Electric Skies - Electric Pipes

Richard A. Dunham and Clifford A. Russell

Almost since the inception of copper tubing for household plumbing there have been studies as to why it is susceptible to pinhole leaks. There have been many theories. This article will set forth a new theory based on convincing scientific evidence.

Pinholes in copper plumbing are a major problem in Central Florida as well as other parts of the state and the country. Why do they occur in certain areas and not in others? Perhaps more important, what can be done to prevent the problem in the first place? The Water Quality Laboratory at Orlando Utilities Commission began examining the problem in 1984. In 1991 it began a more in-depth study.

Types of Corrosion

Although there are at least six recognized types of corrosion associated with copper tubing, there are basically just two that affect plumbing in the Central Florida area: uniform corrosion and pitting corrosion.

Uniform corrosion is caused by reaction of the copper tube with the natural minerals in the water running through the tube. The result of uniform corrosion in copper tubing is a green-colored scale that lines the length of the tube. Uniform corrosion is also responsible for higher than normal copper levels in water.

Pitting corrosion is a site-specific type of corrosion that can lead to a penetration of the tube wall. It is not responsible for high levels of copper in the water. This is the type of corrosion this article will deal with.

Beginning Research

In 1991 Orlando Utilities and CH2M-Hill engineers started a research project sponsored by the American Water Works Association Research Foundation. The purpose of the study was to study the effects of electrical grounding on water quality.

One of the long held theories of pinhole leaks is that they are caused by electrolysis, i.e., stray currents conducted along copper plumbing. Stray currents are caused by load imbalance between the two conductors in a 220-volt system. The imbalance is transferred to the plumbing at various points in a home. Grounding of the electrical system to the cold water system allows the phenomenon to occur.

The electrical current runs along the pipe until it is either transferred to the neutral leg or exits via a type of electrical grounding. It was thought that the current traversing the piping caused corrosion in the form of holes and high copper levels.

To say the least, the results of our project were rather startling.[1] After a year and a half of subjecting a household copper plumbing system to various regimens of grounding, amperage (ac and/or dc) and water qualities, there was no evidence of a correlation between stray currents and elevated copper levels. Nor, upon harvesting coupons from the plumbing system, was there evidence that the stray current caused pinholes.

Pitting corrosion in copper pipe

Strangely, however, copper levels would spike to higher than normal levels at certain times during the course of the research project. These spikes were for a short duration—one day's sampling. One notable series of spikes occerred during the third week in August 1992. After ruling out all else, the only parameter that was noted to be different during week was intense thunder storms over Orlando.

Each evening during that week there was a severe storm accompanied by intense lightning. While it is normal to have thunder storms in the summer in Central Florida, these storms were exceptionally intense. It was noted from samples taken on the following mornings that the dissolved copper levels had gone as high as 24,000 µg/l. It was also noted that the sinks, bathtubs, and commodes had turned dark green from the water. The samples taken the morning after the first evening with no storm indicated copper levels in the range normal for the system.

On two occasions earlier in the year a similar situation of copper spiking had been observed. A check with those who archive meteorological data confirmed that thunder storms had been present in the areas at the time of the spikes.

Continues Page 37

A Full-Scale Study of Corrosion Control

Roger M. Smith, Charles R. Womack, June A. Smith, and Luke A. Mulford

Rule 62-551, F.A.C., which sets forth the criteria and schedule for control of lead and copper in public water systems, establishes that action levels for the 90th percentile of samples collected from consumer taps be 1.3 mg/l for copper. If a water system exceeds the action level, it must complete some or all of the following tasks: notify consumers; identify treatment methods; conduct bench-scale studies; implement a treatment process to reduce copper concentrations; and/or conduct a full-scale study. The Seminole County Public Works Department (SCPWD) has conducted a full-scale study demonstrating that copper concentrations can be reduced significantly.

The SCPWD began monitoring its nine water systems for lead and copper in 1992. While no systems exceeded the action level for lead, four systems did for copper, and a corrosion control study was immediately initiated. The desktop study demonstrated that the water systems exceeding the copper action level were analogous in quality and treatment process, exhibited depressed pH, and were corrosive with respect to the Langlier and the CCPP Indexes. It also showed that a pH range of 7.7 to 8.0 produced a stable water that allowed the formation of a protective interior pipe lining to inhibit corrosion and prevent the subsequent leaching of copper into the drinking water.

The Greenwood Lakes WTP was selected as the site for a full-scale demonstration study. It received relatively soft raw water having low TDS and conductivity from the Floridan aquifer. The water had adequate buffering capacity, and was stable with respect to calcium carbonate. Table 1 gives information on the raw water supply.

Raw water is pumped to plate and tray aerators located on top of ground storage tanks. After aeration, the water is disinfected using chlorine gas. Fluoride is also added to the water in the form of hydrofluosilcic acid.

The plant was modified to incorporate the injection of sodium hydroxide into the finished water to elevate pH to just above stability. The full-scale study was initiated on July 13, 1995. Its results indicate that the selected treatment process reduced copper concentrations of tap samples at 14 of 15 sites, with all but two sites below the 1.3 mg/l action level. The reduction of copper in tap samples was significant, ranging from 21-88%. with an average of 56%.

