

Stainless steel for potable water treatment plants (PWTP)

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Grade Selection

Type 304L, the principal piping material used in PWTPs, has adequate corrosion resistance for most conditions, provided the surface is maintained clean and free of defects.

Type 316L is a more conservative choice and has improved corrosion resistance in the presence of sediment and other deposits when higher levels of residual chlorine exist.

Procurement

- Procure pipe to ASTM A778 or A312 to ensure proper quality for PWTPs.
- Specify "L" grades Type 304L or 316L. Dual certification grades are acceptable.

Piping Design

- Slope horizontal lines so they drain completely.
- Avoid dead legs and sections that cannot be drained during shutdown or stand-by.
- Provide inspection and wash-out ports on horizontal runs to allow flushing of sediment.
- Use Ni-Cr-Mo alloys, 6% Mo stainless steels, or cement-lined steel or ductile cast iron pipe in the section immediately downstream of chlorine or potassium permanganate injection.
- Design for the maximum flow rate consistent with pressure drop to reduce sediment deposition.

- Take advantage of the high C valve (low friction) for stainless steel.

Pipe Fabrication

- Require a welding procedure specification from the fabricator and require that only qualified welders be used.
- Specify required weld quality standards.
- Minimize or prohibit field welding of circumferential butt welds.
- In raw water sections, prevent or remove heat tint oxide on welds as described in the text.

Start-Up and Operation

- Drain promptly and completely after hydrostatic testing or during shutdowns. Circulate at least weekly if the system must be left full.
- Dissolve calcium hypochlorite granules before introducing them into stainless steel piping for disinfection.

General

- When in doubt, design, fabricate, install, and operate in a manner which will keep stainless steel piping clean and in its most corrosion-resistant condition.

Introduction

Types 304L and 316L welded stainless steel piping has been successfully used in over 100 PWTPs and related potable water applications in North America. Table I shows the common name, the UNS number, the British, German, Swedish, and EURONORM designations, with nominal compositions for the wrought alloys. The principal reason to use stainless steels is its outstanding resistance to contaminate potable water with metal ions. Stainless steel has been used since 1965 for the large, central-control, gravity filter in water treatment plants with good performance in over 75 installations.⁽¹⁾ *Figure 1* illustrates two typical central-control units. Types 304 and 316 have been used with equal success in the fabrication of non welded components such as pump shafts and valve stems.

Stainless steels have given excellent performance in transporting potable water from Middle East desalination plants, potable water distribution systems in Tokyo, Korea, and New York City, and in over 100 North American domestic potable water treatment plants. *Figure 2* illustrates a New York City pumping station gallery of laterals in the distribution hub serving potable water for Manhattan. The excellent performance offered by stainless steel depends on factors different from those that influence the performance of ductile cast iron (DCI), galvanized or coated steel, or copper alloys in potable waters. The few failures that have occurred are due to unfamiliarity with factors that affect the performance of stainless steels, as these factors are quite different from those of the older, more familiar materials. This summary and guide is intended to assist design engineers and operators in avoiding the problems that have occurred in PWTPs by ensuring the conditions required to support the optimum performance of stainless steels in these applications are met.

Recommended Applications for Various Stainless Steel Types

Types 304L or 316L are the standard grades of stainless steel used in potable water applications. Type 316L with

2-3% molybdenum is more resistant to pitting and crevice corrosion and is preferred over Type 304L for the more severe services. The low carbon "L" grades have a maximum of 0.03% carbon and should be used for welded fabrication rather than the regular grades which may contain up to 0.08% maximum carbon.

Where mechanical strength is important for design purposes, the slightly lower tensile and yield strengths of the "L" grades should be recognized. It is increasingly



Figure 1 Stainless steel central-control columns for a PWTP.



Figure 2 A gallery of laterals in the New York City pumping station. The laterals are made from cast stainless steel with 48 in. diameter wrought butterfly valves.

