External corrosion is not addressed in as much detail since it is less complex and more easily monitored. Clearly if a certain material is used because of concerns about external corrosion it will also reduce internal corrosion. By contrast external varnishing or powder coating of steel pipes, common in many European countries, only gives good protection against external corrosion.

An extensive overview of the different types of corrosion that can occur inside sprinkler pipe can be found in the appendix to this document.

Although this paper refers to sprinkler systems, its recommendations also apply to water mist systems, which are particularly sensitive to the effects of corrosion due to the potential for blockages of the smaller water pathways in the water mist nozzles.

## References to Corrosion in Sprinkler Standards

The 2019 edition of the European sprinkler design standard, EN 12845, does not address corrosion of sprinkler piping, except for a brief comment on the need to avoid galvanic corrosion when using copper piping. The next edition, currently under development, includes detailed clauses on how and when to inspect sprinkler systems for corrosion, as well as criteria for when to reject and replace piping. It also incentivises the use of nitrogen generators in dry pipe systems by allowing a C-factor of 120 instead of 100 to be used for Hazen-Williams hydraulic calculations. This is the same as for galvanised pipe, which will no longer be recommended because several countries have experienced accelerated pitting corrosion with galvanised pipe. Even worse, in a very small number of cases explosions in wet sprinkler systems fitted with galvanised pipe are believed to have been caused by the production of hydrogen when zinc reacts with water in certain conditions. A further incentive is introduced for internal polymer coatings that are bonded to the steel, where a C-factor of 140 can be used.

*Note 1: The C-factor is used in the Hazen-Williams formula to calculate the pressure losses caused by friction (of an aged system) as water passes through the sprinkler*

*system pipework. The higher the C-factor, the less friction and the smaller the pressure losses.*

US standard NFPA 13: 2022, the most widely-used fire sprinkler standard throughout the world, requires water supplies to be evaluated for their potential to lead to microbially influenced corrosion (MIC) and has some information on the introduction of corrosion inhibitors and biocides to sprinkler systems. In dry systems one option it gives is to use nitrogen generators. It also requires all additives and internal coatings used to inhibit or control corrosion to be listed for use in sprinkler systems. Where a non-metallic pipe material such as CPVC is used in parts of the system, additives and coatings must also be listed for compatibility with it. The standard also calls for air venting valves to be installed in wet systems to remove as much oxygen as possible. As in EN 12845, dry system range pipes should be pitched to ensure proper drainage after the system has been filled with water, such as for hydrostatic testing. Threaded rather than grooved connections should be used to avoid water collecting at joints. NFPA 13 notes that galvanised steel is not considered corrosion resistant.

NFPA 25, which is the US fire sprinkler maintenance standard, has a section headed Internal Piping Condition and Obstruction Investigation. It requires an internal pipework inspection every five years.

Insurer FM Global has published datasheet FMDS-2-1 *Corrosion in automatic sprinkler systems* which includes advice on the selection of pipe materials and systems to reduce corrosion. FMDS-2-1 accepts nitrogen-filled systems for dry, pre-action systems or vacuum systems, encouraging the use of these technologies by allowing a C-factor (roughness coefficient) of 120 for hydraulic calculations with black steel pipes, where certain conditions are met. Nitrogen significantly improves the corrosion performance of wet systems, with FM commenting that, *'Purging the oxygen from the system, whether it is from trapped air or dissolved in the water, can reduce the corrosion rate. FM Global testing has shown that carbon steel with air in a wet-pipe system corrodes up to 14 times faster than a system that has been purged with nitrogen.'* Nitrogen is well-known as an inert gas that by displacing oxygen inhibits corrosion.

FM Approvals has approved polymer-enhanced pipes, where the polymer is chemically bonded to the inside of the pipe. FMDS 2-1 reflects this and comments that it *'offers improved flow rates and a higher C-factor when performing hydraulic calculations.'* One manufacturer's approval permits a C-factor of 140 to be used in dry, pre-action, wet and deluge systems.