Table 2 summarizes the results of Greenwood Lakes WTP point of entry and distribution system water quality monitoring required by the Lead and Copper Rule. The major difference between the raw water quality and the treated water quality is the reduction of both pH and alkalinity. This is the result of the generation of hydrogen atoms during the addition of chlorine and to some extent the addition of fluoride. Table 2 also presents the average Langlier Index (LI) and Calcium Carbonate Precipitation Potential (CCPP) for the point of entry and the distribution system. These indexes indicate whether the water is in equilibrium with calcium carbonate.

If the indexes are both positive, the water is supersaturated with respect to calcium carbonate and calcium which can precipitate to form a protective coating on the pipe.

If both indexes are negative, calcium carbonate cannot precipitate to form a protective coating. The water is corrosive and tends to dissolve any calcium carbonate which has formed a coating.

If the indexes are equal to zero, the water is said to be in equilibrium with calcium carbonate. and it will neither precipitate nor dissolve. The LI gives an indication of the corrosive tendency of the water while the CCPP calculates the concentration of calcium carbonate that will theoretically precipitate or dissolve. In general, a slightly positive LI and a CCPP between 4 and 10 mg/l are desirable for corrosion control.

An evaluation of the Greenwood Lakes WTP point of entry and distribution system water quality shows that the pH of the finished and distribution waters is being reduced as a result of the treatment process. The LI and CCPP indexes calculated for these waters show that they were corrosive in nature. However, samples collected at the WTP before entry into and throughout the distribution system indicated that the raw water source, the treatment process, and the distribution system were not the source of the copper found in tap samples.

Stabilization

Raising the pH for corrosion control is often referred to as stabilization. It is one of the most important parameters in the control of corrosion because of its impact on the solubility of copper complexes and on calcium carbonate. Malachite is the major copper complex identified in general corrosion, which is the most common type of copper corrosion in Central Florida The general formula for malachite is $Cu(CO_3) \cdot Cu(OH)_2$. When pH is increased, bicarbonate converts to carbonate and more hydroxide is

Table 1. Greenwood Lakes WTP Well Water Quality - March and April 1993

Well LD	Alkal. mg/l	TDS mg/l	Sulfide ng/L	Cond. uhm/cm	Total Hard. mg/l	Chloride mg/l	Calcium mg/l	Bromide mg/l	DOC mg/l	pH field	Temp field°C
1	164	237	<0.2	358	196	12	57	<0.1	2.8	7.8	26
2	124	192	<0.2	289	144	21	36	<0.1	<1	7.8	28
3	136	194	<0.2	291	160	15	43	<0.12	1.4	7.6	26
4	120	173	<0.2	260	129	12	34	<0.1	<1	7.8	22

Table 2. Greenwood Lakes WTP Point of Entry and Distribution System Water Quality - Average for September 1992 through November 1993

Sample Point	Temp field °C	pH field	Cond. uhm/cm	Calcium mg/l	Alkalinity mg/l	Lead mg/l	Copper mg/l	Langlier Index	CCPP
Point of Entry	24	7.1	270	42	105	0.003	0.010	-0.57	-19.0
Distribution System	24	7.6	273	43	109	0.004	0.149	-0.05	-1.0

formed. Since the solubility product is constant, increases in carbonate and hydroxide promotes the formation of malachite and reduces dissolved copper. Provided there is sufficient alkalinity and calcium, an increase in pH will also promote the precipitation of calcium carbonate, which forms a protective film and creates a barrier to disrupt the corrosion redox reactions.

Full Scale Corrosion Control System Design

Manual calculations, the RTW model, and in-house computer programs used to simulate the source, treatment process, and distribution system determined that the water would be stable at a pH of approximately 7.7. Previous studies have shown that similar water would inhibit corrosion effectively if the pH of the distributed water is 0.1 to 0.3 pH units above stability. Computer and manual calculations show that for the Greenwood Lakes WTP, a dose of approximately 10 mg/l sodium hydroxide would increase the pH to 8.0 (or 0.3 units above stability pH).

A sodium hydroxide storage and feed system was installed at the Greenwood Lakes WTP for the full scale corrosion control study. The system included: a bulk storage tank for storing sodium hydroxide solution; a horizontal centrifugal transfer pump; a fiberglass building for housing two chemical metering pumps; and miscellaneous piping, valves and appurtenances necessary to inject sodium hydroxide solution into the suction side of the high service pumps. A pH monitoring system was provided on the finished water leaving the facility.

The system was originally designed and installed to store and feed 50% sodium hydroxide solution. However, modifications were made so that the system could operate using 25% solution. The 25% solution is preferable because it does not require the freeze protection that the 50% solution needs.

Full Scale Study Results

Table 3 presents data on consumer tap water samples collected before and during the full scale study. Comparing the July and August 1992, monitoring data to the October 2, 1995, monitoring data, the average reduction in copper concentrations found in tap water samples was 56 percent. Except for one site which showed no reduction, reductions in copper concentration ranged from 21 to 88 percent. The results show that there was a significant reduction in the copper concentrations in tap water samples after the sodium hydroxide was added to control corrosion at the Greenwood Lakes WTP.

The addition of sodium hydroxide into the finished water at the Greenwood Lakes WTP was initiated on July 15, 1995. During the full scale study, six distribution sites were selected and monitored for pH and turbidity. Turbidity is monitored to determine if there will be over-precipitation of calcium carbonate due to the elevated pH. As Table 4 indicates, there was no significant continuous increase in turbidity at any site during the full scale study period. The highest average turbidity was measured at the GWL-10 site. The average for the GWL-10 site was 1.2 NTU during July. However, this value does not correspond with elevated pH which, during that period, was at the lowest during the study.

