

LCR

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Copper Corrosion Under the Lead and Copper Rule Long-Term Revisions

RESULTS OF A RECENT SURVEY SUGGEST THAT WATER SYSTEMS WITH WATER QUALITY CONDITIONS THAT MAY BE AGGRESSIVE TOWARD COPPER SHOULD ADDRESS THE POTENTIAL FOR COPPER CORROSION, EVEN THOUGH IT WILL BE SEVERAL YEARS BEFORE THE LCR LONG-TERM REVISIONS ARE PROMULGATED.

Since 1991, utilities have been required to monitor for lead and copper in distribution systems under the Lead and Copper Rule (LCR). However, this compliance monitoring is biased toward sites that may be conducive to lead corrosion rather than copper corrosion. The LCR requires that samples be collected at the tap from sites served by lead service lines or by copper pipes with lead solder installed after 1982 (but before the effective date of the lead solder ban). While this may increase the likelihood of observing elevated lead levels, it neglects a subsection of sites that would be more likely to exhibit copper corrosion: new construction with copper pipe.

Over time, copper pipe naturally forms a scale of insoluble minerals such as malachite [$\text{Cu}_2\text{CO}_3(\text{OH})_2(\text{s})$] or tenorite [$\text{CuO}(\text{s})$] (Grace et al. 2012, Schock & Sandvig 2009), although these scales form relatively slowly. While these minerals are forming, copper corrosion is controlled by the metastable cupric hydroxide [$\text{Cu}(\text{OH})_2(\text{s})$], which is much more soluble. This process of the pipe scaling and preventing further copper release is often referred to as “passivation.” Therefore, under water quality conditions that are conducive to copper corrosion (i.e., “aggressive” water quality conditions), elevated copper levels would be more likely to be observed in new construction rather than at established LCR monitoring sites. The new copper pipes might never passivate in waters that are considered corrosive to copper.

This discrepancy between the current monitoring sites and sites where copper corrosion may be expected is one of the items the US Environmental Protection Agency (USEPA) is expected to address with the forthcoming LCR Long-Term Revisions. The requirements for copper corrosion monitoring under the LCR Long-Term Revisions are not currently known, as the timeline for USEPA to issue a proposed rule is expected sometime in 2016, with the final LCR Long-Term Revisions likely to be promulgated in 2018 (Cornwell et al. 2015, Roberson 2012). For copper corrosion, there was some interest in establishing a targeted sample pool for copper focusing on new or renovated homes with new copper piping for those systems with water quality characteristics that are aggressive to copper (Slaubaugh et al. 2015). However, the National Drinking Water Advisory Committee recommended that action should be based on the aggressiveness of the water to copper, instead of the results of in-home copper sampling (as is currently practiced for lead monitoring) (USEPA 2015). The aggressiveness of water to copper would be defined by water quality parameter monitoring in the distribution system. Systems that can demonstrate their water chemistry is not corrosive to copper would not need to take any other actions. Systems that have a water chemistry that is corrosive to copper might be able to show that the water is noncorrosive via evaluation with tap sampling for copper at homes with new copper, a pipe loop study, or corrosion control treatment to change water chemistry.

SURVEY OF COMMUNITY WATER SYSTEMS

The National Rural Water Association and AWWA sponsored a survey in early 2015 requesting a description of characteristics related to copper corrosion in US community water systems to assess the distribution of water systems with water qualities that are corrosive to copper.

Utilities were asked to report typical pH and alkalinity levels; current corrosion-control practices; and characteristics of the system such as geographic location, population served, and source water.

Under water quality conditions that are conducive to copper corrosion, elevated copper levels would be more likely to be observed in new construction rather than at established LCR monitoring sites.

Responses were received from 707 community water systems in 49 states plus the District of Columbia, including all 10 USEPA regions. However, the distribution of responses was skewed toward a few states with unusually high response rates. For example, out of the 707 total responses, there were 173 (24.5%), 43 (6.1%), and 46 (6.5%) responses from Kansas, Utah, and Tennessee, respectively, even though these states represent only 0.9, 0.9, and 2.1% of the 2014 US population (US Census 2015). More than half of the responding utilities use groundwater sources, with the remainder of the systems relying on surface water, a combination of surface water and groundwater, or wholesale sources.

