White Paper

Domestic Water Quality and Distribution System Remediation in an Institutional Facility

By David Roach, CPD

Introduction

Located in the heart of Appalachian coal mining country, this facility is a multi-story, steel, concrete, and brick structure. For the majority of the building's 20+ year life, operations and maintenance personnel have received occupant complaints about the building's poor water quality. Water quality complaints included visual discoloration and taste.

Comprehensive water quality tests were conducted throughout the building and at the source of incoming water supply from the local water authority. Samples representative of the incoming water supply to the building met both primary and secondary drinking water standards, however, the water was found to have low-alkalinity, on the order of 12 mg/L $CaCO_3$ (calcium carbonate), and is considered corrosive.

Alkalinity in water

Alkalinity is a measure of the capacity of water to neutralize acids - its ability to resist sudden changes in pH. It measures the presence of carbon dioxide, bicarbonate, carbonate and hydroxide ions that are naturally present in water. Alkalinity of water is influenced by pH, rocks, soils, salts, as well as industrial wastewater discharges. The potential of hydrogen, or pH, refers to the amount of hydrogen present in water, and is measured on a base 10 logarithmic scale between 0 (acidic) and 14 (basic or alkaline). A pH value of 7 is considered neutral and represents a balance between the amount of acid and base in the water. Water with more free hydrogen ions is acidic, while water with more free hydroxyl ions is basic.

The pH of incoming water to the building is 6.12, decidedly acidic. Although there is no primary standard for drinking water pH, the United States Environmental Protection Agency (EPA) recommends that drinking water pH falls between 6.5 and 8.5. Low-alkaline water is defined as water having less than 150 mg/L $CaCO_3$. None of the samples taken had alkalinity levels above 22.1 mg/L $CaCO_3$. In addition to low-alkalinity, water quality samples taken from the building domestic water system showed elevated levels of iron, zinc, lead and copper, which is indicative of the liberation of metals from piping, fittings and fixtures.

Another way to view the aggressive nature of low-alkaline water is through the Langelier Saturation Index (LSI). LSI is a measure of water's ability to dissolve or deposit calcium carbonate on a pipe wall and is often used to indicate the corrosivity of water. A thin layer of calcium carbonate on the pipe wall is desirable as it prevents water from contacting the pipe and slows the corrosion process. A negative LSI value indicates under-saturated water and is corrosive. Alternately, a positive LSI value indicates over-saturated water and ability of calcium carbonate to precipitate from solution to form a protective coating on the pipe wall. The ideal LSI is between -0.50 and 0.50 (balanced water). LSI of water in this facility is -2.2 and indicates an increased potential for corrosion. The LSI can be increased in value if any one or all of the following are increased: pH, hardness, total dissolved solids due to calcium or magnesium, alkalinity as $CaCO_3$, or temperature.

Effects of alkalinity

Due to the acidic nature of low-alkaline water, domestic water piping, fittings, valves and fixture faucets are all subject to corrosion. This is where a series of unfortunate events comes into play leading to the building's degraded domestic water quality. The first ill-fated event was the installation of galvanized steel piping in the domestic water distribution system. Galvanized steel pipe is often threaded or grooved in the field during installation. This destroys the protective galvanized layer allowing for corrosion of the steel pipe and liberation of zinc, lead and iron. The corrosive nature of low-alkaline water will accelerate the oxidizing process. The photos below are of 3-inch and 4-inch galvanized steel domestic cold water piping from the building system that is approximately 20 years old and illustrates what low-alkaline water can do to steel.

Figure 1: 4" Horizontal Galvanized Steel Domestic Cold Water Pipe

Figure 2: 3" Horizontal Galvanized Steel Domestic Cold Water Pipe

The photos on the previous page show substantial tuberculation (rust deposits) caused by corrosion due to the low-alkaline water. This is the source of the discolored and poor tasting water in the building. Additionally, the rust can and does flake off the pipe wall only to foul water heaters, valves and faucets in the plumbing system. Curiously, the existing copper pipe, also in the domestic water distribution system (hot water distribution and cold and hot water branch pipe), revealed little to no degradation of the internal pipe wall from representative samples taken for analysis.

