White Paper

Monitoring Corrosion in Water Based Fire Sprinkler Systems

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Corrosion can be defined as the deterioration of metal through chemical interaction with the surrounding environment. In the simplest chemical expression, the subject metal gives up electrons to form a metal ion that generally precipitates as an oxide by-product. In the case of fire sprinkler systems, black steel or galvanized steel piping reacts with dissolved oxygen in the fire supply water to form iron or zinc hydroxide. The net effect is metal loss from the pipe wall (pit) and insoluble debris in the piping.

Anodic Reactions:

$\mathbf{Fe^o \rightarrow Fe^{+2} + 2e^-}$ iron becomes a water soluble ion

$\mathbf{Zn^o \rightarrow Zn^{+2} + 2e^-}$ zinc becomes a water soluble ion

Cathodic Reaction:

$\mathbf{½O_2 + H_2O + 2e^- \rightarrow 2OH^-}$ oxygen creates demand for e-

Electrochemical Reaction:

$\mathbf{Fe^o + ½O_2 + H_2O \rightarrow Fe(OH)_2\downarrow}$ iron hydroxide precipitate

$\mathbf{Zn^o + ½O_2 + H_2O \rightarrow Zn(OH)_2\downarrow}$ zinc hydroxide precipitate

Corrosive degradation of fire sprinkler piping used in water based fire sprinkler systems is well documented[1,2,3,4]. Empirical evidence from the field indicates that fire sprinkler piping is particularly vulnerable to weld seam corrosion[5]. From a life safety and fire loss standpoint, risk increases when insoluble by-product from the corrosion reaction accumulates within the fire sprinkler piping. Not only can the corrosion debris affect the hydraulic performance of the system design, it can also plug drops and sprinklers. However, the problems caused by water damage due to pin-hole leaks that result from oxygen corrosion may pose the most immediate financial risk for a property owner.

Fire Sprinkler System Corrosion Risks

- Plugging of sprinkler piping
- Plugging of sprinklers
- Reduced hydraulic performance
- Water leaks
- Reduced service life
- Repair costs
- Business interruption

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One of the systemic problems with corrosion in fire sprinkler systems is that the systems themselves tend to fall into the category of "out of sight, out of mind." After they are installed, property owners, business managers and fire personnel alike hope that they will never be needed or deployed. Unfortunately, corrosion continues within the fire sprinkler system piping even though the external manifestations of the corrosion activity may remain hidden for years. Every time an air compressor operates to maintain the pressure in a dry pipe sprinkler system warm, moist oxygen is added to the internal piping environment. Similarly, every time a wet pipe system is drained and filled, fresh oxygen in the air is added and trapped somewhere within the piping network to reignite the corrosion reaction.

Given the nature of corrosion in these systems and the insidious damage that is being done, waiting for the inevitable first leak may be the most risky approach. The first leak may create a very significant financial loss.

Corrosion Management Strategy

Developing a strategy for managing corrosion in any industrial application involves the following five steps:

1. Root cause determination – what is the active corrosion mechanism?
2. Assessment of corrosion damage – remediation, repair or replacement of damaged equipment (location and severity of corrosion)
3. Implementation of corrosion management plan – installation of corrosion control equipment and monitoring devices
4. Equipment inspection and maintenance – routine inspection of corrosion control equipment and preventative maintenance
5. Ongoing monitoring of corrosion – in-situ early warning system to detect elevated corrosion rates

If a plan is to be implemented to reduce corrosion related risk, it follows that there must be a mechanism to gauge the effectiveness of the plan that has been deployed. The more significant the corrosion related risk, the more important the corrosion monitoring. It would not be prudent to implement a corrosion control plan without an accurate early warning system to verify that everything is under control. The discussion presented here will concern itself specifically with monitoring corrosion within the fire sprinkler system piping.

It should be noted that there are settings where the risks associated with a corrosion related failure in the fire sprinkler piping are much higher than other settings. For example, monitoring corrosion in a preaction sprinkler system protecting a mission critical data center would certainly be more important than monitoring corrosion in a dry pipe sprinkler system in a parking structure. But the bottom line is that corrosion related leaks in fire sprinkler piping create financial risk whether they are in a wet pipe sprinkler system protecting a pharmaceutical warehouse or in a retail setting at a home improvement center.

