FAILURE ANALYSIS OF CRACKED BUFFER VESSEL SHELL

EXAMPLE REPORT

*Modified from Original Report*

- Electronic Copy -

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FAILURE ANALYSIS OF CRACKED BUFFER VESSEL SHELL

1.0 INTRODUCTION

No Peaking had experienced leaking of their Buffer #2 vessel during service. Subsequent inspection found a twin vessel to also exhibit through-cracking of its shell.

Both vessels have been in service for fifteen years and comprised of ASME SA240 Grade 321 stainless steel. The insulated/wrapped vessels operated at 80-100ºC and at pressures up to 5 bar. The refinery was located near the Gulf of Mexico operating in a high humidity climate and exposed to sea air.

Steel Image was requested to determine the nature of cracking.

2.0 EXAMINATION

2.1 Examination of the Cracking

Figure 1 displays the shell section submitted for analysis. Visual examination found extensive cracking above the stiffener rings. A high density of cracks was present on the external shell surface, external stiffener rings and associated welds. Only a few small cracks were visible on the inner surface and further examination would find these to have been through-cracks that had initiated from the external surface.

Fluorescent penetrant inspection (FPI) was conducted to reveal the full extent of cracking and to determine the best locations for sectioning (Figure 2). Cracking was most severe along the shell’s external surfaces (OD) above the stiffener ring. The cracks extended into the welds and stiffener rings. The internal surface had been grit blasted prior to receipt which complicated the FPI inspection of the internal surface.

To survey the damage, several cross-sections were taken through the cracked regions (Figures 3, 4 and 5). Stereomicroscopic examination and optical microscopy found cracking at all locations evaluated had initiated from the external surface. The branched, transgranular nature of the cracks were consistent with chloride stress corrosion cracking (Cl-SCC). No cracks were observed (a) initiating from the internal surface or (b) of a different crack mechanism other than SCC (ie. no fatigue, etc).

One of the larger cracks was opened up for direct examination of the crack surface (Figure 6). The opened crack was ultrasonically cleaned and examined using a scanning electron microscope (SEM). The majority of the fracture surface was covered in

SUMMARY

The vessel shell had failed corrosion under insulation (CUI). Prolonged wetting of the insulation had caused external chloride stress corrosion cracking (Cl-SCC). The primary cause of failure had been due to the introduction of water. It is recommended that the source/ingress path of water be investigated and eliminated.
corrosion product or the original micro-fracture features had been damaged by post-cracking corrosion. However some locations exhibited transgranular-like features consistent with stress corrosion cracking.

Energy dispersive spectroscopy (EDS) detected the presence of chlorine (1) directly on the fracture surface and (2) within the cross-sectioned cracks (Figure 7). The presence of chlorine indicated that the most active corrosion agent responsible for stress corrosion cracking had been chlorine/chloride based. Therefore, cracking was confirmed to have been chloride stress corrosion cracking (Cl-SCC).

### 2.2 Material Testing

Overall, the material was found to be of sound quality. No detrimental material issues were found. Corrosion cracking had not been due to a material quality issue.

Chemical analysis of the shell was performed in accordance with ASTM E1019, E1097 (modified) and E1479 (Table 1). The shell conformed to the compositional requirements of ASME SA240 Grade 321 stainless steel.

**Table 1: Chemical Analysis Results**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Composition (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>SA240 321</td>
<td>0.08 Max</td>
</tr>
<tr>
<td>B-3200</td>
<td>0.038</td>
</tr>
<tr>
<td></td>
<td>Cr</td>
</tr>
<tr>
<td>SA240 321</td>
<td>17.0-19.0</td>
</tr>
<tr>
<td>B-3200</td>
<td>17.35</td>
</tr>
</tbody>
</table>

Rockwell hardness testing was conducted in accordance with ASTM E18 (Table 2). The shell exhibited hardness values typical for this material type and condition.

