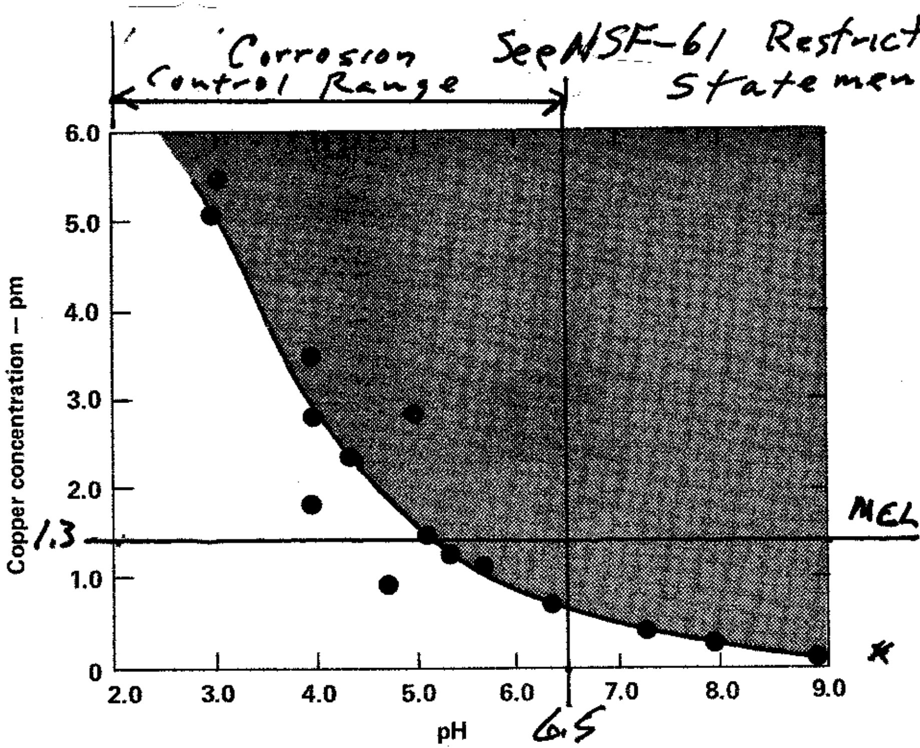

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EPA maximum Contaminant Level (MCL) = 1.3 ppm (mg/l)

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Pitting attack

Almost all well waters can be handled by copper satisfactorily, but some aggressive well waters cause pitting in cold water lines. When such pitting occurs, it is associated with water having a certain specific composition. For example, when the bicarbonate-to-sulfate ratio is less than one, pitting is likely to develop.[16] Surface waters are not involved in cold-water pitting, unless they have been blended with an aggressive well water.[17] Such waters, according to Powell and Lucey[18], form a protective mat of cuprous oxide on the copper surface.

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pH standard 6.5 – 8.5, Not Enforceable MCL by EPA

TABLE 1. Copper Tube: Types, Standards, Applications, Tempers, Lengths

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Annealed
[illegible]	Green	ASTM B 88[3]	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Oil, HVAC, Snow Melting	**STRAIGHT LENGTHS:**		
				¼-inch to 8-inch	20 ft	20 ft
				10-inch	18 ft	18 ft
				12-inch	12 ft	12 ft
				COILS:		
				¼-inch to 1-inch	—	60 ft
					—	100 ft
				1¼ inch and 1½-inch	—	60 ft
				2-inch	—	40 ft
					—	45 ft
[illegible]	Blue	ASTM B 88	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Oil, Natural Gas, Liquified Petroleum (LP) Gas, HVAC, Snow Melting	**STRAIGHT LENGTHS:**		
				¼-inch to 10-inch	20 ft	20 ft
				12-inch	18 ft	18 ft
				COILS:		
				¼-inch to 1-inch	—	60 ft
					—	100 ft
				1¼ inch and 1½-inch	—	60 ft
				2-inch	—	40 ft
					—	45 ft
[illegible]	Red	ASTM B 88	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Gas, HVAC, Snow Melting	**STRAIGHT LENGTHS:**		
				¼-inch to 12-inch	20 ft	N/A
[illegible]	Yellow	ASTM B 306	Drain, Waste, Vent, HVAC, Solar	**STRAIGHT LENGTHS:**		
				1¼-inch to 8-inch	20 ft	N/A
[illegible]	Blue	ASTM B 280	Air Conditioning, Refrigeration, Natural Gas, Liquified Petroleum (LP) Gas,	**STRAIGHT LENGTHS:**		
				⅜-inch to 4⅛-inch	20 ft	[4]
				COILS:		
				⅛-inch to 1⅝-inch	—	50 ft
[illegible]	(K)Green (L)Blue	ASTM B 819	Medical Gas	**STRAIGHT LENGTHS:**		
				¼-inch to 8-inch	20 ft	N/A
[illegible]	Yellow	ASTM B 837	Natural Gas, Liquified Petroleum (LP) Gas,	**STRAIGHT LENGTHS:**		
				⅜-inch to 1⅛-inch	12 ft	12 ft
					20 ft	20 ft
				COILS:		
				⅜-inch to ⅞-inch	—	60 ft
					—	100 ft

1. There are many other copper and copper alloy tubes and pipes available for specialized applications. For information on these products, contact the Copper Development Association Inc.
2. Individual manufacturers may have commercially available lengths in addition to those shown in this table.
3. Tube made to other ASTM standards is also intended for plumbing applications, although ASTM B 88 is by far the most widely used. ASTM Standard Classification B 698 lists six plumbing tube standards including B 88.
4. Available as special order only.

