

STAINLESS STEEL PIPING

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Stainless-steel piping

*Stainless-steel piping
can be cost-effective
for potable water use.*

Arthur H. Tuthill

Stainless steel has been used extensively for potable water since the mid-1960s in desalination plants for handling product water; in potable water treatment plants for gravity filtration and piping; in Tokyo, Japan, for small-diameter household connection piping; and in New York City for large-diameter risers and other piping. The most familiar use of stainless steel is for drinking fountains. Background information and general data are given on types 304 (UNS S30400) and 316 (S31600) stainless steel, and their current use in potable water applications is reported. The behavior of stainless steel used with raw, chlorinated, and finished water as well as of piping buried in soil is reviewed. Postfabrication cleanup and maintenance of exterior appearance and cleanliness are also reviewed. Guidelines for procurement and successful use are suggested.

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tainless steel owes its stainless characteristics to an adherent, durable chromium oxide layer only a few angstroms thick. This chromium oxide layer forms almost instantly in air or water and is self-replenishing when scratched or damaged. Stainless steel is easy to weld, although the technique is somewhat different than that for welding carbon steel. Types 316 and 316L (S31603) and 304 and 304L (S30403) as well as their cast counterparts—CF8M (J93000), CF3M (J92800), CF8 (J92600), CF3 (J92700)—are the wrought and cast grades most widely used. Table 1 shows the composition and mechanical properties of these grades.

One extensive use of stainless-steel piping for potable water has been for the product water from desalination plants in the United States, the Caribbean, and the Middle East. Types 304L and 316L are used for collection troughs in the plant and for piping in the blending plant where the high-purity product water is blended with locally available groundwaters.¹

Differences in composition affect performance

There are two important differences in stain-

TABLE 1 Composition in percent of wrought and cast stainless steels

Grade	UNS Number	Carbon Maximum	Chromium	Nickel	Molybdenum
Wrought					
304	S30400	0.08	18.0–20.0	8.0–11.0	
304L	S30403	0.035	18.0–20.0	8.0–13.00	
316	S31600	0.08	16.0–18.0	11.0–14.00	2.0–3.0
316L	S31603	0.035	16.0–18.0	11.0–15.00	2.0–3.0
Cast					
CF3	J92500	0.03	17.0–21.0	8.0–12.0	
CF8	J92600	0.08	18.0–21.0	8.0–11.0	
CF3M	J92800	0.03	17.0–21.0	9.0–13.0	2.0–3.0
CF8M	J92900	0.08	18.0–21.0	9.0–12.0	2.0–3.0

TABLE 2 Mechanical properties of wrought and cast stainless steels

Grade	UNS Number	Tensile Strength ksi min	Yield Strength ksi min	Elongation in 2-in. Pipe percent
304	S30400	75	30	35
304L	S30403	70	25	35
316	S31600	75	30	35
316L	S31603	70	25	35
CF3	J92500	70	30	35
CF8	J92600	70	30	35
CF3M	J92800	70	30	30
CF8M	J92900	70	30	30

less-steel composition. Some grades contain 2–3 percent molybdenum; some do not. Types 316/316L and CF8M/ CF3M contain 2–3 percent molybdenum, which greatly improves their resistance to localized corrosion. When corrosion of stainless steel does occur, it is quite localized, i.e., one or more small pits. In natural waters, stainless steel does not suffer general metal loss as does carbon steel. The thin but tough and durable chromium oxide film that protects stainless steel from corrosion occasionally contains defects. It is at such defects that stainless steel may corrode when environmental conditions become aggressive enough to take advantage of weaknesses in the film. Except for the rusting of iron particles embedded in the surface during fabrication and handling, corrosion is rare in atmospheric exposures but does occasionally occur in water or soil exposure under unusual conditions. Molybdenum greatly enhances resistance to localized corrosion in those environments where localized corrosion of types 304/304L occurs. Molybdenum grades are available for such a small premium over the standard grades that they are often used to protect against some unknown future change in the environment increasing the likelihood of corrosion.

