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Corrosion of Piping in Dry and Preaction Fire Sprinkler Systems:

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

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ABSTRACT

Internal corrosion of dry and pre-action systems is an ongoing and ever growing problem for owners and operators of such systems. The use of nitrogen as a supervisory gas instead of compressed air is one of several techniques that have been put forth as a way to prevent or retard corrosion. In order to fully investigate and compile verifiable data about the efficacy of nitrogen as a supervisory gas, long-term exposure tests were set up in 2009. Sprinkler pipe sections were assembled to simulate in-service, dry sprinkler piping with residual water. The three different conditions currently being tested in black and galvanized steel, schedule 10, 2½-inch diameter pipe are compressed air, 95% nitrogen, and 98% nitrogen as supervisory gas.

This paper provides a summary of data accumulated to date and presents some of the interim findings at approximately the halfway point of the projected 7-year testing

program. The corrosion mechanisms at work in the different environments are discussed and illustrated with images and analytical data obtained during periodic removal of pipe spools from each of the test systems. The benefits of nitrogen as a supervisory gas are explained and compared to the as-found condition of pipe after extended exposure to such environments in the presence of residual water. Finally, the efficacy of 95% versus 98% nitrogen is compared based on our findings to date. Earlier results of this ongoing study have been previously reported.[1,2]

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1 Van Der Schijff, O.J. & Bodemann, S.C. "Corrosion in Dry and Preaction Systems: Preliminary results of Long-Term Corrosion Testing under Compressed Air and nitrogen Supervision – Part 1", Fire Protection Contractor Magazine – Volume 34, No. 12 – December 2011.

2 Van Der Schijff, O.J. & Bodemann, S.C. "Corrosion in Dry and Preaction Systems: Preliminary results of Long-Term Corrosion Testing under Compressed Air and nitrogen Supervision – Part 2", Fire Protection Contractor Magazine – Volume 35, No. 1 – January 2012.

Introduction

The inclusion of recommendations for use of galvanized steel pipe in dry and pre-action systems in the NFPA 13 installation standard initiated decades of widespread adoption. Although black steel pipe is used occasionally, new dry and pre-action installations are almost exclusively constructed using hot dip galvanized, schedule 10 piping with 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 constantly, partially wetted and exposed to the stagnant water conditions found in many problematic dry or preaction systems.

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 non-conductive 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 be cathodically protected until oxidation of the zinc coating occurs and the underlying steel is insulated by a zinc corrosion product cap diminishing the available cathodic protection. Localized penetration of the substrate steel occurs 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. 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 can potentially further accelerate 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[3]. This finding was confirmed by the negative results obtained during microbiological culturing of deposits from one the sets of pipe samples pulled from the long term test.

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

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

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 (Metal $\rightleftharpoons$ $Metal^{n+} + ne^-$) 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 the interior diameter (ID) of black steel pipe 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.

Experimental Setup

A long-term, exposure testing experiment, consisting of piping materials that are currently used in dry and preaction sprinkler installations, is presently being conducted under controlled and monitored conditions. The test environment is comprised of black and galvanized steel sprinkler pipe sections, approximately half filled with water and subjected to either compressed air, 95% nitrogen, or 98% nitrogen gas supervision. A composite of images of the test setup is shown in Figure 1.

