Common Stainless Steel Corrosion Problems in the Water & Desalination Industries

Why They Happen & How We Can Avoid Them

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Stephen Lamb
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   d. Orange Cty. Water Dist.
   e. Zone 7 Water Agency
   f. City of Santa Cruz, California Water Dept.
   g. Long Beach Water Dept.
   h. Tampa Bay Water
   i. San Diego Cty. Water Auth.
   j. Irvine Ranch Water Dist.
The Challenge

Pump problems keep Oxnard desalter offline

By Gretchen Wenner
Monday, March 18, 2013

There's a hole where it shouldn't be. That much is for sure.

But Oxnard water officials might never know exactly what went wrong with two relatively young pumps at the city's $30 million desalter plant.

"Corrosion science is so complicated," said Anthony Emmert, water resources manager. "It's basically as predictable as the weather."
The SST Challenge

1. Pick a *high enough* grade of steel to provide the required protection *but not more* than you need.
   a. 6 grades of steel.
   b. 120+ compositions.

2. Assemble the piping and other equipment correctly.

3. Operate it properly.
The Problem – Info Is Scattered
Guidance on Selecting Materials Is Not In One Place

<table>
<thead>
<tr>
<th>AWWA Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C220</td>
<td>Stainless-Steel Pipe’ ½-inch (13 mm) and Larger</td>
</tr>
<tr>
<td>C221</td>
<td>Fabricated Steel Mechanical Slip-Type Expansion Joints</td>
</tr>
<tr>
<td>C223</td>
<td>Fabricated Steel and Stainless Steel Tapping Sleeves</td>
</tr>
<tr>
<td>C226</td>
<td>Stainless-Steel Fittings for Waterworks Service, Sizes ½-inch – 72-inch (13 mm – 1,800 mm)</td>
</tr>
<tr>
<td>C227</td>
<td>Bolted, Split Sleeved Restrained and Non-restrained Couplings for Plain End Pipe</td>
</tr>
<tr>
<td>C228</td>
<td>Stainless Steel Pipe Flanges for Water Service, Sizes 2-inch – 72-inch (50 mm – 1,800 mm)</td>
</tr>
<tr>
<td>C230</td>
<td>Stainless Steel Full Encirclement Repair and Service Connection Clamps</td>
</tr>
</tbody>
</table>
## Material Specs Are Similarly Dispersed

<table>
<thead>
<tr>
<th>ASTM Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A240</td>
<td>Chromium and Chromium-Nickel Stainless Steel Plate, Sheet and Strip for Pressure Vessels and for General Applications</td>
</tr>
<tr>
<td>A312</td>
<td>Seamless and Welded Austenitic Stainless Steel Pipes</td>
</tr>
<tr>
<td>A403</td>
<td>Wrought Austenitic Stainless Steel Piping Fittings</td>
</tr>
<tr>
<td>A774</td>
<td>As-Welded Wrought Austenitic Stainless Steel Fittings for General Corrosive Service at Low and Moderate Temperatures</td>
</tr>
<tr>
<td>A778</td>
<td>Welded, Unannealed Austenitic Stainless Steel Tubular Products</td>
</tr>
<tr>
<td>A789</td>
<td>Seamless and Welded Ferritic/Austenitic Stainless Steel Tubing for General Service</td>
</tr>
<tr>
<td>A790</td>
<td>Seamless and Welded Ferritic/Austenitic Stainless Steel Pipe</td>
</tr>
<tr>
<td>A813</td>
<td>Single or Double Welded Austenitic Stainless Steel Pipe</td>
</tr>
<tr>
<td>F593</td>
<td>Stainless Steel Bolts, Hex Cap Screws, and Studs</td>
</tr>
<tr>
<td>F593</td>
<td>Stainless Steel Nuts</td>
</tr>
</tbody>
</table>
And So Are Material Finish Specs

<table>
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<tr>
<th>ASTM Standard</th>
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</tr>
</thead>
<tbody>
<tr>
<td>A380</td>
<td>Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment and Systems</td>
</tr>
<tr>
<td>A967</td>
<td>Chemical Passivation Treatments for Stainless Steel Parts</td>
</tr>
</tbody>
</table>
The Solution:

“Develop a guidance document for engineers and consultants to help them properly specify the type of stainless steel most appropriate for a given water system and/or water treatment chemical system application.”