Vacuum sprinkler systems also greatly reduce the oxygen concentration as the air pressure falls. Low air pressure causes residual water in the system to evaporate and be removed with the air, so that the atmosphere inside the pipes is low in oxygen and is dry – conditions that inhibit corrosion. FM Approvals has approved a manufacturer of this technology.

Aside from the above three technical measures, FMDS-2-1, goes into more detail about corrosion risks and gives advice on how to prevent them. FM Global allows the use of galvanized pipes in dry, pre-action and deluge systems although it also states that, "It should be noted that new dry or pre-action systems can develop through-wall

corrosion pinhole leakage from 2 to 3 years after initial installation due to residual water causing corrosion in galvanized steel pipe.” FM does not recommend the use of galvanized pipes for wet systems. More information is given below.

In the newest version of the VdS CEA Guidelines for Sprinkler Systems – Planning and Installation – VdS CEA 4001: 2021-01 (07) VdS “strongly advises against the use of internally galvanised pipes downstream of wet alarm valve stations”. The reason is the potential formation of hydrogen. More background is given in the VdS Data Sheet “Galvanised Pipework in Sprinkler Systems” – VdS 3891. Furthermore, VdS does not recommend the use of galvanised steel in dry pipe systems due to the potential increase of the corrosion rate. VdS has also approved polymer-enhanced pipe with a C-factor of 140 for hydraulic calculations in wet, dry, pre-action, deluge and low pressure water mist systems.

## **Survey results**

It is hard to find general extensive statistical data on corrosion in sprinkler systems. However, the German notified body, VdS, has been logging data from inner pipe inspections for decades, collecting in considerable data on this issue which has informed its approach to controlling corrosion in sprinkler systems.

25-year and 30-year surveys of dry pipe systems by independent inspection bodies such as VdS have found that they are significantly more prone to corrosion than wet pipe systems. For this reason VdS in Germany first inspects dry pipe systems when they are 12½ years old, while it waits 25 years to inspect wet pipe systems. VdS has also found that galvanising pipe in dry systems did not reduce corrosion problems.

### VdS survey results

- VdS inspects sprinklers for damage, release pressure, k-factor, lodgement and release temperature
- Lengths of pipe are also removed for inspection
- In a wet system one installation per building must be checked but in a dry system all installations must be checked
- One branch pipe per 100 sprinklers must be inspected; or at least 3 pipes
- One of each second nominal diameter pipe per 100 sprinklers must be inspected; or at most 3 pipes per diameter.

Corrosion is divided into 3 categories. If little damage is found the pipe array should just be flushed. If medium damage is found, so that some but not all pipes show increased damage, those pipes must be replaced. If there is considerable corrosion and deposits the complete pipe array or parts of it must be replaced.

VdS found in dry pipe, after 25 years:

-33% class I (little damage)

-45% class II (medium damage)

-22% class III (considerable damage)

And in dry pipe, after 12½ years:

-27% class I

- 51% class II
- 22% class III

Based on these data it could be stated that more than 70% of the current dry pipe systems have to be treated for corrosion within 12½ years, of which some 20% of the systems will have to be almost fully replaced.

VdS found for wet pipe systems, after 25 years:

- 65% class I
- 32% class II
- 3% class III

From this data it can be concluded that the life expectancy of the majority of wet pipe systems is at least 25 years.

### **What to do to minimize the risks?**

Corrosion is a normal process in the ageing of all metallic systems. It is important to view the corrosion process against the required lifetime of the system, as well as in combination with the medium it is transporting and the climate it will be in.

*Note: Although the mechanisms are different, it should be realized that ageing also occurs with non-metallic systems.*

Making the right decisions in the design process up front will prevent owners and users being confronted with major problems afterwards. Solving corrosion problems afterwards due to faulty decisions at the design stage is very difficult to accomplish adequately to prevent further problems and will mostly be an expensive process with a large impact on the user of the premises.

