# Steel Piping Material Corrosion

## Dry and Pre-Action Fire Protection Systems

**PAUL SU & DAVID B. FULLER** | **FM Global**

**Introduction** Corrosion has been a concern in sprinkler piping since the installation of the earliest systems in the 1800s. The simple truth is that steel rusts in the presence of water and oxygen and as a result fire sprinkler systems have finite useful lives. The good news is that in most cases sprinkler system piping generally outlives the buildings in which they are installed.

Sprinkler systems can be divided into two types – wet and dry. Wet sprinkler systems, as the name implies, are filled with pressurized water. In a wet system, when a sprinkler operates due to the heat from a fire, water is immediately discharged. Dry systems are different. They are normally filled with a compressed gas – typically air. In a dry system, when a sprinkler operates, compressed gas (air or nitrogen) is initially expelled from the system. This loss of gas pressure in the system causes the operation of a valve that then floods the sprinkler piping with water and the water then flows from the open sprinkler. Pre-action systems use a separate detection system and release panel and can be fairly sophisticated. Pre-action systems and dry systems operate on the same principal, the only difference being that pre-action systems can introduce water before the sprinkler fusible link operates due to heat exposure (single interlocked) or introduce water into the system after the sprinkler operates (double interlocked). However, for the purpose of a discussion on corrosion, dry and pre-action systems are taken in the same context.

Corrosion rates in dry and pre-action systems can be larger than those in wet systems. This difference is caused primarily by the constant replenishment of oxygen in the form of the supervisory compressed air. Traditionally, to provide some level of protection against corrosion, galvanized pipe was used to provide a sacrificial layer (zinc) to protect the underlying steel. This approach was, and continues to be, a reasonable and cost-effective approach to limiting dry and pre-action system corrosion damage. Galvanized piping should not be confused with being corrosion proof. The zinc layer is limited and once penetrated the underlying steel will corrode. The zinc layer provides protection when the piping is wet for short periods of time. If there is water that remains trapped in the system, the sacrificial zinc layer can be exhausted much faster. The trapped water comes from system commissioning and trip testing that introduces water into the piping. The piping should be pitched back to the sprinkler riser, and other low point drains, as needed to allow for proper draining to avoid trapped water and hence corrosion. In many systems, either the piping is not pitched properly to allow for proper draining or the servicing technician does not allow enough time to drain the system thoroughly, resulting in trapped water in the system. Also, if an air dryer is not used on the system air compressor, water can be introduced via condensation. These features point toward the need to properly pitch sprinkler system piping, allow for a thorough draining of the system after trip testing, and the use of air dryers in humid environments. When installed and maintained properly, galvanized dry and pre-action piping systems can last for a long time.

Recently the use of galvanized piping has been reported to be unnecessary and possibly the cause of rapid corrosion in these systems.[1,2] Also, the use of nitrogen as a supervisory gas is gaining in popularity.[3,4] This article will review the fundamentals of corrosion in sprinkler piping and provide guidance on the use of galvanized pipe and nitrogen in dry and pre-action sprinkler systems.

**Corrosion** Corrosion involves the reaction between a metal or alloy and its environment. It is an irreversible interfacial reaction, which causes the gradual deterioration of metal surface by water (or moisture) and corrosive chemicals. Corrosion is an electrochemical reaction in nature; it involves electron ($e^-$) transfer between anodic and cathodic reaction sites.

Raimondo Fire Systems
13D Pump Systems
Right Size. Right Price.
Just Add Water.
Economical - Custom Built
No Assembly

300 & 400 gallon, standard & deluxe models available.
All Tank Sizes Available.
Call Tom Raimondo
781-279-4344

The following summarizes corrosion basics related to galvanized steel pipe (with Zinc coating) and black steel pipe (without zinc coating) in dry or pre-action fire protection systems

- For corroding metals; the anodic reaction is the oxidation (i.e., loss of electrons: $M \rightarrow M^{n+} + ne^-$ , $Fe \rightarrow Fe^{2+} + 2e^-$, $Zn \rightarrow Zn^{2+} + 2e^-$) of a metal to its ionic state; the cathodic reaction is a reduction (gain of electrons) process, such as oxygen reduction ($O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$) or hydrogen evolution ($2H^+ + 2e^- \rightarrow H_2$) reactions.

