White Paper

The Effective Use of "Fill and Purge" Pressure Cycling During Dry Pipe Nitrogen Inerting (DPNI) for Corrosion Control

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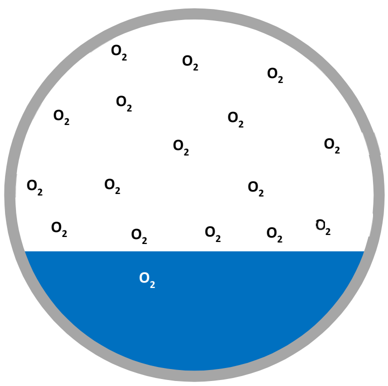
Introduction

There are two (2) fundamental goals for controlling corrosion in dry and preaction fire sprinkler systems using **Dry Pipe Nitrogen Inerting (DPNI)**. Both goals involve the exclusion of oxygen gas from the fire sprinkler system piping to prevent corrosion. Operationally, the first objective is to <u>remove oxygen gas</u> from the air-filled fire sprinkler piping before it has a chance to react with the pipe metal (iron or zinc). The second objective of DPNI is to <u>maintain the inerted atmosphere</u> within the piping with nitrogen as the pressure maintenance gas.

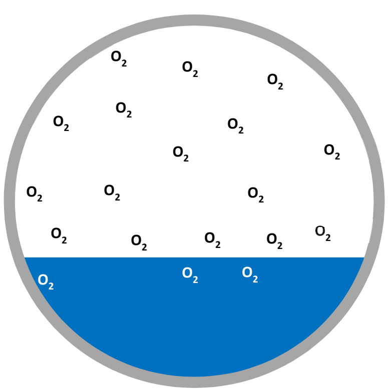
There are several discrete physical/chemical reactions that occur when oxygen gas causes corrosion of fire sprinkler piping:

Step 1: Oxygen gas that is present at 21% in the air-filled piping first **dissolves into liquid** water. Oxygen cannot react with the metal in the corrosion process until it dissolves into liquid water.



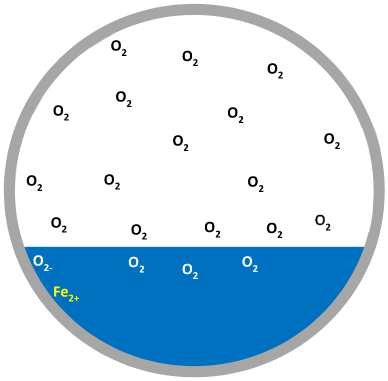
O_2 in the air dissolves into trapped water (FAST)

Step 2: Dissolved oxygen molecules **move through the water** to contact the metal surface (iron or zinc) of the pipe wall that is in intimate contact with the liquid water.



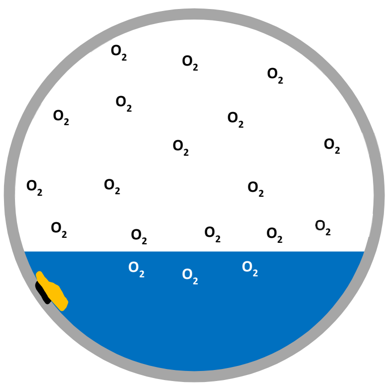
Dissolved O_2 moves to metal surface (VERY SLOW)

Step 3: The dissolved **oxygen chemically reacts** with the metal (iron or zinc); this reaction is called oxidation and two (2) electrons are extracted from the metal to form a water-soluble metal ion (Me^{2+}) and produce a negatively charged oxide ion (O^{2-}).



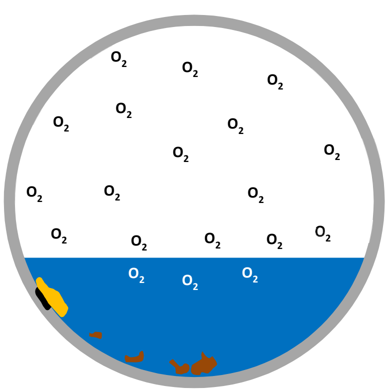
Corrosion reaction produces ions Fe^{2+} and O^{2-} (FAST)

Step 4: The removal of the metal (iron or zinc) from the wall of the pipe into the liquid water **creates a void** in the surface of the pipe called a pit.



