A SIMPLE APPROACH TO ASSESSING COPPER PITTING CORROSION TENDENCIES AND DEVELOPING CONTROL STRATEGIES

By

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Abstract

Localized corrosion of copper plumbing in drinking water distribution systems can lead to pinhole leaks, which are a growing problem for many homeowners. Although water quality is one factor that can be responsible for localized copper corrosion, there is not a good approach to predicting the tendency of water to support localized corrosion and assessing water treatment options to address a problem. The objective of this research was to assess the effectiveness of a simple pipe loop system and protocol to predict localized corrosion, and to assess treatment alternatives in a drinking water that has been associated with customer complaints of pinhole leaks. Regular examination of the internal surface of copper pipes positioned in the loop revealed signs of localized corrosion (isolated mounds of corrosion by-products) after only 72 days. Close examination of pipe sections removed from the loops after 100 days clearly showed that localized corrosion was taking place. Cross-section analysis of the pipe showed pits as deep as 0.75mm that were covered by a thin membrane and mound of blue-green corrosion products. The study showed that simple, inexpensive copper pipe loops can be useful in predicting pitting tendencies of copper piping used for drinking water, as well as to assess the effectiveness of treatment alternatives.

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Introduction

Localized corrosion of copper, or "pitting" corrosion, is a major cause of copper household plumbing failures. In just a few months, after installation of copper plumbing, copper pitting can lead to pipe failure in the form of pinhole leaks. The cost of plumbing repair and the associated expenses of repairing water damaged materials can be frustrating for property owners. Additionally, pinhole leaks may go undetected in walls or basements for months, providing an ideal environment for the growth of mildew and mold which add significant additional costs for the property owner. Many homeowners elect to replace their entire plumbing system to avoid the hassle of continually repairing damage caused by copper pitting. Despite the common nature of this problem, water utilities typically under-report copper pitting and pinhole leak problems.

Copper pitting and pinhole leaks are still poorly understood, remediation strategies are not completely developed, and many communities continue to have widely publicized problems. Because of differences in study approaches, discrepancies in research, and the lack of intense field investigations, the literature offers the results of work that is based on theoretical considerations and speculation, but with little supporting evidence. There is a clear need, therefore, to make better tools available to water utilities in order to assess the tendency of a water to cause pitting corrosion on copper pipe. The objective of this research was to assess the effectiveness of a simple pipe loop system and protocol to predict localized corrosion, and to assess treatment alternatives for a drinking water that has been associated with customer complaints of pinhole leaks.

Experimental system design

A simple copper pipe test loop rig was used to evaluate the tendency of a community water supply to support pitting corrosion. The experimental copper pipe loop rig was designed, constructed, and operated by United States Environmental Protection Agency's (U.S.EPA's) Water Supply and Water Resources Division (WSWRD), Treatment Technology Evaluation Branch (TTEB), in Cincinnati, Ohio. The pipe loop rig was constructed of materials commonly used in household plumbing systems, and materials that were purchased from a local home construction supply store. The system was constructed using basic plumbing techniques. Loops were constructed out of 0.5 inch (12.7 mm) diameter type M copper pipe and 0.5 inch (12.7 mm) diameter schedule 40 polyvinyl chloride (PVC). Pipe loops were mounted on a Unistrut™ metal frame that is fabricated atop casters for easy movement.

The test rig consisted of two pipe loops, each consisting of a flow meter, on-line flow totalizer, check valve, injection port, inline mixer, 0.5 inch (12.7 mm) copper pipe, and 0.5 inch (12.7 mm) PVC pipe (Figure 1). Loop 2 was considered the "control" loop in that it received untreated distribution system water. Loop 1 also received distribution system water, and an injection port was installed to allow for a chemical treatment feed. Water flow continued thru a series of ten (eight 12 inch and two 36 inch) copper pipe sections that were soldered together using a lead-free solder (Oatey silver Safeflo™). Threaded joints on each pipe section allowed for easy removal and replacement (Figure 2a). Two 12 inch (304.8 mm) sections were cut to expose the inner wall of the pipe (Figure 2b) and then installed in each loop. Cut sections of copper pipe were inserted into clear Tygon® tubing sleeves for viewing (Figure 2c). Hose clamps were used to tighten the sleeve over the pipe sections in order to prevent leaking. Water is wasted to the on-site sanitary sewer after a single pass through each pipe loop. The pipe loops were installed at a distribution system pump located in a test community.

Operation

Water passed through each loop at 2.0 L/min (0.5 gpm) and the system was operated 24 hours/day. The system was isolated with check valves to avoid chemical injection into the main service line and to prevent undesirable backflow issues. The operation of the pipe loop system (flowrates) and water sampling were conducted once a week. Since daily monitoring was not feasible, on-line flow totalizers were installed to record cumulative flow. All monitoring records and water quality data were maintained in a log book and computer spreadsheets. Water samples were collected from each loop.

