White Paper

Six Reasons Why Galvanized Steel Piping Should NOT be Used in Dry and Preaction Fire Sprinkler Systems

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Introduction

Galvanizing steel has been used in a variety of industries for many years to prevent atmospheric corrosion of steel. The galvanizing process involves the application of a thin layer of metallic zinc to the substrate base metal which is typically mild steel. There are three different processes for applying the zinc coating to the steel surface: Hot-Dip Galvanizing (HDG), Heavy Mill Galvanizing (HMG) or Electrogalvanizing. The net effect for each process is a thin coating of zinc metal is applied on the steel surface.

In almost every industrial application, galvanizing is used to protect mild steel from atmospheric corrosion by oxygen. Some common examples where galvanized steel provides protection from atmospheric corrosion are guard rails, sign posts, fencing and corrugated steel roofing material. When applied to piping, the galvanizing process typically applies the zinc coating to both the inner and outer surfaces of the piping material.

Insofar as corrosion control is concerned, there are three mechanisms by which the substrate base metal is protected from atmospheric corrosion:

1. The zinc acts as a barrier which prevents the corrosive fluid from contacting the iron in the mild steel base metal. If the substrate iron is not contacted by the water, it will not corrode.
2. Zinc metal is less noble than iron and as such is more prone to give up its electrons than iron. The process of giving up the electrons to form a metal oxide is called corrosion. Zinc will corrode preferentially when coupled to iron and will act as a “sacrificial anode” and will thereby protect the iron from corrosion.
3. Finally, the zinc coating forms a passive film of zinc carbonate on the metal surface. Zinc carbonate is a tenacious, impervious film that can significantly reduce the rate of oxygen corrosion. The zinc passivation process involves three separate chemical transitions. The final transition from zinc hydroxide to zinc carbonate requires that the metal be in direct contact with carbon dioxide in the air:

$\mathbf{Zn_0}$ (zinc metal) → **ZnO** (zinc oxide) → $\mathbf{Zn(OH)_2}$ (zinc hydroxide) → $\mathbf{ZnCO_3}$ (zinc carbonate)

In theory, use of galvanized steel tubing in dry pipe fire sprinkler system applications makes sense. The exterior of the tubing will not rust due to atmospheric oxygen corrosion because the zinc carbonate layer forms and protects the external surfaces and the “essentially dry” state of the interior piping should mean that corrosion is minimal. When it comes to the interior surfaces of dry and preaction fire sprinkler piping, quite the contrary is true. The ensuing discussion presents six primary reasons galvanized steel piping should not be used in fire sprinkler piping.

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Reason No. 1: Ineffective Corrosion Resistance

Galvanized steel pipe is NOT more corrosion resistant than black steel piping under normal use conditions in dry and preaction fire sprinkler applications. The atmosphere inside dry pipe fire sprinkler systems presents a persistently moist, oxygen rich environment which means that the galvanized coating corrodes at a very high rate.

Unfortunately, galvanized steel tubing performs very poorly when used as dry and preaction fire sprinkler pipe. If water is trapped within the piping network the zinc layer will break down quickly and ultimately lead to a pin-hole leak. This problem is complicated further because the nature of the attack is localized. The first manifestation might be a single orange tubercle on the galvanized surface (see Figure 1). Once the zinc coating is breached and the underlying steel is exposed to the corrosive fluid, oxygen corrosion will be concentrated at the point of the breach. This is quite obvious in laboratory testing as the corrosion by-product of iron is the characteristic orange hematite.

The final transition in the passivation reaction to form zinc carbonate requires that the metal surface be allowed to dry completely. The rate of drying is an important factor in the corrosion mechanism because a thin moisture film with high oxygen concentration will accelerate the rate of zinc corrosion[1]. Because of the highly localized nature of corrosion attack in galvanized steel piping, the empirical evidence suggests that through-the-wall penetrations occur faster in galvanized steel corrosion than black steel exposed to the same conditions.

To suggest that dry pipe fire sprinkler systems are actually *dry* is a complete misnomer as they almost always contain water from several sources:

- Poor design and installation of the system piping creates traps for any water introduced into the system; insufficient pitch in the piping, insufficient auxiliary drains, etc.
- Initial hydrostatic testing of the system after installation
- Full flow trip test of the fire sprinkler system as required by code
- Accidental tripping of the fire sprinkler system
- Vapor phase water introduced with compressed maintenance air; the water eventually condenses and pools in the piping due to temperature fluctuations in the ambient environment

In dry pipe fire sprinkler systems oxygen exists in abundance and the amount of wetted metal located just beneath any droplets or small pools of water regulates the overall rate of corrosion. These systems corrode rapidly because the corrosion reactions are very localized and there is always plenty of oxygen to continue reacting with the wetted metal. As the metal oxide is formed and deposits at the metal surface the corrosion reaction continues while more and more metal is removed from the wetted pipe surface (see Figure 2).