Ions react in water to produce rust Fe_2O_3 and a pit (FAST)

Step 5: The liberated water soluble metal ion (Me^{2+}) immediately reacts with oxide ion (O^{2-}) in the water and **precipitates** as insoluble metal oxide sludge – iron oxide or zinc oxide.



Metal ions react with oxide ion to produce insoluble metal oxide (FAST)

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A review of these five (5) physical/chemical reactions can provide the relative speed for each of the steps in the process. The rate at which these reactions occur provides a vital clue regarding the strategy for controlling the oxygen corrosion process within a dry or preaction fire sprinkler system.

1. The rate at which gaseous oxygen diffuses (dissolves) into water is FAST. Oxygen will do this everywhere the air contacts the water surface.
2. Oxygen has very low solubility in fresh water and although it dissolves into the water quickly, when the dissolved quantity reaches about 0.001% (10 parts per million) the water is saturated and no more oxygen can dissolve into the water. Thus, the rate at which a fixed volume of oxygen within the pipe will be consumed by the corrosion reaction is SLOW.
3. The rate at which dissolved oxygen molecules move through stagnant water to the metal surface is VERY SLOW.
4. The rate at which dissolved oxygen in water reacts with the metal surface once it contacts the metal is FAST.
5. The rate at which oxygen corrosion reaction forms a pit in the pipe wall is FAST.
6. The rate at which water soluble iron precipitates as iron oxide (rust) is FAST.

The two SLOW steps in the process create a bottleneck and provide the opportunity to get unreacted oxygen gas out of the piping before it corrodes the pipe. If all the reactions in the process were fast the oxygen would be quickly consumed by the corrosion reaction and damage to the pipe wall would occur almost instantaneously. The DPNI process takes advantage of the time lag that is created by the bottleneck in the corrosion reaction.

After the initial oxygen is removed from the piping network a nitrogen generator is used in place of the air compressor to ensure that new oxygen is NOT added to fuel the corrosion reaction each time pressure maintenance gas is needed. Inert nitrogen gas is used to halt oxygen corrosion damage.

More About Oxygen Corrosion

Liquid water must be present for oxygen to react with steel or galvanized steel piping in the process of corrosion. The initial hydrostatic test of the fire sprinkler system piping always leaves residual trapped water. It is not physically possible to completely drain water from the piping even if auxiliary drains or drum drips are installed and the piping is properly pitched to drain. For oxygen corrosion to occur only a slight sheen of liquid water contacting the metal surface is needed.

Water added during system testing is a second source of water and condensate from the pressure maintenance air compressor is a third source. Wherever there are trapped pools of water within the dry or preaction sprinkler piping, oxygen corrosion will take place at the air/water interface. In dry and preaction systems constructed using galvanized steel piping corrosion failures can occur within 2 - 3 years after installation[1]. Galvanized steel corrodes with highly localized attack at anomalies in the zinc coating on the steel. Black steel piping corrodes by a mechanism that produces general wall thinning under the trapped water. Black steel systems can start leaking 5-10 years after installation.

The Dry Pipe Nitrogen Inerting (DPNI) Process

DPNI has two (2) goals:

1. Remove the oxygen gas from the piping BEFORE it has a chance to react with the pipe
2. Maintain the inerted atmosphere by replacing pressure maintenance air with nitrogen gas

<u>The Problem of a "Complex" Vessel Like a Sprinkler System</u>

There are several publications that describe the method of inerting tanks, vessels and other equipment[2,3,4]. The process involves displacing/diluting and exhausting one gas with another gas within the vessel. In many instances inerting is done for safety reasons to mitigate the explosion risk that might exist when oxygen in the air is present to support combustion in a vessel containing a flammable liquid. In the case of DPNI inerting is used to remove oxygen gas before it can react to cause corrosion damage to metallic fire sprinkler piping.

