FAILURE ANALYSIS OF DEAERATOR PIPING

EXAMPLE REPORT

Modified from Original Report

- Electronic Copy –

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FAILURE ANALYSIS OF DEAERATOR PIPING

SUMMARY

The deaerator stainless steel water inlet elbow and vent pipe had cracked by chloride stress corrosion cracking (Cl-SCC). The combination of design and chlorine/chlorides levels within the process water had caused Cl-SCC of the stainless steel components.

1.0 INTRODUCTION

[Redacted] had suffered leaking of their water inlet elbow to, and vent piping from, Deaerator [Redacted]. Upon removal of the insulation, inspection found cracks on the inlet elbow surrounding the vent pipe weld. During removal, cracks were also found on the length of vent pipe that had passed through the inlet elbow. Figure 1 displays a provided photograph by the vent piping and the cracks found.

Warm water had been feed into the deaerator while the steam escaped through the vent piping. Water chlorine levels ranged to as high as 128ppm. Both the water inlet elbow and vent pipe comprised of ASME SA312 TP304L stainless steel. The valve and pipe tee connected to the vent pipe were also 304L stainless steel. Otherwise, all other surrounding materials were carbon steel. The deaerator body comprised of plain carbon steel and the piping upstream the elbow was ASTM A106 Grade B plain carbon steel.

Steel Image was requested to determine the nature of leaking.

2.0 EXAMINATION

Figure 2 displays the samples submitted for analysis. The locations of cracking in the elbow and vent piping appeared to correlate to surfaces exposed to both the inlet water and thermal heat from the venting steam. The elbow only exhibited cracks around the vicinity of the vent pipe weld (Figure 3). On the vent pipe, cracking had only occurred on the length within the elbow and was most severe near the top region by the elbow-pipe weld (Figure 4). A high density of branched cracking was found at these locations. The outer diameter surface of the vent pipe, contacting the inlet water, also exhibited notable material loss from corrosion.

No damage or cracks were observed along the length of vent pipe external/remote the elbow.

The cracks within the elbow material were identified as chloride stress corrosion cracks (Cl-SCC). The cracks exhibited branched, transgranular morphologies indicative of stress corrosion cracking (Figures 5, 6 and 7). Energy dispersive spectroscopy (EDS) found chlorine within the cracks, confirming that chlorine/chlorides had been the active corrosion agent and the cracking mode was Cl-SCC (Figure 8). As noted before, Cl-SCC cracking had predominantly initiated from the surfaces exposed to the inlet water.

Failure Analysis of 04V-009 Deaerator Piping
No material quality issues were observed with either the elbow or vent pipe material that would have contributed to failure. Chemical analysis found both components to conform to ASME SA312 TP304L (Table 1). Their core microstructures comprised of the intended austenite with no detrimental phases (i.e., no sensitization, sigma phase, etc., Figure 9). The core hardness was within the range expected for this material type (Table 2). Ultimately, the elbow and vent pipe material were deemed to be of sound quality.

**Table 1:** Chemical Analysis Results*

<table>
<thead>
<tr>
<th>Material</th>
<th>C (wt%)</th>
<th>Mn (max)</th>
<th>Si (max)</th>
<th>S (max)</th>
<th>P (max)</th>
<th>Mo</th>
<th>Cr</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA312 TP304L</td>
<td>0.035</td>
<td>2.00</td>
<td>1.00</td>
<td>0.030</td>
<td>0.045</td>
<td>-</td>
<td>18-20</td>
<td>8-13</td>
</tr>
<tr>
<td>Elbow</td>
<td>0.017</td>
<td>1.39</td>
<td>0.39</td>
<td>&lt;0.005</td>
<td>0.020</td>
<td>0.26</td>
<td>18.15</td>
<td>8.97</td>
</tr>
<tr>
<td>Vent Tube</td>
<td>0.018</td>
<td>1.47</td>
<td>0.46</td>
<td>&lt;0.005</td>
<td>0.025</td>
<td>0.15</td>
<td>18.08</td>
<td>8.86</td>
</tr>
</tbody>
</table>

*Conducted in accordance with ASTM E1019, E1097(mod) and E1479.