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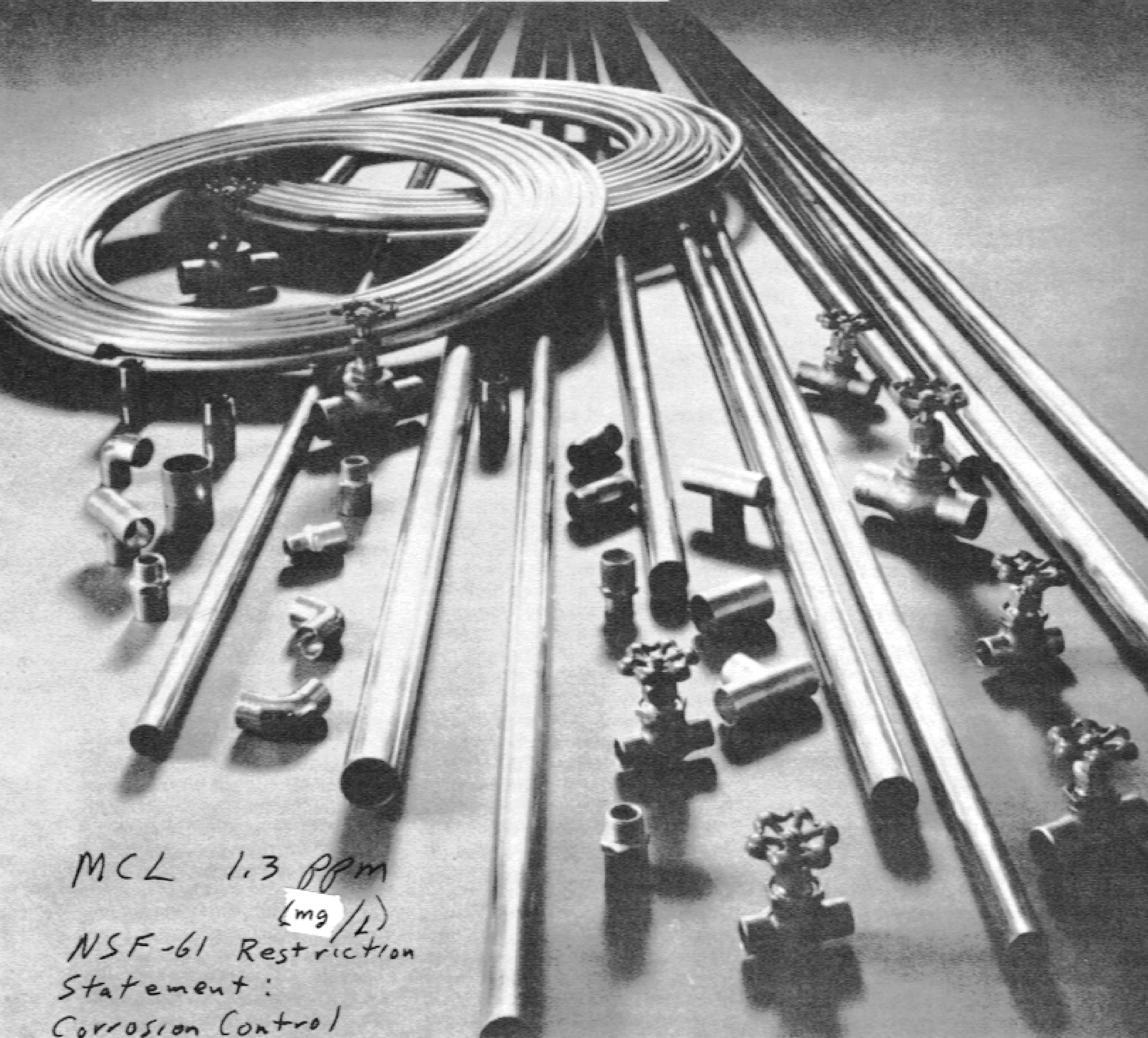
The magazine of mechanical systems engineering and energy management

Copper for Hot and Cold Potable Water Systems



MCL 1.3 ppm (mg/L)

NSF-61 Restriction Statement: Corrosion Control Recommended for pH < 6.5

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Copper for hot and cold potable water systems

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By **ARTHUR COHEN**, Manager,
Standards and Safety Engineering,
Copper Development Association Inc.,
New York, N.Y.

