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Stainless steel in municipal waste water treatment plants

by A.H. Tuthill and S. Lamb

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Arthur H. Tuthill
and Stephen Lamb
are consultants to the
Nickel Development Institute

Guidelines for the use of stainless steel in municipal waste water treatment plants

A.H. Tuthill
S. Lamb

Stainless steel piping has served as the standard material of construction for municipal waste water treatment plants (WWTP's) built in the United States over the past 25 years. A typical plant is shown in *Figure 1*.

Since the late 1960's, over 1600 municipal WWTP's have been built using stainless steel aeration, digester gas and sludge transfer piping, as well as stainless steel slide gates, valves, tanks, screens, handrails and other equipment. Stainless steel was selected originally over galvanized and painted carbon steel in order to reduce the higher maintenance and replacement costs associated with these less corrosion resistant materials. Overall experience has been good to excellent (1). This article reviews the suitability and performance of the several grades of stainless steels that have been used or considered for waste water treatment plants and identifies guidelines that will assist the user to obtain the best results from the stainless steel selected for these plants.

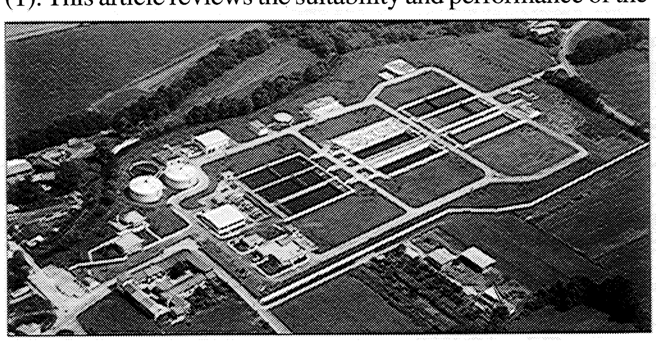


Figure 1 Waste water treatment plant. Canegrate, Italy.

The austenitic grades used in waste water treatment plants have 16-20% Cr, 8-14% Ni and the Mo containing grades, 2-3% Mo. *Table I* shows the common name, the UNS number, the British, German and Swedish designations and compositions for the wrought grades. *Table II* shows the substantially higher ASME allowable design stresses for stainless steel pipe compared to those for carbon steel pipe, especially when stainless pipe is supplied as a dual-certified product,

Table II ASME allowable design stresses (ksi)

		Temperature 0-100°F
Stainless steel welded pipe		
ASTM A 312	Type 304	16.0
	Type 304L	13.3
	Type 316	16.0
	Type 316L	13.3
Carbon steel pipe		
ASTM A 53	Seamless type A	12.0
	Seamless type B	15.0
	Welded type A	10.2
	Welded type B	12.8

Table I Alloy identification and compositions %

Common Name	UNS NO.	British BS	German DIN	Swedish SS	EURONORM EN	C	Cr	Ni	Mo	Fe
304	S30400	304S31	1.4301	2333	1.4301	0.08	18.0	10.0	–	Bal.
304L	S30403	304S11	1.4306	2352	1.4306	0.03	18.0	10.0	–	Bal.
316	S31600	316S31	1.4401	2347	1.4401	0.08	17.0	12.0	2.0-3.0	Bal.
316L	S31603	316S11	1.4404	2348	1.4404	0.03	17.0	12.0	2.0-3.0	Bal.

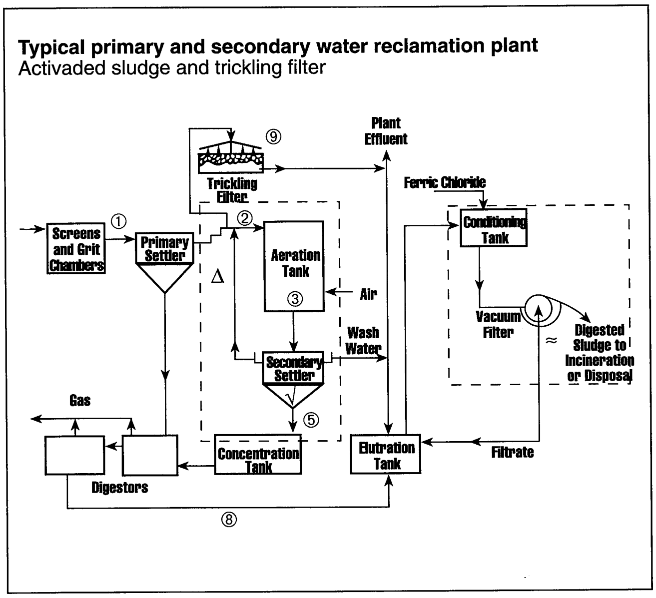


Figure 2 Typical flow diagram for a waste water treatment plant.