Monitoring Corrosion

Corrosion monitoring is a very important element in a comprehensive corrosion management strategy for water based fire sprinkler systems. An effective corrosion monitoring program should provide evidence that the corrosion control program is working to prevent metal degradation. It should also provide "early warning" for elevated corrosion activity so that steps can be taken to return the system to a state of corrosion control before damage occurs and a failure results.

In any corrosive environment physical degradation of the metal can occur in two different ways. General thinning of the metal across broad areas which leads to gradual loss of the wall thickness and pitting attack which results in highly localized loss of the metal at specific points on the pipe surface. Pitting attack is particularly troublesome because it can lead to premature breaches in the pipe wall in an otherwise moderately damaged surface. Most leaks in fire sprinkler system piping occur because of pitting corrosion.

There are three direct effects of the corrosion process that can be measured to provide an indication of the corrosion rate:

1. **Electrons flow out** from the metal that is being corroded
2. **A void** (pit) is created at the metal surface where the corrosion event has occurred
3. A **metal by-product** (oxide salt) is produced from the corrosion event

Corrosion monitoring methodologies take advantage of one or more of these corrosion effects:

1. Measure and record the **electron flow** (current)
2. Measure the **damage** that has occurred at the metal surface (pitting and wall thinning)
3. Measure the accumulation of **corrosion by-product**

Corrosion monitoring can be **instantaneous** or **time-averaged:**

- **Instantaneous corrosion monitoring** generally measures current flow for a sample of the subject metal within the exposed corrosive environment. Measuring the presence or absence of the corrosive gas within the system is also an instantaneous method. The benefit of instantaneous corrosion monitoring is that it can provide real time data regarding the actual corrosion conditions at any point in time. If corrosion rates vary with operating conditions, instantaneous monitoring can identify time intervals when corrosion rates are at maximum and minimum levels.
- **Time-averaged corrosion monitoring** exposes a sample of the subject metal and measures the metal loss over a given exposure period. Time averaged corrosion monitoring can also analyze damage that has occurred in the piping itself over time. The weakness of time averaged

corrosion monitoring is that it cannot differentiate time intervals (events) when the corrosion rate is elevated.

Corrosion monitoring can be **direct** or **indirect**:

- **Direct corrosion monitoring** measures the direct impact of corrosion on the subject metal in-situ as it is exposed to the actual corrosive environment.
- **Indirect corrosion monitoring** measures the production of corrosion by-product (e.g. hydrogen gas, metal ions or by-product) and uses the results to provide some correlation to the corrosion activity within the system.

Corrosion Monitoring in Fire Sprinkler Systems

One complicating factor associated with the corrosion reaction in fire sprinkler systems is that corrosion rates vary greatly throughout the piping system. For example, in wet pipe sprinkler systems the corrosion rate will be greatest at the point that is **proximate to any trapped air** within the system piping. As oxygen in the air dissolves into the water it immediately reacts with the first steel it contacts to form iron oxide. So the air/water interface represents the most active corrosion site within these systems. At fluid packed points within the piping system that are more removed from the trapped air corrosion rates will be quite low. In general, the rate of corrosion is directly proportional to the amount of oxygen that is introduced and available.

In dry pipe sprinkler systems the corrosion rates will be highest at locations where **water has pooled** within the piping. In dry pipe systems there is an excess of oxygen for the small amount of pipe surfaced that is covered with trapped water. In areas within the dry pipe network that remain dry, the corrosion rates will be essentially zero. Other factors that increase the rate of corrosion include temperature, solids and operating pressure.

Given the localized nature of oxygen corrosion in fire sprinkler systems, placement of corrosion monitoring device is very important. Improper placement may lead to readings that do not reflect the highest risk for corrosion failure within the system. In general, the closer the monitoring device can be placed to the highly active corroding sites, the better.