A supply of potable water is an essential requirement for the health and comfort of the inhabitants of a building. The performance of the system that distributes this water depends primarily on four things:

- The corrosiveness of the water supply
- The corrosion resistance of the tubing and fittings
- The design and workmanship of the installation
- The standards of maintenance and use after installation

The designer of a potable water system must recognize the interplay of these factors.[1] He must also familiarize himself with various building codes, materials specifications, and the capability of local contractors.[2] In addition, he must balance economic and related factors, such as the availability of system components and delivery schedules, with many other variables that he cannot control.

Corrosiveness of water supply

In a modern waterworks, the chemist in charge not only prescribes treatments to make the water conform to health regulations, such as to free it of pathogenic organisms, but he must also make arrangements for chemical treatments designed to reduce the corrosiveness of the water. Standards and procedures are available to assist him in this. For example, the Safe Drinking Water Act of 1974* (Public Law 93-523) directed the Environmental Protection Agency to establish interim primary drinking water standards. Promulgated in June, 1975,[3] these standards were implemented in December, 1976. They replaced those contained in the U.S. Department of Health, Education, and Welfare's Public Health Service Drinking Water Standard (Public Health Service Publication No. 956), which to a lesser degree recommended levels for both biological and mineral constituents. National Secondary Drinking Water Regulations are being formulated,[4] and we can look forward to more stringent limitations on water constituents when they are finally adopted.

The water purveyor may not fully recognize his responsibility or the economic advantages of providing a water suitably adjusted chemically to reduce its corrosiveness.[5] In some cases, he may face restraints that can prevent him from providing optimum treatment. Thus, corrosion-resistant materials obviously are required for good and long performance of a water distribution system. Piping, valves, fittings, and other components must all be of high quality and free from defects. Experience has shown that manufactured components occasionally are defective, although in a modern factory, suitable quality control of the products normally rejects defective material or components before they can get to the marketplace. In addition to selecting materials for a plumbing system that are naturally resistant to corrosion, it is also important to select materials that are

Each water source must be checked to see if treatment is necessary

*Copper MCL 1.3 ppm (mg/L)

[1] *Superscript numerals indicate references at the end of the article.*

available from a reliable source with a history of good quality.

After the system designer has evaluated the characteristics of his local water supply and has selected the most suitable materials possible under the code, he must design the system to conform to corrosion principles and for safety, mechanical strength and support, noise reduction, and accessibility for maintenance. If the water supply is corrosive, or if excessive scaling can be expected in the hot water part of the system, additional water treatment at the site may be required. The designer must also specify the manner of installation to ensure good workmanship.

Once the potable water system is installed, some maintenance may be required. At least, the system should be inspected at regular intervals to establish that corrosion, deposits, or abuse have not affected its integrity.

Characteristics of water

Potable waters are developed from a variety of sources, including lakes, rivers, streams, and wells. Reservoirs are used to store water where there is seasonal or annual variation. Surface waters tend to be saturated with air. Waters taken directly from wells may be low in oxygen but may contain much higher levels of carbon dioxide and minerals than surface supplies. Unlike surface waters, well waters are usually free of algae and organic matter.

Waters are routinely treated for biological purity, but in addition, each water source has to be examined to determine whether some form of correction or treatment is necessary to control its corrosiveness. Often, all that is required is pH adjustment. The form of corrective treatment may be to control scaling or to reduce dissolution (corrosion).[2] Treatments with other objectives must be evaluated for the possible effect on the corrosiveness of the water. For example, excessive turbidity is objectionable in drinking water, and potable water must meet the new EPA limit of one turbidity unit. Flocculation, the treatment to clarify turbid water. often uses a coagulant such as alum to remove suspended matter. It has been observed in a few cases that soft, low pH waters treated with alum cause localized pitting in hot water systems. In one community using glacial water for its supply, pitting developed soon after alum was introduced to precipitate glacial rock fines. Prior to the addition of the alum, the corrosion product included some of the suspended rock fines and completely protected the copper in the system.

Suitable treatments are routine in modern waterworks. Where the water purveyor continuously controls the character of the water fed to the mains, he not only ensures optimum corrosion performance of his own supply system but also greatly reduces the customer-related water problems.

Smaller water purveyors in many cases do not provide corrective treatments, either from lack of understanding of the need or from lack of the proper facilities.

From a corrosion performance standpoint, one important characteristic of a potable water is a factor known as its calcium carbonate saturation index. If the index is a positive number, the water will have a tendency to precipitate calcium carbonate, whereas a negative index corresponds to a water that is likely to be corrosive. W. F. Langelier developed a procedure for calculating the calcium carbonate saturation index of a water.[6] Several components are needed for the calculation:

- Total alkalinity (methyl orange)
- Calcium hardness
- Total dissolved solids
- pH
- Temperature

For potable waters, a close approximation of the index can be obtained by the use of charts, a special slide rule, or a simple formula and tabulated data.[7] Two steps are involved. First, the pH is calculated, corresponding to calcium carbonate saturation, pH_s. Second, the saturation index is found by calculating the difference between the actual pH and the saturation pH:

Saturation index = $pH - pH_s$

In many cases, there is not sufficient information to indicate whether a scale will form and whether it will be dense, uniform, or protective.[5] Some waters may be slightly supersaturated and may not deposit a carbonate scale. Thus, it may be necessary to increase the pH to obtain water with the desired protective characteristics. The flow characteristics of the system tend to influence both the amount of scale that develops and the uniformity of the deposit. In practice, it is observed that the scale will start to deposit at slightly supersaturated conditions, depending on the pH.