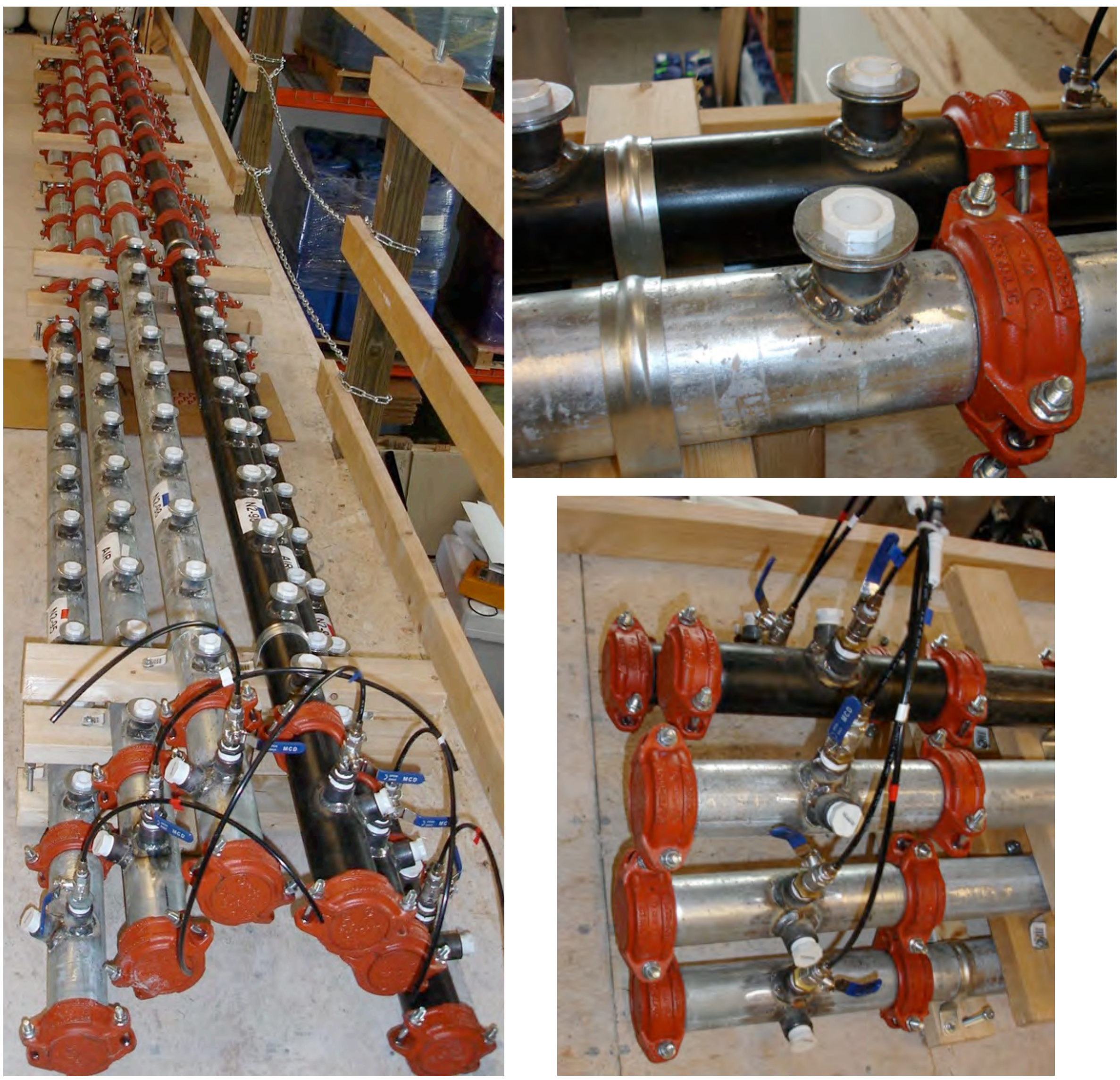

Figure 1. Long-term exposure test setup.

At designated time intervals, 1-foot sections are being removed from each of the individual pipe assemblies for evaluation. Each section is examined and photodocumented in the as-found condition, cleaned with inhibited acid oxide remover, reevaluated and photodocumented. The penetration depth of corrosion pits on the galvanized steel (exhibiting localized rather than uniform corrosion) is measured using a pit gauge and the maximum depth is recorded and reported. This value is subsequently used to calculate the corrosion penetration rate in mils (thousands of an inch) per year.

In order to conduct an accurate remaining wall thickness evaluation for black steel samples (exhibiting uniform corrosion rather than localized pitting), a half-ring, approximately ½-inch wide, is sectioned transversely from the section of pipe on a band saw. The sample is ground on a metallurgical grinding wheel with successively finer grit sanding paper to produce a 600-grit cross-sectional pipe wall surface.

The half-ring section of pipe is subsequently examined with the aid of a stereo-optical microscope under a magnification power of 5X. Following the photo-documentation of the wall, thickness markers are placed on the digital image utilizing a digital measurement system with an accuracy of 1 x 10^{-5} inches (only three decimal places are reported). Based on the difference between remaining wall thickness and the nominal thickness for this schedule and diameter of pipe, the corrosion penetration rate is then calculated.

Experimental Results

Composite images representing both black steel and galvanized steel pipe sections, pulled from the test after 1116 days of exposure and subjected to subsequent cleaning to remove accumulated corrosion product deposits, are presented in Figure 2 through Figure 7. Summarized, cumulative test results after respective exposure periods of 497 days, 759 days, 780 days, and 1116 days, as well as corrosion rate calculations based on cross-sectional measurement of the remaining wall thickness, are reported in Table 1.

