White Paper

Controlling Corrosion in Fire Protection Systems Protecting Cultural Resources

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Providing fire protection systems for cultural resources (museums, libraries and antiquities) poses several interesting dilemmas when it comes to sprinkler design considerations. Although it seems quite prudent to install fire sprinklers to mitigate the risk that fire might damage or destroy the cultural resources, there are real and quantifiable risks associated with the act of placing water filled piping above these invaluable collections or invaluable facilities. Accidental water discharge and leaking pipes can pose intolerable risks.

This risk is further complicated by the fact that fire sprinkler systems are typically constructed of black steel or galvanized steel piping which are both subject to severe corrosion attack. In its quiet, often mysterious way, corrosion can be an insidious enemy which will eventually lead to failures in the piping that will wreak havoc on a cultural resource facility and its proprietors.

The Appropriate Fire Sprinkler Design Choices

There are two broad classifications of water based fire sprinkler systems: wet pipe systems which are always filled with water (and trapped air) and dry pipe systems (including preaction) which only see water during testing or when a fire event occurs. In the normal standby mode, the pipes are filled with pressurized air. The vast majority of installed water-based fire sprinkler systems are wet pipe systems. Dry pipe fire sprinkler systems are used for two broad classifications of structures:

- Structures that are subject to **freezing conditions** which would cause water filled fire sprinkler pipes to rupture – (e.g. parking structures, garden centers, airports, attics, freezers, cold storage facilities, etc.)
- Structures whose contents are **hydrophobic** and cannot tolerate the risk of proximate water above them – (e.g. data centers, museums, libraries, specialty manufacturing, etc.)

The simplest dry pipe fire sprinkler design uses pressurized air in the system piping to hold a clapper on a dry pipe valve closed as the system stands idle. When a sprinkler fuses during a fire event, the resulting pressure drop allows the dry pipe valve to open and release water into the piping network and ultimately through the open sprinkler. Within the dry pipe category, the single interlock preaction design adds another layer of security to the design for "strict hydrophobes". Water cannot fill the single interlock preaction system piping unless both the pressure drop from the fused sprinkler and an electronic signal indicating smoke or heat occur simultaneously. When the two independent signals are received, an electronically controlled latch triggers the preaction valve and water is released to flood the fire sprinkler piping network. Single interlock preaction systems have been the design of choice for protecting cultural resources because they pose the lowest risk of accidental water discharge in the water-based fire protection arena and are often much lower cost than alternative gaseous systems. Often, even if cost were not a factor, it is not practical to employ alternative fire protection strategies.

Understanding the Root Causes of Corrosion in Water Based Fire Sprinkler Systems

For some time now, the fire sprinkler industry and the National Fire Protection Association (NFPA) have focused on the identification and prevention of one specific "influencer" of corrosion activity in fire sprinkler system piping, namely, microbiologically influenced corrosion (MIC). Even the language in NFPA 13 and NFPA 25 standards provide guidelines for sampling, analyzing and responding to MIC within fire sprinkler systems.

It is true enough that certain bacteria can be integral to the corrosion process in many pipeline applications. The most aggressive types, the acid producing bacteria (APB) and the sulfate reducing bacteria (SRB) can contribute directly to the corrosion process by creating a secondary reduction reaction[1] that depolarizes the cathode and speeds up the corrosion reaction. MIC is without question a real, verifiable phenomena[2].

Within the fire sprinkler industry much time and money are spent every year looking down in the pits and crevices of through-the-wall failures in fire sprinkler piping. When the certified laboratory has completed the analysis, the culture media often reveals that there are in fact many kinds of bacteria within the warm, fresh water environs that exist in these systems. Even electron microscopy clearly shows the presence of organisms in most of the failed pipe samples that are analyzed.

The mere presence of bacteria in the pits and crevices and attached to the walls of failed piping does not indict them as the primary driver of the corrosion reaction. After having inspected hundreds of failed pipe samples to investigate metal loss characteristics like pit location, pit depth, pit shape, metal texture and the associated corrosion by-product solids, ECS has concluded that MIC accounts for less than 10% of the through-the-wall pipe leaks[3]. Other labs have verified those findings. When it comes to fire sprinkler system piping, oxygen is by far and away the predominant corrosive specie and accounts for 90+% of the failures that occur.

Corrosion Related Failures in Single Interlock Preaction Fire Sprinkler Systems

All dry and preaction fire sprinkler systems leak air. And although the NFPA standards have specific limits to the amount of leakage allowable after installation, all dry and preaction fire sprinkler systems require compressors or shop air to maintain system pressure due to air leakage. As buildings settle over time and the sprinkler piping shifts with ambient temperature fluctuations, air leakage from the system will ultimately increase with age, so compressors tend to run more often as systems get older. Each time the compressor goes on, warm, moist, oxygen rich air is added to the system.