There are three broad categories for inerting:

1. Blanketing – generally used for simple vessels like tanks
2. Purging – generally used for pipelines and more complex vessels
3. Sparging – generally used to remove gases from liquids

There are several different **purging methods**:

1. Displacement (sweep through) – slow piston-like displacement in simple vessels and pipelines
2. Dilution – requires larger volumes of displacing inert gas; inlet remote from outlet
3. Vacuum – pull a vacuum on a closed vessel and backfill with inert gas
4. Pressure swing – fill and purge pressure cycles in a closed vessel; inlet and outlet close together

Only one of the purging methods is suited for use in the complicated piping that is involved in dry and preaction fire sprinkler systems. FM Global's data sheet on inerting suggests that "if the system is complex, involving side branches through which circulation cannot be established, sweep through purging may be impractical and pressure or vacuum purging might be necessary."[4]

Using vacuum purging is not appropriate in a dry or preaction fire sprinkler system. Pulling a vacuum on the piping would risk altering the seal or damaging the mechanical couplings that are commonly used in fire sprinkler systems.

Empirical testing of both sweep through purging and pressure swing purging on dry pipe systems proved conclusively that only pressure swing purging can efficiently remove oxygen. Further, the Linde Gas Handbook *Inerting in the Chemical Industry*[3] suggests that pressure swing purging is most appropriately used "when the apparatus is a pressure vessel" and "when the inlet and outlet ports are located close together". This description accurately describes the configuration that is used when performing Dry Pipe Nitrogen Inerting on a dry pipe fire sprinkler system with the inlet at the fire water control valve and the outlet (purging vent) on the riser.

Get the Oxygen Out

DPNI accomplishes the first goal of removing oxygen from the piping using "fill and purge" pressure swing purging[3]. During the "fill" portion of the cycle 98%+ nitrogen gas from a nitrogen generator is injected into the fire sprinkler system piping at a rate that causes the pressure within the entire piping network to increase. When this is done, several physical changes occur:

- The oxygen concentration within the piping is diluted and the nitrogen concentration is enriched. Calculating the change is a simple arithmetic formula based on the amount of nitrogen gas that is added to the total pipe network volume.
- By injecting nitrogen gas at a rate which increases the pressure within the pipeline, the gases within the pipe experience dynamic mixing as the nitrogen gas moves under pressure from the control valve deep into the closed piping network. Gas mixing is extremely efficient when a displacing (diluting) gas is introduced in a manner that increases the pressure within the vessel. Each bend in the piping creates turbulence and mixing of the gases.
- As gas movement and mixing occurs, the composition of the gas within the piping network homogenizes so that pockets of high oxygen concentration are instantly diluted.

During each fill cycle, nitrogen gas is added to the piping network until the pressure within the system piping reaches a predetermined maximum. It is possible to calculate the total amount of nitrogen gas that is added during the fill cycle if the system volume, the starting pressure and the ending pressure are known ($P_1V_1 = P_2V_2$). Once the quantity of nitrogen gas added during the fill cycle is known, it can be used to predict the sequential dilution of the oxygen content within the piping that occurs with each "fill and purge" cycle[2,3].

During the "purge" portion of the cycle the oxygen diluted gas within the piping is vented from the system piping. When this is done, several physical changes occur:

- The vent opening allows for gas to escape from an otherwise closed pressure vessel; all the gas within the piping moves in the direction of the pressure drop that occurs at the vent.
- The gas composition within the piping becomes more and more homogeneous as dynamic mixing occurs while the gas moves through the piping network toward the vent; it moves in the opposite direction of the gas movement during the fill half of the cycle.
- When the purge portion of the pressure swing cycle is completed, a portion of the unreacted oxygen is permanently removed from the piping so it cannot corrode the pipe.