**Table 2: Rockwell Hardness Test Results**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Measurements (HRB)</th>
<th>Avg. Hardness (HRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3100</td>
<td>75.5, 72.0, 72.5</td>
<td>73</td>
</tr>
<tr>
<td>B-3200</td>
<td>76.5, 78.0, 79.5</td>
<td>78</td>
</tr>
</tbody>
</table>

Optical examination found the core microstructure to be typical for ASME SA240 Grade 321 (Figure 8). No detrimental phases were observed that would have caused either (a) reduced corrosion properties or (b) contributed to corrosion cracking.
3.0 CONCLUSIONS

The buffer vessel shell suffered corrosion under insulation (CUI). Water ingress through the insulation jacket had wetted the insulation and caused chloride stress corrosion cracking (Cl-SCC). The primary cause of failure was attributed to repeated water ingress into the insulation and prolonged insulation wetting.

Stress corrosion cracking of ASME SA240 321 stainless steel requires water. Dry chlorine/chlorides does not cause corrosion of anything let alone stainless steel. Therefore, the primary cause of failure was due to water ingress into the insulation that kept the external shell surface wet for prolonged periods. Water had tended to collect above and on the stiffener rings, highlighted by the high density of cracks at these sites. Corrosion under insulation generally occurs of several months to years depending the conditions.

At temperatures above 80°C, very low concentrations of chlorides are required to be present to cause Cl-SCC. The chlorides may have been introduced from either (a) salt within the sea air/humidity or (b) leaching from the vessel insulation. In either case, chlorides without water would not have caused Cl-SCC and therefore, the primary concern remained the introduction of water through the insulation jacket.

The shell material was of sound quality. Corrosion cracking was not due to a material quality issue.

Ultimately, the primary contributor to corrosion (CUI) under insulation and the resulting chloride stress corrosion cracking (Cl-SCC) was the ingress water into the insulation. It is recommended that the source/cause of water be further investigated. That investigation should consider damage and/or workmanship issues of the insulation jacket that might have allowed rain water or condensation/moisture to onto the shell.
Figure 1: Photograph displaying the shell section submitted for analysis.
Figure 2: Photographs displaying the cracks on the shell section highlighted by fluorescent penetrant (FPI). Although several through-cracks had formed, field grit blasting of the internal surface prevented them from being readily detected by FPI.
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Failure Analysis of Cracked Buffer Vessel Shell Page 6 of 10

Figure 3: Photograph and macrographs displaying the cross-sections taken through the cracked regions identified by FPI. All cracks observed had initiated from the external surface. The cracks exhibited branching classic for stress corrosion cracking, later confirmed to be chloride stress corrosion cracking (Cl-SCC).
Failure Analysis of Cracked Buffer Vessel Shell

Figure 4: Photographs and macrographs displaying Locations #2 and #3 cross-sections. The cracks within both the shell and stiffener ring were classic chloride stress corrosion cracks (Cl-SCC). All cracks had initiated from the external surface. No other crack mechanisms/modes were observed.
Figure 5: Photograph, macrograph and micrographs displaying the cross-section taken through the shell. The cracks were chloride stress corrosion cracks (Cl-SCC). Lightly etched by electrolytic 10% oxalic acid.
Figure 6: Macrograph and SEM images displaying an opened crack from the shell. Corrosion had damaged the majority of the original micro-fracture features, however intact transgranular features were observed in a few sites. These features were consistent with transgranular stress corrosion cracking. SEI, 15kV.
Figure 7: EDS analysis performed (a,b) directly on the fracture surface and (c,d) of cracks in cross-section detected the presence of chlorine. Therefore, the crack mechanism was confirmed to be chloride stress corrosion cracking (Cl-SCC). 15kV.

Figure 8: Micrographs displaying the core microstructure of the shell. The equiaxed austenitic microstructure was typical for ASME SA240 Grade 321. Electrolytically etched using 10% oxalic acid.