Results

The pipes' tendency to develop localized or pitting corrosion in drinking water was based on a visual examination of the internal surface of the copper pipe sections as well as advanced solids and surface analysis approaches. The intent of the Tygon®-enclosed sections was to visually monitor the appearance of the copper pipe's internal surfaces with time, without having to physically remove the pipe sections from the water for the short period of time (5 to 10 minutes) to make observations while the pipes drained. Unfortunately, condensation developed on the outside of the tubing and a thin opaque film coated the inside of the tubing which made it difficult to ascertain the condition of the internal pipe sections. Typically, only one or two sections from each loop were visually examined on a monthly basis to minimize system disturbances. Pipe sections were removed and visually examined for imperfections and other notable deposits using a flashlight.

The first notable surface change was the formation of a blue-green colored corrosion deposit mound after only 72 days into the study. Corrosion deposit mounds are of particular interest and importance because they could represent a pit cap that covers an active site of localized corrosion attack. The pipe was not removed for advanced materials analysis at that time but, rather, it was left in place to permit further development.

Pipe sections were re-examined at 101 days. No distinct visual differences were noted between the internal pipe surface at 72 and 101 days. The corrosion by-product mound discovered at day 72 on the untreated pipe section was still present and did not appear to have changed in shape and size. The pipes were then removed for surface and solids analysis, and replaced with new sections.

The removed pipe sections were photographed, and then longitudinally cut with a band saw while still wet. Experience has shown that if pipes are permitted to dry before cutting, vibrations associated with cutting can more easily dislodge corrosion by-products on the interior surface of pipes. A number of imperfections and other areas of interest on the pipe section surface were cross-sectioned for detailed analysis (Figure 3). Of particular interest was the large corrosion by-product mound previously noted (Figures 3 and 4c). The mound was approximately 3 mm in diameter, was blue to green in color, and appeared to be partially covered with a cream-colored solid. A cross sectional image through the mound clearly revealed the fact that localized corrosion was taking place below the mound (Figure 5a). The cross section image also showed all of the features of classic pitting corrosion attack: the pit cap, thin membrane, and the pit. The pit cap was as much as 0.75 mm thick, consisted of blue/green solids and had a hollow center core. A thin membrane of dark orange material (likely cuprite, Cu_2O) separated the cap from the pit. The membrane was approximately 0.2 mm deep, or 25% of the copper wall thickness at the cross section. The pit appeared to be full of more clearly defined crystals (appearing cubic in shape under high magnification viewing) that were dark orange in color (likely cuprite crystals). There were also a few areas within the pit that contained a white/green colored solid.

SEM imaging of the cross section of the large pit (Figure 5b) provided more detail regarding the structure and morphology of the area of localized attack. The pit located below the pit cap was approximately 0.15 mm (150 µm) deep. The thin membrane that separated the cap from the pit was copper rich. Where active, elemental chlorine (most likely a chloride compound) was found at the base of the pit, indicating that the pit must be a very important parameter with respect to pit propagation. Similar mapping analysis was also performed on a smaller pit. The pit cap was 0.32 mm thick, and the pit was 50 µm deep.

Discussion and Conclusions

The study demonstrated that a simple copper pipe loop system can be used to assess the tendency of water to instigate localized or pitting corrosion attack in a reasonably short period of time. The usefulness of such a system was demonstrated at a field location in Ohio that has a history of pitting corrosion and reports of pinhole leaks in the household plumbing of consumers.

Pipe loop rigs have historically been used to assess the corrosivity of water to various plumbing materials, with the primary focus being on metal release and the role of control strategies to reduce lead and copper levels. Cost, complexity and time of operation are common complaints of such systems. Pipe loop rigs to test localized corrosion tendencies help mitigate these encumbering factors. Cost to construct the pipe loop system used in this study was $2000, with the major cost attributable to the chemical feed pump. Once in operation, water quality analysis is not necessary and little time and attention are needed to keep the system operating.

The loop rig simplicity allows for most construction supplies to be purchased at a local hardware store.

Lastly, signs of pitting corrosion were not observed until 72 days into the study. Though the period of elapsed days appears to be lengthy, the literature shows, and field experience indicates, that it often takes years from the time a water system first experiences early indication of a pitting corrosion problem to the time that a utility can conclude there is an actual problem.

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For this study, evidence of localized corrosion was simply identified by visual examination of the surface of the pipes. Mounds of blue-green colored corrosion deposits on the interior surface of copper pipes certainly resembled the cap, which is the morphological feature that typically covers the anodic area of localized attack. Such attack, however, can only be confirmed by further surface and solids analysis. Cross-sectional analysis of a mound after 100 elapsed days confirmed localized attack, and was in agreement with the real-community observations of localized corrosion.

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FIGURE 1. Photograph of copper pitting corrosion evaluation pipe loop apparatus.