Examination of the tested black steel pipe sections under both compressed air and nitrogen supervision exhibited uniform loss in thickness of the pipe wall in the portion of the pipe that was submerged in water (Figure 2, Figure 3, and Figure 4). No localized pits were noted in any of the pipe sections. Calculated corrosion penetration rates show a progressive decrease from an average rate of 7.3 mils per year (mpy) under compressed air to 5.9 mpy under 95% nitrogen supervision to 2.5 mpy under 98% nitrogen supervision. Based on the nominal wall thickness of 0.120" for this schedule and diameter of pipe, this translates to respective time-to-penetration periods of 16.4 years under compressed air supervision, 20.3 years under 95% nitrogen supervision and 48 years under 98% nitrogen supervision.

The galvanized steel pipe sections under both compressed air and 95% nitrogen supervision showed localized pits underlying locations where brown to black nodules or tubercles had formed (Figure 5 and Figure 6). No localized penetration of the zinc layer and subsequent formation of localized pits were noted on the galvanized steel under 98% nitrogen supervision (Figure 7). Calculated corrosion penetration rates (based on pit depth measurements for the air and 95% nitrogen supervised pipe sections and cross-sectional remaining wall thickness measurement for the 98% nitrogen supervised pipe section), show a progressive decrease from an average rate of 17.5 mpy under compressed air to 11.5 mpy under 95% nitrogen supervision to 1.3 mpy under 98% nitrogen supervision. Based on the nominal wall thickness of 0.125" for this schedule and diameter of pipe, this translates to respective time-to-penetration periods of 7.1 years under compressed air supervision, 10.4 years under 95% nitrogen supervision and 92.3 years under 98% nitrogen supervision.

Figure 2. Composite image of black steel piping after 1116 days exposure while approximately half-filled with water and under compressed air supervision. Note uniform thinning of pipe wall and absence of any localized pits.

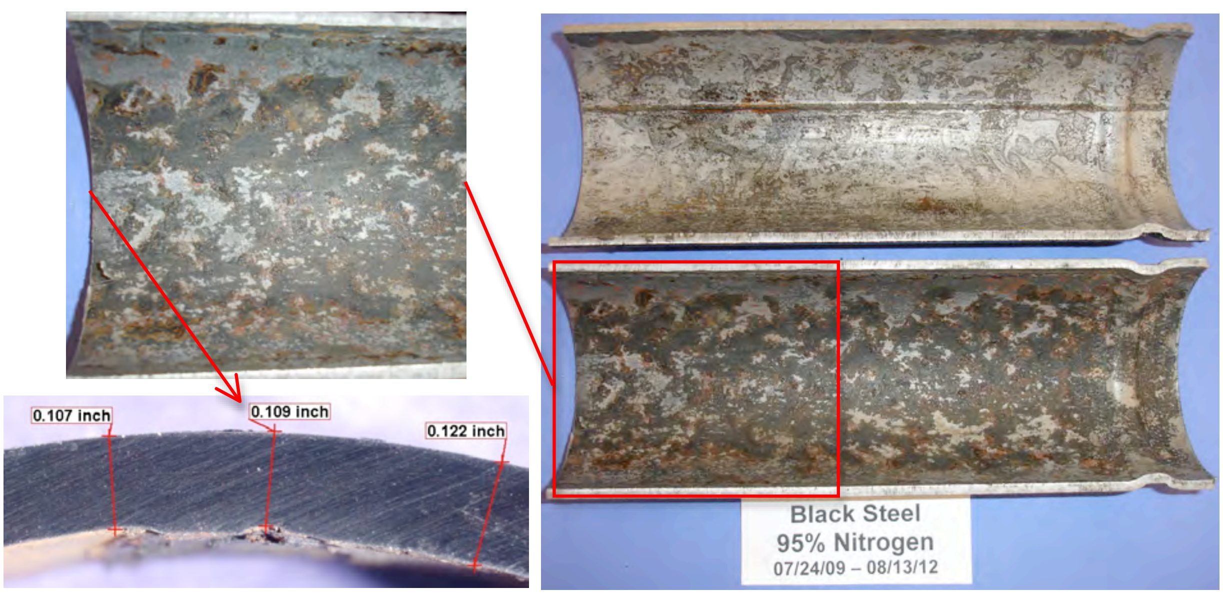

Figure 3. Composite image of black steel piping after 1116 days exposure while approximately half-filled with water and under 95% nitrogen supervision. Note uniform thinning of pipe wall and absence of any localized pits.

