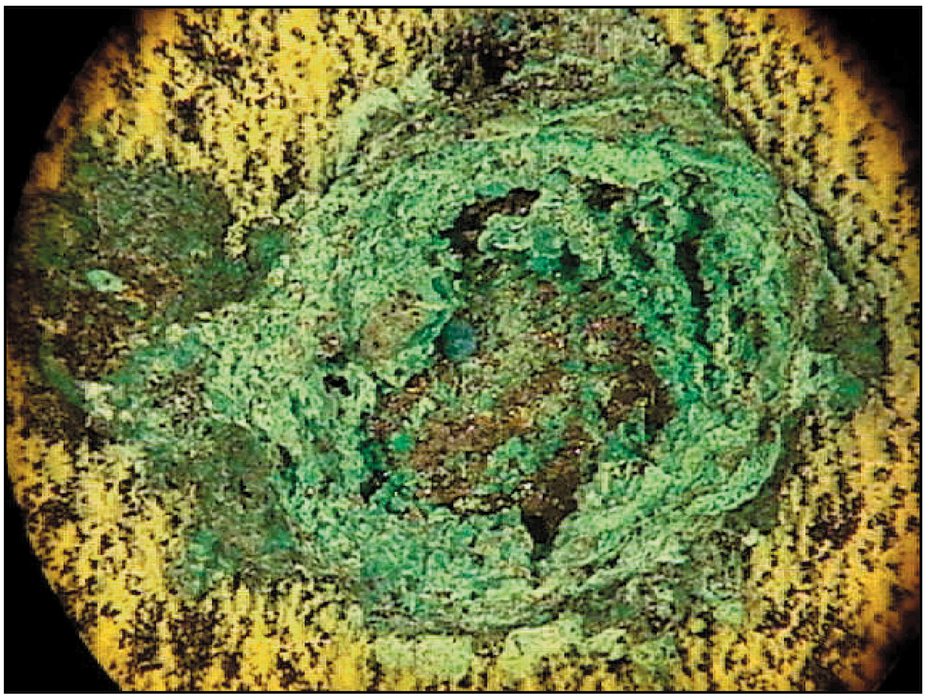
Pit Happens

Copper Corrosion in Household Plumbing



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Copper Corrosion Problem in Household Plumbing: A Case Study