The second difference in stainless-steel composition that users should be aware of is the carbon con-

tent. Types 304L, 316L, CF3, and CF3M (Table 1) contain 0.03 percent maximum carbon, whereas types 304, 316, CF8, and CF8M contain 0.08 percent maximum carbon. The wrought low-carbon grades are used for welded fabrication, such as for piping. The cast low-carbon grades can be specified for the casing of pumps when repair or rebuilding at some future time is anticipated. Using the low-carbon grades ensures that the heat of welding will not “sensitize” the heat-affected zone (HAZ) of the weld to intergranular corrosion (IGC). Sensitization is a term used to describe the reduction in corrosion resistance that occurs in older higher-carbon (0.08 percent carbon) stainless steels in some environments because of the precipitation of carbides during welding in the HAZs adjacent to welds. Sensitization is unlikely to lead to IGC

in most atmospheric and freshwater exposures, but it can lead to severe attack during chemical cleaning operations. It has become standard practice to specify low-carbon grades to avoid sensitization for all welded fabrication, including piping.

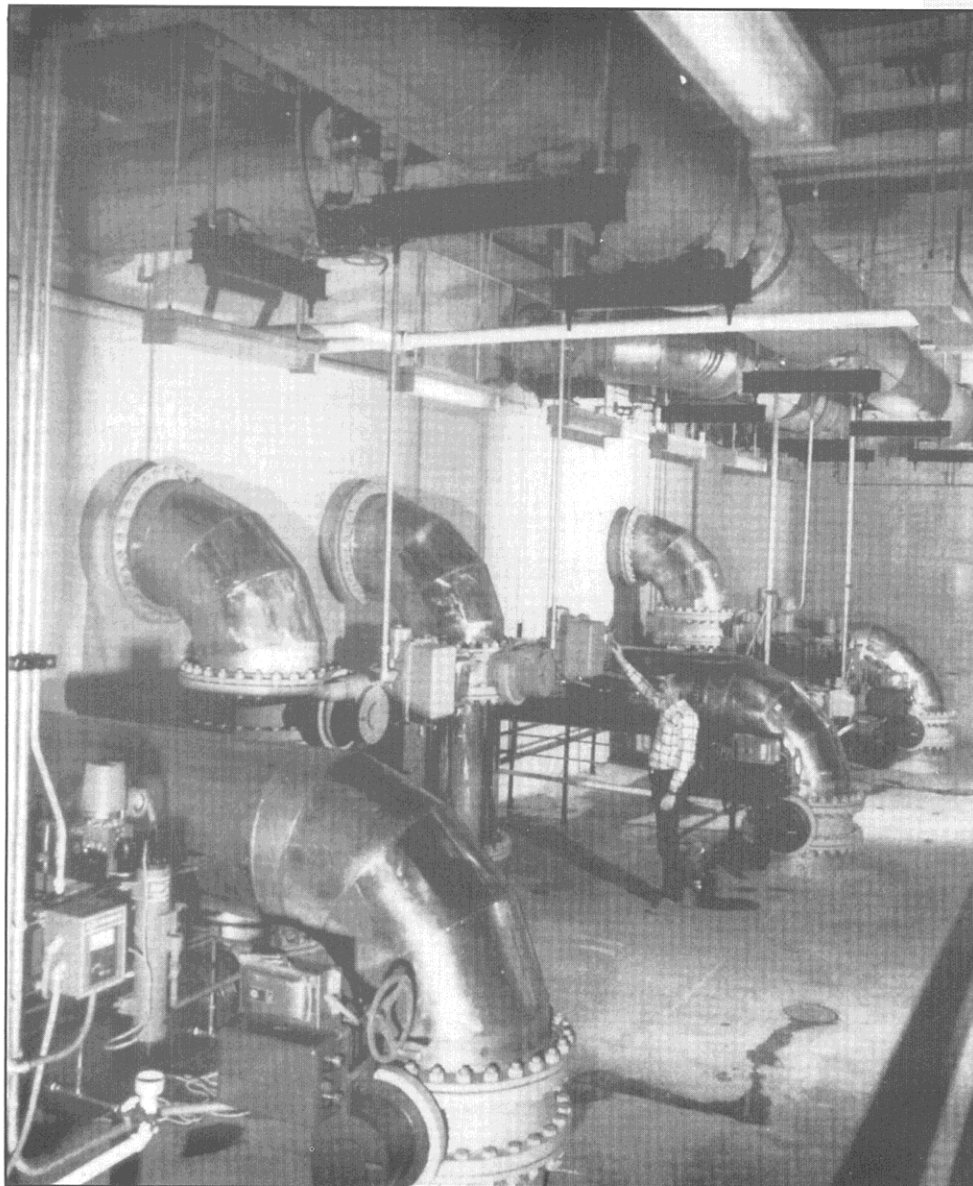
Higher-carbon grades have a slightly higher strength (Table 2). Pump and valve manufacturers

