TECHNICAL REPORT

CORROSION IN DRY AND PREACTION SYSTEMS: RESULTS OF LONG-TERM CORROSION TESTING UNDER COMPRESSED AIR AND NITROGEN SUPERVISION AFTER 2893 DAYS OF EXPOSURE

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INTRODUCTION

Interim results of ongoing long-term exposure testing under both compressed air and nitrogen supervision after 2893 days (approximately 7.9 years), are reported. Details of the test setup as well as earlier interim results have previously been reported[2,3,4]. Similar to the prior evaluations, pipe samples were removed from the test setup for subsequent evaluation. The results of those evaluations are reported and compared to earlier interim results.

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1 Also President of CorrConsult, LLC

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 1", Fire Protection Contractor Magazine – Volume 34, No. 12 – December 2011.

3 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.

4 Van Der Schijff OJ, Bodemann SC. Corrosion of Piping in Dry and Preaction Fire Sprinkler Systems: Interim Results of Long Term Corrosion Testing Under Compressed Air and Nitrogen Supervision. Sprinkler Age, 2013 32(10)

LONG-TERM EXPOSURE TESTING

Long-term exposure tests are currently being conducted to compare the performance of black steel and galvanized sprinkler pipe in compressed air and nitrogen gas environments. The testing was started in 2009 and have, at the time of this report, been running continuously for more than 8 years. The intention is to continue the testing for the next several years until all pipe samples are consumed or through-wall failure of the piping occurs. The test environment is comprised of half-filled Schedule 10 black and galvanized steel sprinkler pipe sections, which are individually subjected to either compressed air, 95% nitrogen, or 98% nitrogen supervision. A detailed description of the test setup can be found in earlier publications listed before.

At designated time intervals, 1-foot sections of the pipe assemblies have been removed for evaluation. Each section was examined and photo-documented in the as-found condition, cleaned with inhibited acid oxide remover, reevaluated and photo-documented. The corrosion penetration depth of pits on the galvanized steel was measured using a pit gauge and the maximum depth was recorded and reported. To conduct an accurate remaining wall thickness evaluation for black steel samples, a half-ring, approximately ½-inch wide, was sectioned transversely from the section of pipe on a band saw. The sample was ground on a metallurgical grinding wheel with successively finer grit sanding paper to produce a 600-grit cross-sectional pipe wall surface.

Each half-ring pipe section was subsequently examined with the aid of a stereomicroscope under a magnification power of 5X. Following the photo-documentation of the wall, thickness markers were placed on the digital image utilizing a digital measurement system with an accuracy of 1×10^{-5} inches (only three decimal places are reported). Based on the difference between remaining wall thickness and the nominal thickness for this diameter of pipe, the corrosion penetration rate was calculated. Since two different corrosion mechanisms were observed, the collected data was normalized by calculating the corrosion penetration rate for each of the pipe samples. This was based on the highest value of observed wall thinning for black steel and the deepest measured pit for galvanized steel. Test results after respective exposure periods of 497 days, 759 days, 780 days, 1116 days, 1664 days, 2036 days, 2398, and 2893 days are presented in

Table 1 for black steel pipe and in

Table 2 for galvanized steel pipe.

Table 1. Corrosion penetration rates for black steel.

Pipe Material	Supervision	Exposure time (Days)	Uniform wall loss or Pit depth (inches)	Penetration Rate (mpy)	Average Penetration Rate (mpy)
Black steel	Compressed Air	497	0.009	6.61	**5.80**
Black steel	Compressed Air	759	0.022	10.59	
Black steel	Compressed Air	780	0.017	7.96	
Black steel	Compressed Air	1116	0.015	4.91	
Black steel	Compressed Air	1664	0.017	3.73	
Black steel	Compressed Air	2036	0.025	4.48	
Black steel	Compressed Air	2398	0.027	4.11	
Black steel	Compressed Air	2893	0.032	4.04	
Black steel	95% Nitrogen	497	0.008	5.88	**4.76**
Black steel	95% Nitrogen	759	0.012	5.77	
Black steel	95% Nitrogen	780	0.016	7.49	
Black steel	95% Nitrogen	1116	0.013	4.25	
Black steel	95% Nitrogen	1664	0.016	3.51	
Black steel	95% Nitrogen	2036	0.021	3.77	
Black steel	95% Nitrogen	2398	0.028	4.26	
Black steel	95% Nitrogen	2893	0.025	3.16	
Black steel	98% Nitrogen	497	0.004	2.94	**1.90**
Black steel	98% Nitrogen	759	0.003	1.44	
Black steel	98% Nitrogen	780	0.007	3.28	
Black steel	98% Nitrogen	1116	0.007	2.29	
Black steel	98% Nitrogen	1664	0.007	1.54	
Black steel	98% Nitrogen	2036	0.007	1.26	
Black steel	98% Nitrogen	2398	0.011	1.68	
Black steel	98% Nitrogen	2893	0.006	0.76	