Each successive "fill and purge" cycle dilutes the concentration of oxygen gas and enriches the concentration of nitrogen gas within the piping. After a fixed number of "fill and purge" cycles the oxygen is diluted and displaced until the concentration of the gases within the system piping reach the same purity of the injected gas, i.e. 98% nitrogen and 2% oxygen. When this point is reached, the "fill and purge" pressure swing cycling is stopped. This usually can be accomplished in 8 - 14 days. Once the fire sprinkler system piping reaches 98%+ nitrogen gas, it is considered fully inerted. The small amount of oxygen left in the system will be consumed by the pipe and will cause a minimal amount of corrosion.

It is not necessary to continue fill and purge pressure swing cycling once the gas in the piping is the same concentration as the gas being produced by the nitrogen generator. Moving forward, the only time the nitrogen generator will cut in to add nitrogen gas to the system is to accommodate the small amount of gas leakage from the system.

Gas Flow and Water Flow in A Dry or Preaction Fire Sprinkler System

"Fill and purge" pressure swing cycling can be used to displace one gas with another gas in any closed vessel[2,3,4]. The variables that must be considered to design an inerting plan include: vessel volume, complexity of the vessel design, fill pressure, fill rate, fill port location, exhaust vent rate and exhaust vent location. The relative densities of the displacing gas from the gas being displaced must also be considered. In DPNI the displacing gas is nitrogen and the gas being displaced is oxygen (in air). The density of nitrogen and oxygen are very close to the same. Oxygen gas is slightly denser than nitrogen gas in direct proportion to its higher molecular weight. In the case of dry and preaction fire sprinkler systems, nitrogen gas already makes up approximately 78% of the gas volume of the air within the pipe.

The piping design that is most commonly used for a dry or preaction fire sprinkler system is called a "tree" system. This design feature means that there is generally no repeating gridded pattern as might be found in a wet pipe fire sprinkler system. The "tree" design is used because it is easier to get water from the control valve to the furthest sprinkler in the system within the shortest period after a trip event.

One of the attributes of a dry or preaction fire sprinkler system that uses a "tree" configuration is that the piping design may have many branch lines which terminate with a sprinkler attached to the smallest diameter piping in the system. This design can be very complex as the piping makes a path through the building structure. It is this complicated design feature that makes simple sweep through purging inappropriate[3].

"Fill and Purge" Vs "Sweep Through"

In analyzing the "fill and purge" pressure swing cycling process it is appropriate to consider a dry or preaction fire sprinkler system as an irregularly shaped pressure vessel. Gas movement through an irregularly shaped vessel is much different from water movement through that same vessel. Water is not compressible and it will flow into any opening in its path. Water is also greatly affected by gravity and it will self-level as the vessel fills.

Gas is compressible and it will always move in the direction of the lowest pressure within the closed vessel. Gas does this much more quickly and easily than water. Two different gases will also mix more efficiently than two liquids. There are many more intermolecular collisions as gases mix. With gases of similar densities like oxygen and nitrogen, the effect of gravity is very minimal.

When nitrogen gas is injected into the sprinkler riser and vented at the end of a branch line, the nitrogen gas will move very efficiently toward the pressure drop at the vent. If the nitrogen gas is injected at a low flow rate the nitrogen is more likely to move directly to the pressure drop with very limited dynamic mixing in route to the vent. This type of gas displacement process can be appropriately characterized as "sweep through" and NOT "fill and purge" pressure swing cycling. Sweep through inerting in a dry or preaction fire sprinkler system with a vent at the end of a branch line and no pressure cycling will result in the following conditions:

- Short circuiting of the nitrogen gas from the riser directly to the vent.
- Very limited gas movement and mixing in the piping that is not in the direct line between the riser and the vent.
- Limited removal of the unreacted oxygen gas from the remote branch lines.

Empirical trials on dry pipe systems have demonstrated that nitrogen gas injected at the riser flows very predictably to any of the branch lines that are equipped with vents. Branch lines that do not have vents receive very little flow of nitrogen gas.