thereby allowing the use of the higher design properties while maintaining the low carbon for weldability.

The low carbon grades, Types 304L and 316L, are used for welded construction. These low carbon grades are designed to be resistant to intergranular corrosion after welding without further heat treatment. The higher carbon content grades have slightly higher strength and are used primarily for pump shafts and valve stems where welding is not involved and the higher strength can be used to advantage in the design. The Mo containing grades are more resistant to localized corrosion and are preferred for more aggressive conditions or simply for greater insurance against unusual conditions which may exist from time to time. The cast equivalent grades have comparable corrosion resistance and comparable mechanical properties.

WWTP ENVIRONMENTS

Figure 2 shows a typical flow diagram for a waste water treatment plant, indicating the locations where corrosion test specimens were exposed to actual plant conditions for different periods of time. These tests were run in different

Table III WWTP environments

Plant Location	Flow Rate	Feedstock	Other Comments
1. Municipal Waste Feed	N.A.	Raw untreated sewage	BOD 175-300ppm Suspended solids 220-650ppm O_2 140ppm
2. Mixed Feed & Activated Sludge	2-3 ft/s	70% sewage 30% active sludge + H_2S	—
3. Aeration Tanks	violent agitation	70% sewage 30% active sludge	—
4. Clarifier (secondary settlers)	Low velocity	Activated sludge with some effluent	—
5. Concentrated Active Sludge	Fairly high	—	—
6. Vacuum Filter to Disposal	No aeration 1 ft/s	Activated sludge to vacuum filter	Some ferric chloride additions
7. Discharge Effluent	2 ft/s moderate aeration	—	—
8. Sewage Effluent	4-5 ft/s extensive aeration	Can have high Chloride and dissolved solids	
9. Trickle Filter	—	—	aeration high

Note: Typical temperature 68-77°F. Typical pH 7.4-7.7.

Table IV Corrosion rates in WWTP environments, mpy (mm/yr)

Plant Location	Type 304	Type 316	1010 Steel
1. Municipal Waste Feed	<0.1[1] (<0.002)	<0.1[1] (<0.002)	3.0 - 9.0[2] (0.075- 0.225)
2. Mixed Feed and Activated Sludge	<0.1 (<0.002)	<0.1 (<0.002)	4.6[2] (0.117)
3. Aeration Tanks	<0.1 (<0.002)	<0.1 (<0.002)	1.5 - 5.0[2] (0.037- 0.127)
4. Clarifier (secondary settlers)	<0.1[1] (<0.002)	<0.1 (<0.002)	3.0 - 6.4[2] (0.075- 0.162)
5. Concentrated Active Sludge	<0.1[1] (<0.002)	<0.1 (<0.002)	4.8[2] (0.122)
6. Vacuum Filter to Disposal	<0.1[1,2] (<0.002)	<0.1[1] (<0.002)	3.7 - 8.3[2] (0.094- 0.210)
7. Discharge Effluent	<0.1[1] (<0.002)	<0.1 (<0.002)	6.3[2] (0.160)
8. Sewage Effluent	<0.1[2] (<0.002)	<0.1 (<0.002)	1.8[2] (0.046)
9. Trickle Filter	<0.1 (<0.002)	<0.1 (<0.002)	2.2 (0.056)

Averaged corrosion rates over 168 - 732 days exposure
Corrosion rate - mpy (mm/yr)

1 Evidence of crevice corrosion attack
2 Pitting attack

TABLE V MWWTP corrosion tests - mpy (mm/yr)
Location 6: activated sludges in dewatering and vacuum filter