(a)

(b)

posed

(c)

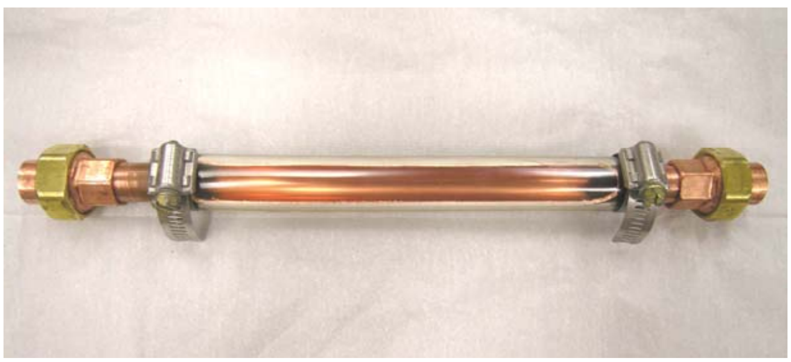

FIGURE 2. Copper pitting corrosion evaluation pipe loop apparatus test components: (a) 1 foot long removable type M copper section (1/2 inch diameter) showing connection unions for quick replacement, (b) 1 foot long removable copper section (1/2 inch diameter) with cut-out section for in-line viewing, and (c) 1 foot long removable bisected copper section enclosed in Tygon® tubing.

FIGURE 3. Interior surface of copper pipes removed after 101 days:

(a)

(b)

(c)

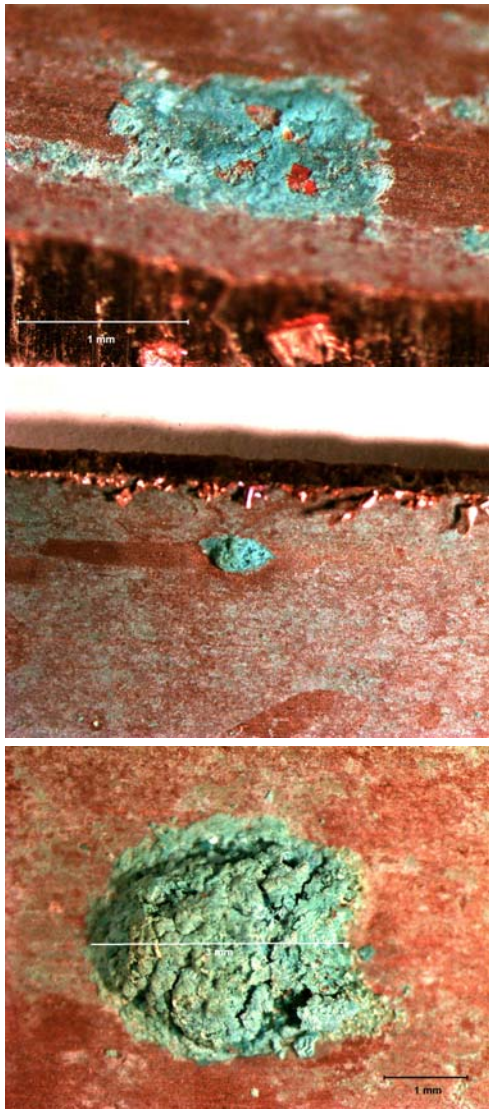

FIGURE 4. Stereomicrographs of areas on interior surface of the copper pipe that may indicate site of pitting corrosion (after approximately 101 days).

(a)

(b)

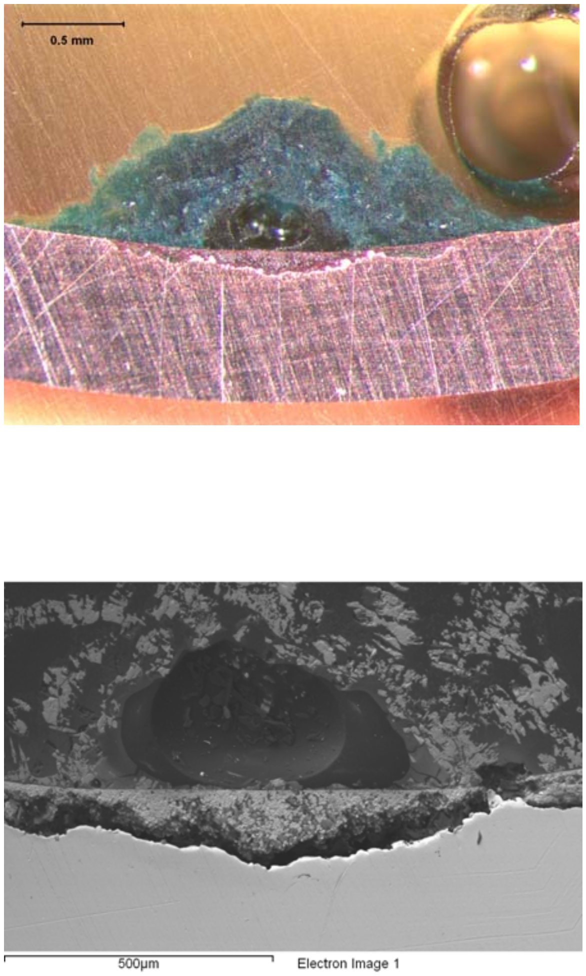

FIGURE 5. Large mound of corrosion deposits on surface of copper pipe. Cross section cut through the deposits clearly shows that localized corrosion is taking place beneath. Depth of attack at this particular cross section is nearly 20% of pipe wall thickness (after approximately 90 days).