- For dry or pre-action systems, trapped water and dissolved oxygen in pipe creates a corrosive environment for steel piping materials, due to inadequate water drainage after hydrotesting or periodic inspector testing.

The following sections discuss corrosion of steel piping materials in dry and pre-action systems, including (a) galvanized steel pipe; (b) black steel pipe; (c) microbiologically influenced corrosion (MIC); and (d) weld seam corrosion:

*a) Galvanized Steel Pipe* The zinc coating on galvanized steel pipe prevents corrosion of underlying steel by forming a physical barrier and by acting as a sacrificial anode if the barrier is damaged.[5] When exposed to trapped water for an extended period, the zinc layer corrodes first, followed by a local penetration point where zinc is depleted and the underlying bare steel is exposed. As the zinc continues to dissolve surrounding the point of penetration and the bare steel area expands, the remaining zinc "throwing power" ultimately becomes inadequate to protect the steel. The exposed steel begins to experience localized corrosion (pitting) attack, forming a tubercle. The dissolved oxygen concentration gradient between the bulk water surrounding the tubercle and the water in direct contact with the metal surface beneath the tubercle (due to depletion of dissolved oxygen compared with the bulk water) is typically the driving force for such under-deposit pitting corrosion. The area (pit) underneath the tubercle (oxygen depleted, anodic – iron corrosion) becomes a small anode compared to the larger surrounding cathode (oxygenated, cathodic – oxygen reduction) and further increases pitting corrosion rate. In addition, the solution inside a pit can be very aggressive (e.g., acid with pH ~2 and $Cl^-$), which increases the metal dissolution rate and is often called an "autocatalytic" process. Eventually, the continued and autocatalytic pitting corrosion of steel penetrates the pipe wall, leading to leakage.

Figure 1 shows corrosion of galvanized steel pipe (NPS 6, schedule 10) where trapped water filled about 40 percent of the pipe's volume in a dry pipe system. Under the water line, white rust (zinc corrosion) and well over a dozen reddish-brown tubercles of various sizes are evident on the bottom half of the pipe. (See Figure 1.)

The white rust, zinc corrosion for galvanized steel pipe, mainly includes zinc hydroxide ($Zn(OH)_2$), zinc carbonate ($ZnCO_3$), and zinc oxide ($ZnO$). White rust and corrosion tubercles shown in Figure 1 are friable, soft and usually hollow inside. Therefore, they are not likely to clog the pipe or sprinklers.

*b) Black Steel Pipe* Figure 2 shows tubercles heavily formed inside a black steel sprinkler pipe (NPS 4, schedule 10) for a wet pipe system, with through-wall pinhole leakage at the base of a tubercle. The reddish-brown iron (III) hydroxide ($Fe(OH)_3$, rust) corrosion product covers tubercle surfaces. If the black steel pipe installed in a dry or pre-action system with trapped water filled 40 percent of the pipe's volume similar to conditions described in Figure 1, heavy formation of tubercles can also be expected from the lower section. (See Figure 2.)

Corrosion products from black steel pipe mainly include iron(III) hydroxide ($Fe(OH)_3$), iron(II) hydroxide ($Fe(OH)_2$), and magnetite ($Fe_3O_4$). The corrosion scale and tubercles shown in Figure 2 can be soft-friable or dense-hard depending on their growth rates. The harder dense tubercles tend to grow slower than softer friable tubercles, and could potentially clog the pipe or sprinklers, if large and hard tubercles are dislodged during the flow of water inside the pipe.

Figure 1. Photograph showing corrosion of galvanized steel pipe (NPS 6, schedule 10) where residual water filled about 40 percent of the pipe's volume in a pre-action system.

Figure 2. Photograph showing tubercles heavily formed inside a black steel sprinkler pipe (NPS 4, schedule 10).

*c) Microbiologically Influenced Corrosion (MIC)* MIC is reported by others[6] to be responsible for 10-20 percent of damage caused by corrosion or 10-30 percent of corrosion in all piping systems in the United States.[7] This type of corrosion is caused by formation of biofilm on metal surfaces. Within the biofilm, metabolism activities of microorganisms (e.g., bacteria and fungi) influence electrochemical conditions on the metal/solution interface, where metal corrosion can be initiated or accelerated. It should be noted, as experienced by FM Global, that tubercles are often misinterpreted to be primarily caused by MIC.