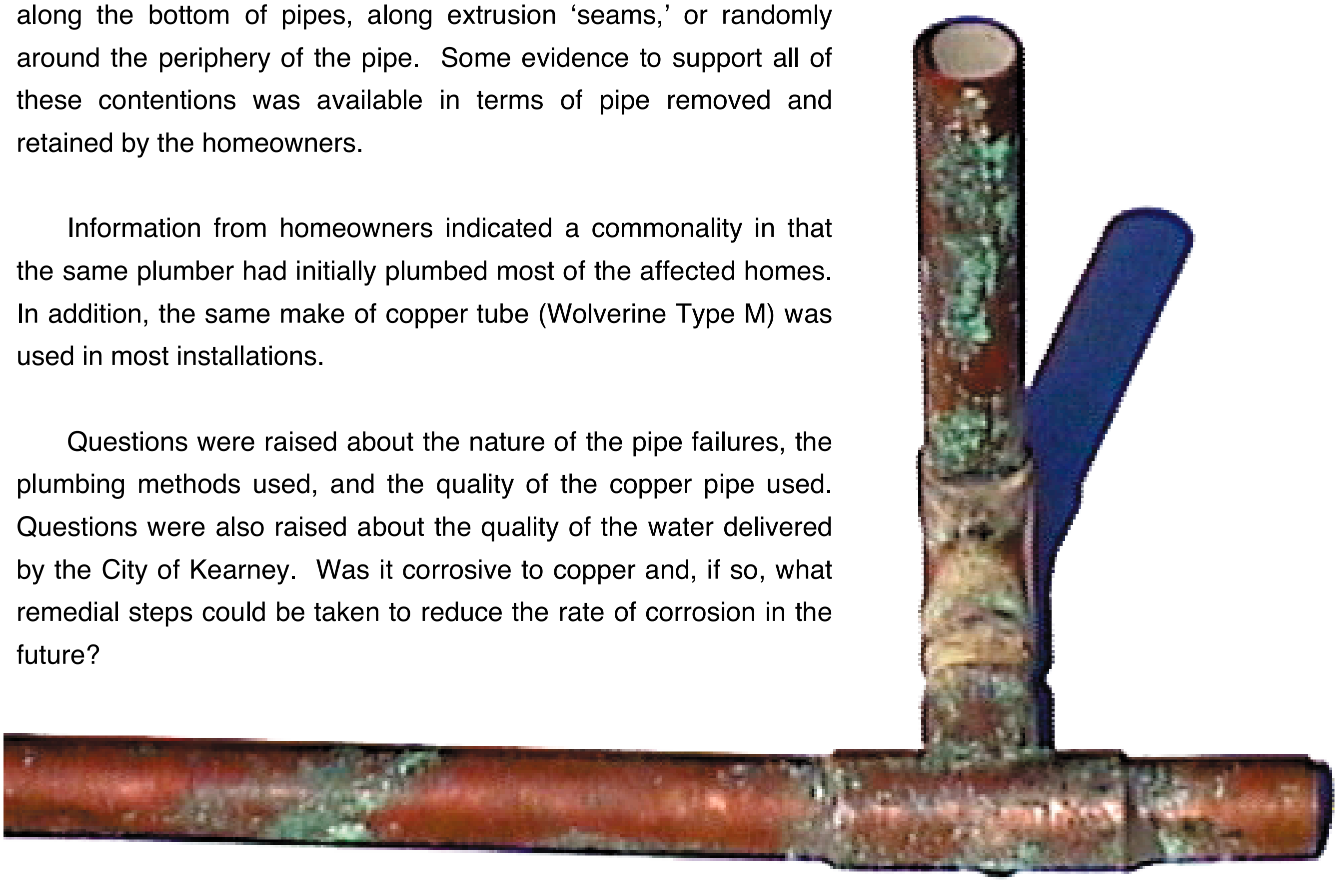
Beginning in March 2001, the City of Kearney, Missouri, began receiving reports of leaks in household plumbing. Over succeeding months, owners of at least sixteen homes reported the development of pinhole leaks in copper piping. The majority of the homes affected were in a localized subdivision where homes were on the order of 10 to 14 years old.

A common feature of the reported leaks was that they occurred almost exclusively in the copper lines used in recirculating hot water systems. Cold water lines were generally not affected, although one homeowner reported the need to also replace cold water lines. Damage to those homes experiencing leakage was significant owing to the pinpoint spray in spaces hidden by drywall or ceiling.

Some homeowners and a plumber performing repairs reported that most leaks occurred in horizontal lines. Others indicated that leaks occurred in random fashion in both horizontal and vertical runs. Conflicting evidence was obtained as to whether corrosion occurred along the bottom of pipes, along extrusion 'seams,' or randomly around the periphery of the pipe. Some evidence to support all of these contentions was available in terms of pipe removed and retained by the homeowners.

Information from homeowners indicated a commonality in that the same plumber had initially plumbed most of the affected homes. In addition, the same make of copper tube (Wolverine Type M) was used in most installations.

Questions were raised about the nature of the pipe failures, the plumbing methods used, and the quality of the copper pipe used. Questions were also raised about the quality of the water delivered by the City of Kearney. Was it corrosive to copper and, if so, what remedial steps could be taken to reduce the rate of corrosion in the future?



Corrosion Chemistry

Copper corrosion is the loss of solid copper metal, Cu^0, to solution. This occurs when electrons, e^-, are lost by the base metal and the solid phase is transformed to soluble, dissolved cuprous, Cu^+, and/or cupric, Cu^{++}, ions. The loss of electrons from the solid metal (electron donor) is called oxidation.

Anodic Reaction: $Cu^0 \rightarrow Cu^{++}\text{(aqueous)} + 2e^-$

In metal corrosion, chemical oxidation occurs at sites called anodes where electrons are released (lost). Alternately, chemical reduction (the gain of the electrons) occurs at the cathode. The electron acceptors are called oxidizing agents.

