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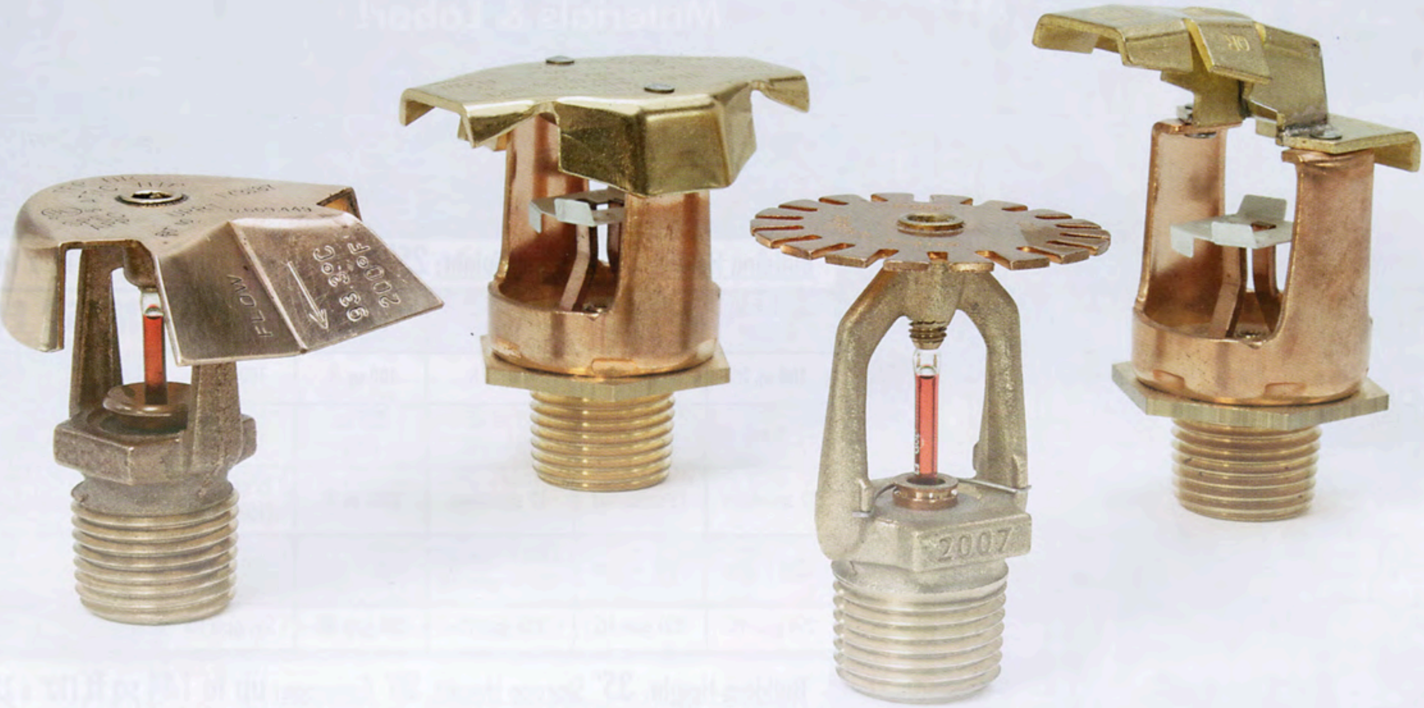

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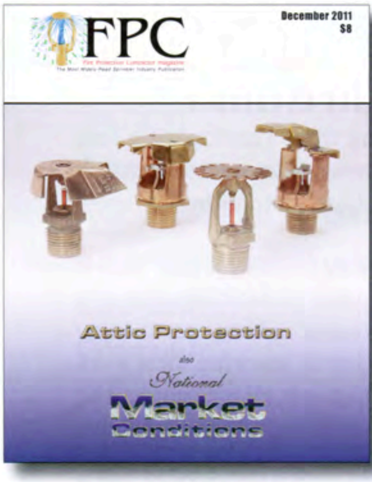

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To get the complete Technical Report and see Table 1, Figure 1, and other photos, contact the Authors.

Part One of a Technical Report on:

Corrosion in Dry and Preaction Systems:

Preliminary Results of Long-Term Corrosion Testing Under Compressed Air and Nitrogen Supervision

By Ockert J. Van Der Schijff, Pr.Eng., Ph.D., and Scott C. Bodemann

Introduction — The inclusion of recommendations for use of galvanized steel pipe in dry and preaction systems in the NFPA 13 installation standard initiated decades of widespread adoption. Currently, new dry and preaction installations are almost exclusively constructed using hot dip galvanized, schedule 10 piping and rolled groove couplings. The premise for recommending its use is based on the principle of cathodic protection, in which the piping's internal zinc coating is sacrificially corroded while protecting the underlying steel. Although based on solid corrosion science, cathodic protection has proved to be ineffective on galvanized pipe surfaces that are partially wetted and exposed to the stagnant water conditions found in many problematic dry or preaction systems.

Corrosion Basics — Unlike galvanized outdoor structures, which are wetted intermittently, the low points in sprinkler piping (where water and condensate accumulate) are constantly wetted and the zinc corrosion product deposits remain where they are formed. Initially, the zinc coating cathodically protects the underlying steel, but as the zinc is oxidized, the zinc corrosion products are deposited on the metal surface. This, in combination with a decrease in the efficiency of the cathodic protection due to coverage of the metal surface by nonconductive oxide, eventually results in localized penetration of the zinc coating and corrosion of the underlying steel.