Corrosion-control practices reported by survey participants were varied. For a detailed review of available corrosion-control practices in drinking water, see Brown et al. (2013), Schock and Lytle (2011), and Schock (1989). About 15% of the survey respondents control corrosion by adjusting pH and alkalinity without adding a corrosion inhibitor, while another 24% report adding some type of corrosion inhibitor such as orthophosphate (PO₄). The majority of the remaining systems reported that they did not employ any treatment for corrosion control. Interestingly, the water quality for the systems answering “No” to the corrosion-control treatment question

may not be very conducive to lead or copper corrosion, since <4% of these systems reported exceeding the lead or copper action levels (ALs) in the past. By contrast, utilities that reported employing some

type of corrosion-control treatment indicated a greater percentage of lead and copper exceedances. However, it is important to note that the reported treatment conditions are current, but any of the noted lead or copper AL exceedances could have occurred in the past under different treatment conditions.

CONDITIONS JUDGED “CORROSIVE” TO COPPER

The water quality data provided by the responding utilities were assessed to determine how aggressive each system’s water is with respect to copper corrosion. The corrosiveness of each water was assessed on the basis of alkalinity, pH, and the PO₄ residual (if PO₄-based corrosion inhibitors were used). In general, combinations of low pH and high alkalinity are corrosive toward new copper. As pH increases, the water is better able to tolerate higher levels of alkalinity without becoming corrosive to copper. Systems with lower pH values can mitigate copper corrosion by adding a PO₄-based corrosion inhibitor or raising the pH. As PO₄ residual increases, the amount of alkalinity the water can accommodate without becoming corrosive to copper increases as well. However, plant operating staff should exercise caution in raising the pH. Many waters with high alkalinity generally also have high hardness. Therefore, calcium carbonate (CaCO₃)

can precipitate if the pH is too high. This tendency to precipitate can be estimated by Langelier saturation models (e.g., MINTEQ, WATEQ, RTW, etc., as discussed in Schock and Lytle [2011]).

The LCRWG defined a range of water quality conditions deemed “corrosive” to copper, which are shown in Figures 1 and 2. Water quality that falls in the unshaded region of each figure is considered to be noncorrosive to copper. Systems in the shaded region of Figure 1 that use PO_4 may not be considered

corrosive, depending on where those systems fall in Figure 2.

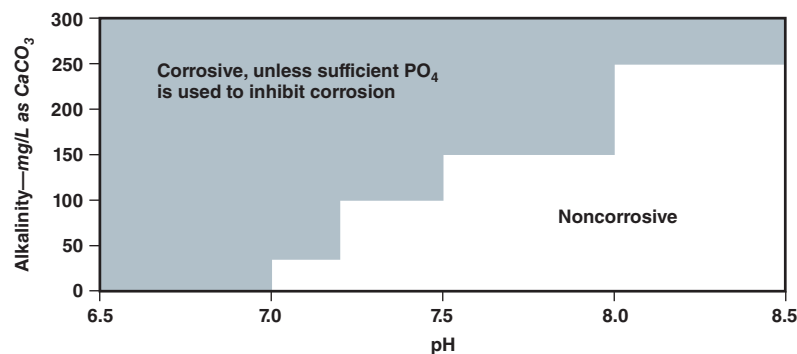
One item that was not addressed in the survey was the use of chlorine or a similar oxidant in the distribution system. Although the shaded region in Figure 2 indicates potentially corrosive conditions, those conditions are corrosive only if the system adds an oxidant or aerates the water. Groundwater systems that are not chlorinated and are anoxic would not be corrosive even if they fall within the shaded region. Because the survey did not inquire about the use of an oxidant, it

is possible that some systems are assessed as corrosive even though they are not corrosive because they are anoxic (Schock & Lytle 2011).