For sprinkler systems, it is often difficult to distinguish contributing factors for corrosion of sprinkler piping between biotic (presence of biological factors, i.e., MIC) and abiotic (absence of biological


Figure 3. Photograph showing preferential grooving corrosion on pipe weld seam with a 1 mm pinhole leakage inside a black steel pipe (NPS 3, schedule 10).

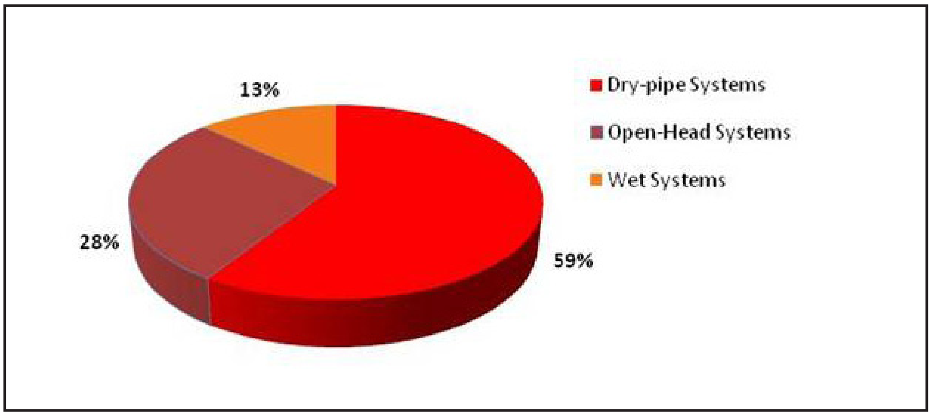



Figure 4. Sprinkler systems involved in Obstructed-Pipe Fires: (Losses reported to FM Global 1982-2001).

factors, i.e., non-MIC) factors, both affecting pitting corrosion and tubercles. In many cases, the presence of MIC related bacteria may exert some influence on corrosion of sprinkler systems, but not as the major corrosion contributor. Therefore, it is necessary to evaluate all corrosion parameters, including chemical (chemical information of environments and identification of corrosion products), microbiological (numbers and types of microorganisms), metallurgical (distribution and morphology of corrosive attacks), and operational data before stating the causes of corrosion.[8,9]

*d) Weld Seam Corrosion* Some concerns have been raised about galvanized pipe weld seams not being heat annealed and this leading to accelerated corrosion (grooving corrosion) at the pipe weld seam.[1] This seam-corrosion is not unique to galvanized pipe and there is no evidence to support that galvanized pipe is more susceptible to this type of corrosion damage than black steel pipe.[10]

Grooving corrosion at the pipe weld seam can occur in all welded seam sprinkler pipe and can be exacerbated by installing the pipe weld seam oriented toward the floor, leading to under-deposit corrosion of pipe weld seam. Figure 3 shows an example of preferential grooving corrosion on a pipe weld seam with a 1-mm pinhole leak in a black steel pipe, after removing corrosion products inside a black steel pipe (NPS 3, schedule 10).

**FM Global Loss Experience** Figure 4 shows that the dry-type sprinkler systems (dry and pre-action) are involved in the majority (59 percent) of fire losses caused by corrosion related obstruction of sprinkler flow, based on FM Global's loss data (history, 1982-2001) analysis described in "Understanding the Hazard – Dry-Pipe Sprinkler Systems Flushing Investigations."[5] It should be noted that this loss data analysis for dry systems predominantly involves black steel pipe. The hard and dense corrosion tubercles in black steel pipe were found to be the most frequent obstructing material.

Galvanized steel pipe is specified in the NFPA 13 for dry or pre-action systems, to minimize the likelihood that sprinklers become clogged when activated to control or to extinguish fires.