Ultimately, a failure will occur at a point just beneath the trapped pool of water.

Condensed water from the compressed moist air injected into a dry pipe system presents another complicating factor regarding corrosion of the system piping. Since the condensed water is essentially distilled and contains no dissolved minerals, it has no buffering capacity to neutralize the carbonic acid formed when carbon dioxide from the air inside the pipe dissolves into water. Most condensed water has a pH in the acidic range of about 5.5. This acidic water will greatly increase the rate of corrosion.

Reason No. 2: Not Heat Annealed

The ASTM standard (ASTM 795-96)[2] for piping used for fire protection systems does not require the piping to be heat annealed to normalize the weld seam on the pipe. Fire sprinkler tubing is typically welded using electric-resistance welds or furnace welds. As a result, once the galvanized layer is breached during the corrosion process, it is highly likely that the pipe seam will exhibit anodic character and corrode preferentially to the other exposed black steel (see Figure 3). Piping with seams that are fortuitously positioned in the bottom of piping that holds trapped water will leak first. The failure will exhibit the characteristic “knife cut” metal loss on or near the pipe’s seam (see Figure 4).

This problem is not unique to galvanized steel piping as black steel piping is also not required to be heat annealed for fire protection systems. However, because of the highly localized corrosion described in the preceding paragraphs pipe seam failure can occur more rapidly in galvanized steel piping.

Reason No. 3: Unnecessary Cost

The installed cost for galvanized steel piping is greater than the corresponding black steel for the same size dry pipe fire sprinkler system. Given the facts presented in Reason No. 1, it does not make sense to pay more for material that does not provide any additional corrosion protection.

In a 2009 RS Means Plumbing Cost comparison (see Table No. 1) the cost premium for installing galvanized pipe was approximately 40% higher than black steel piping for the same size sprinkler system. This cost premium can vary depending on size and design of the system and schedule of the piping; however, the cost of galvanized pipe will always be greater than black steel pipe.

Nitrogen gas has been used effectively to control oxygen corrosion in fire sprinkler system piping by removing oxygen from the system. If nitrogen gas is used to create an inerted, i.e. oxygen free, atmosphere within the dry pipe system, black steel pipe used in actual conditions and galvanized steel pipe used in ideal conditions perform equally in terms of corrosion resistance and it is possible to reduce the schedule of the piping. Ultimately, the additional cost for the galvanized steel pipe is not warranted.

Reason No. 4: Acute Toxicity

Galvanized steel piping subjected to the corrosive conditions typically found in dry and preaction fire sprinkler systems produces discharge water that may be high in levels of zinc both as precipitated solids and as soluble metal complexes. In many jurisdictions the fire sprinkler water from a galvanized fire sprinkler system with high levels of zinc may be considered a toxic waste. As the zinc layer on the interior piping walls is degraded by oxygen corrosion, metallic zinc is converted to a water soluble ion and then to a zinc oxide. The corrosion by-product of galvanized pipe corrosion will produce the following zinc constituents:

- Zinc oxides
- Zinc hydroxides
- Various other zinc salts

The amount of soluble and insoluble zinc depends on the specific conditions within each individual fire sprinkler system. The chemistry of the trapped water will also affect the corrosion rate of the zinc layer. Soft water and high chlorides and sulfates can accelerate the corrosion rate of the galvanized coating[3].

The bottom line is that it is highly likely that any water discharged from a galvanized steel fire sprinkler system will contain significant amounts of zinc. Although individual jurisdictions may vary in the methods and means by which sprinkler discharge water must be handled, most jurisdictions consider zinc a heavy metal contaminant. A cursory review of the related literature indicates that the allowable discharge limits for zinc containing waters is as low as 1.0 mg/L. Zinc is also highly toxic to fresh water fishes[4], including those exposed to sprinkler water drained to storm sewers.

Our analyses of several hundred deposit samples from galvanized dry pipe fire sprinkler systems indicate that the deposits inside the pipe can contain zinc at levels from 1% up to 96%. We have measured water from galvanized dry pipe systems with as much as 1500 mg/L of zinc present in the water.

Reason No. 5: False C Value Benefit

The result of the chemical corrosion reaction is the liberation of metal ions into the water from the metal surface that has been corroded. The physical effect of corrosion on the pipe wall is the creation of a void (a pit) where the metal ion had previously existed as the base metal. The cumulative result of many oxygen corrosion reactions is a measureable change in the surface texture of the pipe wall. This is especially true in the case of galvanized steel piping which starts out as a polished, clean surface. To put it simply, the surface texture exhibits two new characteristics:

- It gets rougher as the surface is pitted
- The surface area grows

In calculating pipe friction losses for fire sprinkler systems using the Hazen-Williams formula, galvanized steel tubing is given a beneficial advantage over black steel when used in dry and preaction fire sprinkler systems. The recommended C value for black steel piping used in dry pipe systems is 100, while the value for galvanized piping is 120[5].

