

Recirculating Hot Water Systems

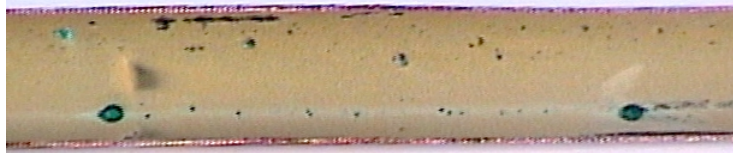
While copper pipe has long been used for the transmission of hot water, the service to which the corroded copper pipe in Kearney, MO was put is a comparatively new application. Each service area (kitchen, bathroom) is served by a pipe loop through which hot water is continually circulated by convection. This permits the user almost instant access to hot water upon opening the tap.

Normally, when not in use and flowing, the water in a hot water copper service line cools down to the ambient temperature of the household (70 to 80 °F). Only during periods of water use do temperatures rise to heated water temperatures. In Kearney's recirculating hot water systems, temperatures in the loop are continuously high. Moreover, the constant flow of water prevents stagnation in the line and continually flushes anodic areas with water containing chlorine and oxygen. Both high temperatures and the presence of oxidants, such as chlorine and oxygen, would be expected to accelerate copper corrosion rates. The rate of copper corrosion has been observed to increase fivefold as temperature increases from 80 to 170 °F.

In assessing the operation of the hot water recirculating system, it was noted that significant amounts of gas precipitated from the hot, but not the cold, water in the affected households. The gas evolved from the release of line pressure to atmospheric pressure. Not only did the gas evolve in the water withdrawn at the tap, it may also have precipitated throughout the pipe loop.

Upon closing the hot water tap, the tiny precipitated gas bubbles may have either coalesced into larger bubbles or redissolved into the water. It was hypothesized that any bubbles formed may have attached themselves to the interior pipe surface, initiating the formation of anodes at which corrosion could take place. While not exclusively, bubble attachment would be expected to take place predominately along the upper surface of horizontal pipe runs.

To test the bubble hypothesis the orientation of corroded pipes were subsequently marked prior to removal. The lines of pits were found to be along the bottom rather than at the top.



Interior surface shows both a line and a random peripheral distribution of pits

Delivered Water Quality and Particles in Tap Water

One of the earliest experiences with pitting corrosion was documented by a homeowner who made numerous observations and saved the copper pipe removed from service as leak damage was repaired. He also conducted inquiries indicating that at least 16 other nearby homes had experienced pinhole leaks in copper plumbing. For these reasons, more detailed studies were conducted at his home. Analyses were performed to observe the quality of the hot and cold water at taps in two separate bathrooms, one in intermittent and one in routine (daily) service.

Oxygen

It was anticipated that oxidizing agents, such as oxygen and chlorine residuals, would be depleted or absent, particularly at the bathroom tap that had not been used for a period of time (estimated to be four weeks). However, the first draw tap samples revealed 7.8 and 9.0 milligrams per liter of oxygen in the cold (room temperature, 22°C) and hot water (50°C, 122°F), respectively. This is approximately equal to oxygen saturation with the atmosphere (8.7 mg/l oxygen) at the temperature of the water delivered to the household.

Gas Supersaturation

The implications of these results are that the water does not suffer adversely from microbial activity which would deplete oxygen in a closed distribution system. Moreover, as the water is heated, the oxygen and other dissolved gases (primarily nitrogen) become supersaturated. At 50°C, oxygen saturation would be approximately 5.5 mg/l. At an observed concentration of 9.0 mg/l, the hot water is over 80 percent supersaturated. As a result, a substantial amount of fine bubble formation (precipitation of air) is observed when the hot water is withdrawn at the tap.