Figure 3 depicts survey responses regarding the use of PO_4 -based corrosion inhibitors. Figures 4 and 5 use the definitions for “corrosive to copper” from Figures 1 and 2 to evaluate which of the systems with PO_4 were corrosive to copper (Figure 4) versus systems without PO_4 that were corrosive to copper (Figure 5). Figure 6 collates the results from Figures 4 and 5 to indicate the total number of systems reporting conditions that are corrosive to copper. Some of the utilities responding to the survey could not be evaluated as a result of gaps in the information provided. Of those systems providing data, approximately 42% fell within the range of conditions considered corrosive to copper (Figure 6). Approximately 22% of the utilities providing sufficient data to be evaluated reported a PO_4 residual (Figure 3). Interestingly, more than 60% of those systems using PO_4 for corrosion control were considered to be corrosive (Figure 4), even after the PO_4 addition. The opposite was true for systems that did not add PO_4 (i.e., >60% were noncorrosive; see Figure 5). These results show that although many utilities are actively trying to control corrosion with a corrosion inhibitor, a majority of those systems that provided data for this survey are not feeding sufficient levels of PO_4 to successfully prevent copper-corrosive conditions. If the waters where PO_4 is fed are considered corrosive to copper, then the PO_4 dose could be increased. It is important to recognize that PO_4 reduces copper corrosion but polyphosphates do not. Polyphosphates act as sequestering agents and thus do not reduce copper corrosion.

Figures 7, 8, and 9 show the percentage of systems with water corrosive to copper broken out by geographic location, population served, and source water type, respectively. Note that these relationships are interrelated. For example, as Figure 9

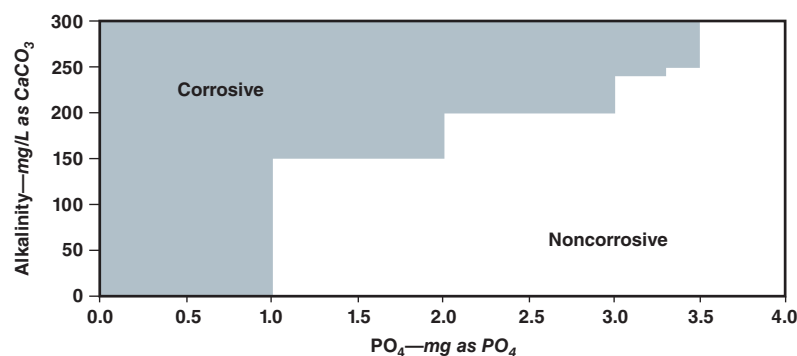
FIGURE 1 Conditions that are corrosive to copper as defined by the LCRWG—pH and alkalinity



$CaCO_3$ —calcium carbonate, LCRWG—Lead and Copper Rule Working Group of the National Drinking Water Advisory Committee, PO_4 —orthophosphate

Systems in the shaded region may be considered potentially corrosive unless sufficient PO_4 is used to inhibit corrosion. Refer to Figure 2 to determine PO_4 dose needed to inhibit corrosion.

FIGURE 2 Conditions corrosive to copper as defined by the LCRWG— PO_4 and alkalinity



$CaCO_3$ —calcium carbonate, LCRWG—Lead and Copper Rule Working Group of the National Drinking Water Advisory Committee, PO_4 —orthophosphate

All systems in the shaded region are considered potentially corrosive.

shows, groundwater sources were much more likely to be corrosive than surface water sources. Therefore, it follows that USEPA Regions 5 and 7 have the highest percentage of corrosive systems, since the percentage of reporting utilities using groundwater sources was highest in these areas. Figure 8 shows that as the population served increases, the percentage of systems with corrosive water decreases. The red bars in this figure indicate that these percentages resulted from at least 50 responses in each category, with 205 responses in the 500 to 9,999 population group. While there are insufficient data to draw causation from this correlation, one might infer that larger systems are more likely to have adequate resources to implement optimized corrosion control treatment. A higher percentage of groundwater systems have conditions estimated to be corrosive to copper (63%) than those with surface water sources (15%). Since smaller systems tend to use groundwater sources, based on this assumption, the results shown in Figures 8 and 9 are consistent.

Figure 10 compares the responses for systems reporting at least one lead or copper AL exceedance in the past versus treatment conditions defined as corrosive to copper in the previous discussion. As expected, the results in Figure 10 indicate a greater percentage of copper AL exceedances in systems with corrosive conditions rather than noncorrosive conditions (12.2 versus 7.8%). Conversely, the lead AL exceedances were much higher in systems designated noncorrosive to copper than those designated corrosive (17.9 versus 8.5%). It is important to point out that the noted treatment conditions are current, but any of the noted lead or copper AL exceedances could have occurred in the past under different treatment conditions. Therefore, it is possible that a system with noncorrosive conditions currently could have had different conditions that were corrosive to copper at the time of the reported copper AL exceedance.