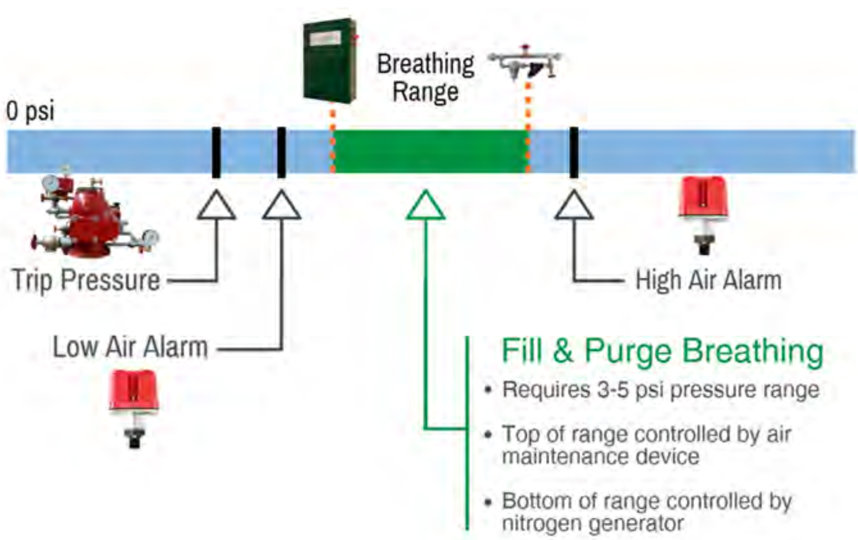

Figure 1: Graphical Representation of Fill and Purge Pressure Swing Cycling

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When "fill and purge" pressure swing cycling is used, the vent can be positioned anywhere within the system piping because during the purge portion of the cycle all of the gas within the system moves toward the pressure drop that occurs at the vent. There are several benefits to placing the vent on the riser above the system control valve:

1. It is simpler and less expensive to install the vent at the riser.
2. A vent in the riser room creates less leak risk than a vent installed remotely on a branch line.
3. During "fill and purge" pressure cycling the nitrogen gas moves deeply into the fire sprinkler system piping away from the riser during the "fill" phase. During the "purge" phase the oxygen diluted gas mixture moves in the opposite direction toward the riser; this promotes mixing and homogenization to efficiently remove unreacted oxygen.
4. Sampling gas from the vent on the riser during the DPNI process will be much more representative of the gas composition within the system piping.

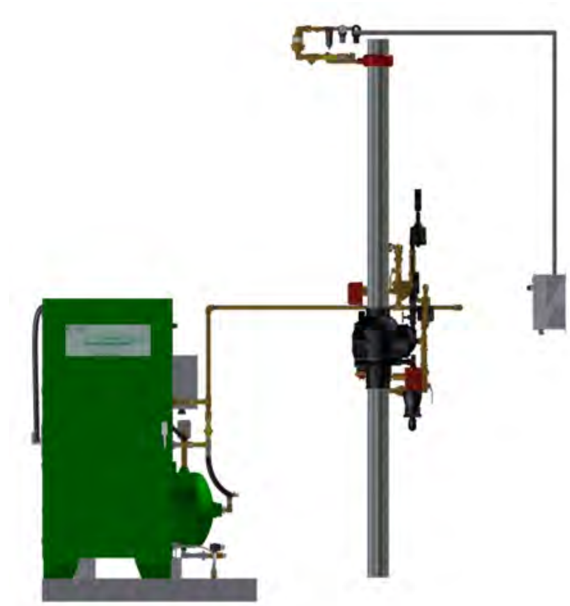

Figure 2: Nitrogen Generator Supplying Dry Pipe System with a Vent Installed on Sprinkler Riser

Monitoring Oxygen Gas Composition in Fire Sprinkler Piping

In the DPNI process, an oxygen analyzer can be installed on the vent and used to easily monitor two (2) critical items:

1. During the "fill" phase the gas analyzer on the vent measures the exact output purity of the nitrogen generator as it is pushed past the vent on the riser into the fire sprinkler system piping.
2. During the "purge" phase the vent discharges the composite gas mixture from within the system piping.

Using this approach, it is possible to track the sequential dilution of the oxygen concentration and enrichment of the nitrogen concentration for the entire piping network. This has been validated during empirical field trials on many different dry and preaction fire sprinkler system configurations[6].