Dissolved oxygen in the small pools of trapped water within the fire sprinkler piping is the primary cause for the corrosive conditions that exist within single interlock preaction systems. And although there is an awareness that pitching the pipes and draining water is important, it is virtually impossible to remove all of the moisture. If water could be completely removed or prevented from ever entering the system corrosion of the black steel and galvanized piping could be virtually stopped. Corrosion cannot occur without liquid water. Even a small amount of moisture combined with the oxygen that is introduced with the pressure maintenance air creates a very corrosive environment. There are typically three sources for the trapped water:

1. Water that cannot be drained by gravity from the system piping after initial hydrostatic testing of the system after installation (required by the NFPA 13)
2. Water that condenses from the moist air that is injected with the pressure maintenance air
3. Water that is introduced during periodic fire sprinkler system testing (required by the NFPA 25)

Desiccant and regenerative dryers have been used in conjunction with compressors to try to prevent the introduction of new moisture when the compressors operate, however, the dryers cannot remove water that is already trapped within the system piping and dryers require maintenance to consistently dry the compressed air. The bottom line is that the internal environment of the piping can be considered *persistently moist and oxygenated*.

The amount of wetted metal found within the piping is the rate limiting component that controls the frequency and severity of corrosion that occurs in single interlock preaction systems. Oxygen exists in abundance to drive the corrosion reaction inside the pipe. The corrosion reaction is the same, whether the metal is iron or zinc:

Anodic Reactions: $Fe^{o} \rightarrow Fe^{+2} + 2e^{-}$ iron becomes a water soluble ion
$Zn^{o} \rightarrow Zn^{+2} + 2e^{-}$ zinc becomes a water soluble ion

Cathodic Reaction: $\frac{1}{2}O_2 + H_2O + 2e^{-} \rightarrow 2OH^{-}$ oxygen creates demand for e-

Electrochemical Reaction:

$Fe^{o} + \frac{1}{2}O_2 + H_2O \rightarrow Fe(OH)_2\downarrow$ iron hydroxide precipitate
$Zn^{o} + \frac{1}{2}O_2 + H_2O \rightarrow Zn(OH)_2\downarrow$ zinc hydroxide precipitate

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Galvanized Pipe - A Potential Corrosion Control Approach for Preaction Fire Sprinkler Systems?

The use of galvanized piping has been proposed as a remedy for corrosion in dry and preaction fire protection systems. Although there are several different galvanization methods, the end result is that alloyed layers of zinc are applied to the base metal which is mild steel. The zinc coating that is applied to the mild steel provides two forms of corrosion protection:

1. The zinc acts as a barrier which prevents the corrosive fluid from contacting the iron in the mild steel base metal. Since the iron never contacts the water, the base metal will not corrode.
2. Zinc is less noble than iron and as such is more prone to corrosion than iron. Zinc can act as a "sacrificial anode" for the iron in the base metal and will thereby protect the base metal.

In order for galvanized steel to provide effective corrosion protection the zinc layer must form a passive film of zinc carbonate on the metal surface. Zinc carbonate is a tenacious, impervious film that can significantly reduce corrosion. The zinc passivation process involves three separate chemical transitions:

Zn^{o} (zinc metal) → **ZnO** (zinc oxide) → **$Zn(OH)_2$** (zinc hydroxide) → **$ZnCO_3$** (zinc carbonate)

The final transition from zinc hydroxide to zinc carbonate requires that the metal be in direct contact with carbon dioxide in the air. The final transition also requires that the metal surface be allowed to **dry completely**. If the metal surface does not dry completely, then the zinc metal continues to dissolve in the water and forms a zinc hydroxide scale deposit. The rate of drying is an important factor because a thin moisture film with high oxygen concentration actually **accelerates** the rate of zinc corrosion[4].

In dry and preaction fire sprinkler systems that have persistently wet low spots, the protective layer of zinc carbonate that is required for the galvanized coating to protect the base metal never forms. As the zinc hydroxide continues to dissolve, the zinc coating is eventually breached and the iron in the base metal is exposed to the corrosive water. The exposed mild steel will corrode quite rapidly in the oxygen rich environment that the dry system creates in the trapped water. The bottom line is that galvanized steel piping **IS NOT PROTECTIVE** in systems that are persistently exposed to moisture as is the case in virtually all dry and preaction fire protection systems.

There is now a significant body of evidence that suggests that the use of galvanized steel pipe in dry and preaction fire sprinkler systems may expose those facilities that have opted to use galvanized pipe to the risk of premature system failure due to internal corrosion. Conditions that typically exist within dry and preaction fire sprinkler system piping create an environment in which zinc coated mild steel will corrode, sometimes quite aggressively.

Galvanized steel piping is marketed as a solution for preventing corrosion in dry and preaction fire protection systems. The raw piping cost comes at a 30 – 40% cost premium. When there is water present inside the piping, the galvanized coating will corrode and it will eventually be breached. The irony is that once the breach in the zinc layer is created, the exposed uncoated black steel will corrode at a much ***faster rate*** than the rest of the piping where the galvanized layer remains. The end result of this process is a deep pit and with time a pin-hole leak that forms much faster than it would in a black steel system. Dry and preaction systems utilizing galvanized steel piping have had failures in as few as 18 months and have required complete replacement in as little as 4 years.