Environment	Type 304	Type 316	1010 Steel
Activated Sludge to Vacuum Filter (No Aeration)	<0.1 (<0.002)	<0.1[1] (<0.002)	6.3[2] (0.16)
Conditioning Tank + 250-300 ppm Ferric Chloride	0.16[1,2] (0.004)	<0.1[1,2] (<0.002)	8.3[2] (0.21)
Filtrate From Dewatering of Activated Sludge (Moderate Agitation)	<0.1[1] (<0.002)	<0.1 (<0.002)	3.7 (0.094)
Filtrate From Dewatering and Elutriated Sewage Sludge (Extensive Aeration) + 2% by Weight Ferric Chloride (pH 5.5 - 6.0)	<0.1[1,2] (<0.002)	<0.1[1] (<0.002)	NA

Averaged corrosion rates over 168-732 days exposure
[1] Evidence of crevice corrosion attack [2] Pitting attack

plants during the 1960's and early 1970's with the results being analyzed and reported by the International Nickel Company (Inco).(2)

Tables III, IV and *V* summarize data for Type 304, Type 316 and 1010 carbon steel from the INCO test rack exposures. The plant location for each test is identified by the numeral that corresponds to those shown in the flow diagram. Corrosion rates for carbon steel varied from 3 mpy (0.075mm/yr) in the raw incoming sewage to 16 mpy (0.4mm/yr) in the clear effluent. The greater the oxygen, the greater was the corrosion for carbon steel (corrosion rates are in direct proportion to the amount of oxygen reaching the surface of the carbon steel). The corrosion rates of carbon steel in all locations are high enough to require continual maintenance and early replacement. Galvanizing and coatings may extend the life of carbon steel piping systems for several additional years, but they still do not offer an optimum solution to long term protection in WWTP environments. These coatings can become damaged or sacrificial in nature.

Stainless steel Types 304/304L and 316/316L are the principal materials used for bar screens, grit removers, weirs, bolting, slide gates and aeration basin, digester and sludge piping in municipal waste water treatment plants today. For the past 20 years or more, these materials have become standard materials of construction, based upon the field testing undertaken by International Nickel. Reference to *Tables III, IV* and *V* show weight loss corrosion rates for Types 304 and 316 stainless steels were <0.1 mpy, except in one activated sludge exposure reported in *Table V*, which will be discussed later. A corrosion rate of <0.1 mpy indicates that material would be expected to have a useful life well in excess of 20 years.

These very low corrosion rates mean that stainless steel equipment does not have to be specified with a "corrosion allowance" added to the design wall thickness, as must be done for carbon steel and ductile cast iron equipment. This leads to a significant saving in weight/material when stainless steel is specified.

Evidence of crevice corrosion initiation was reported on some of the stainless steel specimens. This type of corrosion can occur in localized areas, where "shielded" or "creviced" areas exist, e.g. at bolted joints, at incomplete welds or beneath adherent sludge deposits. To minimize this type of attack, crevices should be eliminated wherever possible, all weld joints fully penetrated and periodic cleaning scheduled to remove adherent deposits. In the case of aeration basins, deposit removal is usually accomplished when they are taken out of service for odour control cleanings. These precautions have resulted in long term, continuing service with no significant problems. Agitation and oxygenation in the aeration basin during operation further benefit the performance of stainless steels.

Atmospheric Corrosion Resistance

As chromium is added to steel, corrosion resistance increases. The amount of chromium needed to make stainless steels "stainless" can be defined by the weight loss of steels with varying amounts of chromium (3). Faulrings's data indicates that the weight loss for steels with 12.5% and higher chromium contents is quite low after 25 years exposure to marine atmospheres. These "straight chromium" grades of stainless steel (ferritic and martensitic), develop a surface layer of rust making them unsuitable for most atmospheric applications, where appearance is important. By contrast, the austenitic grades Types 304 and 316 containing 8-10% nickel, are more resistant and usually retain their bright appearance in atmospheric exposures for many years.

Hydrogen sulfide gas is generated in the digesters and throughout much of a WWTP, contributing to the corrosion that occurs in copper alloys, aluminum and carbon steel. According to De Renzo, the corrosion rate of Type 304 and Type 316 in moist H_2S is <0.1 mpy (<.0025mmy), indicating a negligible corrosion rate (4). Type 304L is the standard material used for digester gas piping and has performed well.