Table 4. Greenwood Lakes Distribution System Monitoring Summary, 1995

ID	GWL-05	GWL-08	GWL-10	GWL-11	GWL-17	GWL-23	Plant
pH							
July	7.7	706	7.7	7.7	7.4	7.5	7.8
August	7.9	7.8	7.7	7.9	7.5	7.6	8.0
September	7.9	7.7	7.9	7.6	7.4	7.8	8.2
Turbidity (NTU)							
July	0.62	0.53	1.20	0.48	0.35	0.58	
August	0.75	0.70	0.54	0.56	0.43	0.70	
September	0.78	0.66	0.58	0.64	0.35	0.60	

Note: NaOH addition at the Greenwood Lakes WTP initiated on July 15, 1995.

Conclusions

The results of the full scale corrosion control study at Greenwood Lakes indicate that stabilization through the addition of sodium hydroxide can significantly reduce copper concentrations for waters with sufficient calcium and alkalinity.

SCPWD is currently in the process of constructing corrosion control systems at two more WTPs. Each of the new systems will utilize a sodium hydroxide storage and feed system similar to the Greenwood Lakes WTP. Additionally, SCPWD is considering the addition of pH probes to the potable water piping that supplies hosedown stations at existing wastewater lift stations. The existing lift stations are located throughout the distribution system and are equipped with SCADA systems. This will allow continuous monitoring of pH throughout the system and should reduce manhours associated with field sampling.

Roger M. Smith, P.E., is utilities manager and Charles R. Womack is water operations supervisor with Seminole County Public Works Department. June A. Smith, P.E., and Luke A. Mulford, P.E., are associate engineers with Brown and Caldwell Consultants.

Table 3. Greenwood Lakes Consumer Kitchen Tap Copper Concentrations

I.D.	Address	Before NaOH Addition			After NaOH Addition				
		7&8/92	3&5/93	5/8/95	8/8/95	8/14/95	8/23/95	9/15/95	10/2/95
1B	584 Lakeshore Cir.	1.50	n/a	1.30	0.14	0.25	0.98	1.10	1.00
2A	3850 Lake Emma Rd.	n/a	0.89	1.20	0.20	0.72	0.19	0.74	0.66
3A	570 Lakeshore Cir.	n/a	0.93	1.00	0.71	0.57	0.69	0.47	0.44
6	588 Lakeshore Cir.	2.20	2.20	0.81	0.06	0.26	0.05	0.07	0.58
12	549 Lakeshore Cir.	1.70	n/a	1.10	0.72	1.00	0.91	0.70	0.58
26	312 Buttonwood Dr.	1.40	1.40	1.60	n/a	0.82	0.68	0.74	0.78
29	469 Lakeshore Cir.	3.20	n/a	0.53	0.18	0.38	0.42	0.38	1.20
31	446 Lakeshore Cir.	1.40	1.60	0.28	0.18	0.08	0.05	0.10	0.26
32	449 Lakeshore Cir.	2.10	2.20	1.10	0.83	0.09	0.05	0.10	0.26
38	418 Lakeshore Cir.	4.90	1.30	1.90	1.10	1.30	0.93	0.50	0.96
40	477 Lakeshore Cir.	2.80	0.34	2.40	1.70	2.10	0.87	2.60	2.80
47	216 Teakwood Ct.	2.50	1.20	1.30	1.10	n/a	1.30	1.50	0.58
49	405 Lakeshore Cir.	2.30	3.20	2.00	n/a	0.63	0.28	n/a	n/a
62	573 Lakeshore Cir.	1.40	1.30	1.70	0.87	0.88	0.77	0.74	1.10
71	550 W. Springtree Way	2.30	1.40	0.91	1.80	1.70	1.30	1.30	n/a
73	542 W. Springtree Way	2.70	0.36	0.46	2.70	3.20	2.20	0.13	2.10
76	531 W. Springtree Way	1.60	1.20	0.50	0.20	0.19	0.23	0.13	0.51

Note: All results listed as mg/L Cu.

Grounding Can Affect Water Quality

S. J. Duranceau, G. E. C. Bell, M. J. Schiff, R. M. Powell, and R. L. Bianchetti

The practice of using water piping as part of the grounding system of the building has been common place for more than 80 years [1]. The practice was predicated on the assumption that with grounding there was little or no effect of alternating current (ac), as compared to direct current (dc), on the corrosion behavior of metals [1]. When electrical transformers serve multiple buildings and customers, this results in the water service piping and distribution piping acting as both grounding electrodes and transformer neutral return paths for the shared electrical systems [1-3.] The National Electrical Code has mandated since 1923 that the external buried water service piping be used as all or part of the ground electrode system [4, 5].

From the beginning, the water utility industry had concerns regarding the effect of grounding currents on water quality. Early studies on the effects of grounding on water quality, including Warren [6], Eliassen [7], American Research Committee on Grounding [8], and Eliassen and Goldsmith [9]. These studies were primarily concerned with the effects of grounding on water quality in terms of odor and taste. Alternating and direct current studies were conducted along lengths of electrically continuous metallic water service piping. Changes in metal content of the water were measured using the analytical techniques available at the time. These early studies concluded that the presence of ac and dc current on electrically continuous metallic water service piping did not effect water quality.