Examination of the tested black steel pipe spool samples under compressed air supervision showed mostly uniform loss in thickness of the pipe wall in the portion of the pipe that was submerged in water. A small number of wide, shallow, localized pits were noted in the pipe under compressed air supervision. Representative images of the pipe samples before and after removal of corrosion product deposits are presented in Figure 1 and Figure 2 below. Wall thinning had occurred evenly in the wetted portion of the partially filled pipe, but some localized pitting appears to have initiated as well. (Field observations of long-term service, failed black steel pipe under compressed air supervision have shown pinholes associated with localized pits. However, it has been observed that such pits only occur after development of differential aeration cells under a thick layer of corrosion product deposits and/or tubercles. As shown by the reported results of the exposure testing, the mechanism for the initial several years is uniform corrosion resulting in relatively uniform thinning of the pipe wall).

In galvanized pipe, corrosion of the underlying steel occurs at localized breaches in the zinc coating. Localized pits penetrate into the base metal, while the surrounding material shows only superficial corrosion of the zinc coating.

Measurements of wall loss (black steel), and pit depth (galvanized steel) under air supervision, and subsequent calculation of the respective corrosion penetration rates in thousands of an inch per year (mils/yr) yielded average rates of 5.80 mpy for black steel and 12.64 mpy for galvanized steel. Under 98% nitrogen gas supervision, these rates dropped to 1.90 mpy for black steel and 0.71 mpy for galvanized steel (the higher rate of penetration for galvanized steel is due to localized pitting). This translates into a projected extension of service life from 21 to 63 years for Schedule 10 black steel pipe (nominal wall 0.120") and from 10 to 176 years for Schedule 10 galvanized steel pipe (nominal wall 0.125"), which both exceed normal design life of approximately 40 years. It must be emphasized that the extrapolation of the calculated corrosion penetration rate to predict service life based on pit depth is a simplification that is usually not supported by actual in-service experience. The autocatalytic nature of the established pit is known to cause acceleration of the penetration rate as the pit grows deeper, resulting in non-linear penetration rates. Several instances of failure of galvanized pipe within 3 to 4 years after installation have been documented. The aforementioned exposure testing is ongoing and results will be reported as they become available over the course of the next several years. However, based on these results, it is apparent that the replacement of supervisory compressed air with high purity nitrogen effectively inhibits internal corrosion of sprinkler piping and could significantly extend the service life of sprinkler pipe.

Table 2. Corrosion penetration rates for galvanized steel.

Pipe Material	Supervision	Exposure time (Days)	Uniform wall loss or Pit depth (inches)	Penetration Rate (mpy)	Average Penetration Rate (mpy)
Galvanized steel	Compressed Air	497	0.028	20.58	**12.64**
Galvanized steel	Compressed Air	759	0.034	16.36	
Galvanized steel	Compressed Air	780	0.036	16.86	
Galvanized steel	Compressed Air	1116	0.050	16.36	
Galvanized steel	Compressed Air	1664	0.063	13.83	
Galvanized steel	Compressed Air	2036	0.028	5.02	
Galvanized steel	Compressed Air	2398	0.039	5.94	
Galvanized steel	Compressed Air	2893	0.049	6.19	
Galvanized steel	95% Nitrogen	497	0.003	2.20	**9.93**
Galvanized steel	95% Nitrogen	759	0.040	19.25	
Galvanized steel	95% Nitrogen	780	0.020	9.37	
Galvanized steel	95% Nitrogen	1116	0.047	15.38	
Galvanized steel	95% Nitrogen	1664	0.046	9.99	
Galvanized steel	95% Nitrogen	2036	0.054	9.69	
Galvanized steel	95% Nitrogen	2398	0.042	6.40	
Galvanized steel	95% Nitrogen	2893	0.057	7.13	
Galvanized steel	98% Nitrogen	497	0.000	0.00	**0.71**
Galvanized steel	98% Nitrogen	759	0.003	1.44	
Galvanized steel	98% Nitrogen	780	0.007	3.28	
Galvanized steel	98% Nitrogen	1116	0.002	0.65	
Galvanized steel	98% Nitrogen	1664	0.000	0.00	
Galvanized steel	98% Nitrogen	2036	0.000	0.00	
Galvanized steel	98% Nitrogen	2398	0.001	0.15	
Galvanized steel	98% Nitrogen	2893	0.001	0.13	