Although there is no intentional exposure to moist chlorine vapours, several cases of general pitting have been reported on the outer surface of piping in confined location with poor ventilation near chlorine storage areas. Both Types 304L and 316L stainless steel are subject to staining and general pitting in atmospheres where moist chlorine vapours can accumulate and condense, usually in enclosed areas. These occurrences were remedied by appropriate ventilation or minimized through regular water spraying and cleaning of the stainless steel surfaces.

Chlorine - Ozone

Stainless steels are generally resistant to chlorine at the concentrations normally encountered in waste water treatment plants. *Table VI* gives test specimen exposure data for type 1010 steel, cast iron and Types 304 and 316 stainless steel in chlorinated fresh waters with typical residual chlorine concentrations(5). Both 304L and 316L exhibit excellent corrosion resistance in inland waters with up to 2 ppm residual chlorine, whereas corrosion rates for carbon steel and cast iron are doubled. For continuous exposure to 3-5 ppm residual chlorine, the data indicate that Types 304/304L become prone to crevice corrosion and Type 316L would be a more conservative choice. Stainless steels are not suitable for chlorine injection systems which may contain fifty to several hundred ppm chlorine.

Ozone is an increasingly common alternative oxidizing agent which can be used separately or in conjunction with chlorine. Type 316 has been the preferred material of construction for ozone generators, although background and data are lacking as to why Type 316L was originally selected over Type 304L.

Other Chemical Additives

Ferrous sulfate is a chemical that is frequently added in WWTP's: De Renzo also gives the corrosion rate of Types 304 and 316 in ferrous sulfate, contaminated with sulfuric acid at pH 1 - 2.5 (spent pickle liquor), as <0.8 mpy (<0.02 mm/yr) which is indicative of excellent resistance. In WWTPs, sulfuric acid is not normally present, and consequently, the corrosion rate for stainless steel in acid-free ferrous sulfate environments will be negligible.

Ferric chloride is sometimes used for flocculation in the conditioning tank where sludge is further concentrated and dewatered for incineration and disposal. Types 304 and 316 specimens installed in activated sludge location 6 (Table III), where there were 250-300 ppm ferric chloride present, suffered both pitting and crevice corrosion. The data in Table V indicates Type 316 is slightly more resistant to ferric chloride than Type 304 and might represent a more conservative choice downstream of ferric chloride injection points, where significant concentrations of ferric chloride may be present. However, despite the adverse test data, Type 304 piping is normally used to handle treated, flowing sludge.

Microbiological Influenced Corrosion

Welds in the standard grades of stainless steels, and areas adjacent to welds, are occasionally subject to microbiological influenced corrosion (MIC) in stagnant and slowly moving waters. One example of MIC attack occurred on Type 409 (11% chromium) stainless steel frames of experimental rotating biological contractors (RBC's) in one WWTP. *Figure 3* shows an RBC unit being disassembled. *Figure 4* shows a MIC mound more or less centered on the weld of the frame. The RBC's, with their stainless steel frames slowly rotating in and out of the sludge at about 2 rpm, create conditions almost ideal for MIC. Other instances of MIC in WWTP's are rare.

The unusually low incidence of crevice corrosion and MIC in municipal waste water treatment plants may well be due to several of the following factors favouring good performance:

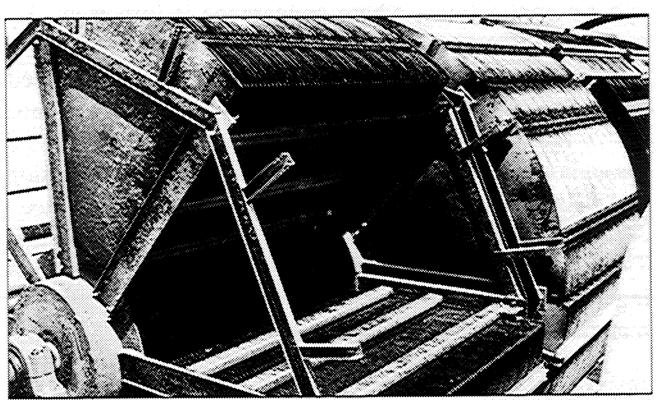


Figure 3 Type 409 stainless steel Rotating Biological Contractor (RBC) disassembled with MIC attack on arms.