**Table 2:** Hardness Results*

<table>
<thead>
<tr>
<th>Location</th>
<th>Measurements (HV500gf)</th>
<th>Avg. Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HV500gf</td>
</tr>
<tr>
<td>Vent</td>
<td>174, 176, 174, 170, 180</td>
<td>175</td>
</tr>
<tr>
<td>Elbow</td>
<td>211, 220, 226, 221, 225</td>
<td>221</td>
</tr>
</tbody>
</table>

*Tested in accordance with ASTM E384 using a 500gf load.

### 3.0 CONCLUSIONS

The stainless steel elbow and vent pipe had cracked by chloride stress corrosion cracking (Cl-SCC). The nature of damage indicated a corrosion cell had formed, concentrating the chlorine within the inlet water. This suggested that the venting steam had provided enough heat to cause steam generation within the warm inlet water. Steam generation and the associated concentration cell had caused chloride stress corrosion cracking (Cl-SCC) of the elbow and vent pipe.
Chloride stress corrosion cracking of duplex stainless steel occurs due to the combination of (a) water, (b) chlorine/chlorides and (c) temperature. Discussion with [redacted] had included that water chlorine levels may be as high at 128ppm. Although these bulk chemistry chlorine levels alone would not have been harmful to ASME SA312 TP304L, the formation of a concentration cell from the venting steam heat had significantly increased the local chlorine levels along the venting pipe. This concentration cell had been formed from sufficient venting heat to cause chlorine to boil out of the inlet water, rising and concentrating at the top of the vent pipe/elbow region. Over time, this concentration cell had raised the local chlorine/chloride concentrations to levels sufficient to cause chloride stress corrosion cracking (Cl-SCC) of stainless steel.

Carbon steel has a much lower susceptibility to Cl-SCC. It was unlikely that the upstream carbon steel piping and carbon steel deaerator had suffered Cl-SCC damage.

No material quality issues were observed. The elbow and vent pipe conformed to the ASME SA312 TP304L compositional requirements. Their materials also exhibited the desired microstructures and typical hardness values. Failure was not attributed to a material issue.

Ultimately, this piping design was overly susceptible to corrosion cracking when the inlet water contained chlorine/chlorides. It is recommended that [redacted] review whether design modification, such as changing to carbon steel, can be made to reduce the risk of repeat failures.
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Figure 1: Provided photograph of the elbow and vent pipe.

Figure 2: Photograph displaying the submitted samples. The weld had been removed yet cracks remained on the immediate surrounding elbow and internal/submerged portion of the vent pipe.
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Figure 3: Photograph and macrographs displaying the cracks on the elbow surrounding the elbow/vent weld. Some of these cracks were through cracks, providing leak paths. Further examination would find that these cracks had formed first along the internal, waterside surface.

The only cracks found on the elbow were close to the vent pipe, close enough to have experienced increase temperatures from the venting steam.
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Figure 4: Photographs of the length of the vent pipe that had been within the elbow and exposed to inlet water. Numerous cracks were present around the former elbow/pipe weld. Portions of the pipe exhibited material loss from corrosion. All surfaces of this portion of the vent pipe had been internal the elbow and exposed to either inlet water or venting steam.
Figure 5: Macrograph displaying the high density of stress corrosion cracks present within the internal segment of the vent pipe. All surfaces of this portion of the vent pipe had been process exposed. As-polished condition.
Figure 6: Micrograph and SEM images displaying corrosion pitting and stress corrosion cracks on the internal surface of the elbow. Further analysis would identify these as chloride stress corrosion cracks (Cl-SCC). As-polished condition.
Figure 7: Micrographs displaying stress corrosion cracks on the internal portion of the vent pipe. The entirety of this portion of the pipe had been process exposed, indicating the corrosion agents (confirmed to be chlorides) responsible for cracking had been present within the process water. As-polished condition.
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Figure 8: EDS spectra displaying chlorine within the cracks of the internal vent pipe. Therefore, cracking of the 304L stainless steel had been caused by chloride stress corrosion cracking (Cl-SCC). SE1, 15kV.
Figure 9: Micrographs displaying the core structures of the (a) elbow and (b) vent pipe. Both comprised of typical austenitic structures for ASME SA312 TP304L. No detrimental phases, such as sensitization or sigma phase, were observed. Electrolytically etched using 10% oxalic acid.