Chlorine

Confirming the results of the oxygen analyses, chlorine residuals are also found to persist to the tap. Total chlorine was found to be 1.73 mg/l and 1.07 mg/l as chlorine in the cold and hot water, respectively. The lower residual in the hot water might be attributable to the acceleration of reactions of chlorine with organic matter or pipe materials at elevated temperatures. However, the presence of the residuals is encouraging and necessary from the standpoint of demonstrating the stability of the water and the continued protection of public health from the treatment works to the consumer's tap.

Copper

The most direct evidence of copper corrosion is the presence of copper in solution. USEPA and MDNR have established a 'copper action level' of 1.3 mg/l for first draw samples at the consumer's tap. Analyses for copper at the bathroom tap of the study residence showed 0.00 mg/l copper in the cold

water and 0.01 mg/l in the hot water. This is consistent with the results obtained by MDNR in their compliance testing for the Lead and Copper Rule.

For comparison, a sample was taken for copper analysis from the *Country Hearth Inn and Suites*. This motel facility was in operation for only five weeks at the time of sampling, so that its plumbing was new and would be expected to be uncoated with internal deposits. The hotel hot water was found to contain only 0.01 mg/l copper.

pH

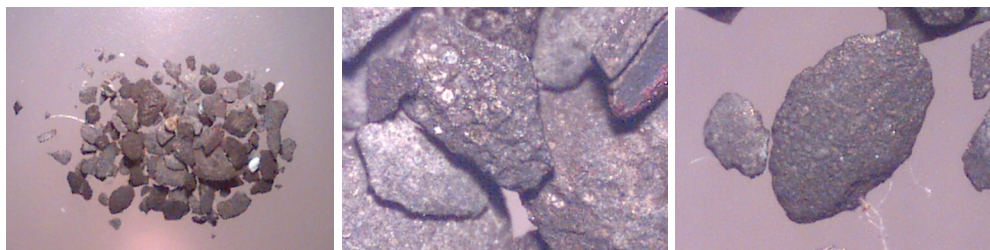
Since it is a major factor in controlling the rate of metal corrosion, pH was measured at 9.04 in the cold water and 8.68 in the hot water. These pH values are well above those required to minimize copper corrosion.

Scale Formation on Household Taps

A predominately white, hard scale was scraped from a bathroom tap at the Marler residence. The appearance and hardness of the scale seemed typical of calcium carbonate.



Removal of the faucet aerator screen revealed the presence of predominately black, hard flakes that were retained on the screen.



Kearney Water Supply: 1990-2001

In an effort to determine if current or previous water conditions may have contributed to the corrosion of the copper piping, water department records for the period 1990-2001 were examined to determine whether changes in source water quality or treatment practice may have occurred which mask previous corrosive properties of the Kearney water supply.

Water Treatment at Kearney

The Kearney water treatment plant receives ground water from three wells. The raw well water contains hardness-producing ions (Ca^{2+} and Mg^{2+}) as well as lesser amounts of sodium, sulfate, and chloride ions. The water is quite typical of ground waters in the region and would be considered to be a good water supply.

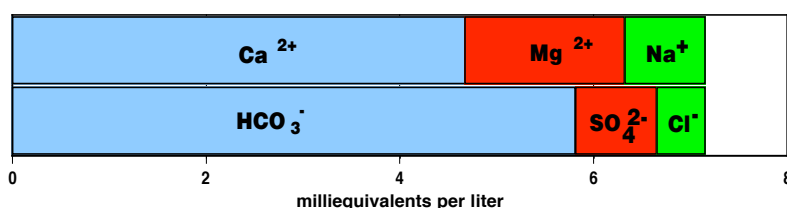
Treatment consists of aeration for removal of dissolved gases and the introduction of oxygen. Dissolved oxygen serves to assist in the oxidation of ferrous ion (iron) in the ground water.

Following aeration, the water is softened by the addition of lime, CaO , to precipitate calcium carbonate and magnesium hydroxide. The lime softening is very effective, as can be seen from the bar graph below. Calcium and magnesium are greatly reduced and the finished water contains far less dissolved minerals.