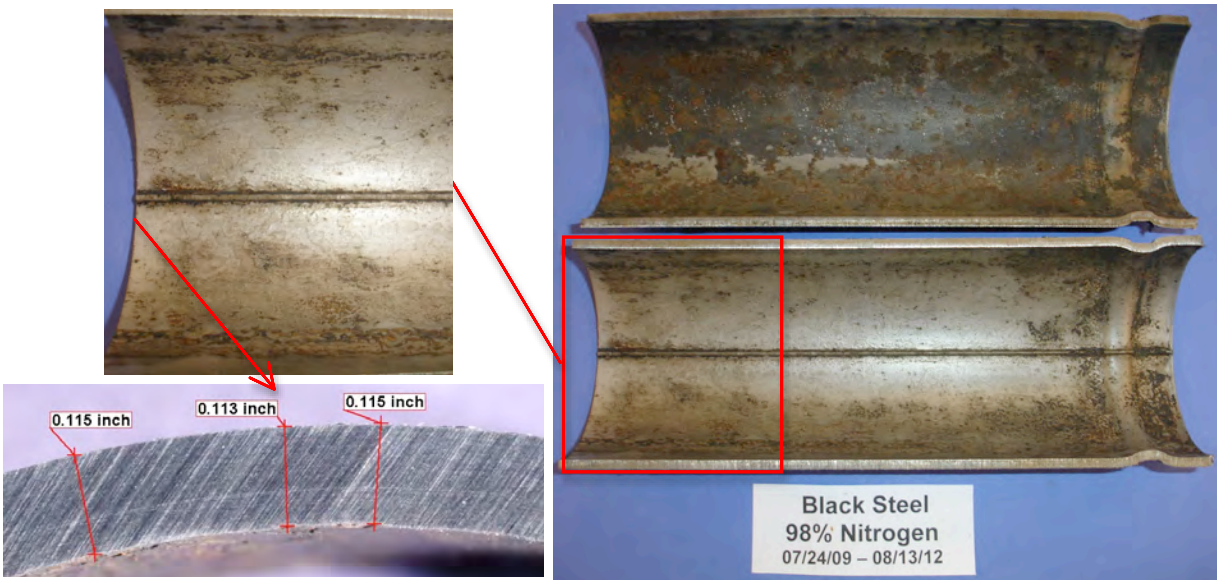

Figure 4. Composite image of black steel piping after 1116 days exposure while approximately half-filled with water and under 98% nitrogen supervision. Note uniform thinning of pipe wall and absence of any localized pits

Figure 5. Galvanized piping after 1116 days exposure while approximately half-filled with water and under compressed air supervision. Note localized pitting at locations where zinc coating has been breached.

Figure 6. Galvanized piping after 1116 days exposure while approximately half-filled with water and under 95% nitrogen supervision. Note localized pitting at locations where zinc coating has been breached.

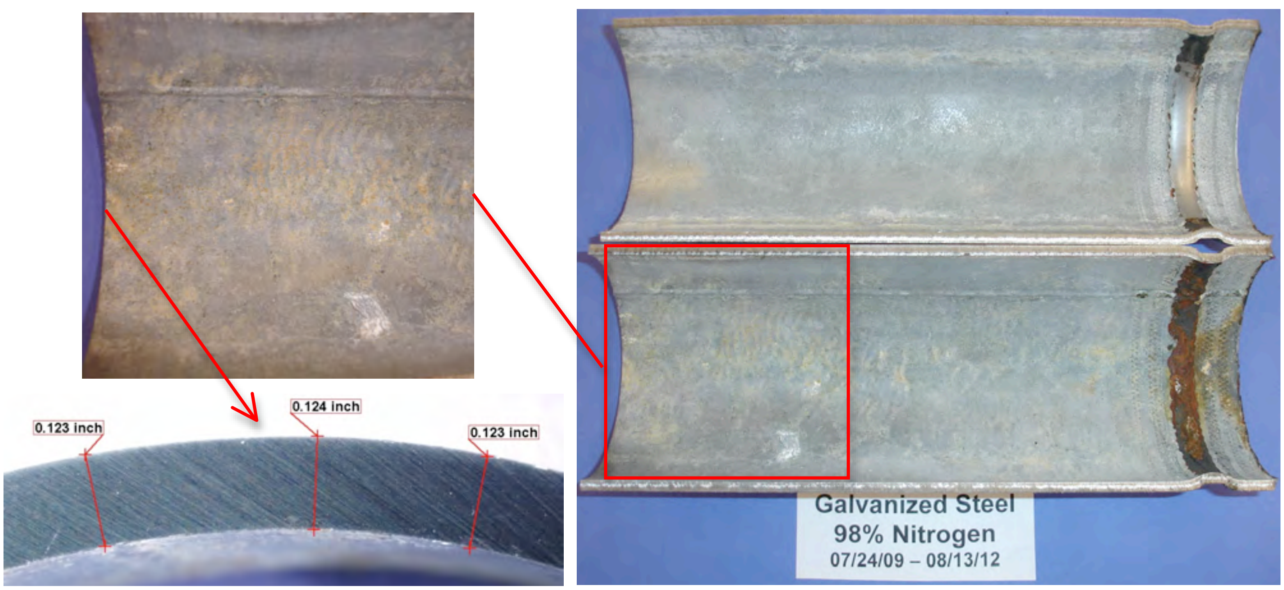

Figure 7. Galvanized piping after 1116 days exposure while approximately half-filled with water and under 98% nitrogen supervision. Note absence of any localized breaches in zinc coating except for rolled groove.