The promulgation of the Safe Drinking Water Act Lead and Copper Rule in 1991 again raised concerns about the effect of grounding currents on water quality. A recent study by the Orlando Utilities Commission [10] was performed using a model house system. The study concluded that grounding currents flowing on electrically continuous potable water pipes do not cause characteristic and distinct increases in metal concentrations for the conditions investigated. However, post-testing metallographic examination of the pipe surfaces indicated changes in protective oxide films, suggesting a depolarization effect of ac current. Further, increases in metal concentrations were measured during lightning storms. Similar results regarding effects of lightning on internal corrosion and metal release were reported by Guererra [11].

As part of a research project for the American Water Works Association Research Foundation entitled *The Effects of Electrical Grounding on Pipe Integrity and Shock Hazard* [12], the increasing use of plastic service piping and other dielectric or electrically insulating connections in water services became apparent. In addition, field research found that rubber gasketed water meter connections can become resistive over time and effectively act as electrical insulators. Electrical resistance or insulation in the normally conductive pipe will force some current to flow through the parallel internal water and external soil paths. Discharge of current on the inside of the pipe increases metal concentrations in the service line, while discharge of current on the exterior of the pipe could increase service line failures.

Previous studies on the effects of grounding on water quality and metal release did not investigate the effects of resistance or dielectric fitting on water quality. These earlier studies [5-9] applied either ac or dc or both ac and dc to *an electrically continuous section* of pipe and measured the change in metal ion concentration over a period of time. Without significant resistance in the metal pipe wall, electrical current continues to flow in the much more conductive pipe wall [13]. No current is discharged on the inside or the outside of pipe and it is not surprising that no effect on water quality was previously found when electrically continuous pipe sections were tested. In this study, the effects of dielectric fittings on water quality and metal release was studied.

EBMUD and PCU Studies

EBMUD and Pinellas County Utilities (PCU) agreed to participate in the water quality study. The objectives of the additional studies were:

- To repeat and confirm preliminary screening results from field and lab tests performed as part of the pipe integrity study [12];
- To investigate the effects of short sections of plastic pipe as insulators on water quality; and,
- To evaluate the effect of lead solder surfaces and solder joints on metal (lead, copper and zinc) release.

Test Conditions And Test Article Design

Four voltages (120, 25, 10, and 5 volts-ac) were intended to be investigated in the follow-on testing. Three different types of test articles ("A", "B" and "C") were used in the testing for three lengths of time (24, 72, and 168 hours). Each type of test article had an associated control with no applied voltage for 168 hours. Test articles "A" investigated dielectric unions on lead-free soldered copper pipe systems. Test articles "B" investigated the use of 6 in. of PVC as an insulating method. Test articles "C" investigated the effects of dielectric unions on systems where lead solder was used to make joints with copper. The test articles were wired in parallel so that the applied voltage across all the test articles were equal. A 10-ohm resistor (± 2%) on the neutral side of the test articles acted as a current measuring shunt for each test article.

Data Collection Procedures

At start-up of a test series (i.e. 120 V-ac, 25V-ac and 5V-ac) measurements of ac voltage and 10 ohm resistor voltage drop (10 millivolts = 1 milliampere) every 5 minutes were made for the first half hour. After this initial start-up period, at least three daily measurements (morning, noon, and end of day) of ac voltage across insulator or PVC tubing along with current flowing in each 10 ohm resistor were made. It is recommended that measurements should be made with properly rated test leads and meters by personnel trained with respect to electrical safety and familiar with the hazards related to the tests.

At the end of the test period for each test article (24, 72 and 168 H), the power was turned off and the test article water emptied into a labeled container. The power was then turned back on and the start and stop times for the power were recorded. The temperature, pH and dissolved oxygen of the water sample were measured on site per EPA approved method. Laboratory analysis of the test article water samples and control samples per EPA approved methods for TDS and/or conductivity, total and calcium hardness, total alkalinity, lead, copper, and zinc were performed.

Results

Tests were identified by the test article, applied voltage, and exposure time. For example, A-005-024 designates the test conducted with test article type "A" with 5 Vac applied across the insulator for 24 h. Unfortunately, PCU was unable to perform tests at 120V due to high currents which caused shorting across one of the dielectric unions and increased water temperature above 60°C. Measured resistances were about four times lower at PCU ground water as compared with the EBMUD snow melt water. PCU conducted tests with a maximum of 50 Vac applied voltage instead of the 120 Vac.

Figures 1 through 3 depict the dependence of metal pick up of the water as a function of the product of the average milliamperes of ac and the contact time (ac-ma*h) for Cu, Zn and Pb for some of the testing performed at EBMUD and PCU.

For the A-series test articles, which consisted of copper tubing separated by a dielectric union fabricated with lead-free solder, copper, zinc and lead increased with increasing ac-ma*h for both the EBMUD and PCU data. The level of metal release was less for PCU as compared to EBMUD, despite the fact higher currents were present at PCU as compared to EBMUD. Total metal concentrations were substantially lower for both PCU and EBMUD for the B-series, which consisted of copper tubing separated by 6 inches of PVC pipes as an insulating connector. The lower metal concentrations are directly attributable to the higher resistance and, thus, lower currents present in the test systems. EBMUD showed significant copper pick-up with very little zinc increase. Lead release in the EBMUD-B series was sporadic and in some cases significant.