Stainless steel owes its stainless characteristics to an adherent, durable chromium oxide layer only a few angstroms thick.

frequently use the higher-carbon grades for pump shafts and valve stems when the slightly higher strength is an advantage and welding is not a factor.

Stainless steel used in distribution systems in Tokyo and New York

The Tokyo Water Bureau, after a decade of testing, has pioneered the use of stainless steel for the connecting piping (connector) from the submain in the street to the meter at the dwelling, primarily to reduce leakage rates (Figure 1). By 1997 all dwellings in the city of Tokyo are scheduled to be served by stainless-steel pipe connections. Tokyo has also initiated the use



Type 304-L stainless-steel piping was used in the Taunton, Mass., treatment plant at a savings of \$50,000 over the cost of ductile iron.

date with no replacement or significant repairs required.

Stainless steel achieves cost savings

Stainless-steel piping has been used instead of ductile iron in more than 30 potable water treatment plants, largely because of the cost savings achieved.⁵ Savings attributed to the use of stainless steel over ductile iron were estimated at \$50,000 for the Taunton, Mass., potable water treatment plant.⁶

Corrosion is less of a problem

The thin chromium oxide film to which stainless steel owes its corrosion resistance forms almost instantly in air, water, or other media containing oxygen. Pickling removes the film and any defects therein, allowing it to reform as stainless steel is removed from the pickling bath.

Dissolved oxygen is the principal constituent of water that affects the corrosion behavior of stainless steel, and the effect is highly beneficial. The agitation, turbulence, and high velocity of water that are so troublesome to carbon steel, cast iron, and ductile iron are all highly beneficial to the durability and performance of stainless steel. There is no known limit to the durability of clean stainless steel in clean, aerated, low-chloride waters.

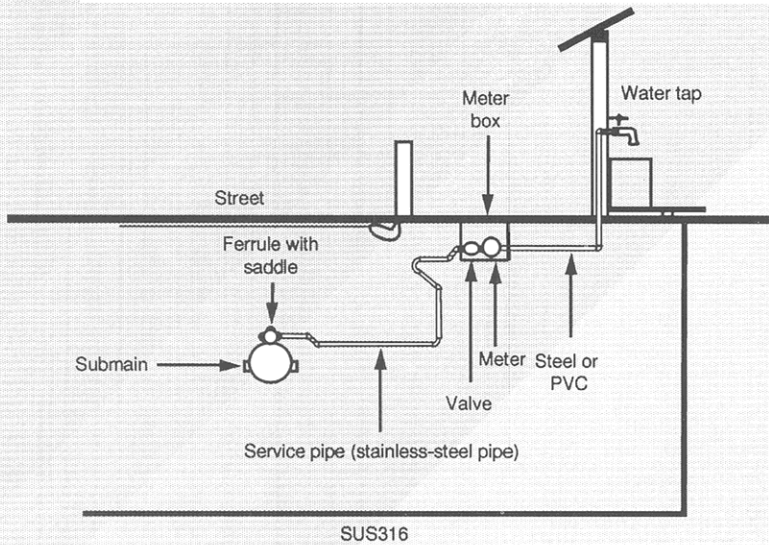
In crevice corrosion, the operative factors are cleanliness and chloride concentration. Sediment-laden water and crevices (such as those that originate from incomplete fusion of circumferential welds) under some conditions can lead to a localized pitting-type attack if chlorides are present in sufficient concentrations. Below 200 mg/L chlorides, crevice corrosion of type 304 stainless steel is rare in natural waters, and crevice corrosion of type 316 stainless steel is equally rare below 1,000 mg/L chlorides.⁷

of stainless steel piping on road bridges to replace troublesome underriver lines.²