Hazen-Williams formula: $$p = \frac{4.52Q^{1.85}}{C^{1.85}d^{4.87}}$$

where:
p = frictional resistance (psi/ft)
Q = flow (gpm)
C = friction loss coefficient
d = actual internal pipe diameter (in) [5]

Treating other variables as constants, higher C values equate to lower frictional resistance. However, this calculation becomes more inaccurate as the sprinkler system corrodes. The damaging effects of oxygen corrosion will reduce the friction loss benefit in galvanized steel as the interior of the pipe walls degrade. Accordingly, the original hydraulic calculations used to determine correct pipe and sprinkler orifice sizes may be invalid once the fire sprinkler system has been exposed to water.

Reason No. 6: Tin Whiskers

In mission critical data center applications the external coating of zinc that exists on the galvanized steel pipe used in the preaction fire sprinkler system may contribute to the formation of "tin whiskers" (see Figure 5). Tin (and zinc) whiskers have been linked to electrical shorting problems within the electrical circuits in the data center environment. The exact cause of the phenomena is not completely understood, however, tin and zinc present in the data center environment are thought to be contributing factors in the formation of tin whiskers.

There is an extensive amount of background information regarding the "tin whiskers" phenomenon at http://nepp.nasa.gov/whisker/background. Until the root cause for "tin whiskers" can be identified, it is prudent to assume that any galvanized steel components used in mission critical data center environments might be contributing to their formation. The simplest mitigation approach is to avoid the use of galvanized steel fire sprinkler piping and electrical conduit.

Conclusions

The use of galvanized steel piping within the fire sprinkler industry is a complete misapplication of the construction material. The bottom line is that the conditions inside the piping that must exist in order for galvanized steel piping to be effective against oxygen corrosion, i.e. completely dry, are also ideal for the use of black steel piping. As has been stated, the evidence suggests that under the same conditions inside the pipe, black steel will outperform galvanized steel because the corrosive attack in black steel piping is not as localized. Regarding the exterior surface of the piping, it makes more sense to paint black steel piping to prevent atmospheric rusting rather than pay the premium for galvanized steel.

The original intent of converting from black steel to galvanized steel as a means of improved corrosion protection in dry and preaction fire sprinkler systems was well intentioned. However, the scientific data from the field has clearly demonstrated the poor performance of galvanized steel piping under the typical conditions that exist in dry and preaction fire sprinkler systems. All of the evidence presents a compelling argument for change.

It is time for the fire sprinkler industry to consider completely eliminating the use of galvanized steel as an option for dry and preaction fire sprinkler system piping. Additionally, galvanized steel should never be considered in wet pipe fire sprinkler system applications. Black steel piping is the most cost-effective approach in terms of initial installed cost and long term service life when used in conjunction with nitrogen inerting to control oxygen corrosion. This is true for both wet pipe applications and dry/preaction applications. Nitrogen inerting as a means for oxygen corrosion control does not pose any of the complications that are inevitable when chemical corrosion inhibitors are employed[6].

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References

[1] *"Corrosion of Zinc"* National Association of Corrosion Engineers (NACE) Key to Metals www.key-to-nonferrous.com

[2] ASTM A795-96 - Standard Specification for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Fire Protection Use

[3] *"White Rust: An Industry Update and Guide Paper 2002"* Association of Water Technologies – technical committee of Association of Water Technologies

[4] "*Acute Toxicity of Zinc to Some Fishes in High Alkalinity Water*" by Paula Reed, Dorothy Richey, and Donald Roseboom. Illinois State Water Survey Urbana 1980. ISWS/CIR-142/80 Circular 142 State of Illinois, Illinois Institute of Natural Resources

[5] NFPA 13 - Standard for the Installation of Sprinkler Systems, 2010 Edition

[6]White Paper - *"Controlling Corrosion in Wet Pipe Fire Sprinkler Systems Using Chemical Corrosion Inhibitors"* J.T. Kochelek and G. Van Moorsel.