Figure 4 MIC mound at welded cross beam.

Table VI Corrosion behaviour of 1010 steel, cast iron and Stainless steel in chlorinated fresh waters

Chlorine Residual (mg/L)	Corrosion Rates mpy (mm/yr)		Exposed Surface - Max. Pit Depth (mils)		Maximum Depth Crevice Attack (mils)	
	1010 Steel	Cast Iron	Type 304	Type 316	Type 304	Type 316
0	1.4 (0.004)	1.7 (0.004)	0	0	0	0
0.8-1.0	2.5 (0.064)	3.0 (0.075)	0	0	0	0
2	3.4 (0.086)	3.4 (0.086)	0	0	0	0
3 - 5	10.7 (0.272)	N.A.	<1	0	4-14	1-5

- Removal of heat tint scale by pickling or mechanical cleaning on the exterior of the aeration piping exposed to the sludge in aeration basins.
- Smooth contoured and crevices free circumferential butt welds of piping exposed to sludge.
(Note: Removal of heat tint (6) and the absence of crevices have been found to significantly enhance resistance to MIC and other forms of localized corrosion)
- Aeration and agitation of the sludge reduces the tendency of the sludge to adhere to the surface of the piping.
- Thorough wash down cleaning of the sludge from the outside diameter of the piping when the aeration basin is taken out of service.

General Experience

Most, if not all, of the stainless steel piping installed in the older WWTP's, built in the 1960's and 1970's, as well as those built later, are still in service. A typical application is shown in *Figure 5* where stainless steel aeration piping is used in a sludge aeration basin. Stainless steel has performed better in actual service than might have been predicted from the test specimen exposure data summarized earlier, especially where good housekeeping practices have been employed.

A few instances of under-deposit corrosion have occurred on the outside of submerged aeration piping. In these instances, the corrosion occurred under small adherent residues that had not been completely removed in the normal cleaning of the aeration basins.

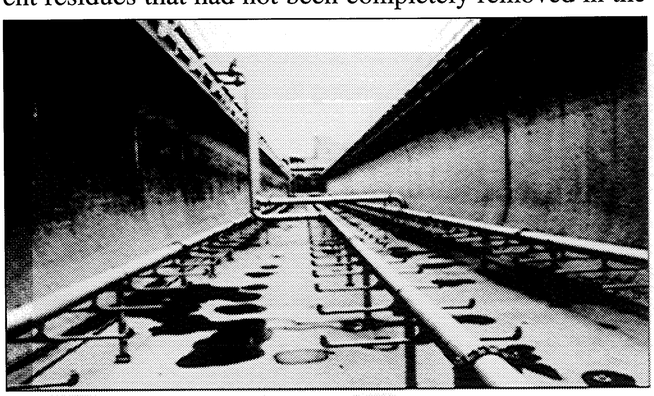


Figure 5 Aeration piping sludge tank.

As noted in the test rack exposures, corrosion occurred on specimens in activated sludge, where ferric chloride was being added. However, stainless steel sludge piping has generally performed well in handling activated sludge environments, except in one instance where crevice corrosion was recently reported in a sludge line in an open recess at an O-ring type mechanical joint and in an elbow in the same line. Sludge became packed in the open recess and led to severe crevice corrosion around the O-ring. Low flow and stagnant conditions apparently persisted long enough to allow corrosion to initiate under the accumulated deposit that was packed into this open recess in the piping. To minimize under-deposit corrosion, stagnant and low flow conditions should be avoided in sludge lines. Free flowing conditions will assist in reducing deposit formation.

Crevice corrosion can also occur in some soils. External corrosion of buried stainless steel is dependent upon soil analysis and soil resistivity. Soils differ in their corrosiveness depending upon the wetness, pH, aeration, stray currents and surface drainage. The potential for crevice corrosion of buried stainless steel piping tends to increase as the moisture content of soils increases and is greatest in swamps, under river crossings, and in wet soils. Based on tests run in Japan, stainless steels have performed well in a variety of soils and especially soils with high resistivity(7). The Japanese have had great success with buried stainless steel connectors bringing potable water from the submain in the street to the dwellings in the city of Tokyo. Almost half a million connectors are now in service with no known corrosion problems since installation began on a major scale in 1980. For wet soils and critical piping, stainless steel pipes can also be cathodically protected, as is standard practice for buried piping.