For those cultural resource facilities managers and museum proprietors who have installed galvanized steel piping with a single interlock preaction system believing this approach was the optimum approach for mitigating the risk due to corrosive failures this message is very clear. Installing this type of system and assuming all the problems with corrosion are solved does not eliminate risks but may in fact increase the risks.

Heat Annealing Not Required for Fire Sprinkler Piping

Another corrosion complication arises from the fact that the ASTM standards (ASTM 795-96) for piping used in all fire protection systems DOES NOT require that the piping be heat annealed to normalize the electric-resistance or furnace welded seams in the metal tubing. As a result, once the galvanized layer is breached, it is highly likely that the pipe’s seam will exhibit anodic character and corrode preferentially to the other exposed black steel. Piping with seams that are fortuitously positioned in the bottom of piping that is persistently moist will leak first. The failure will exhibit the characteristic “knife cut” metal loss on or near the pipe’s seam.

A Call for Action – DO NOT Wait For the First Leak

Given the aggressive nature of the corrosive attack of galvanized steel, complacency is not an option. Once again, the rate of corrosive attack is tied to the amount of wetted metal within the system. As such, if the fire sprinkler system was designed properly to facilitate draining of all the trapped water then the incidents and severity of corrosion would be reduced. It will still exist, but the damage will be less severe. The problem can be further reduced if auxiliary drains have been installed to remove water and condensate from the piping system on a routine basis. But for those galvanized systems that have large amounts of piping with trapped water, once the leaks start, the number and frequency will accelerate quickly. As the leak events continue to increase, complete system replacement becomes the only option.

It has been said that insanity is continuing to do the same thing and expecting different results. Replacing a failed galvanized single interlock preaction fire sprinkler system within a cultural resource setting with a second galvanized system may not be insane, but it is incredibly risky. Some have followed the logic that since dry and preaction systems fail more frequently that wet systems, using galvanized steel piping with a wet pipe fire sprinkler system might be a viable solution. It is not. The same corrosion mechanisms exist but instead of corroding the bottom of the pipe near the pools of trapped water, the failures occur wherever there is an air/water interface. Oxygen corrosion dissolves the zinc coating at the interface first and gradually dissolves the zinc coating within the entire wetted pipe diameter.

Waiting for the first leak to occur is not a prudent strategy. It is imperative that facilities that have installed galvanized single interlock preaction fire sprinkler systems to protect cultural resources be opened up and inspected to determine the extent of corrosion damage that has already occurred. If the system has been in service for more than 3 years, a thorough system assessment should be performed and should include:

- Video scoping of the mains and cross mains
- Pipe sampling from strategic locations within the system
- Complete analysis of water and deposit samples from the system

The assessment report should provide the following answers:

- Definition of the root cause of corrosion with a complete evaluation of metal loss on the pipe samples
- Locations within the system where piping must be replaced
- Video record of the system piping at key locations
- Recommendations for system design modifications
- Recommendations for corrosion control
- Recommendations for in-situ corrosion monitoring

Nitrogen Inerting is the Complete Answer

Understanding that oxygen corrosion is the primary cause for corrosion related failures in dry pipe including single interlock preaction fire sprinkler systems is the first key to implementing a solution. Using nitrogen gas to purge the fire sprinkler system piping of oxygen can be accomplished using a nitrogen generation system.

In effect, by continuing to increase the percentage of nitrogen in the space over any trapped water, dissolved oxygen can actually be stripped out of the water. When this is accomplished, the oxygen is no longer available to corrode the metal surfaces of the pipe. Henry's Ideal Gas Law is at the heart of the process of using nitrogen gas to control corrosion in fire sprinkler systems. This approach has proven to be completely effective in long term

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testing on dry and preaction fire sprinkler systems composed of both black steel and galvanized steel[5].

By venting the fire sprinkler system during nitrogen gas addition, the concentration of oxygen in the piping can ultimately be reduced to a point where corrosion can be completely controlled. Trapped water in the piping that has been stripped of its dissolved gases, particularly oxygen and carbon dioxide, is **no longer corrosive**. So even if water remains in the pipe, if it is under an atmosphere that is 98-99% nitrogen it will be essentially non-corrosive water. By continuing to vent the system with dry nitrogen gas, trapped water can also be removed from the system. The end result is complete corrosion control.

Conclusions

Protecting cultural resources from corrosion related leaks in fire sprinkler systems is of paramount importance. Taking steps to mitigate risks can only be done with a complete understanding of the root causes of the corrosion and the proper means for prevention.

Microbiologically Influenced Corrosion (MIC) is not the root cause of corrosion related leaks in fire sprinkler systems. Oxygen corrosion is the primary cause of corrosion related failures in all water based fire sprinkler systems. Using galvanized steel piping without a means for eliminating oxygen from the fire sprinkler system is not a viable solution.

Using a nitrogen generation system to provide a continuous source of dry inert gas for pressure maintenance in dry pipe and single interlock preaction fire sprinkler systems provides the optimum means for mitigating the risks from a corrosion related leak.

References

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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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