> Installations where there is continuous demand for water are less likely to experience pitting

A high positive number for the index indicates that heavy deposits can be expected. These can lead to increased frictional resistance, clogging of valves and controls, and decreased heat transfer rates in water heaters.

The corrosion reaction may also influence the degree of calcium carbonate deposition. For a borderline water, the pH increase at a local cathode may be sufficient to cause calcium carbonate to precipitate.[5]

Realistically, the Langelier index is not a reliable indicator of whether or not copper alloys will be subject to corrosion. In fact, distilled or deionized water is corrosive on the Langelier index, but years of experience have clearly shown that the corrosion performance of such water is excellent. All a negative index means is that the metal in the distribution system must rely on itself for protection against corrosion.

Obviously, other factors come into play. Analyses of many waters high in dissolved carbon dioxide do show acceptable Langelier indexes, but pitting corrosion takes place nevertheless. In addition, water that has undesirable properties at room temperature (*i.e.*, an unacceptable Langelier index) will often become innocuous when heated.

Excessive carbon dioxide is often found in soft well waters, particularly in parts of New England. It may be reduced by vigorous aeration of the water. If the treated water has a pH much below 8.0, some adjustment with an alkali may be desirable. This is particularly true for a very soft water, where the addition of a quantity of lime to provide a slightly positive calcium carbonate saturation index will result in a noncorrosive and often better tasting water. If a hard water, such as is produced in a limestone formation, is to be softened to improve its quality, the pH normally will have to be adjusted following treatment. The need for pH adjustment depends on the method used to soften the water. As before, the object is to bring the water into the slightly scaling range of the Langelier index. This is also achieved in many cases by bypassing some of the water with a proportioning valve and blending it with the softened water. Some adjustment of the valve may be needed, as corrosion of scaling experience is gained in the potable water system.

Even when the designer of a system is assured that the water supply has been treated to reduce corrosion to a minimum, he must consider changes that may occur between the water plant and the distribution system. On-site chemical analyses for oxygen, carbon dioxide, and pH should be made and compared with the treatment plant's analysis. The passage of potable waters through steel, cast iron, asbestos cement, or cement-lined steel mains can alter the chemistry of the supply.

Some waters, such as those with excessive amounts of chloride or sulfate, can be corrosive to piping systems in spite of treatment. There is no inexpensive water treatment to eliminate or reduce chloride and sulfate contents.

Obrecht and Meyers have characterized potable waters into 15 groups.[2] Each of the classifications, shown in Table 1, is based mainly on the corrosiveness of the water to iron piping in hot and cold water service. The authors have limited their analysis to four compositional variables, namely, calcium, sulfate, silica, and dissolved oxygen. They fully recognize, however, that other variables, such as chlorides, could also influence these classifications.

Copper is resistant to most of the corrosive waters listed in the table. To judge whether a problem exists with copper, additional information is required. For example, category 1A describes a very soft water with dissolved oxygen present. If excessive dissolved carbon dioxide is present, green staining may de-

Table 1 — Potable water categorization is applicable to all metals for scaling but only to iron, steel (not stainless) and galvanized steel for corrosiveness.

Category	Calcium (Ca), ppm	Sulfate (SO_4), ppm	Silica (SiO_2), ppm	Dissolved oxygen, ppm	Character
1A	—	As found	0-15	1-10	Extreme corrosion hot and cold.
1B	0-18	0-25	0-15	0-1	Moderate corrosion hot and cold. Extreme corrosion with CO_2 > 8 ppm.
1C	—	0-60	>15	1-5	Slight corrosion cold, considerable hot. Aggressiveness reduced and perhaps not troublesome due to high natural SiO_2.
2A	—	>Ca but not <25	0-15*	1-10	Considerable corrosion hot, moderate cold. May be slightly scale forming very hot.
2B	18-35	0-25	0-15	1-10	Moderate to slight corrosion hot and cold. May be scale forming hot.
2C	18-35	<Ca	>15	1-8	Corrosion unlikely. May be scale forming hot.
2D	18-35	<Ca	As found	0-1	Corrosion unlikely. May be scale forming hot.
3A	35-75	<1½Ca	0-15	1-10	Moderate corrosion hot, slight cold. Considerable scale formation hot.
3B	35-75	>1½Ca	0-15	1-10	Considerable corrosion hot, slight cold. Considerable scale formation hot.
3C	35-75	<1½Ca	>15	1-10	Considerable scale formation. Slight corrosion hot.
3D	35-75	As found	As found	0-1	Considerable scale formation. Corrosion unlikely.
3E	35-75	>1½Ca but <3Ca	>30	1-10	Corrosion unlikely hot and cold. Excessive scale formation.
4A	>75	<2Ca	0-30	1-10	Excessive scale formation. Corrosion unlikely to slight cold, slight to moderate hot.
4B	>75	>2Ca	0-30	1-10	Excessive scale formation. Galvanic corrosion considerable hot and cold.
4C	>75	<3Ca	>30	1-10	Excessive scale formation. Corrosion unlikely.