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Table 1: Dry Pipe Sprinkler System Cost Comparison - June 2009

Option 1 - BLACK STEEL sch. 10 mains & branchlines			**Option 2 – GALVANIZED sch. 10 mains, sch. 40 branchlines**		
435 gallon dry pipe fire sprinkler system					
Pipe Size	Cost/L.F.	Total	Pipe Size	Cost/L.F.	Total
1"	$ 11.15	$ 8,072.60	1"	$ 16.70	$ 12,090.80
1 1/4"	$ 12.90	$ 4,398.90	1 1/4"	$ 19.05	$ 6,496.05
1 1/2"	$ 14.75	$ 9,484.25	1 1/2"	$ 21.50	$ 13,824.50
2"	$ 19.45	$ 5,465.45	2"	$ 28.00	$ 7,868.00
2 1/2"	$ 25.00	$ 1,475.00	2 1/2"	$ 32.50	$ 1,917.50
3"	$ 28.00	$ 924.00	3"	$ 36.40	$ 1,201.20
4"	$ 33.50	$ 2,345.00	4"	$ 41.90	$ 2,933.00
6"	$ 55.50	$ 5,883.00	6"	$ 69.40	$ 7,356.40
Pipe Total **		$ 30,048.20	Pipe Total **		$ 53,687.45
645 gallon dry pipe fire sprinkler system					
Pipe Size	Cost/L.F.	Total	Pipe Size	Cost/L.F.	Total
1"	$ 11.15	$ 13,513.80	1"	$ 16.70	$ 20,240.40
1 1/4"	$ 12.90	$ 18,189.00	1 1/4"	$ 19.05	$ 26,860.50
1 1/2"	$ 14.75	$ 5,752.50	1 1/2"	$ 21.50	$ 8,385.00
4"	$ 33.50	$ 19,932.50	4"	$ 41.90	$ 24,930.50
Pipe Total **		$57,387.80	Pipe Total **		$ 80,416.40

Pipe Size	**System Size**	
	435 gallon linear ft	**645 gallon linear ft**
1"	724	1212
1 1/4"	341	1410
1 1/2"	643	390
2"	281	0
2 1/2"	59	0
3"	33	0
4"	70	595
6"	106	0

435 Gallon System Comparisons			
Option	**System Cost ($)**	**Added Cost ($)**	**%**
1	$ 38,048.20	-	0
2	$ 53,687.45	$ 15,639.25	41%

645 Gallon System Comparisons			
Option	**System Cost ($)**	**Added Cost ($)**	**%**
1	$ 57,387.80	-	0
2	$ 80,416.40	$ 23,028.60	40%

(*) Cost per liner foot values from 2009 RSMeans Plumbing Cost Data and average costs obtained from manufacturers; prices reflect threaded pipe for sch. 40 and grooved pipe for sch. 10.

(**) Totals include labor, overhead and profit. Average values used for construction cost, labor and material indexes.

Note: comparison for initial install piping cost only; costs do not include constants such as sprinklers, valves, hangers, etc.

Figure 1

Figure 2

Figure 3

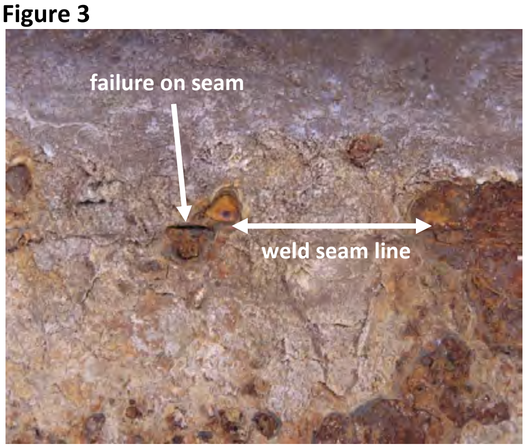


Figure 4

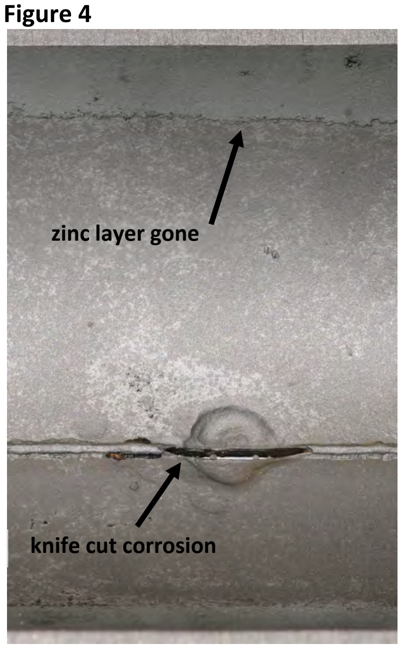
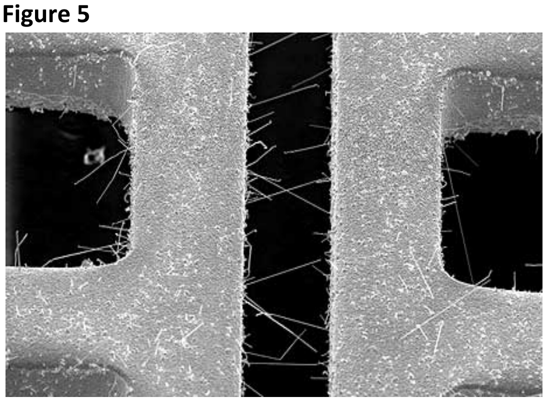


Figure 5



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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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