The source of the lead in the EBMUD tests was probably brass plugs in the test articles. PCU data for B-series test articles showed low copper pick-up but significant zinc release. The source of zinc is not clear and may be related to solder fluxes used during fabrication. Lead levels were low for the PCU B-series tests when plastic plugs were used in place of brass plugs to seal the end of the test article.

For the C-series test articles, which consisted of copper tubing separated by a dielectric union with 50:50 lead:tin solder surfaces exposed to the water, copper, zinc and lead increased with increasing ac-ma*h for both the EBMUD and PCU data. The level of copper releases was less for PCU as compared to EBMUD, despite the fact higher currents were present at PCU as compared to EBMUD. Levels of zinc were somewhat higher for EBMUD, and lead increases for PCU were higher than EBMUD.

Discussion

Copper, lead and zinc release were significant and in many cases exceeded the action levels for primary or secondary drinking water standards. Differences in metal release behavior between the PCU and EBMUD are obvious and indicate that the differences are due to the different sources and treatment of water at the two utilities.

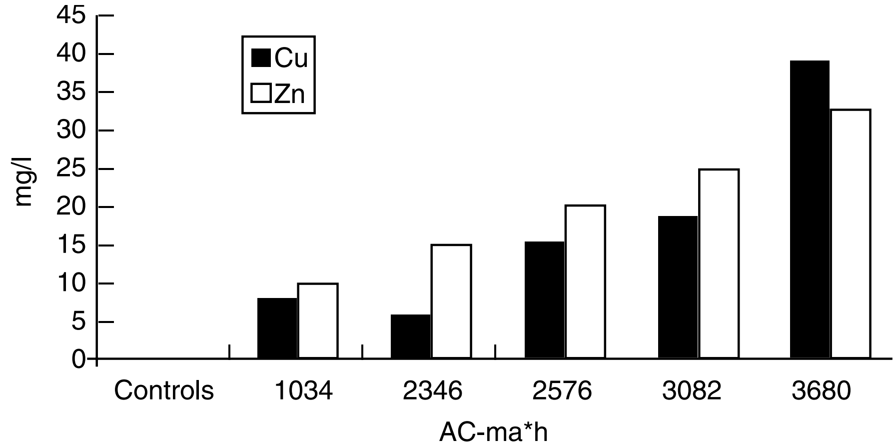


Figure 1. Copper and zinc concentrations as a function of AC-ma*h for initial scoping tests at EBMUD with 123 VAC applied.

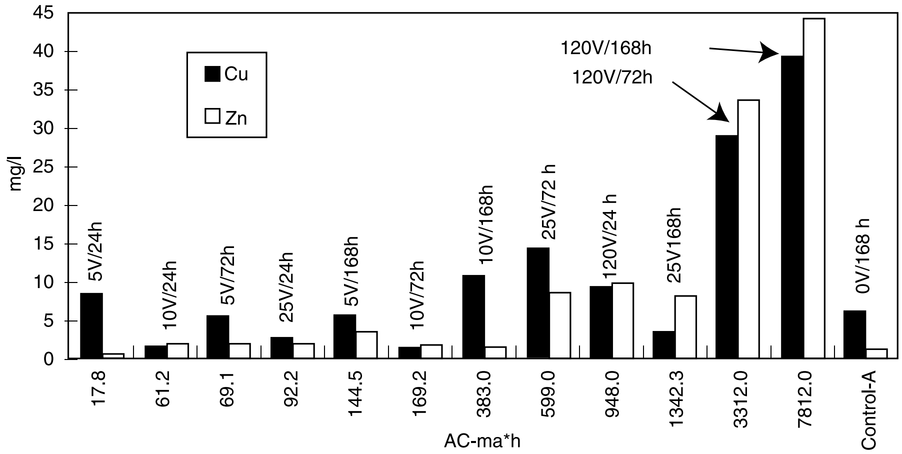


Figure 2. Copper and zinc concentrations as a function of AC-ma*h for follow-on tests at EBMUD with Type "A" test articles.

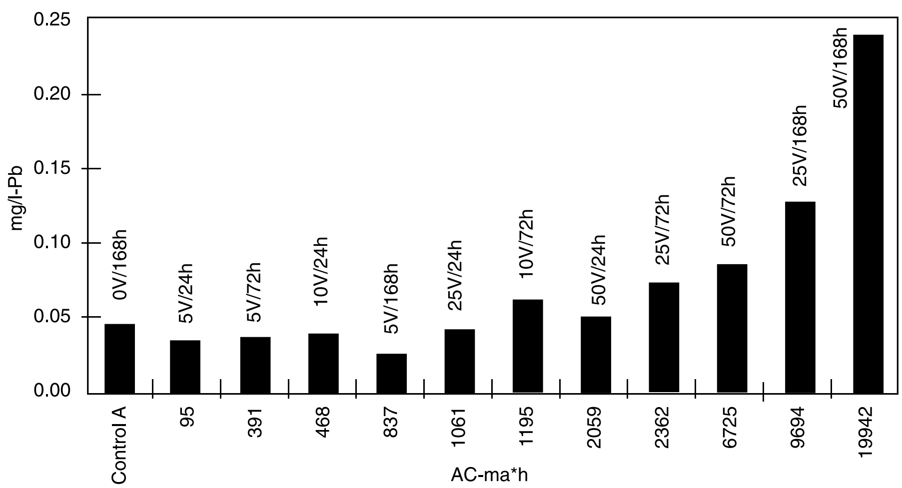


Figure 3. Lead concentration as a function of AC-ma*h for follow-on tests at PCU with Type "A" test articles.