*With SiO_2 over 15 ppm, corrosion may be reduced in proportion to SiO_2 content.

Notes: Presence of chlorides in concentrations greater than 100 ppm, with high sulfates, renders a water more corrosive than indicated by category above. Presence of carbon dioxide in concentrations exceeding 5 ppm accelerates corrosion processes where category groups indicate corrosion. In concentrations exceeding 20 ppm, it may cause an indicated noncorrosive water to be corrosive.

Terms: Extreme or excessive — where effects necessitate immediate corrective action.
Considerable — where corrective action is desirable.
Moderate — where corrective action is questionable and depends on economy effected.
Slight — where effect is too slight to warrant corrective action.
Unlikely — where effects are possible but not probable.

velop. Well waters high in calcium bicarbonate and with excessive dissolved carbon dioxide (in excess of 5 ppm) may promote cold water pitting of copper, particularly if the sulfate content is also high, as in category 3B.

Fortunately, most water utilities adjust the water supply to control or eliminate its corrosive effect on the iron piping in a distribution system. When pH is raised to give the water a slightly positive calcium carbonate saturation index, corrosion problems with copper are unlikely.

Where a water supply is not completely amenable to correction by chemical adjustment, such as water high in sulfate or chloride, the use of a corrosion inhibitor should be considered. Beneficial results have been achieved by additions of silicate, polyphosphate, and zinc polyphosphate, all of which, however, are subject to regulation by the health authorities.[8, 9, 10, 11]

Distribution system materials

Many materials have been employed to convey potable water. Among the oldest are copper and lead. The ancient Egyptians used a crudely made copper pipe rolled from a sheet. Some potable waters in ancient Rome were distributed in lead pipe. At an early stage in American history, wooden mains were made from hollowed logs. At the turn of the century, black iron and wrought iron pipes were being used. Galvanized steel was recognized as an improvement a decade or so later. In the last 30 years, copper has dominated the market for potable water systems, though plastic pipe has entered the market in recent years, largely replacing galvanized steel. The greater portion of plastic pipe and fittings are in cold water service, though some grades are now being recommended for hot water distribution.

The selection of a material for a potable water system must include evaluation of the economics, safety,

Table 2 — ASTM specifications for copper plumbing tube and pipe.

	Seamless	Welded
Copper	B42 B88 B302 B306	B447
Copper alloy	B43 B135 B585	B586 B587

availability, and code and labor requirements, as well as the resistance to deterioration and corrosion.[12] A major objective in the selection process is to find a material low in installed cost, high in resistance to corrosion and deterioration, and readily maintained in service, with a proven performance record.

Characteristics of copper

Copper is the dominant material used in potable water systems today. Its combination of corrosion resistance in hot and cold systems, its ease of installation, and its uninflammable, nontoxic properties make it a leading choice.

Coppers are classified according to their chemical composition. The phosphorus content may vary from zero to 0.04 percent. The corrosion resistance of all grades of copper to potable water is essentially similar. Table 2 lists the numerous specifications for copper and copper alloys that can be used in water service. (It will simplify matters when these are consolidated, as has been proposed by the Copper Development Association through the Copper Committee of the American Society for Testing Materials.) Today, water tube is available in both seamless and welded forms and in both copper and copper alloys, and all these products are essentially interchangeable.

There is a straightforward solution to pitting problems: change the water's character

Service experience in general dictates that copper plumbing tube will tend to outlast the building in which it is installed. Over the years that copper systems have been in service, a considerable amount of experience has accumulated: since 1950, about 10 billion pounds of copper tube has gone into U.S. plumbing systems, nearly 4 million miles.[13] Copper has shown excellent corrosion resistance in all areas of the country. As with all materials, copper can be attacked by some highly aggressive waters, and problems arise occasionally with certain well waters, with very soft waters high in carbon dioxide, and in systems where the water flow velocity in excess of about 5 fps causes erosion, especially in forced-circulation hot water systems.