Procurement And Specifications

Most of the problems that have been encountered with stainless steel piping in WWTP's arise in procurement, design, fabrication and erection. The common specifications for welded austenitic stainless steel piping and fittings are shown in *Table VII.*

Table VII Comparison of stainless steel piping specifications

Specifications	ASTM A312	ASTM A778	ASTM A409
Coverage	Welded & Seamless	Welded	Welded, large diameter, light walled pipe
Fittings Specifications	ASTM A403	ASTM A774	ASTM A403/A774
Sizes	1/8" - 30"	3" - 48"	14" - 30"
Wall Thickness	SCH 5S - 80	0.062" - 0.5"	SCH 5S - 10
Solution Anneal	Required	As - Welded	Optional
Filler Metal Additions	Autogenous Or Matching	Matching	Matching
Mechanical Testing	Tensile & Weld Face Bend	Tensile & Weld Guided Bend	Tensile & Weld Guided Bend
Hydro Test	Required	Optional	Required
Scale	Removal Required	Removal Optional	Removal Required

ASTM specifications A312 (pipe) and A403 (fittings) define the welded austenitic stainless steel pipe and fittings developed for use in aggressive corrosion environments, typical of the chemical and other process industries. Most of the common stainless steel alloys are covered by these specifications in both the low carbon and regular grades, with sizes ranging from 3 mm (1/8") to 0.75 m (30") in diameter. ASTM specification A312 requires a final solution anneal and removal of heat tint scale.

ASTM specifications A778 (pipe) and A774 (fittings) were developed for less severe services where the low carbon and stabilized grades are normally used in the as welded condition. (Only low carbon and stabilized grades are included in this specification.) The size ranges covered by these specifications are from 75 mm (3") to 1.22 m (48") in diameter. Solution annealing after welding is not required by these specifications since only the low carbon and stabilized grades of stainless steel are covered. Although removal of heat tint scale is left optional, it should be removed and be specified in procurement documents in order to avoid potential corrosion problems that have occurred on unpickled pipe with heat scale remaining on its surface.

Design And Fabrication

ASTM specifications do not cover circumferential butt welds required for shop or field fabrication of the piping. The user, or the engineering firm handling design and construction, must develop in house welding specifications. It is important that these specifications include:

1) A requirement for full penetration and smooth ID circumferential welds.
2) Use of inert gas backup on the inside of the piping during welding to minimize oxidation and heat tint.
3) The use of a matching composition or higher Mo content filler metal.
4) Protection of the piping with well secured protective end caps to minimize contamination during shipment and clean indoor or outdoor storage.
5) Ensure clean indoor or outdoor storage areas (off the floor/ground).
6) Removal of heat tint scale from the OD of aeration basin piping.

The circumferential welds in those areas exposed to the handling of sludge - the OD of the aeration piping and the ID of the digestor and sludge piping, should be free of crevices and fully penetrated.

Some piping systems, such as aeration piping, are subject to vibration in service. Although Types 304 and 316 exhibit excellent fatigue strength with high endurance limits (8) of approximately 35,000 psi, see S-N curve in *Figure 6*, it is important to carefully design areas such as transition sections or where intersecting members of an assembly occur. These areas represent the weakest point of the structure where vibrational stresses tend to concentrate.

Consequently, the use of saddles and pull-through branch connections will allow joints to be made away from these intersecting connections. The use of a saddle will allow a full-penetration weld to be made in the connector, shown in *Figure 7*, and allow the connecting weld to the header to be moved away to form a more traditional pipe weld. A design of this nature eliminates the need to complete a weld in an otherwise tightly designed intersecting joint, which may result in flux entrapment when using manual arc welding techniques or the creation of crevices (incomplete weld penetration) on the underside of the joint.

The use of supporting gussets for the header would be beneficial in minimizing the vibrational stress effects for this typical aeration piping application.