The mechanism of ac corrosion has been postulated to be caused by rectification of alternating current to direct current by “metallic” rectifiers at the metal/oxide interface 3, 15, 17. In metallic rectifiers such as copper/copper oxide the rectifying junction is between the oxide semiconductor and the metal surface. The direction of the current is from the semiconductor to the metal. For copper surfaces, copper oxides act as the semiconductor on the copper metal surface and produces a half wave rectifying circuit which results in net direct current.

PCU is a groundwater source while EBMUD is a surface water source utility. As such, PCU has much lower dissolved oxygen (DO = ~2 mg/l) in their make-up water as compared to EBMUD (DO = ~10 mg/l). Since the formation of copper oxide is related to the amount of oxygen present in the make up water and dissolved oxygen would be consumed in corrosion reactions which are causing metal release, the reduction in DO was correlated with the increase in metal ion equivalents in the solution.

For EBMUD conditions of higher initial DO, there is good correlation between increased metal ion content of the water and the reduction in DO. The correlation does not hold for the lower initial DO PCU data This suggests that DO plays a role in the magnitude of the release of metal. In addition to the differences in DO, PCU utilizes a blended phosphate corrosion inhibitor to control copper corrosion. EBMUD does not use a corrosion inhibitor. The presence of the inhibitor probably contributes to differences in metal release with respect to copper and zinc, between the two utilities.

In addition, the literature and data collected in the EBMUD and PCU lab testing show that voltages and currents which increase metal release on the interior of the copper piping with insulators in the water service can also increase soil-side corrosion on the exterior of underground copper water services. Whether or not this increase in corrosion rate due to ac is significant over the life of the building is unknown.

Summary And Conclusions

A series of test were conducted to investigate the effect of electrically insulating unions on water quality in the presence of applied alternating current voltages of 123 and 50 volts. The following conclusions can be drawn from the data presented:

I) The data indicate that there was a pronounced effect of ac voltage on copper release for both the 123 and 50 volt-ac tests. Copper and lead contents measured after 24 hours of exposure at the lower applied voltage exceeded EPA Lead and Copper action levels, 0.015 mg/l and 1.3 mg/l for lead and copper, respectively.

2) Metal release generally increased with charge transfer, in accordance with Faraday's law.

3) Based on the metal release data collected in these limited tests, the ac corrosion rate is calculated as 0.14% of the corresponding dc rate for the conditions investigated here.

Acknowledgments

This research was sponsored by the American Water Works Association Research Foundation (AWWARF) under contract number 913-93 with Boyle Engineering Corporation. The technical assistance and persistence of Dana Drath of EBMUD was invaluable in designing and performing the tests. The advice and help provided by the Project Advisory Committee (Pac) and AWWARF project officer, Roy Martinez, were sincerely appreciated. The PAC consisted of Bob Behnke, System Engineering Manager and John Ackerman, Vice President, St. Louis County Water Co., Richard Bonds, Technical Director, Ductile Iron Pipe Research Association, and Don Goff, Protection Engineer, U.S. West Communications, Inc.

References

1. Steffan, R. F. "Grounding of Electric Circuits to Water Services: National Electric Code Versus AWWA Policy, *JAWWA*. p. 82, (February 1980).
2. Kennedy, R. C. Ground-Wire Attachments To Water Pipes. *JAWWA*. 44(5): 383-386 (1952).
3. Waters, F. D. A. C. Corrosion. *Materials Protection*. 1. (March):26-32 (1962).
4. Hertzberg, L. B. "The Water Utilities Look At Electrical Grounding." *IEEE Transactions*. IGA-6(3): 278-281 (1970).
5. National Electrical Code. Batterymarch Park, MA: National Fire Protection Association- 1993.
6. Warren, H: S. Electrical Grounds on Water Pipes. *J. New England Water Works Association*. 48(September):350-371 (1934).
7. Eliassen, R. Program For Research On The Effects of Electrical Grounding On Water Pipes. *JAWWA*. 33(9): 1541 - 1552 (1941).
8. American Research Committee on Grounding. Interim Report of Investigations. *JAWWA*. 36(April): 383-405 (1944).
9. Eliassen, R. and P. Goldsmith, "Effects of Grounding on Water Pipe", *JAWWA*. 36, 563, (May 1944).
10. Orlando Utilities Commission and CH2M Hill, *The Evaluation of the Effects of Electrical Grounding on Water Quality*. AWWARF, Denver, CO, (1994).
11. Guerra, A. A. Experience With Grounding of Electrical Circuits To Water Pipe. In Prog. 1979 AWWA Annual Conference, San Francisco, CA: AWWA (1979).
12. Bell, G.E.C., M.J. Schiff and S.J. Duranceau, "Observation of the Effects of Grounding on Water Piping," CORROSION/95, Paper No.95603, March 26-31, 1995, Orlando, FL.
13. Rossun, J.R, "Corrosion from Improper Grounding Questioned," in Letters to the Editor, *JAWWA*, 73:1:38 (1981).
14. Hamlin, A. W. "Alternating Current Corrosion." *Materials Performance*. 25(1): 55-58(1986).
15. Kulman, F.E. Effects of Alternating Currents Causing Corrosion. *Corrosion*. 1(3): 34-35 (1961).
16. Galimberti, C.E. Corrosion of Lead By Alternating Current. *Corrosion*. 20(5): 150t-157t (1964).
17. Bruckner, W. H. "Soil Corrosion of Steel By Alternating Currents." In Prog. 19th Annual Conference of National Association of Corrosion Engineers. Houston, TX: NACE International (1963).
18. Williams, J. F. "Corrosion of Metals Under the Influence of Alternating Current." *Materials Protection*. 5(2): 52-53(1966).