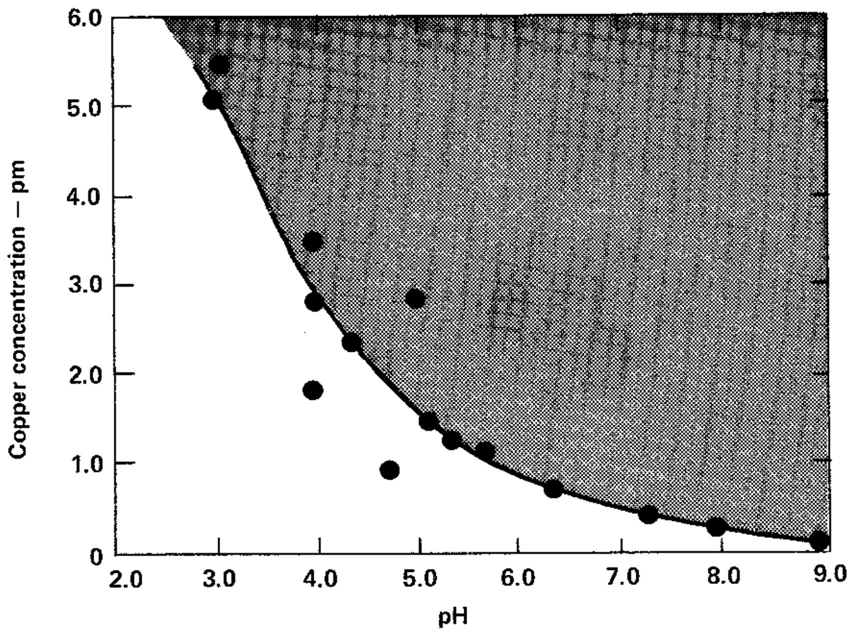
Green water staining

A soft water is one with very little mineral content, less than 25 ppm. Sometimes, such waters also have a relatively high carbon dioxide content. Such waters are found, among other places, in parts of New Jersey and in New England, and they are mainly surface waters derived from quartz formations. Because of the high carbon dioxide content, the water is slightly acidic. These waters cause negligible general attack, and the useful life of the system is not significantly affected.[14] Water velocity also has a role, since a water's chemistry may not be sufficient to cause problems at a lower velocity but may become a problem at a higher velocity. Temperature is also a factor in hot water systems.

Soft waters with 15 ppm or more of carbon dioxide, under stagnant conditions, will pick up traces of copper. If enough copper is picked up to affect taste, the operation of the line for a brief time after a stagnant period will restore the normal taste of the potable water.

When an aggressive soft water containing dissolved copper is permitted to leak from a dripping faucet onto a porcelain fixture, unsightly green stains can form. While these are readily removed by a mild scouring cleanser, their presence is a source of annoyance. The green staining problem is readily eliminated by proper water treatment.

Successful treatments have included aeration, which reduces the carbon dioxide responsible for the low pH. Elevation of the pH to neutralize the carbon dioxide is nor-



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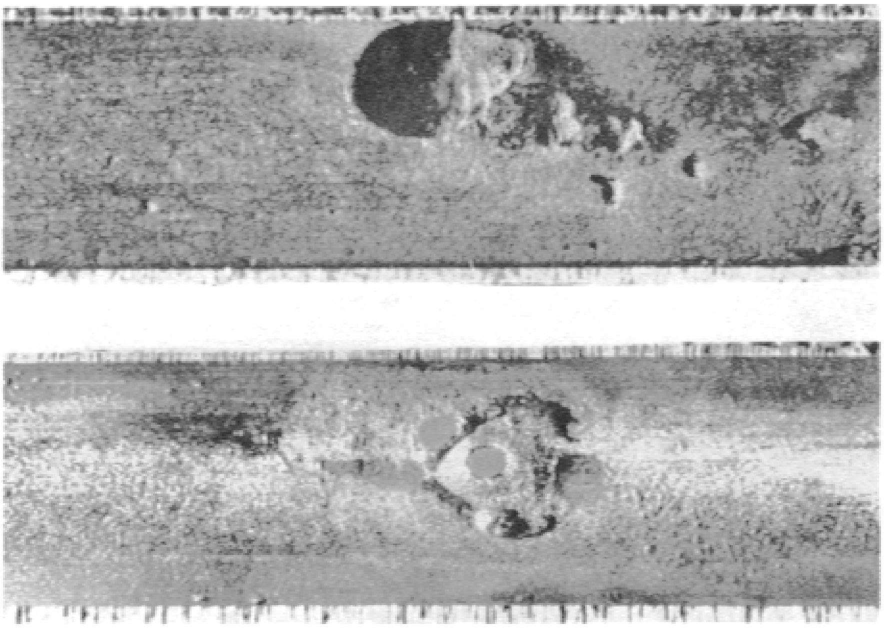


2 Typical interior surface of copper water tube that has failed due to pitting corrosion. Upper half shows tubercle or mount whose size reflects size of underlying pit. Bottom half reveals tube surface after chemical cleaning to remove tubercle and scale.

number of new pitting failures occurred, reducing almost to zero.

Von Franque has studied the water analyses associated with cold and hot water pitting.[21] German experience differs somewhat from that in this country, in that about one-third of the pitting, in those rare instances when it does occur in Germany, is in hot water systems. Relatively soft waters, below pH of 6.5, with 10 to 50 ppm of carbon dioxide, and low in chloride, sulfate, and nitrate ions, were found to cause this type of pitting. Cold-water pitting in the U.S. was found on copper exposed to moderately hard bicarbonate waters with a pH ranging from 7.0 to 8.0.