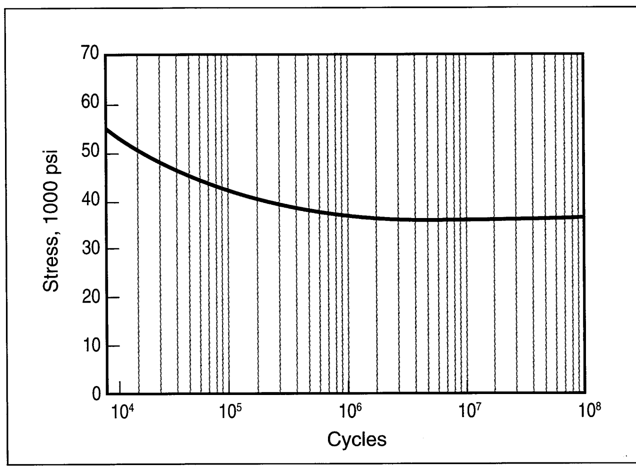
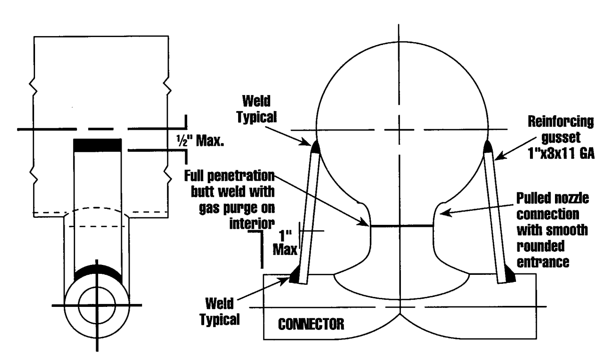


Figure 6 S-N curve in bending for annealed, Type 300 stainless steels.



Connector welded to header – note that connector is made so that the weld is in the pipe avoiding the more difficult and crevice prone branch connection weld.

Figure 7 Transition with supporting gussetts, preventing corrosion due to vibration.

Pickling

Pickling is important to the successful performance of stainless steel WWTP piping. It ensures good corrosion resistance for aeration piping handling aeration basin sludges. Pickling is effective in removing heat tint scale, embedded iron and other pit initiating defects from the metal surfaces. Although most shops take care to minimize contact with carbon steel layout tables, platens, lifting chain, iron can still become embedded in the surface. Also, during cutting and welding, the adjacent metal is heated into a range where heavy brown or black oxide films (heat tint scale) form. Fabricators have a choice; they can ship as fabricated material and hope that customers may not object to staining or streaking from iron and other surface contamination arising from fabrication, or they can pickle and restore the surface to its most corrosion resistant condition. This can be done in acid vats or by the application of pastes and mild acid solutions to the contaminated areas, followed by a thorough neutralizing wash to remove the excess acid and pastes from the metal surfaces.

In aqueous environments where stainless steel has been selected and used for its corrosion resistance, a recent study undertaken by the University of Tennessee (9), supports the need to remove heat tint scale. *Figure 8* shows the polarization curves for as-welded Type 304L (with heat tint) and as-welded and pickled Type 304L (heat scale removed). The curve for the pickled condition, with heat scale removed, shows the normal passive (protective) behaviour associated with the austenitic stainless steel materials. The vertical section of the polarization curve defines the wide passive range characteristic of stainless steels. The lack of a similar passive range for the heat affected zone (HAZ) of as-welded samples, with heat tint present, indicates that localized corrosion is likely in aggressive environments.

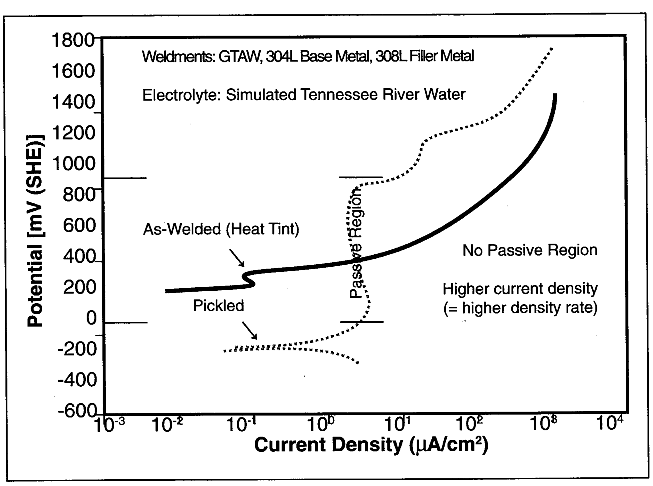


Figure 8 Polarization data showing effects of heat tint on corrosion resistance.