### **Workmanship**

Poor workmanship and the use of poor quality materials will in general lead to poor quality installation. This also goes for corrosion problems in sprinkler systems. In many European countries there are systems in place for third party approval of installed sprinkler systems and third party accreditation of sprinkler designers and installers. These designers and installers have demonstrated their competence in all areas of design, installation and maintenance to achieve high quality installed systems. Using these companies will effectively grant the largest chance for the correct quality of the installed sprinkler system.

### **Dry Pipe and Pre-Action Systems**

Dry pipe and pre-action systems are more prone to corrosion than wet pipe systems. They contain air at a few bars pressure. During commissioning the systems are hydrostatically pressure-tested to make sure they do not leak and can withstand the dynamic forces resulting from quickly flooding the pipework in case of fire. During

the lifetime of the system testing is also required, introducing water into it. Despite pitching the range pipes to improve draining, removing all the moisture from the system is almost impossible. Also the compressed air in itself introduces a little moisture and oil into the system. The resulting internal atmosphere is moist and the compressed air means there are more oxygen molecules per unit volume, creating a potential for accelerated oxidative corrosion.

Given the inherent substantial corrosion risk in dry pipe systems good workmanship is particularly important, as is following the sprinkler standards for design, installation, maintenance and use. It is for example important to drain all the water after the pressure test. Additionally, upright sprinklers are fitted wherever possible to ensure water is not left in arm pipes. Range pipes are fitted at a slight slope to assist drainage. A dehydrator should also be fitted to the incoming air supply.

One method to reduce the inherent corrosion risk in dry and pre-action systems is to fill them with nitrogen instead of air. The inert environment has been shown in accelerated ageing tests to lead to much slower corrosion rates and negligible corrosion if the nitrogen concentration is held at 98%. Nitrogen can be supplied from gas bottles or from a nitrogen generator. While the generator has a higher capital cost it is much easier to maintain than replacing heavy gas bottles and offers more accurate monitoring and control of nitrogen concentrations. Due to concerns that nitrogen gas bottles may not be replaced, the use of a C-factor of 120 rather than 100 for Hazen-Williams hydraulic calculations only applies in the new draft of EN 12845 when the nitrogen is continually maintained by a generator.

*Note: Some older dry pipe valves have a layer of water above the clapper, which means the atmosphere in the pipe network is always moist. More modern valves do not require water to achieve a seal and it is therefore possible to desiccate the air entering the pipe network, reducing the potential for corrosion. Nevertheless the use of nitrogen will reduce the likelihood of significant corrosion.*

Another option to reduce the risk of corrosion is to bond a protective polymer to the steel pipes. This technology has long been successfully used in the automotive industry to prevent steel corrosion and has recently been applied to sprinkler pipe. This technology provides a polymer protection which is permanently bonded with the steel surface, both on the exterior and on the interior of the pipes. The polymer-enhanced pipes prevent the contact of water with the steel, significantly reducing the effects of corrosion. A C-factor of 140 may then be used for hydraulic calculations.

A further option to reduce the risk of corrosion in dry and pre-action systems is to draw a vacuum inside the pipe network. At a fraction of atmospheric pressure there are fewer oxygen molecules inside the pipe. The low pressure also causes any residual water to evaporate, so that the conditions inside the pipe are dry and low in oxygen, meaning that corrosion is inhibited. FM allows a C-factor of 120 to be used with black pipe in vacuum sprinkler systems.

*Note: The use of plastic pipe, e.g. CPVC, is not an option in dry systems as their listing is limited to wet systems due to the risk of damage by the fire before the sprinkler activation.*

## **Deluge systems**

Deluge sprinkler systems use open sprinklers or nozzles to protect high-risk areas. As the sprinklers and nozzles are open, atmospheric air is present throughout the entire pipe network. As explained above, certain pockets of trapped water are inevitable in any systems and as the pipes are also in contact with the moisture and oxygen in the air, they are prone to higher levels of corrosion.

Typically, galvanised pipes are used in deluge systems. Other options are to use the polymer-enhanced steel pipes outlined above, or more corrosion-resistant materials such as stainless steel.