Erosion

Some contractors on occasion install water tube that is undersized for the demands of the system. This leads to an excessively high velocity and tends to result in a noisy system with water hammer and turbulence. Under these conditions, copper may eventually fail by erosion corrosion (impingement). Adhering to the recommended practices in the CDA's *Copper Tube Handbook*[22] and *Tube Size Calculator*[23] will prevent this problem.

Erosion attack occurs at locations where turbulence develops in the system. This turbulence interferes with normal protective film formation.[8] When a high velocity stream suddenly changes direction or cross section, as at tube ends in a joint, impingement can be observed directly downstream. A burr or an improperly prepared tube end can cause local turbulence that results in impingement attack. Fig. 3 shows typical erosion corrosion. Restricting the velocity to a maximum of 4 to 5 fps will usually prevent this attack.[24]

pH adjustment depends on the method used to soften the water

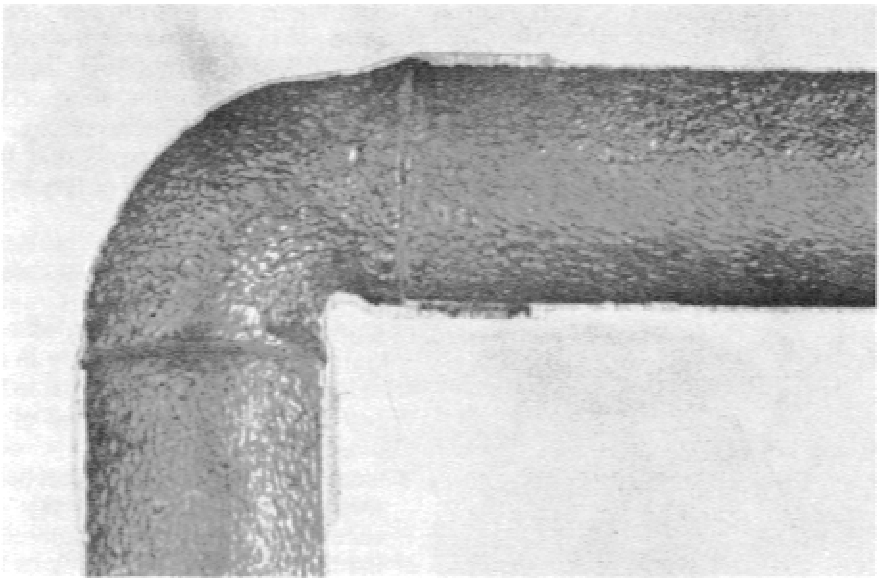
Impingement attack is readily identified from the characteristic appearance of the damaged surface. A typical surface has deep horseshoe pits with the open ends facing downstream. The attack is typically most severe just downstream of a joint or obstruction in the system. In some cases, the attack progresses downstream, because as the pitted areas develop, they in turn promote increased turbulence. Sometimes the attack is so severe that the entire surface is rough, and the characteristic horseshoe pits are not clearly evident. In cases where the velocity conditions are less severe downstream from the zone of severe turbulence, laminar or streamline flow may return, so that this section of the tube will not show localized attack.

Hot water recirculation systems sometimes fail in service because of erosion. Out of a total of 36 failures, Mattson has classified ten as erosion. The excessive velocity in the recirculation systems results, in the typical case, from the use of an oversized pump. Since the cold water part of the system is not being recirculated, it only rarely sees the excessive velocities encountered in the hot water part. This may be the reason for the general impression that erosion failures are more prevalent in hot water systems.[10, 25] Softened waters also generally exhibit greater sensitivity to erosion than hard waters.

There are several choices for corrective action to eliminate the problem of erosion. All are based on reducing the velocity or eliminating the excessive turbulence at connections and fittings.[2] Options include a bypass around the pump to reduce its effective output, a smaller capacity pump, a throttling valve downstream of the pump to restrict flow, and a larger tube in that part of the system affected. In addition to reducing flow, it is good practice to control domestic hot water to a maximum of 140 F. Lane has suggested a maximum of 3 fps at 180 F.[9] In a high velocity situation, a significant reduction in corrosion can be obtained by substituting Copper Alloy No. C70600 (90:10 Copper-Nickel) for the copper.[11]

Elevated temperature

Increasing the temperature of a potable water will affect its corrosive effect on copper and other metals. In a nonscaling water, several factors contribute to the tendency for increased attack. In spite of its decreased solubility with temperature, oxygen will be kept in solution by the higher pressure. Carbon dioxide, which has a much greater solubility, also tends to remain in solution. As the temperature increases, the diffusion rate of oxygen



3 Typical impingement corrosion characterized by eroded interior surface. Such erosion is caused by excessive water velocities compounded by sudden changes in direction of flow. Unreamed tube ends leave burrs that promote increased turbulence.

to cathodic areas is raised. This is accompanied by a reduction in viscosity, allowing greater penetration of deposits by the water, and by a concurrent increase in conductivity, permitting higher corrosion currents between cathodes and anodes on the surface.