Common Name	UNS No.	EURONORM EN 10088	British BS*	German DIN*	Swedish SS*	Nominal Composition (%)				
						C	Cr	Ni	Mo	Fe
304	S30400	1.4301	304531	1.4301	2333	0.08	18.0	10.0	-	Bal
304L	S30403	1.4306	304511	1.4306	2352	0.03	18.0	10.0	-	Bal
316	S31600	1.4401	316531	1.4401	2347	0.08	17.0	12.0	2.0-3.0	Bal
316L	S31603	1.4404	316511	1.4404	2348	0.03	17.0	12.0	2.0-3.0	Bal

*Have been superseded by EURONORM

Physical Characteristics, Tests, and Processes	Specifications		
	A312 Welded & Seamless	A778 Welded	AWWA C220 (1) Welded & Seamless
Pipe Form	A312 Welded & Seamless	A778 Welded	AWWA C220 (1) Welded & Seamless
Size	1/4 - 30"	3-48"	4" or Larger
Wall Thickness	Sch. 5S - 80	0.062 - 0.5"	(1)
Solution Anneal	Required	Not Required	(1)
Mechanical Test	Tension & Face Bend	Transverse Tension & Guided Bend	(1)
Hydrostatic Test	Required	Optional	(1)
Filler Metal Addition	None Allowed	Matching	(1)
Surface Scale Removal	Required	Required	(1)
Associated Fitting Specification	ASTM A403	ASTM A774	

(1) AWWA C220 allows use of either ASTM A312 or A778. See the ASTM specification for particular requirements.

common to encounter dual certified Type 304/304L and Type 316/316L stainless steel in warehouse stock. Dual certification means that it meets the 0.03% carbon maximum requirement for the "L" grades and also meets the higher mechanical properties of the regular grades.

Materials

Pipe and fittings are usually specified to one of the material specifications in *Table II*. Important provisions of the piping specifications are summarized.

Corrosion Behavior of Stainless Steel in Potable Water

Stainless steel performs best in clean, flowing water i.e., flow rates greater than 1.5 to 2 ft/s (0.5 to 0.6 m/s). In raw water, the suggested minimum design flow is 3 ft/s (1 m/s) to reduce sediment deposition.

High velocities and turbulence which limit the performance of materials such as ductile cast iron, carbon steel, and copper alloys are beneficial to the performance of stainless steel. Stainless steel offers excellent erosion/ corrosion

<i>Velocity - Avoid stagnant conditions</i>	
•	Up to 100 ft/s (30 m/s) - OK
•	> 3 ft/s (1 m/s) preferred for raw water with sediment
•	1.5 to 2 ft/s (0.5 to 0.6 m/s) for finished water
Flow	
•	Reduces opportunity for bacteria and slime to form growth sites
•	Reduces the possibility for microbiologically influenced corrosion

resistance to handle turbulent flows. Reference conditions for potable water are shown in *Table III*.

Because of its very low corrosion rate, stainless steel does not require the corrosion allowances used for ductile cast iron and carbon steel. Corrosion, when it occurs, is usually localized in crevice areas. There are two types of crevices:

- Man-made, originating from design or construction
- Natural, occurring in crevices formed by sediment or deposits.

A typical and very damaging man-made crevice is that formed at the root of incomplete penetration welds. Weld root crevices can trap sediment and allow chlorides to concentrate to several times the concentration in the bulk water increasing the likelihood of under-deposit crevice corrosion. Procurement specifications should require full penetration welds with smooth ID contour. Other man-made crevices such as those at flange faces under gaskets, pressed fittings, and mechanical joints pose few problems in low chloride potable waters.

Naturally occurring crevices from sediment can be reduced by high flow rates. When design or operating conditions are such that deposits may occur, the best practice is to provide periodic flushing with a high pressure water stream. The design should provide the necessary flushing ports.

A black Fe-Mn deposit forms on the pipe wall when raw waters are treated for the removal of iron or manganese with oxidants such as chlorine or potassium permanganate. The Fe-Mn deposits are normally benign to Type 304L stainless steel, but have contributed to under-deposit crevice corrosion in the presence of heat tint oxide from welding. The removal of heat tint oxide is discussed in the paragraph entitled *Fabrication of Piping Systems*. Guidelines for the injection of chlorine are discussed in the paragraph entitled *Effects of Oxidizers*.

Effect of Chlorides

The chloride level of the water is an important factor in determining the resistance of stainless steel to crevice corrosion.⁽²⁾ The chloride level can be readily measured and used by engineers as a first indicator for the likelihood of crevice corrosion. Beware that there are other important interacting factors that may have a major role, such as the presence of strong oxidants, crevice geometry, and pH.

Laboratory trials supported by service experience suggest that for the majority of natural, raw, and potable water with pH in the range 6.5 to 8:

- Crevice corrosion of 304/304L is rare below about 200 mg/l of chlorides
- Crevice corrosion of 316/316L is rare below about 1000 mg/l of chlorides.

A much more conservative approach, as may be required when other conditions are particularly unfavorable, is to use 304/304L when chlorides are below about 50 mg/l and 316/316L when chlorides are below about 250 mg/l.