S. J. Duranceau, Ph.D., P.E. is with Boyle Engineering Corporation, Orlando. G. E. C. Bell, Ph.D., P.E. and M. J. Schiff, P.E., are with M. J. Schiff & Associates, Inc. in Claremont, CA. R. M. Powell is with Pinellas County Utilities in Clearwater, FL. R. L. Bianchetti, P.E. is with East Bay Municipal Utilities District in Oakland, CA.

Lightning from Page 4

From these observations it was concluded that lightning in some way had contributed to the excess dissolved copper in the water samples. Taking this observation to its final conclusion leads to the theory that lightning can cause pinholes in the copper plumbing.

Hole Characteristics

Direct strikes of lightning on or near plumbing, usually in the service line, have been known to put holes in tubing. These holes are characteristically large and round. On the other hand, pinholes are thought to be caused by either the flux used to solder the joints or by the quality of the water.

The corrosiveness of flux on copper tubing has been well documented in the literature. To some degree, the effects of water quality have also been documented.

A flux induced pinhole usually occurs in what is termed a flux ghost—an area where the flux has been washed away. On the inside of the tube there is a mound of dark green corrosion products that covers the affected area. On the outside of the tube there is also an area of green corrosion products. The hole penetrates from the inside to the outside of the tube wall. The hole is very small, allowing only a drip in most cases. Depending on how old the hole is, it may, by erosion, form a somewhat larger hole. Corrosion usually causes the circumference of the hole to be irregular.

A hole caused by lightning is usually round and has a smooth circumference. It penetrates from the outside to the inside, as indicated by the down-turned edge of the hole. It has no dark green corrosion products on either its outside or inside. For now at least, it is assumed the holes are rather large in size.

Upon Further Examination

In examining a known lightning induced hole under a microscope using 30X magnification, there are two other outstanding features. One is a lightly etched halo around the circumference of the hole on the outside of the tube. The second is a glossy, ruby red area that surrounds at least part of the hole on the inside of the tube.

The ruby red material is intriguing. What is it and where did it come from? The copper compound section in the *Handbook of Chemistry and Physics*[2] lists copper (1) oxide (Cu_2O) as having a reddish color and copper (2) oxide (CuO) having a black color. A paper by Edwards, et al.[3] suggests that both Cu_2O and CuO exist on the interior surface of copper tubing. Not only are they both present, but they are self limiting by each other's presence. Individual layers are not distinguishable on newly oxidized tubing. In fact, the coating is neither red nor black, but a shade of brown—a mixture of both red and black.

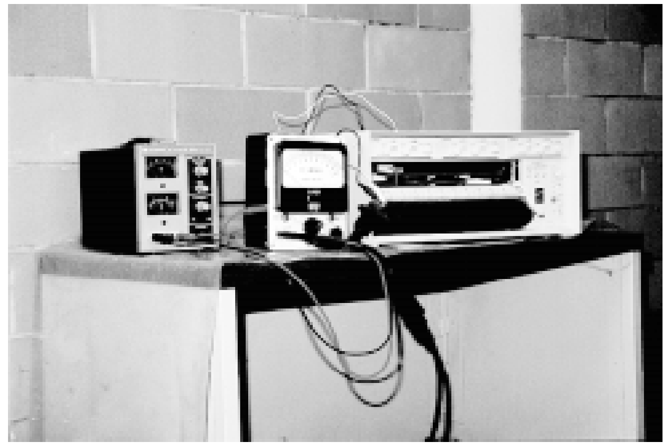
Inspection of actual Cu_2O indicates that it is a dull, almost crimson red—certainly not the bright, glossy, ruby red observed in our study.

The section on copper found in a college chemistry text book[4] indicates that red Cu_2O is formed by the heating of copper in oxygen to 1000 degrees Celsius. It can also be formed by heating black CuO at a high temperature.

Now there appear to be three sources of red Cu_2O to form the glossy, ruby colored material.

Since the expected color of copper oxide is a dull red, how does the glossy, glass-like red occur? The key word may be glass—silica heated to a molten temperature.

Central Florida drinking water normally contains a small amount of dissolved silica. An x-ray scan of a section of copper plumbing indicated that silica is, to some degree, deposited on the walls of the tubing. Thus, if there were enough heat present, the silica would have the potential to form glass. Combining Cu_2O, silica, and heat should give a glassy, red material.



Setup used to detect lightning on ground rod

Experiment

An atomic absorption spectrophotometer equipped with a graphite furnace was used to test the theory. The test was conducted in the normal argon atmosphere associated with the graphite furnace technique. A small amount of CuO was placed inside a graphite cuvette. The cuvette was then mounted into the furnace head and heated to a final temperature of 1200°C. We found that the black CuO had changed into the red Cu_2O.

Next, small sections of pure copper foil were placed in the cuvette. After the cuvette was mounted in the furnace head, the cuvette was heated to 1050°C. This time the argon atmosphere was replaced with air. The result was a small copper ball.