On the basis of 15-year evaluations of candidate materials, New York City initiated substantial use of stainless steel (304L) in municipal water distribution systems for the large-diameter risers in water tunnel 3, stage 1, which went into service in 1993. Even more extensive use of stainless steel piping is under way in stage 2, which is under construction. Stainless-steel piping is being used selectively for sections that are difficult to replace and in which maximum durability is desired.³

Stainless steel was introduced for use in the large central-control gravity filters in water treatment plants in 1965 and has since been used in more than 75 plants.⁴ Figure 2 shows a central control and filter section of a typical treatment plant. The manufacturer reports good performance of all the more than 75 stainless-steel central control columns installed to

FIGURE 1 Diagram of a buried service connection



iron. At 3–5 mg/L residual chlorine, the corrosion rate of carbon steel is as much as 7.6 times the rate in unchlorinated raw water.

For stainless steels, metal loss, should any measurable loss occur, is localized. Therefore, it is pit depth, not corrosion rate, that must be compared. Sensitized specimens are exposed to determine whether the HAZs of welds have lower corrosion resistance than the base metal. The data in Table 3 indicate that it is essential to use the low-carbon grades of stainless steel—types 304L and 316L—to avoid corrosion in the HAZs of welds at the 1–2-mg/L residual chlorine concentrations normally encountered in potable water.

Nevertheless, crevice corrosion can and sometimes does occur in waters of lower chloride content, if sediment, other deposits, or manmade crevices are able to occlude and concentrate chlorides from the water.

Although no failures of stainless steel, with possibly one exception, from overchlorination have been reported in domestic water treatment plants, the potential exists and must be recognized. Several failures from gross overchlorination have occurred in stainless-steel product-water lines in desalination plants in the Middle East.¹

Table 3 gives data on the effect of chlorine on carbon steel, cast iron, and stainless steel. These previously unpublished data were developed from International Nickel Company test rack exposures in three Lake Ontario locations and one inland freshwater location. In each case a baseline exposure in unchlorinated water was made for comparison.

Chlorine in the normal range of 1–2 mg/L doubles the general corrosion rates of carbon steel and cast

At 3–5-mg/L residual chlorine, encountered in some water treatment plants, these data indicate base-plate pitting has begun (<1 mil) for type 304/304L stainless steel, and crevice corrosion is well under way (4–14 mil). Type 316/316L base plate is resistant up to 5-mg/L residual chlorine.

These data and the author's experience indicate that to better resist the somewhat higher concentrations of residual chlorine encountered in some sections of some water treatment plants, type 316L would be a more conservative choice than type 304L. These data also suggest that some care should be taken at the point of injection to ensure good mixing and avoid high residuals.