Cost Comparisons

Stainless steels offer a very cost effective approach for the design of light weight components and piping systems. Although the initial capital costs may be greater than for other material systems, stainless steel provides long term durability, lower overall maintenance costs and cost savings over the long term. In a European case study (10) undertaken by the European Stainless Steel Development and Information Group (EURO INOX) on an Italian WWTP, life cycle costs for stainless steel over carbon steel showed break-even after just 10 years of operation, despite the initial installation cost being approximately 25% more expensive for the stainless steel construction. This analysis includes the cost of capital, maintenance and repair and only considered a conservative estimate of 10% weight savings when designing with stainless steel. Stainless steel equipment included mechanical screens, travelling bridges and handrail assemblies, where galvanized steel is often used.

Conclusions

Types 304L and 316L stainless steel have been used extensively and very successfully for piping and a wide variety of other applications in waste water treatment plants. The higher design properties for stainless steel and its very low corrosion rates allow for lighter weight construction. Good housekeeping practices in-plant further enhance the excellent performance offered by these materials.

1. The ASTM specifications A312 and A778 are generally adequate for the procurement of pipe, provided that heat tint oxide scale removal is specified when ordering to ASTM A778.

2. In house specifications must be developed for circumferential butt welds, as these are not covered by ASTM specifications. These should include requirements for full penetration, rather than "commercial quality" welds.

3. Designing full penetration joints with smooth design contours and smooth weld bead profiles, rather than using fillet welds at branch connections, will optimize performance against vibration.

4. For waters where chlorides exceed 200 ppm (mg/l) or where residual chlorine exceeds 2 ppm, Type 316L is preferred to 304L.

5. For sludge service, maintaining flows above 2 ft/sec and avoiding recessed and creviced areas that are sites for sludge accumulation is essential for best performance.

6. Stainless steel 304L and 316L have been used for aeration, digester gas and sludge transfer piping in 1600 municipal waste water treatment plants built in the US since the late 1960's.

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North America

Nickel Development Institute
214 King Street West - Suite 510
Toronto, Ontario
Canada M5H 3S6
Telephone 1 416 591 7999
Fax 1 416 591 7987

Europe

Nickel Development Institute
42 Weymouth Street
London, England W1N 3LQ
Telephone 44 171 493 7999
Fax 44 171 493 1555

Nickel Development Institute
European Technical Information Centre
The Holloway, Alvechurch
Birmingham, England B48 7QB
Telephone 44 152 758 4777
Fax 44 152 758 5562

Japan

Nickel Development Institute
11-3, 5-chome, Shimbashi
Minato-ku, Tokyo, Japan
Telephone 81 3 3436 7953
Fax 81 3 3436 7734

Central & South America

Nickel Development Institute
c/o Instituto de Metais Não Ferrosos
R. Pirapora, 310
São Paulo-SP, Brasil 04008-060
Telephone 55 11 887 2033
Fax 55 11 885 8124

India

Nickel Development Institute
55A Uday Park (First Floor)
Khel Gaon Marg
New Delhi 110 049
India
Telephone 91 11 686 5631
Fax 91 11 686 3376

Australasia

Nickel Development Institute
150 Drummond Street, Suite 3
Carlton, Victoria 3053
Australia
Telephone 613 9650 9547
Fax 613 9650 9548

South Korea

Nickel Development Institute
Olympia Building, Room 811
196-7 Jamsilbon-Dong, Songpa-Ku
Seoul 138 229, South Korea
Telephone 82 2 419 6465
Fax 82 2 419 2088

China

Nickel Development Institute
Room 677, Poly Plaza Office Building
14 Dongzhimen Nandajie
Beijing, China 100027
Telephone 86 10 6500 1188 (ext. 3677)
Fax 86 10 6501 0261

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