More typically, in potable waters that are scale forming, the increase in temperature tends to promote a higher degree of protective scale formation.

Summary

To provide dependable potable water systems for commercial, industrial, or residential buildings, the designer must consider a number of variables. A major factor is the quality of the potable water delivered to the site. It is essential to establish that the water has had adequate chemical treatment to eliminate its corrosiveness. Equally important are the materials of construction, which should be both corrosion resistant in water service and have suitable properties to meet design, installation, and building code requirements. In addition, the overall economy of the installation, the amortization of the initial cost, and the annual maintenance expense require careful evaluation. Problems may arise if the installation does not follow good design practices. Undersized components can lead to excessive turbulence, resulting in a noisy system that is likely to develop erosion corrosion.

In the actual installation, it is essential to provide proper supervision to assure good workmanship. Key points in the system, such as drain valves and main connections, should be accessible to allow for regular inspection and preventive maintenance. Ω

References

1) J.R. Myers and M.F. Obrecht, "Potable Water Systems: Recognition of the Cause Vital in Minimizing Corrosion," *Materials Protection and Performance*, April 1972, pp. 41-46.

2) Myers and Obrecht, "Potable Water Systems in Buildings: Deposit and Corrosion Problems," *Heating/Piping/Air Conditioning*, May 1973, pp. 77-83.

3) Environmental Protection Agency, *National Interim Primary Drinking Water Standards*, June 1975.

4) Environmental Protection Agency, "Proposed Regulations for the National Secondary Drinking Water Regulations," *Federal Register* 42, No. 62 (March 31, 1977).

5) H. Cruse and F.J. Bauman, "What is a Corrosive Water?" Paper presented at the National Association of Corrosion Engineers Western States Corrosion Seminar, May 8, 1975.

6) W.F. Langelier, "The Analytical Control of Anti-Corrosion Water Treatment," *Journal of the American Water Works Association* 28 (1936), p. 1500.

7) E. Nordell, *Water Treatment for Industrial and Other Uses*, 2d ed. (New York: Reinhold, 1961), pp. 287-288.

8) G.C. Hatch, "Unusual Cases of Copper Corrosion," *Jour. AWWA* 53 (November 1961), p. 1417.

9) R.W. Lane and T.E. Larson, "Water Treatment Techniques and Corrosion Monitoring," NACE 1971 Annual Meeting Paper No. 80.

10) S. Sussman, "The Many Faces of Corrosion in Potable Water Systems in Buildings," NACE 1971 Annual Meeting Paper No. 88.

11) R.W. Lane et al., "Corrosion in Domestic Hot Water Systems," NACE 1973 Annual Meeting Paper No. 134.

12) F.M. Reinhard, *Design for Corrosion Control of Potable Water Distribution Systems*, Naval Civil Engineering Laboratory Publication No. AD/A 006 806 (Port Heuneme, Calif., 1975).

13) W.S. Lyman and A. Cohen, "Service Experience with Copper Plumbing Tube," *Materials Protection and Performance*, February 1972, pp. 48-52.

14) H.S. Campbell, *Materials Used for Domestic Water Systems*, British Non-Ferrous Metals Technology Center Misc. Publication No. 552 (London: May 1965).

15) K.E. Shull et al., "Cold Water Corrosion of Copper Tubing," *Jour. AWWA* 52 (August 1960), p. 1033.

16) E. Mattson and A.M. Fredrickson, "Pitting Corrosion in Copper Tubes: Causes of Corrosion and Counter Measures," *British Corrosion Journal* 3, No. 5 (September 1968), pp. 246-257.

17) H.S. Campbell, "A Natural Inhibitor of Pitting Corrosion of Copper in Tap Water," *Journal of Applied Chemistry* 4 (December 1954), pp. 633-647.

18) B.E. Powell and L.V. Lucey, *Physical Studies of Water-Formed Corrosion Products on Copper*, Final Report to the International Copper Research Association (London: British Non-Ferrous Metals Technology Center, March 1966).

19) C.A. Rambow and R.S. Holmgren, "Technical and Legal Aspects of Copper Tube Corrosion," *Jour. AWWA* 58 (March 1966).

20) C.A. Rambow, "Corrosion of Copper in Domestic Water Service," Paper presented at the 1968 NACE Corrosion Seminar, San Dimas, Calif.

21) O. von Franque, "Results of Examinations of Water-Formed Deposits on Copper Tubes," *Werkstoffe und Korrosion* 26, No. 4 (April 1975), pp. 255-257. [In German.]

22) Copper Development Association, *Copper Tube Handbook* (New York: CDA, 1976).

23) Copper Development Association, *Tube Size Calculator* (New York: CDA, 1976).

24) R.W. Lane and C.H. Neff, "Materials for Piping in Chemically Treated Water Systems," *Materials Protection and Performance*, February 1969, pp. 27-30.

25) H.L. Shuldener, "Effect of Operating Conditions on Corrosion in Hot Water Piping in Buildings," *Corrosion*, March 1954, pp. 85-90.

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