FIGURE 3 Evaluation of survey responses—use of PO₄ for control of copper corrosion

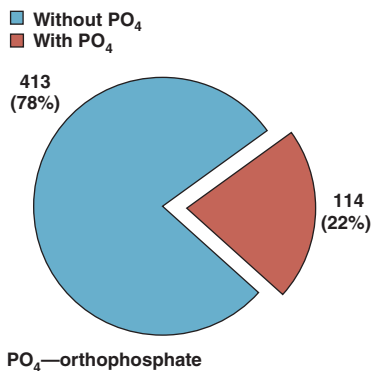


FIGURE 4 “Corrosive” versus “noncorrosive” to copper—survey responses from systems feeding PO₄ for control of copper corrosion

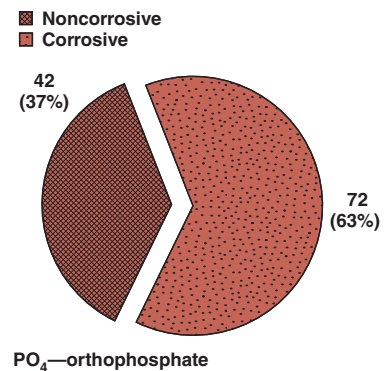


FIGURE 5 “Corrosive” versus “noncorrosive” to copper—survey responses from systems not feeding PO₄ for control of copper corrosion

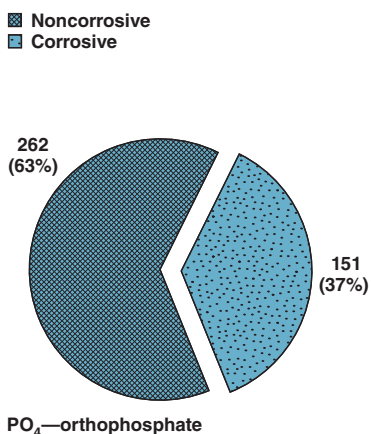


FIGURE 6 “Corrosive” versus “noncorrosive” to copper—survey responses from all systems

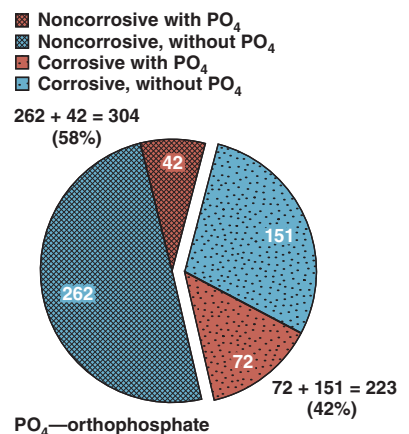
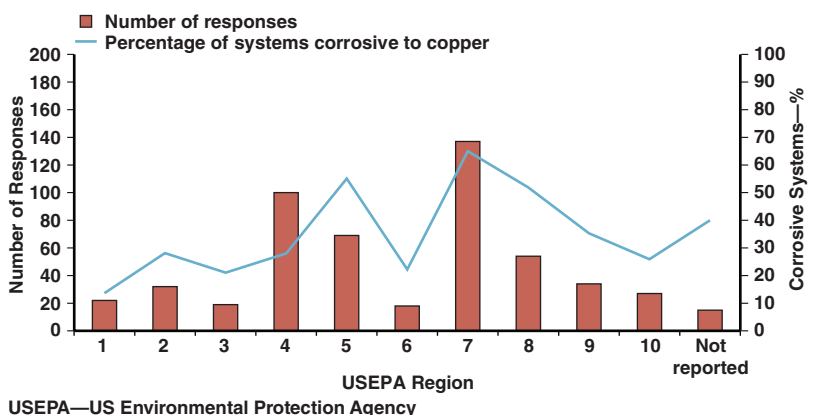
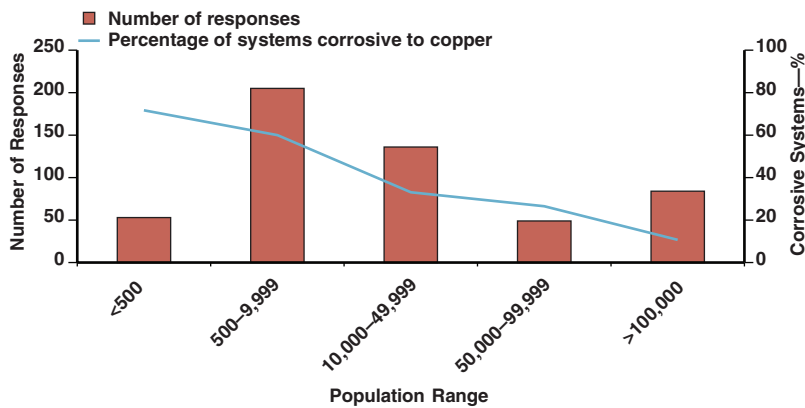