NFPA 13 Corrosion Monitoring Requirements

The 2013 edition of the NFPA 13 Standard for the Installation of Sprinkler Systems discusses the use of corrosion monitoring in conjunction with the following sections:

24.1.5.1 *Where conditions are found that contribute to MIC, the owner(s) shall notify the sprinkler system installer and a plan shall be developed to treat the system using one of the following methods:*

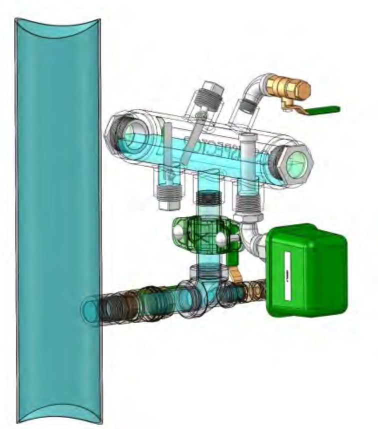
1. *Install a water pipe that will not be affected by the MIC microbes*
2. *Treat all water that enters the system using an approved biocide*
3. *Implement an approved plan for <u>monitoring the interior condition</u> of the pipe at established time intervals and locations*
4. *Install <u>corrosion monitoring station</u> and monitor at established intervals*

24.1.5.2 *Where conditions are found that contribute to unusual corrosive properties, the owner(s) shall notify the sprinkler system installer and a plan shall be developed to treat the system using one of the following methods:*

1. *Install a water pipe that is corrosion resistant*
2. *Treat all water that enters the system using an approved corrosion inhibitor*
3. *Implement an approved plan for <u>monitoring the interior condition</u> of the pipe at established time intervals and locations*
4. *Install <u>corrosion monitoring station</u> and monitor at established intervals*

Riser-Mounted Corrosion Monitoring Station

The most common type of time-averaged, direct corrosion monitoring is the use of corrosion coupons. In this technique, pre-weighed samples of the subject metal are inserted into the corrosive environment and exposed for a measured period of time. The weight loss relative to the initial weight is used to determine the level of corrosion activity. In order to accurately reflect the corrosion within the system, it is very important that the metal coupons match the piping material and that they be installed at a location where corrosion is most active.



In many industrial process applications it is common to insert removable corrosion coupons at a point within the system piping where they can be easily removed for inspection. Coupon placement within fire sprinkler system piping is restricted because the coupons within the path of water flow can create an obstruction. As a result, within the fire sprinkler industry corrosion monitoring stations have been installed on the fire sprinkler riser to mimic the conditions within the fire sprinkler system piping. To simulate wet pipe sprinkler systems a trapped air pocket is created within the station. To simulate dry pipe sprinkler systems a pool of trapped water is created within the station. Corrosion coupons are installed in the stations to measure the effect of oxygen corrosion on the subject metal. Additionally, a thin walled probe can be used to provide an early warning signal through the use of an attached pressure switch. Although the approach has limitations, to this point it has been the most common corrosion monitoring technique in the fire sprinkler industry.

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Concerns:

- Corrosion monitoring station may not see the same environment as the actual fire sprinkler system piping – temperature, solids, water flow during testing of the system
- The volume of oxygen per exposed unit of metal within the system piping may be significantly higher than the amount that is present within the corrosion monitoring station
- Corrosion coupons are not completely representative of the interior surfaces of the fire sprinkler system piping itself – lack of weld seam, solids build up
- Coupons do not provide an early warning signal – data regarding the corrosion rate is only available when the coupons are pulled and inspected

Gas Analyzer

Gas analyzers can be used as instantaneous, indirect measure of the level of corrosive gas within the fire sprinkler system piping. With the advent of nitrogen inerting in dry pipe fire sprinkler systems, this technique is very useful because it measures the amount of oxygen and assumes that there is a direct correlation between the amount of oxygen gas that is available and the instantaneous corrosion rate.