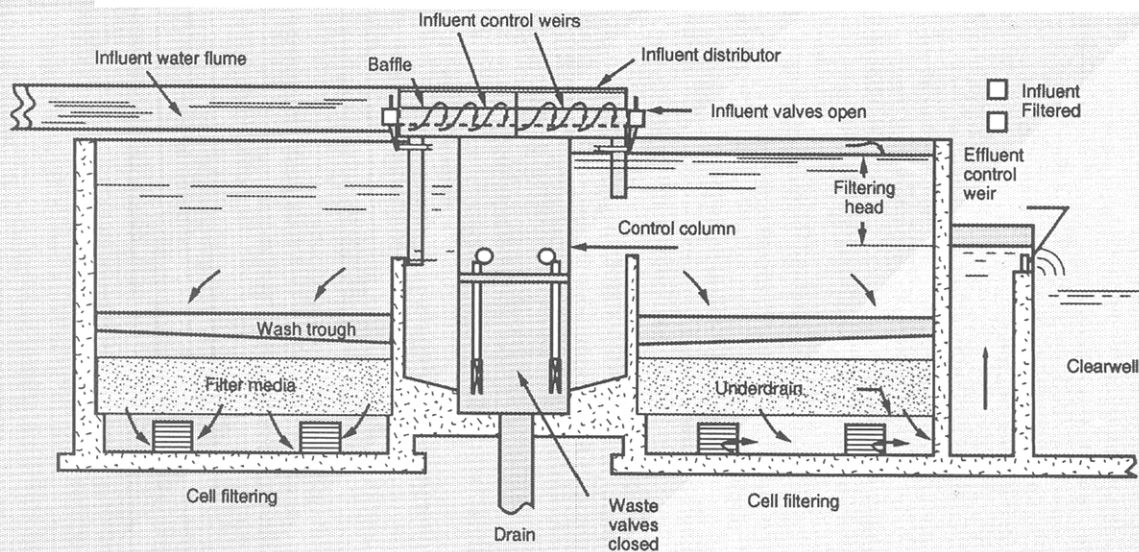
Two plants⁸ have reported multiple pitting-type corrosion in stainless-steel piping, which was attributed to moist chlorine collecting in the pipe. In one instance a backwash line not in use was left open in an area where chlorine vapors could enter and collect in the line. In the second instance, flow was so low that the pipe was only half full, allowing chlorine

TABLE 3 Behavior of type 1010 carbon steel, cast iron, and types 304 and 316 stainless steel in four chlorinated freshwaters with different residual chlorine concentrations

Chlorine Residual mg/L	Corrosion Rates		Maximum Depth Attack—Base Plate mls				Maximum Depth Attack—Crevice mls				
	Carbon Steel mpy	Cast Iron mpy	Type 304	Type 316	Sensitized		Type 304	Type 316	Sensitized		
					Type 304	Type 316			Type 304	Type 316	
0	1.4	1.7	0	0	0	0	0	0	0	<1	0
0.8–1.0	2.5	3.0	0	0	0	0	0	0	0	<1	<1
2	3.4	3.4	0	0	30	0	0	0	0	35	1
3–5	10.7	NT*	<1	0	NT	NT	4–14	1–5	NT	NT	NT

*NT—not tested

FIGURE 2 Type 304L piping as used in the Taunton, Mass., water treatment plant



dissolved in the water to collect in the vapor space in the upper half of the pipe. Closed atmospheres containing moist chlorine can be quite aggressive to both type 304L and 316L stainless-steel piping.

Although standard chlorination practice for potable water provides excellent protection against bacterial strains that cause microbiologically induced corrosion, there are situations in which it appears to have occurred.

Piping systems such as those in water treatment plants are normally hydro-tested with locally available water. If the water used for hydro-testing is not promptly and completely drained but is allowed to remain standing in the piping, it can become an ideal environment for the growth and multiplication of bacteria. Two treatment plants⁸ have experienced microbiologically influenced corrosion of the welds in 304L stainless steel piping from hydro-test water left standing in the piping.

In some finished-water and distribution systems, there are dead ends and sections where water may stand idle for a month or more. In one finished-water system, microbiologically induced corrosion was reported in a section of stainless-steel piping designed to retain water for extended periods. It is believed that the oxygen and residual chlorine in the stagnant section were consumed by natural processes, e.g., biological or chemical oxygen demand, allowing bacteria to revive and microbiologically induced corrosion to develop.