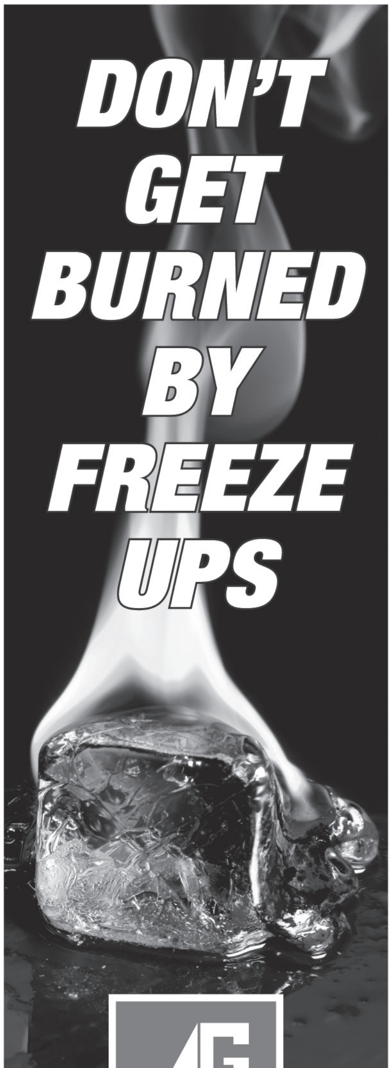
**C Value Calculation** Since galvanized pipes do corrode, there is a concern that the hydraulic friction loss constant, C = 120, may not accurately reflect the interior condition of a galvanized sprinkler pipe. This concern is unwarranted due to safety margin that is built into the C-factor used for sprinkler system calculations and the type of corrosion that occurs in galvanized pipe. In poorly maintained systems, the C-factor can be negatively affected by the effects of pipe interior corrosion, however there is a significant safety margin used in the friction loss calculations to avoid unacceptable performance (all new pipe has a C-factor much higher than 120). The nature of galvanized pipe corrosion leaves much of the sprinkler pipe surface in good condition (certainly much better than black steel wet sprinkler piping for which a C-factor of 120 is used for calculations; e.g., Figure 1 vs. Figure 2) and therefore the C-factor of 120 remains appropriate.

**Nitrogen** Dry Nitrogen gas has been used as a supervisory inerting gas to control metal corrosion in various industries, including steel sprinkler piping materials, with good results.[6] The source of dry nitrogen gas can be from cylinders, plant supply, or nitrogen generators. To the authors' knowledge, several organizations are evaluating the effectiveness and long-term performance of nitrogen generation in mitigating steel and galvanized steel pipe corrosion in the fire protection systems. Clearly there are no adverse effects to its use other than cost to the user.

**Pipe Corrosion Mitigation Strategies** It is beneficial to pursue corrosion mitigation strategies for dry or pre-action systems by first tackling the most frequently occurring factors, such as trapped water, dissolved oxygen, and grooving corrosion of pipe weld by draining trapped water, removing oxygen, and pipe weld management.

The following corrosion mitigation methods for galvanized pipe used in the dry or pre-action sprinkler systems are recommended:

- Install pipe with proper pitch to promote drainage of all test water and/or condensate;
- Pressurize the system using dry nitrogen from cylinders, plant supply, or a nitrogen generator;[3,4]
- Keep low-point drains clean and drain condensate as often as needed to prevent water buildup;
- Detect pipe corrosion early with inspection;
- Fix air leaks to keep system as tight as possible;




PATENT PENDING

COLLECTANDRAIN

ANTI-TRIP DRUM DRIP

COLLECTANDRAIN™ features an Anti-Trip plate and integral water detector that alerts maintenance personnel when your drum drip requires draining. Don't pay for unnecessary repairs caused by forgotten water freezing in your dry and pre-action sprinkler systems, install COLLECTANDRAIN™.


Use your smartphone to read more about COLLECTANDRAIN™

www.testandrain.com


- Orient pipe weld seams (if possible) for electric-resistance welded steel pipe toward the building roof to reduce grooving corrosion type leakage by preventing the weld from being located underneath corrosion scale/tubercles for active localized corrosion.

**Organizations** The NFPA 13, *Installation of Sprinkler Systems*, and the NFPA 25, *Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*, committees have included information related to corrosion in fire protection sprinkler systems in both of these standards.