Pull the info together that explains how to pick the right steel and how to use it properly.
The Approach

1. Summarize the literature.
2. Capture what people are experiencing.
3. Fill in data gaps.
4. Develop formal guidelines.
What Is Stainless Steel?

A metallic alloy whose Cr content is >12% by weight.

For austenitic & duplex SS, Cr$_2$O$_3$ layer forms a corrosion-resistant barrier on the surface.
What Is Stainless Steel?

Steel alloy @ >12% Cr

Others, e.g., martensitic and ferritic, don’t have a Cr coating.
What Is Stainless Steel?

Steel alloy

Protective Cr₂O₃ layer,  ≥12%

The basic alloys used in water treatment are 304/304L and 316/316L austenitic stainless steels.
How Does Corrosion Occur?

The surface becomes damaged, dirty, or otherwise compromised.
Warmer temperatures, chlorine, and chlorides speed this process up.
Crevice Attack

An electrochemical cell forms in a tight M-to-M joint. The crevice gap dimension is critical. Cl- is a catalyst.
Pitting Attack

- Cl\textsuperscript{-} is attracted to anode, form M-Cl, pH at bottom drops, process accelerates.
- Process speeds up with increasing Cl\textsuperscript{-}, T.
MIC Can Be a Significant Problem

1. Like crevice corrosion attack.
   a. Bacteria form a biofilm.
   b. Becomes a tubercule.
   c. Anodic and cathodic sites develop and a corrosion cell is formed.
   d. Aggressive chemicals can accumulate and accelerate the rate of corrosion.

Mitigating Corrosion

STEP 1 – FIGURE OUT WHAT MATERIAL YOU NEED
### Cutoffs Where Crevice Corrosion Aided by Cl\(^{-}\) &/or OCl\(^{-}\) at Ambient T. Is Unlikely

<table>
<thead>
<tr>
<th>Material</th>
<th>Concentration of Free Chlorine in Feed Water</th>
<th>Chloride Concentration</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0 mg/L</td>
<td>2 - 3 mg/L</td>
</tr>
<tr>
<td></td>
<td>&lt; 250 mg/L</td>
<td>&lt; 100 mg/L</td>
</tr>
<tr>
<td>304/304L stainless steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>316/316L stainless steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex 2205</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex 2507</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 254SMO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AL-6XN</td>
<td>15,000 mg/L</td>
<td></td>
</tr>
<tr>
<td>Ferralium 255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zeron 100</td>
<td>&lt; 15,000 and up to</td>
<td></td>
</tr>
<tr>
<td>Ferralium 255</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alloy 654Mo</td>
<td>20,000 mg/L</td>
<td></td>
</tr>
<tr>
<td>Zeron 100; 654SMO</td>
<td>&gt; 20,000 mg/L</td>
<td></td>
</tr>
</tbody>
</table>

These are rules of thumb. pH, temperature, aeration, high free chlorine, high chloride & chlorine mixes will influence the best choice.

Duplex are best
When Choosing a SST Alloy, PREN Is a Valuable Guideline

1. PREN = Pitting Resistant Equivalent Number

PREN = \% Cr + 3.3(\% Mo) + 16(\%N)
PREN Provides a General Indication, Test Data Provides Empirical Support

1. ↑PREN = ↑Pitting resistance
   a. ↑Mo, ↑N, ↑Cr

2. Combine with test data (ASTM G48 & G150)
   a. E.g., “under X WQ, corrosion of SST followed PREN values.”

<table>
<thead>
<tr>
<th>TYPE</th>
<th>PREN</th>
</tr>
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<tbody>
<tr>
<td>AUSTENITIC STAINLESS STEEL</td>
<td></td>
</tr>
<tr>
<td>304/304L</td>
<td>19</td>
</tr>
<tr>
<td>LDX2101</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>SUPER AUSTENITIC ALLOYS</td>
<td></td>
</tr>
<tr>
<td>AL6XN</td>
<td>40</td>
</tr>
<tr>
<td>254 SMO</td>
<td>43</td>
</tr>
<tr>
<td>654 SMO</td>
<td>48</td>
</tr>
<tr>
<td>7% Mo</td>
<td>57</td>
</tr>
</tbody>
</table>
There Is Limited Lab Data on the Effect of Chlorine on SST Corrosion