Galvanized steel pipe has an average useful life expectancy of 40 to 50 years under normal operating conditions. Up until the 1960's, galvanized steel piping was widely used in domestic water systems with the assumption that it provided better corrosion management and prevention and would thereby result in extended service life of the system. However, testimonials from building owners and contractors has proved this assumption wrong, and that galvanized pipe was a misapplication of material selection in the domestic water system.

It is true that galvanized steel has been and is used successfully for corrosion prevention in various applications without experiencing rapid failure. The pipe's zinc layer provides resistance to corrosion by acting as a sacrificial anode when attached to steel, and in the presence of moisture, zinc reacts with oxygen and carbon dioxide from the air to form a protective coating of zinc carbonate ($ZnCO_3$) when it dries out.

So why does galvanized steel piping fail so quickly in the domestic water plumbing system? Basically, the protective passivating layer of zinc carbonate does not form when the zinc layer doesn't have the chance to dry. Under consistently oxygenated and moist or wet conditions, aggressive localized oxygen corrosion and low-alkaline water will dissolve the zinc layer and expose the underlying steel. This corrosion results in the formation of iron oxides (rust) at the site of the initial penetration of the zinc layer. Corrosion mechanisms result in a higher corrosion rate underneath the iron oxide tubercles, which results in more iron oxides. As can be seen, this self-catalyzing process can result in rapid deterioration of, or failure in the pipe wall.

Delayed building occupancy

Another unfortunate occurrence was to let the building sit unoccupied for nearly two years after being built before first occupancy. We don't design buildings to be shut down for months or years! The domestic water piping in the distribution system never had a chance to develop a protective zinc carbonate layer on the inside of the galvanized steel pipe. Instead, low-alkaline water was allowed to corrode the internal wall of the steel pipe in the system as it sat unused. Even after the date of substantial building occupancy, the building is lightly used with the majority of tenant's teleworking, further contributing to the corrosion through nonuse of the plumbing system components.