Figure 1. As found condition of interior surface of black steel piping after 2893 days of exposure while half-filled with water and under compressed air supervision.

Figure 2. Composite image of cleaned black steel piping after 2893 days of exposure while half-filled with water and under compressed air supervision. Note uniform thinning of pipe wall with a few localized, shallow pits.

Figure 3. As found condition of interior surface of black steel piping after 2893 days of exposure while half-filled with water and under 95% nitrogen supervision.

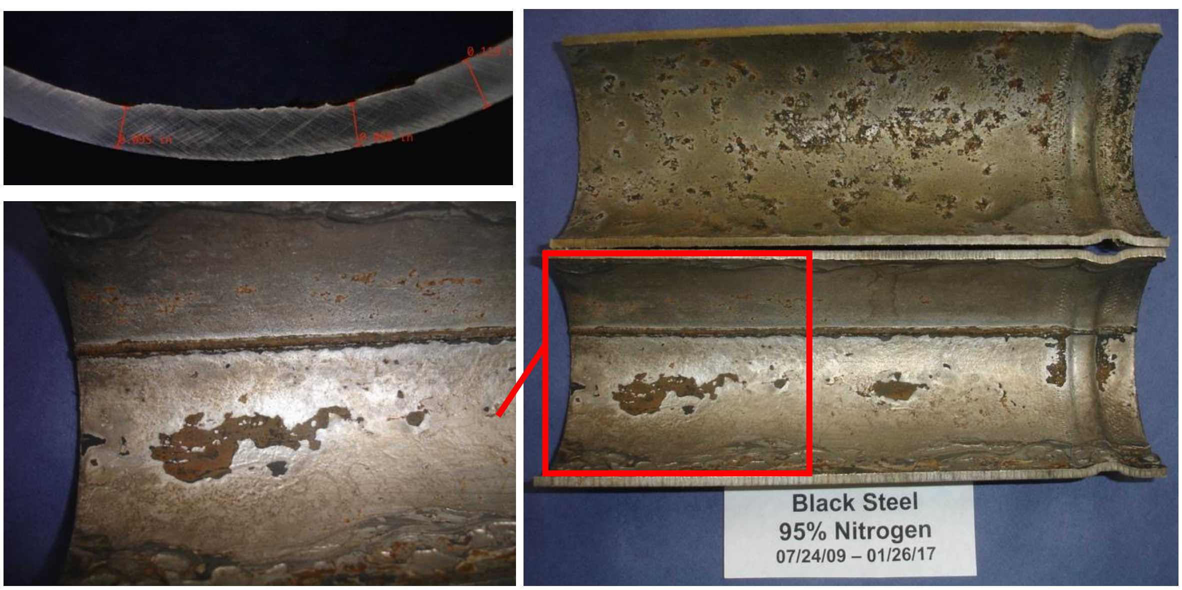

Figure 4. Composite image of cleaned black steel piping after 2893days exposure while half-filled with water and under 95% nitrogen supervision. Note uniform appearance of pipe wall and absence of any localized pits.

Figure 5. As found condition of interior surface of black steel piping after 2893 days of exposure while half-filled with water and under 98% nitrogen supervision.