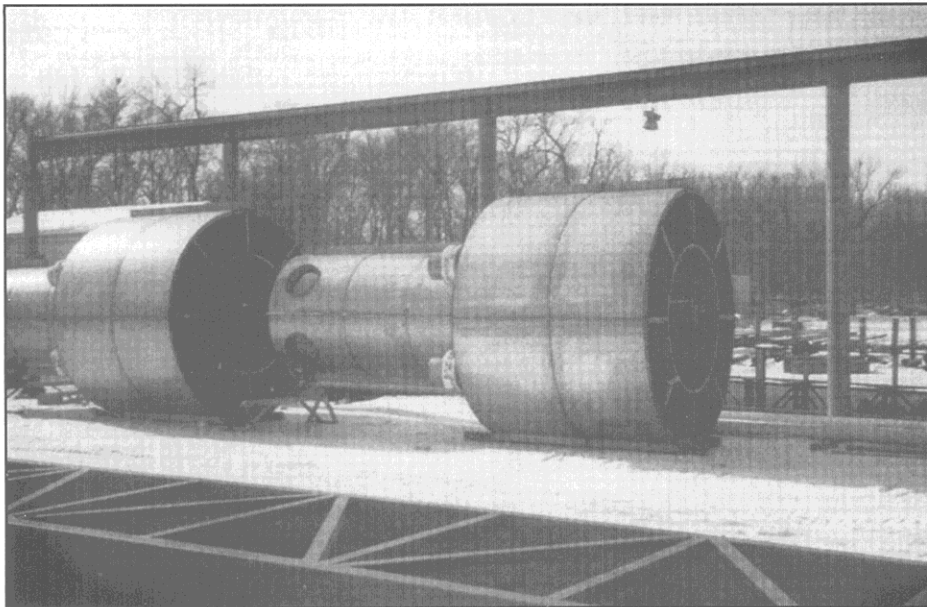
There are situations in which microbiologically induced corrosion occurred in certain freshwater cooling systems that had appreciable concentrations

of manganese. Tverberg et al⁹ have documented cases of microbiologically induced corrosion in piping and heat exchangers resulting from chlorine additions to waters so high in manganese that the systems became coated with a black manganese-containing deposit. The deposit itself is normally benign, unless oxidizing bacteria capable of oxidizing the manganese ion to manganic are present and chlorine is added. When chlorine is added to manganese-bearing waters with oxidizing bacteria present, such as *Gallionella*, a self-sustaining corrosion reaction is initiated, resulting in

Chlorine in the normal range of 1-2 mg/L doubles the general corrosion rates of carbon steel and cast iron.

severe pitting of stainless steel.⁹ Although corrosion of this type has not been reported in potable water plants, it is possible and should be considered when raw waters contain appreciable manganese.

The author has investigated a case in which manganese deposits, in the absence of oxidizing bacteria, led to crevice corrosion in the heat-tinted area of circumferential welds. The pitting corrosion occurred in the heat-tinted area, but not in the base plate or weld metal, which were also covered by the black manganese deposit. The black manganese deposit formed by chlorine injection is rather adherent and is apparently a good crevice former.⁸ In manganese-bearing waters with or without oxidizing bacteria, injecting chlorine at the plant outlet rather than at the plant inlet would have avoided the corrosion that occurred.



Good performance has been reported for all of the more than 75 stainless-steel central-control columns installed in water treatment plants.

Extensive testing over a 10-year period in Tokyo soils convinced Japanese utility personnel that 316L piping could be buried without external protection. Since extensive use began 10 years ago, no failures have been reported. Other tests and experience indicate that stainless steels perform well in well-drained soils with clean backfill. In poorly drained soils, however, such as under river crossings and in poor backfill, underdeposit and microbiologically induced corrosion may occur. It is best to follow practices designed for carbon steel and wrap or cathodically protect buried stainless-steel piping.

When two dissimilar metals are coupled together in the presence of an electrolyte, the corrosion rate of one is increased and that of the other is decreased, as compared with their respective uncoupled corrosion rates. Scholes and Rowland¹⁰ give the acceleration factor for equal areas of carbon steel coupled to 316 in seawater as 3 (i.e., the uncoupled corrosion rate of carbon steel would be increased three times). Scholes and Rowland give the uncoupled corrosion rate for steel as about 2 mpy in unchlorinated water and 3.5 mpy in water with 2-mg/L residual chlorine. When coupled, the rates would be 6 mg/L and 10.5 mg/L, respectively. The factor for freshwater is believed to be the same, although it has not been studied as has seawater. In freshwater the increased corrosion of carbon steel tends to occur closer to the junction of the two metals than it does in seawater. In Japan stainless-steel pipe connectors were insulated from the ductile iron submain in the street and from the meter at the dwelling. The stainless-steel river crossings were also insulated at either end to avoid galvanic

effects. Cast-iron and ductile-iron valves have been used in stainless-steel piping in water treatment plants, with no adverse effects reported. Galvanic corrosion in piping systems is uncommon and unlikely to be a significant problem.