1. Type 304/304L becomes vulnerable @ 3-5 ppm.
2. High conc. of chlorine ⇒ use higher alloyed material.

<table>
<thead>
<tr>
<th>OCl - Resid. (mg/L as Cl₂)</th>
<th>Maximum Depth of Attack (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 304 SS (PREN = 19)</td>
</tr>
<tr>
<td></td>
<td>Base Plate</td>
</tr>
<tr>
<td>0 ¹</td>
<td>0</td>
</tr>
<tr>
<td>0.8-1 ¹</td>
<td>0</td>
</tr>
<tr>
<td>2.0 ¹</td>
<td>0</td>
</tr>
<tr>
<td>3 - 5 ²</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>

Notes:
1 Water contained 23 mg/L of chloride.
2 Water contains 790 mg/L of chloride.

Source: The Nickel Institute.
Mitigating Corrosion

STEP 2 – LEARN FROM FIELD EXPERIENCES
The “Bad Actors”

1. Problematic welds & improper passivation.
2. Scratches & surface contamination.
3. Dissimilar metals (i.e., galvanic corrosion).
4. Paint/oil/tape.
5. MIC.
   a. Use & disposal of construction test waters.
   b. Sticky sediments.
Design or Fabrication Mistakes Can Be Sources of Crevice Attack

1. Human-mediated
   a. Stationary O-rings.
   b. Gasket surfaces.
   c. Non-metallic connectors.
   d. Poor root pass pipe welds.
   e. Skip welds.
   f. Paint, oil/grease, tape.
   g. Bolted joints.
Design or Fabrication Mistakes Can Be Sources of Crevice Attack

1. MIC
   a. Crustaceans.
   b. Sticky sediments.
   c. Bacterial colonies.
   d. Sediment deposits.


http://www.pairodocspro.com
Don’t Field Weld

1. The best QC is in a pipe fabricator’s shop.
   a. Plan out the pipe fabrication.
   b. Field verify dimensions.
   c. Then build it.

Note: This actually saves contractors money by not having to mobilize a certified welding crew.

Note: Where field welding is allowed, purge inside the pipe with an inert gas (e.g., Ar) and passivate the welded area (inside and out) – exact procedures may vary with material type.
Write Careful Specs and Require They Be Followed

1. Specify shipping procedures:
   a. Ship the piping material on pallets with the ends capped off with non-metallic covers.
   b. Foam and shrink wrap surfaces.
   c. Piping should not rub against each other or other non-SS surfaces.
Write Careful Specs and Require They Be Followed

2. Specify storage and handling procedures:
   a. Piping should be stored on pallets, not on ground.
   b. No iron contaminants (grinding or weld slag) should come into contact with piping.
   c. Lift with nylon straps, not metallic chains.

3. Specify testing conditions for piping to incl:
   a. Drain and dry piping so that stagnant water is not present.
   b. Flush and drain high dose chlorinated solutions from piping immediately after disinfection testing.
Other Important Considerations.

1. Approaches to welding.
2. Parts fabrication.
3. Surface finishes.
4. Approaches to passivation & pickling.
Take-Home Message

1. Specifying SS is important but not always well understood in our industry.

2. Critical considerations include:
      • Cl\(^-\) OCl\(^-\), T.
   b. Proper handling and installation.
      • Keep things clean.
      • Don’t scratch the pipes.
   c. Good maintenance to control MIC.

3. There’s a lot of information to sift through.

   A step-through guidance document will help us make the right decisions.
For Next Time

1. Guidelines.
   a. Selection of materials.
      • Preparation.
      • Installation.
   c. Operations & maintenance.
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