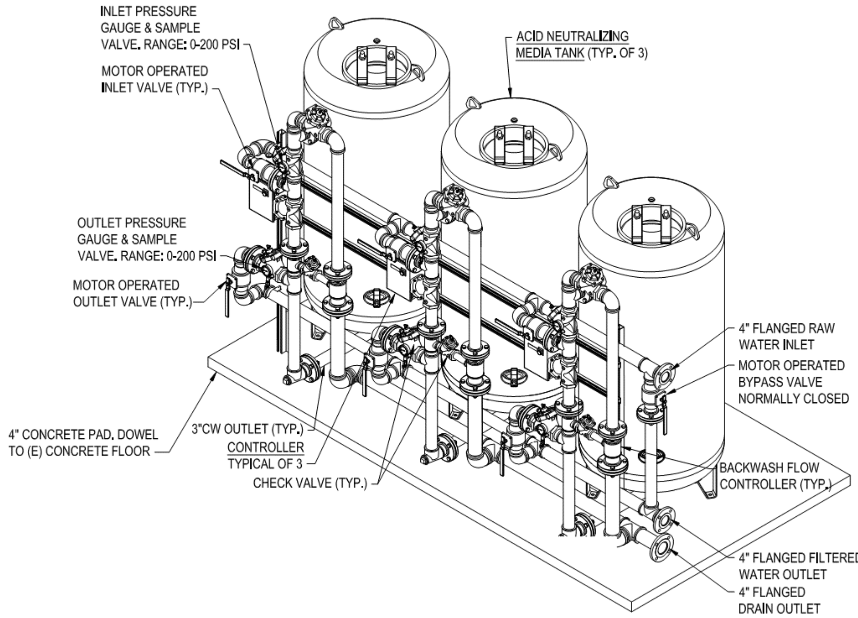
Code compliant fixtures

The last unfortunate event to plague the building's domestic water system is that the plumbing fixtures and fittings were installed in 1998 and were allowed a higher lead content than is permissible by current codes. The Reduction of Lead in Drinking Water Act was enacted on January 4, 2011 and defines "lead free" as a weighted average of 0.25% lead calculated across the wetted surfaces of the pipe, pipe fitting, plumbing fitting and fixture and 0.2% lead for solder and flux. Prior to 2011, "lead free" meant pipes, pipe fittings, plumbing fittings and fixture fittings could contain up to 8% lead. Given the caustic nature of low-alkaline water to metal, and when coupled with plumbing system components containing up to 8% lead, it's not difficult to understand why there are elevated levels of lead within water samples taken from the plumbing system.

Finding the solution

So how do we fix this mess you might ask? The building's water quality is influenced by the low-alkalinity of the water supply causing steel pipeline corrosion and elevated levels of metals through the liberation of lead, zinc, and copper. To reduce pipeline corrosion and the release of metals into the water means we must increase the alkalinity of the water by adding $CaCO_3$ prior to water entering the building's domestic water system. This is accomplished by running the incoming raw water supply through an acid neutralizing system (see Figure 3 below).

Figure 3: Acid Neutralizing System



The acid neutralizing system consists of three tanks, each filled with calcite media ($CaCO_3$), with each sized to handle 50% of the building's estimated domestic water load. This allows for one tank to be off-line for maintenance while the remaining two tanks satisfy the domestic water load. The calcite media is basically comprised of limestone chips which slowly dissolve over time and impart calcium carbonate into the domestic water as the raw water is passed through the media. The calcium carbonate will neutralize acidic or low pH water to a neutral 7.0 pH, thereby raising water alkalinity to a create a less corrosive effluent.

What do we do about the existing deteriorating steel piping and elevated levels of lead, zinc and copper in the system? It certainly does not make sense to continue using the existing deteriorating distribution infrastructure, outdated lead-containing plumbing fixtures and lead-fouled domestic water heaters with the new acid neutralizing system. All of the existing steel piping in the domestic water distribution system will be removed and replaced with copper pipe. Additionally, all of the lavatory faucets, sink faucets and drinking fountains will be replaced with lead-free versions under the current guidelines, as well as replacing the gas-fired domestic water heaters.

One hurdle to overcome is that the building will be fully occupied and operational during construction. In order for the building to remain open and operational, the plumbing systems must be maintained in operation. This is addressed by building a completely separate copper pipe domestic water distribution system running in parallel with the existing system which allows the existing system to continue to serve building needs during construction. Once the new domestic water distribution system and acid neutralizing system is completed, disinfected, and commissioned into service, the existing copper pipe runouts to bathroom groups and individual plumbing fixtures can be decoupled from the existing steel distribution pipe and connected to the new copper pipe distribution system. After all the existing plumbing fixtures and equipment have been decommissioned from the old steel pipe distribution system and connected to the new copper pipe distribution system, the existing steel piping distribution system can be removed.

Conclusion

What can be learned from this project?

1) Galvanized steel pipe, although less costly than copper pipe and more durable than plastic pipe, is not a suitable material for use in the domestic water piping system. The most obvious rationale for not using galvanized steel pipe in a potable water system is corrosion and the problematic release of lead into the domestic water system, a problem which can be exacerbated if copper piping is mixed with galvanized pipes.

2) Building owners and designers should be aware of the quality of water delivered by the local water authority to their existing facility or proposed building in design. Being mindful of the water chemistry, especially prior to a new building design, will help to determine if further localized water treatment will be necessary. It will also provide valuable information about what materials to specify for use in the domestic water plumbing system, thereby delaying future renovation and remediation for complications that could have been mitigated during the original building design.

About the author

David Roach, CPD, is a Senior Plumbing Designer for Summer Consultants, Inc. He has over 25 years of plumbing and mechanical design experience including domestic and heating water and storm water systems. His experience spans across various clients, facilities, and roles in the plumbing design industry.

David received his bachelor's degree in Physiology from the University of California at Berkeley. He is Certified in Plumbing Design and is a member of the American Society of Plumbing Engineers.