FIGURE 7 Percentage of systems in each USEPA region reporting conditions “corrosive” to copper^a



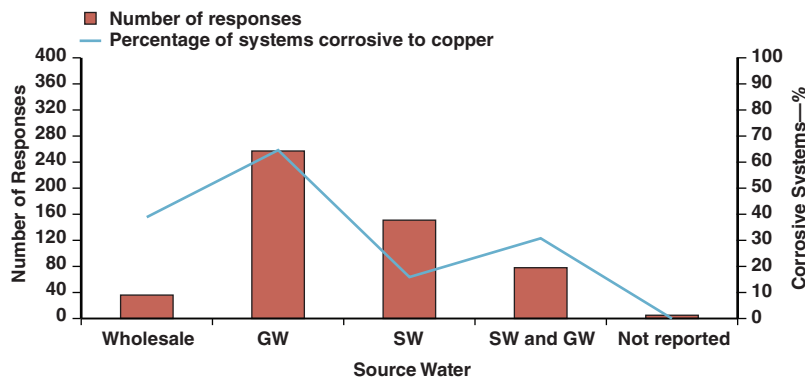
^a“Corrosive” to copper as defined in Figures 1 and 2

FIGURE 8 Percentage of systems in each population range reporting conditions “corrosive” to copper^a



^a“Corrosive” to copper as defined in Figures 1 and 2

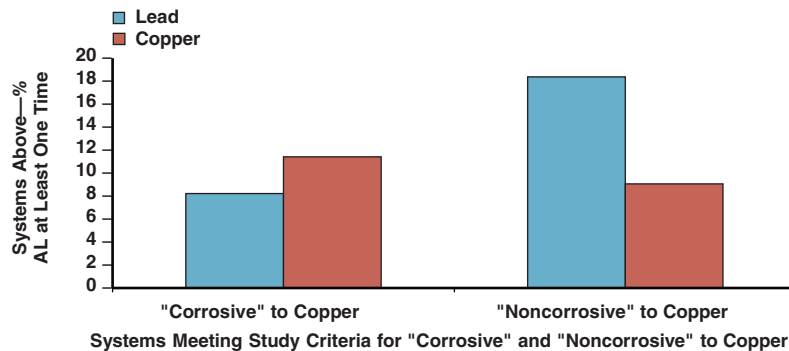
FIGURE 9 Percentage of systems for each source water category that reported conditions “corrosive” to copper^a



GW—groundwater, SW—surface water

^a“Corrosive” to copper as defined in Figures 1 and 2

FIGURE 10 Survey responses indicating exceedances of lead and copper ALs versus water quality conditions that are “corrosive” to copper^a



AL—action level

^a“Corrosive” to copper as defined in Figures 1 and 2

SYSTEM OPERATING PRACTICES TO CONTROL FUTURE COPPER CORROSION

Water systems with water quality conditions that may be aggressive toward copper can take steps now to reduce the potential for copper corrosion. Use of a PO₄-based corrosion inhibitor is a proven method for reducing copper corrosion if it is fed in sufficient quantities. As this survey shows, many utilities currently relying on PO₄ for corrosion control are not actually feeding enough of the inhibitor to properly control copper corrosion, or a utility using a polyphosphate could switch to an PO₄. A further complication for operations to consider is that a polyphosphate will sequester iron and manganese, while an orthophosphate will not. Utilities should review their water quality characteristics and, if using PO₄ to inhibit copper corrosion, review their dosing plan to verify that they are feeding sufficient quantities to successfully inhibit copper corrosion.

Although it will be several years before the LCR Long-Term Revisions are promulgated, the results of this survey suggest that many utilities should address copper corrosivity.

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