Table 1. Calculated corrosion rates

Pipe Material	Supervisory Gas	Exposure time (Days)	Uniform wall loss or Pit depth (inches)	Penetration Rate (mils/yr)	Average Penetration Rate (mils/yr)
Black steel	Compressed Air	497	0.009	6.6	7.3
		759	0.022	10.6	
		780	0.017	8.0	
		1116	0.015	3.9	
Black steel	95% Nitrogen	497	0.008	5.9	5.9
		759	0.012	5.8	
		780	0.016	7.5	
		1116	0.013	4.3	
Black steel	98% Nitrogen	497	0.004	2.9	2.5
		759	0.003	1.4	
		780	0.007	3.3	
		1116	0.007	2.3	
Galvanized steel	Compressed Air	497	0.028	20.6	17.5
		759	0.034	16.4	
		780	0.036	16.9	
		1116	0.050	16.4	
Galvanized steel	95% Nitrogen	497	0.003	2.2	11.5
		759	0.040	19.2	
		780	0.020	9.1	
		1116	0.047	15.4	
Galvanized steel	98% Nitrogen	497	0	0	1.3
		759	0.003	1.4	
		780	0.007	3.3	
		1116	0.002	0.7	

Discussion

Black steel pipe

Our observations to date indicate that the corrosion mechanism of partially filled black steel pipe under both compressed air and nitrogen gas supervision is of a uniform nature with even thinning of the pipe wall and no indications of localized pitting. Based on the data collected to date, the use of nitrogen instead of compressed air significantly slows down the corrosion process as evidenced by an approximate reduction in the corrosion penetration rate of 20% under 95% nitrogen and 66% under 98% nitrogen supervision. From the data presented it is also evident that the general trend indicates a slowdown in the corrosion penetration rate with time. This is most likely related to the protective properties of the layer of corrosion product deposits on the metal surface. However, field experience has shown that the corrosion mechanism in black steel pipe eventually transforms into localized pitting once a thick layer of corrosion product deposits have developed, which facilitates the development of under-deposit differential aeration cells. This then results in eventual failure of the pipe due to the formation of pinhole leaks. It is therefore possible that this scenario will play out in the compressed air supervised pipe as time passes.

Galvanized pipe

Based on the data collected to date, galvanized pipe under both compressed air and 95% nitrogen supervision is subject to localized pitting at locations where the zinc coating is breached and corrosion of the underlying steel initiates. Nitrogen gas with a purity of 95% does retard the corrosion penetration rate somewhat, but does not prevent the formation of localized pits. (It must be noted here that extrapolation of the calculated corrosion penetration rate based on pit depth to predict service life is a simplification that is not always supported by actual in-service experience. This is due to the fact that the penetration rate often increases as pits grow deeper resulting from chemistry and pH changes in the pit. However, whether it will occur and to what extent cannot be predicted.) The higher purity, 98% nitrogen gas effectively prevents localized penetration of the zinc coating as evidenced by the absence of localized pits and low uniform corrosion rate of the zinc coating in the pipe sections pulled from the test to date. This represents a reduction of approximately 93% in the observed corrosion rate when compared to galvanized pipe under compressed air supervision. Given our observations to date, nitrogen of 98% purity is adequate to prevent pit formation

Conclusions to date

The data presented above are the results after three years of testing in a continuing, long-term, exposure testing project. Given that, results and conclusions may change as more data become available. Based on the data collected to date, the following can be concluded:

- A uniform wall thinning corrosion mechanism dominates on black steel under both compressed air and nitrogen supervision.
- A localized pitting mechanism dominates on galvanized steel under compressed air and 95% nitrogen supervision.
- The use of 98% nitrogen gas supervision in black steel piping significantly slows down the corrosion penetration rate. This amounts to a 66% reduction of the corrosion penetration rate when compared to the rate recorded under compressed air supervision.
- The use of 98% nitrogen gas supervision in galvanized pipe effectively prevent the formation of localized pits and reduces the corrosion penetration rate by approximately 93% when compared to that under compressed air supervision.