## **Wet pipe systems**

As shown from the statistics the chances of corrosion problems in wet pipe systems are much lower than for dry pipe systems. Wet pipe systems in a regular indoor climate, filled with potable water, properly installed and maintained according to the applicable sprinkler standards, will in most cases not show an excessive formation of corrosion and be able to last their expected lifetime.

Preventing draining and refilling of the system as much as possible during alarm valve maintenance, by using a stop valve above the alarm valve, will help to reduce the speed of corrosion because less oxygen is added into the system. Similarly, the functional test of the alarm can be conducted without introducing aerated water into the system. Venting trapped air in the system after filling will also help to reduce the speed of corrosion. Vent valves are already required in NFPA 13 and FM data sheets and will be required in the next edition of EN 12845. Purging the system with nitrogen before filling it with water can significantly reduce the rate of internal pipe corrosion (by as much as 14 times in testing conducted by FM Global).

As for dry pipe applications, polymer enhanced pipes may be used in wet systems.

## **Additional risks**

Additional risks could be introduced by:

- The use of non-potable water in the system such as water from lakes, canals or wells. This will introduce bacteria that can cause MIC and possibly dirt into the system, increasing the risk of pit corrosion. Also high concentrates of chlorides can be introduced into the system
- Harder water, which has a higher pH and contains more salts, increasing its conductivity and the rate of steel corrosion
- Desalinated water, which being low in dissolved salts has a high potential to dissolve solid materials, corroding pipes. This tendency can be reduced by adding naturally occurring minerals such as calcium or magnesium salts
- Outside conditions and more aggressive climates in which the system has to function. Such can be the case at paper mills, indoor pool areas, salty sea air conditions or chemical plants

- Non ambient temperatures such as extremely high or low temperatures, or frequent temperature changes. This affects both the speed of processes inside as well as the corrosion resistance of the pipes.

The risk review in the design process should lead to measures to prevent the risk of excessive corrosion:

- The application of material with a higher corrosion resistance:
  - Using pipe with higher wall thickness to create more allowance for corrosion. This will be effective with surface oxygen-based corrosion, but less effective for pitting corrosion, which can be more rapid
  - Use of pipes with a listed or approved treatment for combating corrosion
  - Using higher grades of steel, such as a type of stainless steel. The type of steel needs to be appropriate for the conditions
  - Using plastic type tubing like CPVC, PPR or PE multilayer. Although corrosion resistant, these products cannot be used in most industrial and many commercial applications. The correct application is always specified in their third party system approval
- Using a corrosion inhibitor. This should be done with a dosing system as the inhibitor will be flushed during the testing of the sprinkler system.
- Using specific maintenance and testing schemes, including automatic testing devices, to limit refilling of the system and prevent aggressive water from entering it.
- Increased inspection frequency to monitor the amount of corrosion damage so as to allow intervention before corrosion becomes excessive.

### How to monitor the effects on my system?

Ultrasound can detect residues inside pipe or reduced pipe thickness. Since pressure loss increases with the square of flow rate, what may seem a small reduction in cross-sectional area can have a significant effect on pressure loss, especially in smaller diameter pipes. The deposits also roughen the interior pipe wall, further increasing frictional pressure loss as the C-factor reduces. Note that solid materials dislodged during flushing can accumulate in arm pipes and block pendant sprinklers.





*Photos: ANPI Belgium*

It is also possible to internally inspect pipes using an endoscopic fibre-optic probe. Sections of pipe can also be removed for a more thorough inspection. These inspections take the system out of service and therefore should only be performed at lengthy intervals or if the system is out of service for another reason.



*Photo: FM Global*

A severely corroded pipe from a 12 year old wet pipe system

### **Corrective measures**

When it has become apparent from inspection that there has been considerable damage done to the system, or that the performance of the systems is at considerable risk due to deposits reducing the cross-sectional area, corrective measures need to be taken. First of all an analysis is needed to determine which specific corrosion processes have been responsible for the damage and what the root causes for these processes have been (normal ageing, incorrect design, poor workmanship, poor material quality, poor water quality, etc). It is important to understand the causes of the corrosion since that will indicate which corrective actions should be taken.