This part of the test was repeated at 1200, 1400, 1450, 1500, 1600, and 1800°C. At 1450°C the copper foil produced both a copper ball and black CuO. At 1600°C the entire piece of copper foil was converted to CuO.

Finally, HPLC grade bare silica was placed in the furnace cuvette along with a small amount of red Cu_2O. The furnace was heated to a final temperature of 1800°C, just above the melting point of silica. The final product was indeed a glassy, red ball.

These tests provide a scenario by which the glassy, red material seen around the known lightning-induced hole could have been formed. The necessary materials are present—the oxides, the silica, and metallic copper. All that remained was a source of heat.

But How?

Lightning is a static electrical charge built up by the movement of clouds. When the charge builds to a certain point, a discharge takes place.

One of the most common types of discharge is from the cloud to the ground or something attached to the ground.

In a recent article[5] describing lightning and its formation, the temperature of a lightning strike is said to be 55,000°F. Fulgurites, fused silica shapes formed when lightning hits sandy soil, are evidence of the heat carried by a lightning strike.

But how does this apply to the theory that lightning causes pinholes in copper plumbing systems? Assume for a moment that when the lightning strikes the ground it

OUC model house

travels a certain distance before the charge is neutralized. Anything in its path could possibly pick up the charge and become a conductor. On a house there is typically one thing that is in contact with the earth: the driven ground rod required by the national electrical code.[6]

Now assume a lightning strike occurs and the associated charge is moving through the soil when it encounters a driven ground rod. The charge moves up the ground rod and, by virtue of the required bond with the cold water pipe, the charge is now on the copper plumbing.

The static charge, seeking neutrality, has to go somewhere. On a house with a continuous metallic plumbing system all the way out to a metal water distribution system, the charge follows that path until it is dissipated with no harm done.

However, the majority of houses built in Central Florida since the mid 1970's have PVC entrance lines, the continuity to the distribution system does not exist. The next best conductor for the static charge is the water within the copper pipes.

The resulting charge on the copper pipe has the possibility to build up to a point that it actually discharges through the tube wall into the water. The copper tube now has a hole in it with the characteristic penetration from the outside to the inside.

It is not difficult to surmise that a discharge through the pipe wall, a miniature version of the original lightning strike, produces considerable heat, which is the source of heat necessary to create the glassy, red material around the discharge hole, commonly called a pinhole.

An effort was made to confirm that the driven ground rod did indeed pick-up lightning current and transfer that energy to the plumbing.

Using the model house constructed for the AWWA Research Foundation project previously cited, a monitoring device was set up to measure this possible phenomena. The device was a Swain, dc-AMP, meter with a 1-inch Sea Clip connected to a strip chart recorder measuring milli-amps. A 12V dc power supply was used in lieu of batteries in the meter.

Because the nature of lightning is dc, the direction of travel is easy to ascertain. The Sea Clip was connected to the #4 copper wire from the driven ground in such a way that current coming from the rod to the model house plumbing would register a positive deflection on the strip chart. Now all that was needed was a lightning storm.

Three years later, on Tuesday, July 18, 1995, a severe storm passed through Orlando. With every close lightning strike a positive deflection was logged on the strip chart. The closer the strike the larger the deflection.

Some strikes were as close as 100 feet, some were 4 blocks away. As one would expect, the closer the strike the more energy transferred to the house plumbing.

Field Studies

Field studies to determine how many pinholes would meet the criteria stated above were conducted with the assistance of the "Leak Doctor," a licensed plumber named George Surrey who has made a business out of detecting and repairing pinhole leaks only.

Coupons taken from his clients' homes were delivered to the OUC lab for examination of pinholes—did they have puncture-like appearances, did they have halo around them, and were they round and smooth.

Many of the coupons were then split to examine the insides for red, glassy material around the holes.

Of the coupons examined, 95% exhibited the features.

Conclusions

The results of this project indicate a direct relationship between lightning and specific type of copper plumbing failure.

Lightning-caused holes are usually round with a lightly etched halo around the hole. The hole penetrates from the outside to inside as indicated by the down turned edges.

The most significant discovery is the red, glassy, material associated with the hole. Holes cause by flux, dissimilar metals, etc., do not display the red material. It has also been shown that the red material can be reproduced in the laboratory.

In reproducing the red material, it was found that a temperature near 1800°C was needed to transform the copper metal, copper oxides, and silica into the glass like substance. Nothing less than the energy associated with lightning could produce such a momentary temperature.

It has also been shown how lightning can get on household plumbing by way of the driven ground rod. And although this may be the most expeditious point of entry, it is probably not the only one.

While this study has defined a mechanism for the majority of pinholes in home plumbing in Central Florida, the real task will be to define the cure.

Bibliography

1. AWWARF, "Evaluation of the Effects of Electrical Grounding on Water Quality," *AWWA Research Foundation*, 1994.
2. *Handbook of Chemistry and Physics.* 71st ed., CRC Press, 1991.
3. Edwards, Marc; et al; "The Pitting Corrosion of Copper," *Journal AWWA, July*, 1994.
4. Frey, Paul, *College Chemistry*, 3rd ed.; Prentice-Hall, Inc., 1965.
5. Newcot, Wm. R.; "Lightning Nature's High Voltage Spectacle," *National Geographic*, July, 1993.
6. *National Electric Code*, 1993.

Richard A Dunham is manager, water quality laboratory, and Clifford A Russell, P.E., is director, engineering and technical suppport, Orlando Utilities Commission.