Concerns:

- Oxygen sensor may require frequent calibration if subject to drift
- Unless the gas from the system piping is monitored continuously, the gas reading only provides instantaneous measure of oxygen concentration at that point in time
- Does not provide actual corrosion (metal loss) data – indirect correlation

In-Line Corrosion Monitor

The ideal corrosion monitoring device for a fire sprinkler system would have the following attributes:

- Can be sized to be installed in-line directly within the fire sprinkler system piping network at the point where oxygen corrosion is expected to be the most severe:
    - Where air is trapped within the piping in wet pipe sprinkler systems
    - Where water is pooled within the piping in dry (preaction) sprinkler systems
- Does not create an obstruction risk to the water flow within the fire sprinkler system piping
- Can provide a 360^{o} interior pipe surface that is identical to the fire sprinkler system piping
- Can be composed of the same metallurgy as the fire sprinkler system piping – black steel or galvanized steel

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- As an in-line device it can be exposed to all of the environmental factors that the system piping sees – flow tests, solids, temperature fluctuations
- Provides an early warning "failure" signal to indicate that the corrosion rate is at an unacceptable level
- Can be easily installed and removed for inspection post mortem in the event of a failure signal

The in-line corrosion monitor should be comprised of the following:

1. The core component is a piece of fire sprinkler pipe that matches the system that will be monitored in size, schedule and composition (figure 1).
2. A portion of the pipe is milled down from the outside to create a "thin-walled" section at the center of the pipe (figure 2).
3. A secondary housing is welded over the thin-walled section of the pipe to create a pressure chamber (figure 3).
4. A pressure switch is attached to the pressure chamber to provide a detection response in the event that the thin-walled section is breached by the action of corrosion (figure 4).
5. The ends of the pipe section are roll grooved for easy installation into the fire sprinkler system piping network.
6. The pressure switch signal is connected to the building management system or to the fire alarm panel as a supervisory signal.

Figure 1

Figure 2

Figure 3

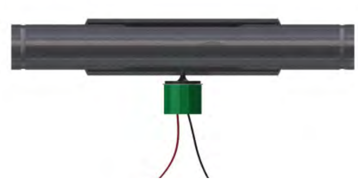

Figure 4

Measuring the effectiveness of any corrosion control program through ongoing monitoring of the protected system is essential. The unique attributes of wet pipe and dry pipe fire sprinkler systems means that the corrosion monitoring program must provide early warning and not affect the effective operation of the fire sprinkler system itself. The in-line corrosion monitor design described above meets those criteria.

References

[1] ***"Under-Deposit Corrosion at Weld Seams in Carbon Steel Piping"***, Andrew G. Howell, NACE International Corrosion 97.

[2] ***"MIC is NOT the Primary Cause of Corrosion In Fire Sprinkler Systems"***, Jeffrey T. Kochelek, Sprinkler Age Magazine, October 2009

[3] **"Galvanized Steel Piping in Dry and Preaction Systems – Six Reasons Why it Should NOT Be Used"**, Lucas Kirn and Jeffrey T. Kochelek, Sprinkler Age Magazine, May-June 2011

[4] ***"Steel Piping Material Corrosion – Dry and Pre-Action Fire Protection Systems"***, Paul Su and David B. Fuller, Sprinkler Age Magazine, February 2013

[5] Evidence from ***Failed Sprinkler Pipe Analysis*** done by St. Louis Testing Laboratories on field samples from operating fire sprinkler systems – source Engineered Corrosion Solutions, LLC

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Engineered Corrosion Solutions, LLC is a corrosion management consulting firm that offers fire sprinkler system assessment and analysis coupled with design services and a full suite of corrosion management strategies that include equipment and integrated devices for controlling corrosion in water-based wet, dry, and preaction fire sprinkler systems. We understand the science of corrosion in fire sprinkler systems in a complete variety of different settings from parking structures to warehouses to clean rooms to data centers.

Engineered Corrosion Solutions, LLC offers proprietary dry pipe nitrogen inerting technology (DPNI) and wet pipe nitrogen inerting technology (WPNI), which includes the ECS Protector Nitrogen Generator, Pre-Engineered Skid Mounted Nitrogen Generator, Gas Analyzers, SMART Dry Vent, Two (2) Wet Pipe Nitrogen Inerting Vents and the industry's first real time in-situ corrosion monitoring device the ECS In-Line Corrosion Detector. Finally, we offer the first comprehensive remote corrosion monitoring system that provides live validation of the corrosion control strategy that is in place within your facility.

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