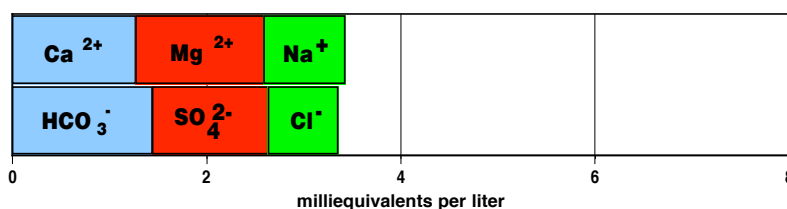
Softening by lime precipitation also serves to remove any vestiges of iron, manganese and other trace metals, including copper, zinc, cadmium and lead. The high pH of lime addition also serves to partially disinfect the water.

Recarbonation, the application of carbon dioxide gas, is practiced prior to filtration in order to reduce the high pH resulting from the addition of lime and stabilize the water with respect to calcium carbonate post-precipitation. The finished, filtered water is neither corrosive nor greatly supersaturated with respect to substances that will deposit in the mains and household plumbing.

Kearney Well Water (Average Composition)



Kearney Finished (Softened) Water

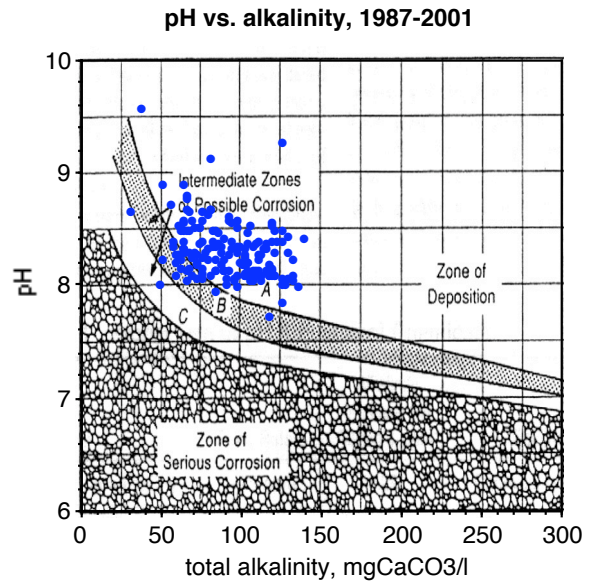


pH and Alkalinity

The evidence for the low corrosivity of Kearney's water supply is particularly strong. This lime softened ground water is comparatively high in pH and alkalinity. The addition of carbon dioxide for stabilization of post-precipitation of calcium carbonate does not result in the production of an acid or aggressive finished water.

Primarily, two parameters are used to assess and control the corrosivity of water supplies. The alkalinity (acid neutralizing capacity) and pH (a function of hydrogen ion concentration) are routinely monitored to ensure that metals, such as lead and copper, are not dissolved from plumbing or solder, thereby creating a threat to the public health.

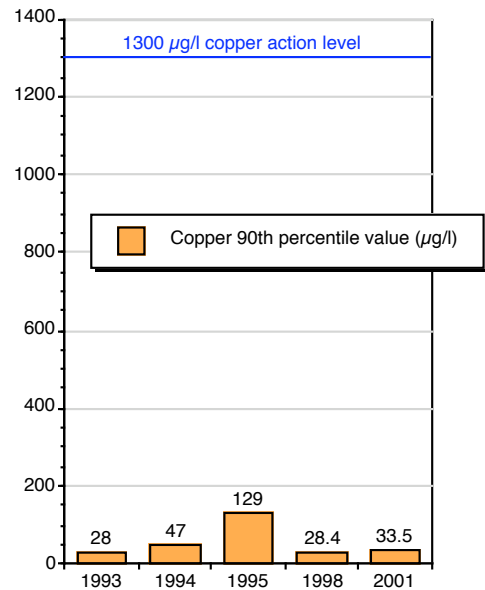
Although there are no specific standards for these parameters, pH is commonly maintained at 8.0 or above and alkalinity above 20 mg/l as calcium carbonate equivalent. Kearney's water supply has consistently been well above both of these values for more than the past decade. Even with the installation of facilities for recarbonation in 1993, sufficient alkalinity has been maintained to ensure continued supersaturation of the finished water with respect to calcium carbonate. As a result, the Kearney water supply has not exhibited high concentrations of lead or copper at consumers taps.