Numerous owners of galvanized pipe systems have experienced premature failure due to multiple pinhole leaks in as little as three years after commissioning. In all of these instances, subsequent investigations revealed a common set of conditions:

- Multiple pockets of trapped water
- Lack of adequate means to completely drain the system after initial hydrotesting
- Localized tubercles at breaches in the zinc coating with underlying pits penetrating into the steel base material
- Intact zinc coating covering surfaces surrounding the localized tubercles

Based on data collected during more than a decade's experience with such systems, galvanized piping that is partially filled with water will only be cathodically protected by the sacrificial zinc coating until localized penetration of the zinc coating occurs and the underlying steel is exposed. As the corrosion reaction progresses, the penetration rate of the localized pitting increases due to the occlusion resulting from the growing mound of corrosion products covering the pit. As a result of the reduction in the availability of oxygen in the bottom of the pit (referred to as differential aeration by corrosion engineers), changes in the local chemistry and pH occur, which cause an increase in the rate of local oxidation of the steel and lead to an "electrochemical drill" effect. Localized corrosion of the exposed steel then proceed at a rapid pace. This is due to a phenomenon known as the "area effect," where the large area of intact zinc coating surrounding the local penetration acts as a cathode and the small area of exposed steel acts as an anode. These areas of localized corrosion usually manifest themselves at the six o'clock position and water/air interface in the form of distinctive reddish-brown nodules of iron oxide covering the site of localized corrosion in the steel. The presence of these deposits also creates conditions occluding the underlying steel from the bulk solution, thereby accelerating the rate of localized corrosion with the creation of a differential aeration cell (also referred to as a concentration cell). By this mechanism, the oxygen under the deposits is consumed, while the surrounding exposed area remains cathodic relative to the area under the deposits. This further accelerates the rate of the localized corrosion. The presence of tubercles is often misinterpreted as evidence that the damage is the result of microbiologically influenced corrosion (MIC). However, more than a decade's worth of accumulated results of microbiological culturing of deposit samples collected from affected pipe from all over the United States show that the corrosion cannot be attributed to the actions of bacteria[1].

Once localized pits are established, they continue to grow by a self-sustaining, or autocatalytic, process. The propagation of pits involves the dissolution of metal and the maintenance of a high degree of acidity at the bottom of the pit by the hydrolysis of the metal ions in solution. Anodic metal dissolution in the pit ($\text{Metal} \rightleftharpoons \text{Metal}^{n+} + ne^-$) is balanced by the cathodic, oxygen reduction reaction on the surrounding surface ($O_2 + 2H_2O + 4e^- \rightleftharpoons 4OH^-$). Due to the increasing concentration of metals cations in the pit, negative ions in solution such as chloride Cl^- migrates into the pit to maintain charge neutrality. In the case of chloride, the metal chloride (MCl) is hydrolyzed by combining with water to form a metal hydroxide and free acid. The presence of the acid lowers the local pH, which causes accelerated localized dissolution of the metal. This process has been found to be much more pronounced and severe in galvanized steel pipe than in black steel pipe. This is due to a fundamental difference in the observed corrosion mechanisms in black steel as compared to galvanized steel. The absence of any protective coating on black steel in this type of environment typically results in even and uniform thinning of the steel pipe wall, unlike the very localized and fast penetrating pitting on galvanized pipe. As such, practical industry experience has shown that even though corrosion occurs, the rate of penetration and time to failure is considerably slower and more predictable in black steel than in galvanized steel. (As time passes and a thicker layer of corrosion products develop on the black steel, the corrosion mechanism is likely to change to a localized mechanism with the development of localized tubercles with underlying pits. However, this typically happens much later in the service life of black pipe and only if the two-phase compressed air/water condition persists.)

Corrosion Prevention Strategies — Prevention of such corrosion can be achieved as follows: 1) By completely removing all residual water and moisture from the dry or preaction system, thereby rendering the internal pipe surfaces completely dry. This effectively eliminates the availability of an electrolyte, which is a prerequisite for corrosion to occur. However, industry experience with this remedy has shown that it is virtually impossible to achieve completely dry conditions within the sprinkler piping. These systems are routinely flooded for initial and periodic hydrotests, resulting in significant amounts of water remaining in the piping due to inadequate sloping or lack of drainage points. Additionally, the internal profile of commonly used rolled grooves for pipe fittings create a natural "trap" for moisture, even if the pipe is sloped in accordance with the requirements of NFPA 13. That, combined with the availability of an inexhaustible source of oxygen in the compressed supervisory air to sustain the corrosion reaction, renders this method marginally effective at best. 2) By replacing supervisory compressed air with high purity, inert, dry, supervisory nitrogen gas, the thermodynamic driving force for the cathodic oxygen reduction reaction is effectively removed and corrosion slows down to a negligible rate. This method is based on an understanding of basic electrochemical theory. It has proven to be very effective in many galvanized pipe installations that previously had failed within three years after their original installation.

Long-Term Exposure Testing — Long-term exposure tests have been conducted to compare the performance of black steel and galvanized sprinkler pipe in compressed air and nitrogen gas environments over the past two years. Our intention is that these tests will be continued for the next several years. The test environment is comprised of half-filled black and galvanized steel sprinkler pipe sections, which are individually subjected to either compressed air or 98% nitrogen supervision. This real-world experiment, consisting of materials that are currently used in dry and preaction sprinkler installations, has been conducted under carefully controlled and monitored conditions. These tests provide the first science-based data for evaluation of the effectiveness of nitrogen gas supervision. A composite of images of the test setup is shown in Figure 1.

[1] Van Der Schijff, O. J. *MIC in Fire Sprinkler Systems — Field Observations and Data*. NACE International, Corrosion 2008 Conference and Expo, New Orleans, LA, March 16–20, 2008.

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