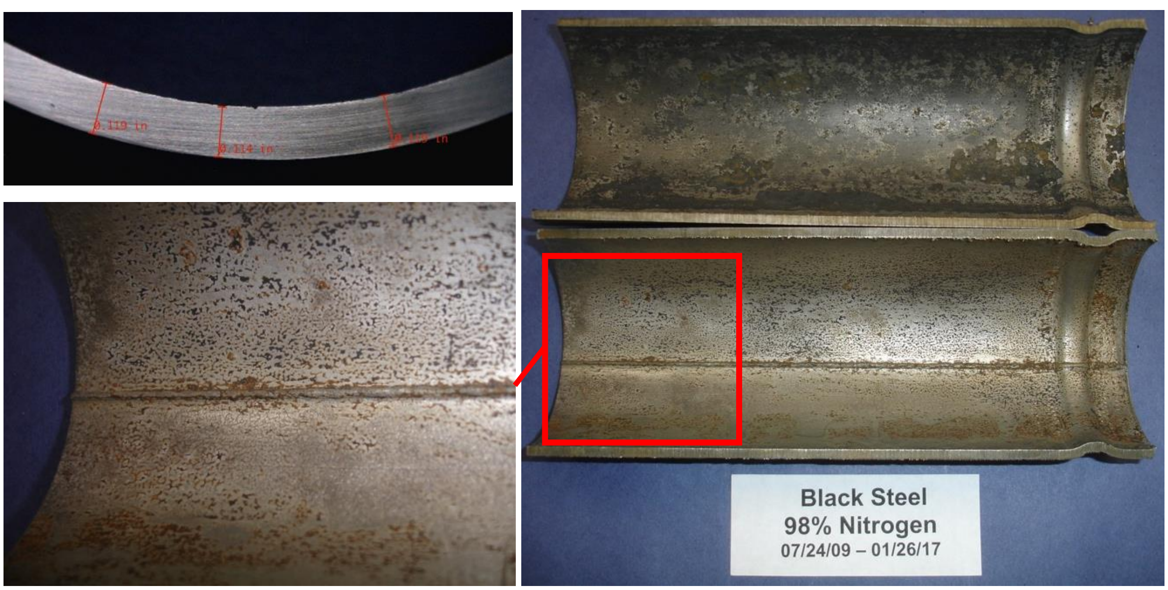

Figure 6. Composite image of cleaned black steel piping after 2893 days of exposure while half-filled with water and under 98% nitrogen supervision. Note uniform appearance of pipe wall and absence of any localized pits.

Figure 7. As found condition of interior surface of galvanized steel piping after 2893 days of exposure while half-filled with water and under compressed air supervision.

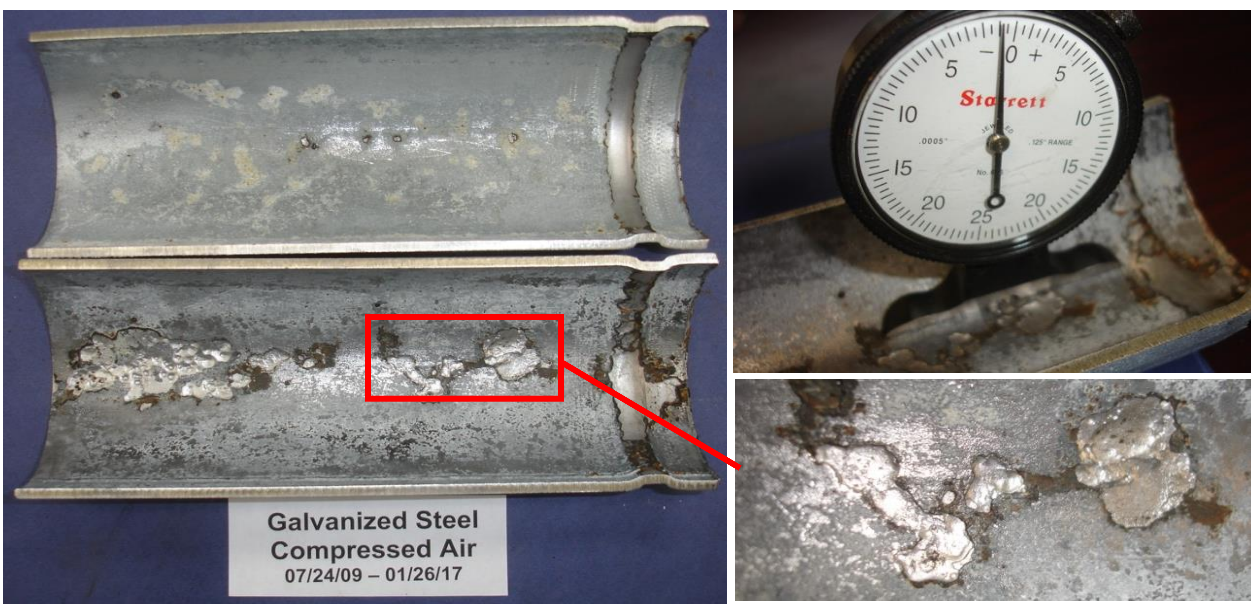

Figure 8. Composite image of cleaned galvanized piping after 2893 days of exposure while half-filled with water and under compressed air supervision. Note localized pitting at locations where zinc coating has been breached.