When the chloride level is over 1000 mg/l, a higher molybdenum or duplex stainless steel may be required, and it is advisable to consult an expert.

Waters in PWTPs normally contain oxygen. In fully de-aerated waters, much higher chloride levels can be tolerated. Stainless steels are generally resistant to crevice corrosion in totally de-aerated waters, including sea water which contains about 18,000 mg/l chlorides.

Effect of Oxidizers

Chlorine, ozone and potassium permanganate are common oxidizers used in PWTPs for various purposes.⁽³⁾ Figure 3 shows 36 inch diameter, 30 ft. high, stainless steel mixing towers that are typically used for both chlorine and ozone mixing. In this installation, chlorine concentration is maintained below 4 mg/l and, typically, at 2 mg/l. Oxidant additions, up to some limiting concentration, can be beneficial to stainless steel in preventing microbiologically influenced corrosion (MIC). The effect of chlorine on the corrosion of stainless

steel is shown in *Table IV*. The data were gathered from corrosion test spools that were exposed in four locations.



Figure 3 Typical stainless steel chlorine/ozone mixing towers

Table IV Effect of Chlorine on Corrosion of Stainless Steel				
Chlorine Residual	Maximum Depth of Attack mils (mm)			
	Type 304		Type 316	
	Base Plate	Crevice	Base Plate	Crevice
0 ⁽¹⁾	0	0	0	0
0.8 – 1. ⁽¹⁾	0	0	0	0
2.0 ⁽¹⁾	0	0	0	0
3 – 5 ⁽²⁾	<1 (0.03)	4-14(0.1 - 0.4)	0	1-5 (0.03 - 0.1)

(1) Water contained 23 mg/l of chlorides
 (2) Water contained 790 mg/l of chlorides

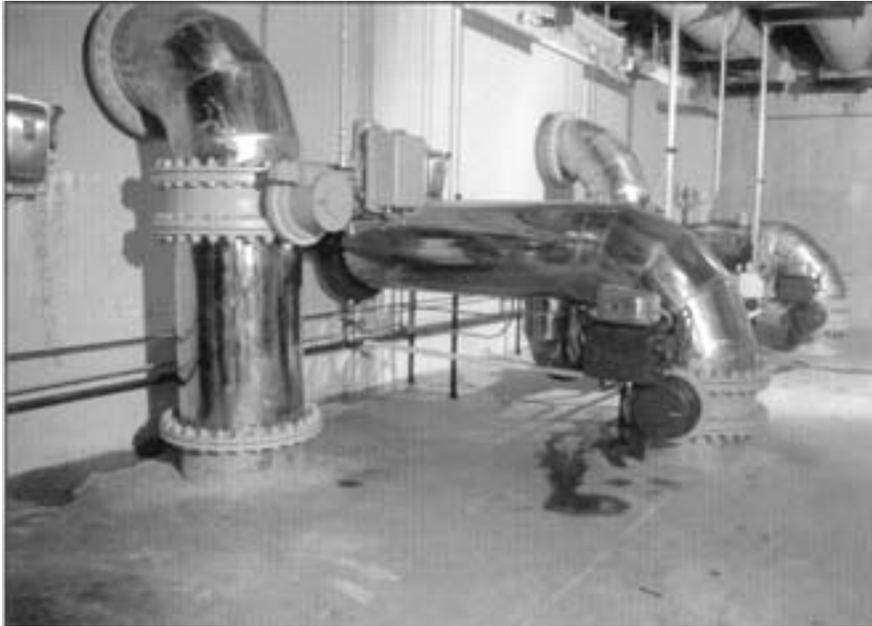


Figure 4 A section of stainless steel piping in the PWTP in Taunton, Massachusetts where cost savings were realized by using lighter weight stainless steel instead of ductile cast iron.

water district has been using stainless steel structurals in clearwells since the late 1950s and has not encountered the need for replacements. With long exposure, the staining is followed by shallow pitting over the entire exposed surface. Vapor-side staining and pitting attack have been reported in several PWTPs where pipe galleries were not well ventilated near the chlorine injection area.

Microbiologically Influenced Corrosion (MIC)

Potable waters are disinfected to kill pathogens and control bacteria. However, there are instances where MIC probably occurred in both raw water and process lines in PWTPs, especially where water has been

allowed to stand and stagnate overtime.⁽⁴⁾

- In at least three PWTPs, the hydrostatic test water was not promptly drained; the probable cause of MIC attack at the circumferential welds where the heat tint oxide was present. Longitudinal welds had been pickled and were resistant to MIC.
- One plant has also reported corrosion in a longitudinal weld of a horizontal run of stainless steel where finish water stood stagnant for long periods.