The NACE International (National Association of Corrosion Engineers, Houston, Texas) has formed two technical committees "TEG 159X – Building Fire Protection Systems: Corrosion and Deposit Control" and "TG 381 – Fire Protection Systems," to be responsible for exchanging knowledge and developing corrosion mitigation methods for building fire protection sprinkler systems. The interested reader is recommended to engage in these activities.

## Conclusions

1. Galvanized pipe does not eliminate corrosion but is the best option and has served the industry well.
2. Bare/black steel pipe should not be used in a dry or per-action system due to the high volume of corrosion products that can obstruct piping and sprinklers.
3. Using dry nitrogen as a supervisory gas from cylinders, plant supply, or a nitrogen generator offers an additional option to mitigate corrosion in the fire sprinkler systems. ■

ACKNOWLEDGEMENTS: The authors thank Dr. Louis A. Gritzo (VP, Manager of Research, FM Global) and Dr. William W. Doerr (AVP, Research Area Director, FM Global) for thoughtful reviews and recommendations of this paper.

REFERENCES:
1 Kochelek, J., and Kirn, L., "Galvanized Steel Piping in Dry and Preaction Systems, Six Reasons Why It Should Not Be Used: Part 1," Sprinkler Age, 19-22, May 2011.
2 Kochelek, J., and Kirn, L., "Galvanized Steel Piping in Dry and Preaction Systems, Six Reasons Why It Should Not Be Used: Part 2," Sprinkler Age, 23-25, June 2011.
3 FM Global Data Sheets 2-0 "Installation Guidelines for Automatic Sprinklers," FM Global, Johnston, RI.
4 "Understanding the Hazard – Dry-Pipe Sprinkler Systems Flushing Investigations," FM Global, Johnston, RI, 2002.
5 Porter, F., "Zinc Handbook – Properties, Processing, and Use in Design," Marcel Dekker, Inc., New York, NY, 1991.
6 Flemming, H. C., "Economical and Technical Overview," in "Microbially Influenced Corrosion of Materials," Flemming, H. C., Sand, W. (eds), Springer-Verlag Berlin, 1996.
7 Hague, D.R., "Water-Based Fire Protection Systems Handbook," 2nd edition, NFPA 25, p. 321, 2008.
8 Dexter, S. C., "Microbiologically Influenced Corrosion," ASM Handbook, Vol. 13A, "Corrosion: Fundamentals, Testing, and Protection," pp. 398-416, 2003.
9 Ray, R. I., Lee, J. S., and Little, B. J., "The Anatomy of Tubercles on Steel," CORROSION 2011, P. 11217, NACE International, Houston, TX, 2011.
10 Su, P., Tatar, F. W., Chivukula, S., and W. W. Doerr, "Weld Seam Corrosion of Steel Sprinkler Pipe," to appear in CORROSION 2013, NACE International, Houston, TX, 2013.

ABOUT THE AUTHORS: Paul Su is a senior research specialist and technical team leader at FM Global. He has specialized in corrosion and materials research with over 23 years of experience, including corrosion evaluation and control, fire protection system corrosion, equipment failure analysis, CPVC sprinkler piping degradation, smoke damage, nanotechnology hazards, aging aircraft, and chemical product development. Su currently chairs the "TEG 159X - Building Fire Protection Systems: Corrosion and Deposit Control" and the "TG 381 - Fire Protection Systems" committees in NACE International. He received a B.S. degree from Tsing Hua University in Taiwan, an M.S. degree from Carnegie-Mellon University, and a Ph.D. from University of Connecticut, all in the field of materials science and engineering.

David B. Fuller is an assistant vice president at FM Global. Based in company's Norwood, Mass., offices, Fuller manages the fire protection and special hazards sections of the Engineering Standards group which is responsible for producing the FM Global Property Loss Prevention Data Sheets. He is the company subject matter expert for fire protection system installation, maintenance and testing; fire protection in cold storage facilities; fire pumps; and fire protection equipment corrosion. Fuller has more than 22 years with the company and has been in his current position since 2011. He is a member of NFPA and currently serves on the NFPA sprinkler installation, fire pump, inspection test and maintenance, and foam-water sprinkler technical committees, and holds a bachelor's degree in electrical engineering from Northeastern University, Boston, Mass.