Lead and Copper

Results of testing under the Lead and Copper Rule (graph at right) indicate that copper levels are consistently low, and the 90th percentile values used to determine compliance are well below the 1,300 $\mu\text{g/l}$ copper action level. This indicates that Kearney's finished water is not inherently aggressive towards copper.

Owing to the use of aluminum sulfate as a coagulant, concentrations of aluminum up to 200 micrograms per liter were observed in the Kearney distribution system.



Saturation Indices

Based upon theoretical indices of calcium carbonate saturation, Kearney's finished water ($\text{pH} \approx 8.3$) has a saturation index near zero and would be considered to be in equilibrium with calcium carbonate. This means that the water would be expected to have neither scale-forming nor scale-dissolving tendencies.

When water is heated within the home, the $\text{pH}_{\text{saturation}}$ decreases and the saturation index becomes positive, supersaturating the water and increasing its tendency to deposit calcium carbonate. A thin, soft, uniform film of deposited precipitates was found on the inside of all the corroded hot water pipes. Normally, this film would be expected to provide a protective coating, minimizing the internal corrosion of the pipe. However, this film was neither sufficiently dense nor uniform enough to do so.

Conclusions

Currently, the exact causes of pitting corrosion are not fully understood. All available technical literature to 2002 confirm the tentative and incomplete nature of scientific understanding. Published recommendations for remediation are diverse, speculative and site specific. However, it is possible to identify the major factors contributing to copper pitting corrosion in households in Kearney.

The most important factor influencing copper corrosion in Kearney is the operation of hot water recirculating systems. More than any other factor, this single variable predicts the development of leaks due to pitting corrosion. Elevated temperatures, oxygen supersaturation, and constant movement of the water are physical features of these recirculating systems. While one occurrence of leakage due to pitting in cold water lines has been reported, the majority of complaints are highly localized and center around recirculating hot water systems.

Secondary contributing factors might include residual particles or pipe impurities that may have served to initiate the formation of anodic sites. The inclusion, embedment or deposition of these particles or impurities may have occurred during copper pipe manufacture, installation or system operation. These particles could derive from:

- inclusions during pipe manufacture (e.g., impurities, carbon films)
- debris that was in the pipe when new (copper filings) or formed during installation (acid flux)
- aluminum deposition (post-precipitating) in hot water piping
- bubble formation upon pressure release

It has been suggested (Rossum, 1995) that delays in flushing newly installed copper lines will facilitate the initiation of long-term pitting corrosion. While early line flushing is undoubtedly good installation practice, only circumstantial evidence was presented to indicate that delays of several months would materially affect the degree of corrosion observed in future years.

It is also possible that stray electrical currents play a role in the pitting corrosion process.

Recommendations for Affected Homeowners

Disable hot water recirculating systems.

Maintain hot water temperatures at or below 125°F.

Maintain a magnesium sacrificial anode in the water heater.

Plan to have more leaks in the future. The corrosion process has momentum that won't be immediately stopped by removing the primary cause.

Shut off the main incoming water valve when leaving home for extended periods of time.

Keep pipe clamps on hand to stop leaks until repairs can be made.

When leaks occur, mark the site of the leak. Save the removed portion of the pipe, labeled with its orientation (top, bottom).

Consider using plastic pipe [Chlorinated PolyVinyl Chloride (CPVC) or Crosslinked Polyethylene (PEX)] or thicker copper tubing when replacing corroded copper plumbing.

It was not recommended that the city feed polyphosphates or silicates. It is uncertain that they would have any beneficial effect on this type of corrosion.