There are a number of measures that can be undertaken in treating the effects and the cause of excessive corrosion:

- Exchanging poor material choice for better quality
- Internal cleaning of the system
- Treating the surface of the pipes with coatings
- Improving the water quality by use of water treatment
- Taking the oxygen out of the system
- Restoring poor workmanship

Generally a combination of the above will be necessary to deal effectively with the problem. There are no quick fixes once the wrong decisions have been made up front. Independent corrosion experts can advise the appropriate measures to be taken.

## **Some specific topics**

### *Dezincification*

In water with higher pH values there have been cases where zinc has leached out of the brass and left the remaining metal structure porous. This has happened with sprinklers as well as with valve clappers. Increasing the copper content of the brass seems to have cured the problem. Since 2004 UL has tested sprinklers for their tendency to become porous and the sprinkler manufacturers have increased the copper content of the brass alloys used in sprinkler bodies to above 85%.

To reduce the risk of dezincification, water with a pH above 9.0 should not be used in sprinkler systems.

### *Welding*

Stainless steel pipe can be required if the external or internal environment is corrosive, or for hygiene purposes as in the pharmaceutical and food industries. Connections are often welded in these systems. Welding of steel can cause its composition to change around the weld. This produces a streaked look. If the composition of the steel is not consistent electro-chemical corrosion can occur.

Whenever pipe connections are made by welding, it should be done in controlled, preferably off-site, conditions where a sufficient supply of backing gas and surface treatment of the weld can be guaranteed.

### *Biocides*

One solution to prevent anaerobic corrosion is to treat the water with biocides such as chlorine, iodine, hydrogen peroxide, ozone, ammonium compounds, organo-sulphur compounds, bromines, carbamates and isothiothiazalone. These chemicals destroy the bacteria and their bio-film habitats. However, use of these chemicals may be banned or limited due to health concerns, in particular for service fitters who would be regularly exposed to them. Moreover introduction of these chemicals in the proper concentration is difficult as is their removal, in particular in systems with pendent sprinklers. Some chemicals have been found to be incompatible with water seals and gaskets, leading to leaks over time.

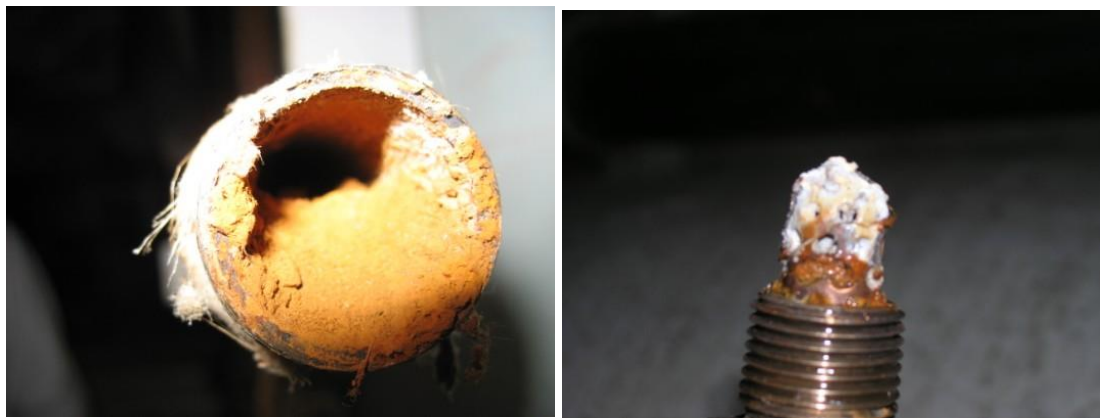
### *Corrosion inhibitors*

Another approach is to coat the pipe internally with a dynamic bio-static corrosion inhibitor. This can be applied during manufacture of the pipe or by mixing it with the water used during system commissioning pressure test. Some of these products can weaken CPVC pipe, which itself is resistant to corrosion but which is always downstream of a steel manifold and riser in a sprinklers system. Fortunately some corrosion inhibitors are compatible with CPVC so consult the CPVC pipe manufacturer.