Cathodic Reaction: $Cl_2^0 + 2e^- \rightarrow 2Cl^-$

In pitting corrosion, the anodes are small, fixed points at which copper metal is lost. The remainder of the entire pipe surface serves as the cathode. Since the electron acceptors are chlorine (the disinfectant residual) and oxygen, the rate of corrosion is sensitive to the concentrations of both of these oxidizing agents.

The rates of virtually all corrosion reactions in water are strongly influenced by temperature and pH. High temperatures markedly accelerate reaction rates whereas higher pH reactions normally decelerate them.

USEPA Recommended Corrosion Control Methods

Four methods have been cited by USEPA for optimum copper corrosion control treatment (OCCT):

• pH/alkalinity adjustment	to decrease solubility of carbonates, oxides,
• calcium adjustment	to increase calcium carbonate supersaturation,
• polyphosphate addition	to cause formation of phosphate films on piping,
• silicate addition	to cause formation of silicate films on piping.

The first and most obvious treatment requires the adjustment of pH and alkalinity. Lead and copper are known to corrode most rapidly in low pH, low alkalinity waters, such as in the soft waters of New England and the Southeastern United States. In Kearney's ground water, however, pH and alkalinity are initially sufficiently high that corrosion rates would be expected to be moderated without further adjustment. Following softening, Kearney's water is stable with respect to pH and alkalinity.

Kearney's ground water is also rich in calcium. Even following softening, Kearney's treated water has sufficient calcium to be considered stable with respect to calcium carbonate.

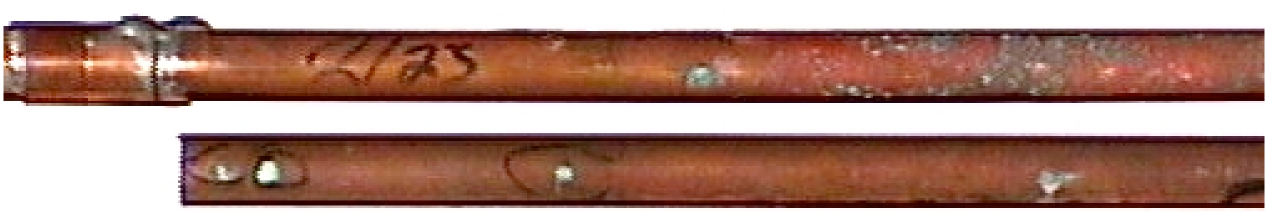
By default, the optimal corrosion control option for Missouri ground waters appears to be limited to treatment of the distributed water by the continuous addition of a chemical 'inhibitor'. Since there are at least 200 commercially available variants of these compounds, water utilities are commonly faced with the need for complex evaluations of numerous proprietary chemical formulations containing phosphate or silicate.

Most often, phosphate formulations are used for copper corrosion control. The phosphates form insoluble precipitates with calcium. Hopefully, these precipitates will form films on the interior copper pipe surfaces which will block the oxidative reactions at the pinpoint anodes. At the low dosages employed in drinking water systems, the reported results of phosphate treatment have been mixed.

Findings

Pipe Installation

Examination of pipe removed from the households provided substantial evidence for the findings of the present study. While not universally true, it appeared that much of the corrosion occurred in the middle of copper runs rather than near the joints of the pipe. This evidence did not support the contention that improper joining techniques were responsible for the pipe failures. Where improper installation is observed, particles of copper (chips from burrs) or excessive amounts of aggressive flux are spalled into the pipe in the vicinity of the joint. These particles of copper or flux may become points or discontinuities at which copper pitting corrosion is initiated.