Figure 9. As found condition of interior surface of galvanized steel piping after 2893 days of exposure while half-filled with water and under 95% nitrogen supervision.

Figure 10. Composite image of cleaned galvanized piping after 2893 days of exposure while half-filled with water and under 95% nitrogen supervision. Note the presence of localized pits in areas where zinc coating is no longer present

Figure 7. As found condition of interior surface of galvanized steel piping after 2893 days of exposure while half-filled with water and under 98% nitrogen supervision.

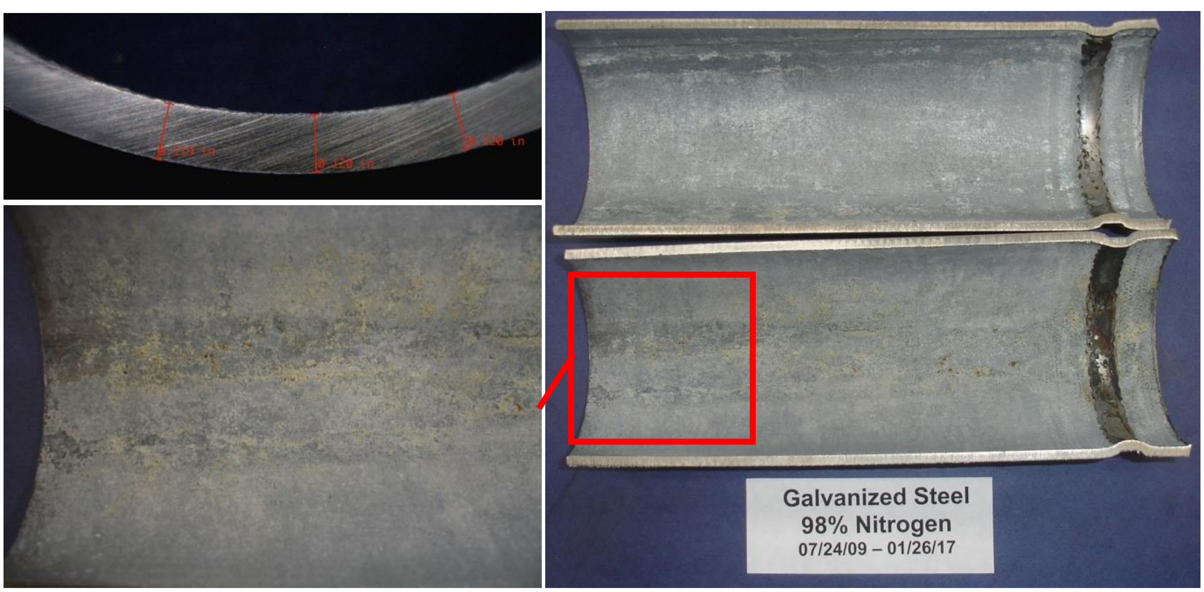

Figure 8. Composite image of cleaned galvanized steel piping after 2893 days of exposure while half-filled with water and under 98% nitrogen supervision. Note uniform appearance of pipe wall and absence of any localized pits.

CONCLUSIONS

The results of pipe analysis testing after 2893 days of uninterrupted testing of galvanized and black steel under compressed air, 95% nitrogen, and 98% nitrogen can be summarized as follows:

Black steel:

- To date, the mechanism of corrosion for both compressed air and nitrogen-supervised black steel is uniform wall-thinning.
- The average penetration rate of black steel under compressed air supervision is approximately 6 mils/yr. (This is likely to increase if and when mechanism converts to predominantly localized pitting.)
- The average penetration rate of black steel under 98% nitrogen supervision is approximately 2 mils/yr. (This rate appears to be decreasing with exposure time)

Galvanized Steel:

- The mechanism of corrosion on galvanized steel supervised by air and 95% nitrogen is localized pitting.
- The average galvanized steel penetration rate under compressed air supervision is approximately 13 mils/yr and approximately 10 mils/yr under 95% nitrogen supervision due to localized pitting.
- The average galvanized steel penetration rate under 98% nitrogen supervision is approximately 0.7 mils/yr with no indications of localized pitting.