## Appendix

### What is Corrosion and where does it occur?

All metallic parts of a sprinkler system, i.e. the pumps, valves, pipes, supports and sprinklers may be subject to corrosion. In some cases this can lead to a hole in a pipe, complete blockage of a pipe, a valve or a sprinkler refusing to open or pipes being inadequately supported. All types of systems can be affected, although field experience has shown that dry pipe systems are more prone to serious corrosion than wet pipe systems. Sprinkler pipe is usually black pipe or plain carbon steel. At ambient temperature and in contact with water and oxygen this steel will oxidise. This is the most common corrosion mechanism but there are others and often more than one can be at work. Below is a short account of the different types of possible corrosion mechanism.



*Photos: ANPI Belgium*

### Electro-chemical corrosion (wet corrosion)

Chemical reactions can cause corrosion leading to pits and sedimentation. Steel pipe is 98% iron. Iron forms positively charged ions which dissolve in the water. Oxygen dissolved in the water can form hydroxide ions which react with the iron to form iron hydroxide. This process is faster in small crevasses. Every time a wet pipe system is flushed, fresh oxygen is introduced and this process is encouraged.

### Under Deposit Corrosion

Under deposit or crevice corrosion can form under sediment, deposits of debris or corrosion products. This is very common and is one of the primary mechanisms of corrosion in sprinkler system pipe. The corrosion products settle at the bottom of the pipe in both wet and dry systems, setting up an ideal environment for a corrosion pit or crevice to develop. As the corrosion deepens the pit, the corrosion process accelerates. Very often a large structure of corrosion products called a tubercle will grow over the pit and restrict water flow through the pipe.



*Photo: FM Global*

Sprinkler pipe interior showing an under deposit pit following the removal of a large tubercle. This pit resulted in a pin-hole leak in the sprinkler pipe.

### **Galvanic Corrosion**

Different metals, in physical contact with each other and in the presence of an electrolyte such as the water in a wet pipe system, create an electric current between them, with the strength of the current and consequent speed of corrosion affected by the difference in the electrode potential of the metals. Ions migrate into the water from the metal with the more negative electrode potential. An example is a steel plug in a stainless steel pipe. The iron dissolves and the plug can fall out. This error has led to major leaks of expensive foam concentrate from foam extinguishing systems.

### **Microbiologically Influenced Corrosion (MIC)**

Microbiologically influenced corrosion or MIC can cause pinhole leaks and obstructive growth. Bacteria are naturally present in soil, water and dust so one way to reduce the potential for this form of corrosion is to make sure pipes are clean by flushing them during commissioning and filling them with clean water. The bacteria can be aerobic or anaerobic, aerobic meaning they need oxygen. Corrosion due to aerobic bacteria in dry pipe systems can be largely prevented by using nitrogen rather than compressed air in the pipe network.

There are different types of anaerobic bacteria, for example acid-producing bacteria and sulphate-reducing bacteria. Acid-producing bacteria produce a number of organic acids able to corrode steel, iron, copper zinc and even the bronze body of a sprinkler. Acetate ions produced by these bacteria are a nutrient for sulphate-producing bacteria. They release hydrogen sulphide, H<sub>2</sub>S, which has the characteristic smell of bad eggs

and dissolves in water to form a weak acid. In solution sulphide ions attack the iron in the pipe to form iron sulphide, which can give sprinkler system water a black colour.



*Photos: ANPI Belgium*

### **Limescale Accumulation**

Bicarbonates dissolved in water react to form insoluble calcium carbonate, water and carbon dioxide.



The limescale can affect the proper release of the water seal on a sprinkler and can form a site for the development of MIC.