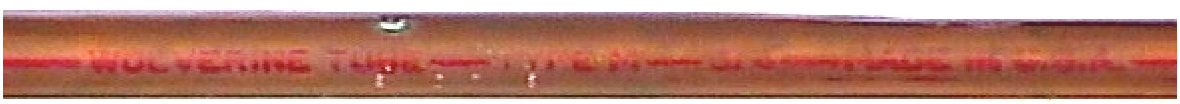
Exterior view of copper pipe (top) shows pitting starting 6 inches from joint.
External view of horizontal copper pipe run (bottom) shows series of aligned pits

Pipe Manufacture

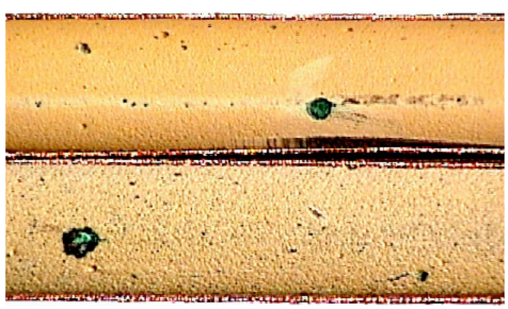
Potential manufacturing defects include impurities and interior carbon films [often caused by breakdown of drawing lubricant residues during the bright annealing process (Campbell, 1950)].

Despite the fact that most corrosion has occurred in Wolverine type M pipe, one homeowner was able to provide one sample of Cerro brand pipe which had developed pits while in service. Another homeowner reported replacing large amounts of Wolverine and another brand of pipe (possibly Cerro) in a roughly 80%/20% ratio. Both brands showed similar patterns and degrees of pitting corrosion. This would indicate that the pitting corrosion of the copper pipe was generic and not due to an individual “bad batch” of pipe.

The plumber who plumbed most of the affected homes reported that copper pipe from the batch used in Kearney was also used in Pleasant Valley, MO. Pleasant Valley’s Public Works Department reported that they have had no reports of copper corrosion in these homes (or anywhere else in town). Although uncertain, a Public Works Department employee suspected that there were no hot water recirculating systems in Pleasant Valley.



Wolverine Tube 1/2 inch Type M Made in U.S.A.

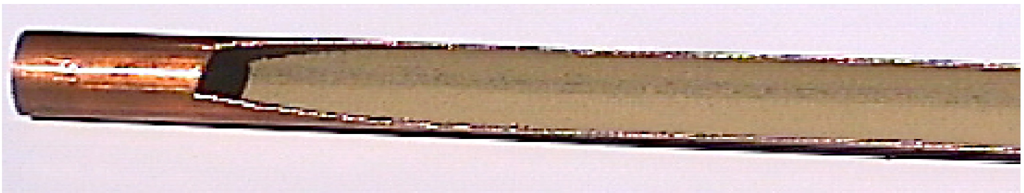


Interior Sections of Wolverine (top) and Cerro Pipe (bottom) showing circular pit formation.
Note incipient formation of numerous pits along horizontal line in pipe at top.

Erosion Corrosion

The pipe sections examined showed no evidence of internal "erosion corrosion." Erosion corrosion creates stream lines or grooves (striations) which result from excessive water velocities. To avoid this condition, it is generally recommended that pipe diameters be large enough to limit flow velocities to less than 5 feet per second (fps) in cold water lines; 4 fps in hot water lines, and 3 fps in recirculating hot water systems. From these recommendations, it appears that hot water recirculating systems are most at risk.

The homes experiencing pitting corrosion used convection (gravity) rather than pumps to recirculate the water from the hot water heater. In those homes, excessive velocity should not have been a contributing factor leading to erosion corrosion. Alternately, the constant movement of hot water over the anodic areas undergoing pinpoint corrosion would be expected to accelerate the chemical transport processes which allow corrosion to proceed more rapidly. Specifically, the anodic regions would be constantly exposed to the supply of chlorine and oxygen present in the recirculating water.



Pipe sections without obvious pits show uniform deposits of soft magnesium precipitates. There are no stream lines or evidence of microbial slime build-up.

Fingernail removal of soft scale reveals hard (black) cupric oxide surface coating and hidden incipient pits.