External rust spots from iron embedded in stainless-steel pipe during fabrication (as a result of contact with steel rolls and layout tables), handling (wire slings), and rusting in the HAZs of welds (carbon steel wire brushes) are common complaints. Inclusion of a requirement for a final water test in procurement documents would help eliminate the embedded iron. Few pipe fabricators can argue for charging extra for a simple water test to show they have not contaminated the surface with embedded iron. The test is simple. Wet down the surface, and inspect for rust spots the next day. It is also desirable to require pipe ends to be securely plugged after final cleaning and to require contractors to leave the plugs in place until the pipe is installed, even during on-site storage.

AWWA C220 section 3.8 requires pipe to be free of scale, (heat tint in the HAZ of welds is scale) and contaminating iron particles. This is a critical requirement and should be enforced without exception.

Tests and experience indicate that stainless steels perform well in well-drained soils with clean backfill.

AWWA C220 section 3.2.1 sets standards for circumferential butt welds. This section should be rigorously enforced because many pipe fabricators feel they are forced to deliver pipe with "commercial quality" (rather than "full penetration" welds as the new AWWA specification requires) in order to remain competitive. American Society for Testing and Materials specifications do not cover circumferential butt welds made in pipe fabricating shops, which means each user must develop and enforce in-house specifications for or suffer the failures that

so frequently occur in commercial quality circumferential butt welds. Most codes require full penetration welds, not commercial quality welds with incomplete penetration.

Heat tint has long been known to increase leaching and degradation of high-purity water. Research work on microbiologically induced corrosion has also clearly shown that the removal of heat tint, by pickling or electropolishing, enhances resistance to both crevice corrosion and microbiologically induced corrosion.¹¹ Users should consider prevention or removal of heat tint from circumferential welds when specifications for circumferential welds are developed. The full inherent corrosion resistance of stainless steel is restored by preventing or removing heat tint.

Conclusions

The use of stainless steel in selected portions of potable water distribution and treatment plants has been growing slowly since it was first introduced in the mid-1960s. The few failures that have occurred could probably have been avoided if the users had had a better knowledge of the corrosion behavior of stainless steel, a shortcoming this report is designed to overcome.

The clean, chlorinated water environment characteristic of potable water distribution systems is almost ideal for stainless steel. Stainless steel is a strong candidate for those portions of the system that are difficult to fabricate or replace and where the greatest durability is required. Stainless steel is unlikely to be a candidate for wholesale replacement of cement-lined carbon steel, ductile iron, or cast iron.

Consideration should be given to type 316L instead of type 304L for potable water treatment plants, which have more varied environments than distribution systems, especially with regard to residual chlorine and to chlorides.

Successful use of stainless-steel piping in raw water and potable water is dependent on careful attention to the following factors:

- procurement specifications and inspection that ensure full penetration welds;
- prompt and complete drainage of water used for hydro-testing;
- location of chlorine injection at the outlet rather than the inlet of water treatment plants handling manganese-bearing waters;
- injection of chlorine in a manner that ensures complete mixing in order to prevent high concentrations of chlorine from reaching the sidewalls of the pipe;
- designing distribution piping systems so there is minimal opportunity for moist chlorine vapors to come in contact with the inside or outside of stainless-steel pipe;
- limiting the use of stainless steel in raw waters to lines that can be flushed with water periodically before sediment can collect and lead to undersediment corrosion;

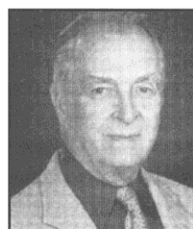
- limiting the use of stainless steel in stagnant sections and lines in which flow is so low that the pipe is not flowing full;
- preventing or removing heat tint from circumferential welds when maximum resistance to microbiologically induced corrosion, crevice corrosion, or both is needed.

Acknowledgment

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