Stagnant water conditions can be avoided by draining promptly after hydrostatic testing, provided horizontal runs have been sloped for drainage. Dead legs should be eliminated through design. Sections that must be placed on stand-by can either be drained or the water can be circulated periodically. There is evidence that it takes at least 30 days for MIC to develop and initiate corrosion. Consequently, raw water systems should be circulated at least weekly to avoid stagnant conditions which could contribute to MIC in the weld heat tint oxide area.

Design

The use of stainless steel piping rather than ductile cast iron can yield the important advantages of thinner wall, lower weight, and fewer field connections - all of which reduce installation labor. *Figure 4* shows a section of the Taunton, Massachusetts PWTP where the use of stainless steel piping rather than the heavier DCI saved

In each case a baseline exposure in unchlorinated water was made for comparison.

These data indicate that in the 3-5 mg/l residual chlorine range, Type 304L becomes vulnerable to crevice corrosion. Type 316L can be expected to be more resistant to crevice corrosion in the 3-5 mg/l range of residual chlorine. Since residual chlorine may be up to 1.8 mg/l in finished water at the PWTP in order to meet the 0.2 mg/l minimum at point of use, Type 304L is an excellent material to use for finished water and distribution systems.

Stainless steel can tolerate considerably higher levels of chlorine for short time periods. The AWWA C653 disinfection treatment of 25 mg/l of chlorine for 24 hours is standard practice and there have been no reported problems.

The section immediately downstream of chlorine injection requires special attention. The critical section length is 10 times the diameter of the pipe. The concentration of chlorine injected is higher than stainless steel normally tolerates unless there is extremely rapid mixing. Alternate materials for this section are the Ni-Cr-Mo alloys, the 6% Mo super austenitic stainless steels and the 25% chromium super duplex stainless steels.

Chlorine, but not ozone, has another important effect. In the moist vapors just above the water line, chlorine concentrations may reach concentrations that stain and even pit Types 304, 304L, 316 and 316L stainless steel. This is more of a cosmetic problem than structural. One

\$50,000 (US). A summary of design guidelines is shown in Table V.

Fabrication of Piping Systems

Quality workmanship during the fabrication, erection, and field welding is essential for optimum service. Utilizing reputable organizations with experience in stainless steel fabrication will greatly minimize the likelihood of corrosion problems.

All PWTP circumferential pipe welds that are welded only from the OD should be made using the gas tungsten arc welding (GTAW) or TIG process for the root pass along with an internal inert gas purge to exclude oxygen in the weld root area.

Heat tint oxide in the weld heat-affected zone is one of the major contributors to under-deposit corrosion and microbiologically influenced corrosion in potable water treatment systems. The heat tint oxide can vary in color and thickness ranging from a thin, light, or straw-colored oxide to a dark, (black) oxide of appreciable thickness. The heavier the oxide, the more likely that it will contribute to the initiation of corrosion.

Heat tint oxide alone will not initiate corrosion in potable water. An abnormal condition in the environment is also necessary. Stagnant water left in the system for 30 days or more has initiated MIC at welds with heat tint oxide. The black Fe-Mn deposit that forms in the section



Figure 5 Rust on welds from wire brushing with carbon steel wire brush.

between the point of chlorine or permanganate injection and the filters has also initiated localized corrosion at welds with heat tint oxide. Base metal and welds that were cleaned of heat tint oxide were resistant.

Practical actions to remove or eliminate weld heat tint oxide differ according to pipe size.

1. *24 in. diameter and larger pipe:* Pipe sizes 24 in. and larger are accessible for internal conditioning. Remove heat tint oxide by pickling the interior weld surfaces, by grinding with an abrasive tool such as a rotating silicon carbide-impregnated fiber brush, or by electropolishing with a hand-held electropolishing probe.
2. *3 in. diameter and smaller pipe:* Remove heat tint oxide by pickling the pipe assembly or by using mechanical joints. Alternately, assurance of heat-tint-free welds usually requires automatic orbital welding with very precisely machined joint preparations.
3. *Pipe sizes greater than 3 in. and less than 24 in. diameter:* The piping fabricator should be required to remove or prevent the formation of heat tint oxide using one of the following options best-suited for the particular assembly.
 - Limit assembly length to accommodate pickling the unit or placing welds so they are accessible for internal grinding.
 - Prevent any significant heat tint oxide formation through very precise weld joint preparation and careful internal purging procedures. Automatic orbital welds can be made free of heat tint. The fabricator should be required to demonstrate the ability to make heat-tint-free welds.