Microbially-Induced Corrosion

In many instances, particularly where warm temperatures are favorable for their development, specific species of microorganisms grow and colonize the interior surfaces of household plumbing. The accumulations of microorganisms can create conditions which accelerate metal corrosion. The presence of microbial accumulations is commonly accompanied by the depletion of chlorine residuals and the loss of dissolved oxygen. Sulfate-reduction, resulting in the formation of hydrogen sulfide, frequently accompanies what can described as "microbially-mediated corrosion."

To test this possibility in a Kearney household plumbing system, hot and cold water samples were taken from an affected household and incubated with culture media specific to sulfate-reducing organisms. After nine days of incubation, no sulfate-reducing organisms were observed. This result is consistent with the absence of reports of a hydrogen sulfide odor in the heated water. If microorganisms were involved in the corrosion of the household plumbing, the effect would also be expected to be more uniform and widespread throughout the city.

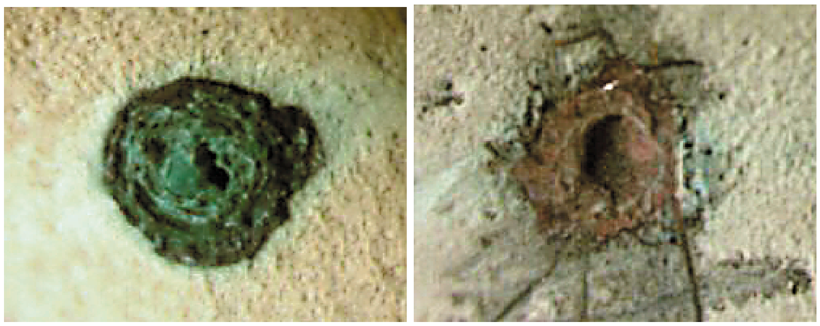
Stray Electrical Currents and Dissimilar Metals

There is uncertainty regarding the effect of stray currents and grounding on copper pipe corrosion. However, affected homeowners report that their electrical systems are not grounded to their plumbing.

Corrosion due to dissimilar metals tends to occur at the interface of the two metals rather than in pits throughout the pipe. No apparent instances of dissimilar metals were observed or reported.

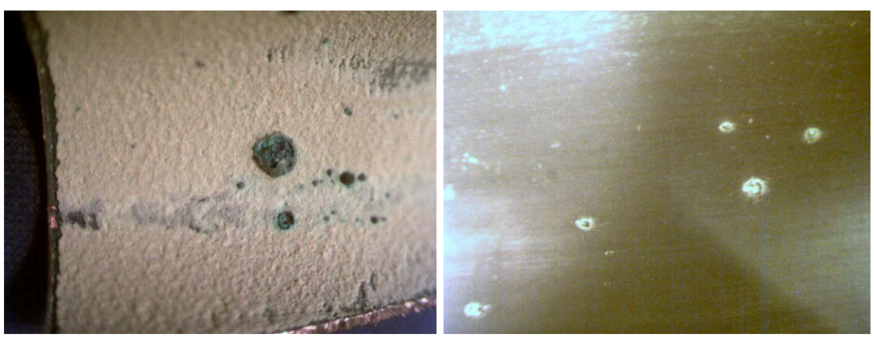
Pitting

Since the leaks in copper plumbing were due to pitting corrosion, the sites of pipe failures were examined microscopically.



Interior view of pits, before and after scraping to remove blue-green copper precipitates

Where significant corrosion had occurred, there were small (2 to 3 mm), circular discontinuities containing crystalline, blue-green precipitates (possibly, a mixture of copper sulfate and malachite, a co-precipitate of copper carbonate/copper hydroxide). These discontinuities appeared to serve as pinpoint anodes at which copper corrosion (oxidation) proceeded until the tube wall was pierced. Often, the same blue-green precipitate was also evident on the outside of the tube.



Interior copper pipe surface, before and after removal of soft scale

Pipe Thinning and Copper Corrosion

Overall, except for the numerous points of incipient corrosion and pinholes, little thinning of the wall of the copper tube had occurred. This is consistent with the observation that virtually no copper was found in solution in either the hot or cold water. Repeated monitoring for compliance with the USEPA Lead and Copper Rule, which regulates these contaminants in tap water, confirms the absence of these metals over the period of monitoring.