Injecting nitrogen gas at the control valve and venting the gas at the end of a branch line with a single vent as is done with “inject and vent” will always provide misleading data regarding the composition of the gas within the piping network. By measuring the gas composition at the end of a single branch line the results are likely to indicate an artificially low oxygen concentration within the piping. This is because the nitrogen gas injected at the control valve short circuits directly to the vent. There are three (3) negative consequence from this approach:

1. Nitrogen gas is not displacing oxygen gas within the bulk of the piping, rather moving straight from the control valve and out of the vent.
2. None of the unreacted oxygen gas that is remote within the system piping away from line of flow from the riser to the vent will be displaced; given sufficient time this oxygen will corrode the pipe
3. The gas in the line between the riser and the vent is artificially enriched with nitrogen gas and provides a false signal regarding the rest of the piping network.

If this signal is used as a means of demonstrating that the system piping is “nitrogen inerted” corrosion damage will occur as the un-swept oxygen that is left in the piping reacts with the pipe to cause corrosion.

Conclusions

The DPNI process which employs “fill and purge” pressure swing cycling provides several significant benefits for reducing the risk associated with oxygen corrosion in dry and preaction fire sprinkler systems:

1. It efficiently removes the oxygen from the fire sprinkler piping before it can cause corrosion.
2. Installing the vent on the riser can fully utilize the benefits of “fill and purge” pressure cycling to perform the nitrogen inerting process.
3. Monitoring the internal gas composition to ensure complete removal of oxygen can be done at the vent in the riser room with complete confidence that the reading is reflective of the nitrogen concentration in the purging gas and the composite gas composition from within the fire sprinkler piping.
4. After the fire sprinkler piping has been nitrogen inerted, the nitrogen generator is used to provide pressure maintenance gas so that oxygen is never introduced to the piping.
5. The DPNI process can be restarted any time the dry or preaction fire sprinkler system is flow tested or opened for any system modification.

In October 2016 FM Global released the revised Property Loss Prevention Data Sheet 2-1 entitled “Corrosion in Automatic Sprinkler Systems.”[5] Regarding the subject of corrosion in dry and preaction fire sprinkler systems FM Global suggests:

- In typical dry pipe systems where compressed air is used as the supervisory gas, the presence of water in the piping will result in rapid corrosion of the system.
- New dry and preaction systems can develop through-wall corrosion pinhole leakage from 2 to 3 years after initial installation due to residual water causing corrosion in galvanized steel pipe.
- Pressurize dry and preaction systems using an FM Approved nitrogen generator.
- Black steel pipe is acceptable in dry pipe and preaction sprinkler systems if nitrogen will be used throughout the life of the system.

After nine (9) years of field deployment of the Dry Pipe Nitrogen Inerting (DPNI) process using the "fill and purge" pressure swing cycling method for oxygen removal, it is evident that the method completely removes oxygen from the system piping before in can cause corrosion. Using an FM Approved nitrogen generator to provide pressure maintenance gas on dry and preaction fire sprinkler systems will prevent the repetitive addition of oxygen rich air to greatly reduce the oxygen corrosion risk.

References

[1] FM Global Research Technical Report "Corrosion and Corrosion Mitigation in Fire Protection Systems" by Paul Su and David Fuller – July 2014.

[2] "Properly Purge and Inert Storage Vessels" George R. Kinsley, Jr. CEP Magazine (American Institute of Chemical Engineers AIChE) February 2001.

[3] Linde Gas Handbook "Inerting in the Chemical Industry" by Linde Gas Division Seitnerstrasse 70, 82049 Pullach, Germany 2017.

[4] "Inerting and Purging of Tanks, Process Vessels, and Equipment" FM Global Data Sheet 7-59 May 2000.

[5] FM Global Property Loss Prevention Data Sheet 2-1 "Corrosion in Automatic Sprinkler Systems" October 2016.

[6] Engineered Corrosion Solutions field installations of nitrogen generators and integral vents on dry and preaction fire sprinkler systems were started in 2008.

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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