Table V Guidelines for the Design of Stainless Steel PWTP Piping Systems
<p><i>Mechanical Features</i></p> <ul style="list-style-type: none"> • Slope the horizontal lines so that they will completely drain, including the low points between supports. • Provide access for inspection and flushing out of sediment, debris and deposits in the raw water piping. • Use eccentric reducers where appropriate to facilitate draining. <p><i>Velocity-Avoid stagnant conditions and dead legs.</i></p> <ul style="list-style-type: none"> • Normal good design flow rates minimize the opportunity for bacteria to build biomounds and initiate MIC. • Minimum flow rates to reduce possible sediment accumulation and corrosion are: 3 ft/s (1 m/s) for raw water with sediment, 1.5-3 ft/s (0.5-0.6 m/s) for finished water where the sediment is less likely.

- Use mechanical connections on joints where heat tint oxide removal is not practical.

Other minimum fabrication requirements should include the following:

- Proof of acceptable welding procedure specifications for the work to be performed and verified welder performance qualifications. The engineer and/or customer should review and verify both. Suggested guides are ASME Section IX and AWS B2.1.
- Require full penetration welds, free of cracks, overlaps and cold laps.
- Limit misalignment for manual welds to 1/16 in. (1.6 mm) or half the wall thickness, whichever is less. Automatic orbital welding procedures are usually more restrictive on misalignment.
- Limit on weld reinforcement and concave root (11/16 in. [1.6 mm]), or to agreed-upon limits.
- Limit on undercut, e.g. 1/32 in. (0.8 mm) or 10% of base metal thickness, whichever is less.
- Provide for secure end closures and leave in place until final assembly.
- Provide for prompt and complete drainage of the piping systems after hydrostatic testing.

Post-Fabrication Cleaning

Embedded free iron on stainless steel surfaces causes rust marks to form and in some instances provides the sites for the initiation of corrosion.⁽⁶⁾ Figure 5 shows the development of rust at a weld brushed with a carbon steel wire brush; only stainless steel wire brushes should be used. Nitric acid and other "passivation" treatments described in ASTM A380 are not fully effective in removing iron and other surface defects. Pickling with nitric-hydrofluoric acid removes free iron and a thin surface layer of metal that may contain surface defects; the metal surface is then passive and in the most corrosion-resistant state. If a nitric-hydrofluoric acid pickle is not practical, the free iron can be removed mechanically. Acceptable methods include the use of medium to fine-grit abrasives such as clean flap-per wheels, flexible disks, or blasting with clean abrasives such as glass beads, garnet, or walnut shells. Free iron and heat tint oxide can also be removed by a hand-held electropolishing probe.

The water wetting and drying procedure described in ASTM A380 is a very effective test to check for the removal of free iron. The procedure calls for wetting the surface with distilled or deionized water or fresh water followed by drying. After the wet-dry cycles, the surface should show no evidence of rust stains or other corrosion products. The ferroxyl test for free iron described in A380 is even more sensitive but may not be acceptable for use in potable water systems.

Operations and Maintenance

Failure to drain promptly after hydrostatic testing or allowing water to remain stagnant in piping or tanks for extended periods of time has led to MIC. In stagnant water, bacteria have an opportunity to develop biomounds and multiply, leading in some instances to MIC at welds where there is heat tint oxide. Over 90% of the reported instances of MIC occur in the vicinity of welds. There are occasional reports of MIC on bare metal away from welds, but these occurrences seem to be in severe MIC environments. The following actions avoid MIC even when heat tint oxide is present.

- Drain promptly and blow dry after hydrostatic testing or when the system is placed in extended standby. Alternately, circulate water if draining is not possible.
- Place in service within a few days after hydrostatic testing and provide for prompt draining should the system be placed in standby at some future date.
- Slope horizontal runs sufficiently so they will drain without leaving water between support points.

Other guides for the operation and maintenance of stainless steel piping systems includes the following practices:

- Establish a schedule to flush out sediment and debris on horizontal runs of raw water piping.
- During downtime, drain completely and dry or, alternately, circulate water for one hour daily.
- For the initial disinfecting treatment, dissolve calcium hypochlorite granules before introducing them into or onto the surface of stainless steel piping. Calcium hypochlorite granules dissolve slowly and have created a severe micropitting environment when resting on stainless steel.
- Provide proper ventilation to clear chlorine from all enclosed spaces.

References

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