THE LARGEST COKE DRUM BULGE REPAIRS IN INDUSTRY HISTORY

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Overview

• Technical Background.
• Repair implementation.
Technical Background
History of Shell Bulging & Cracking

• Major problem for decades.
• Despite design improvements, still a problem—perhaps more severe today.
API Surveys

• 1968 Survey:
  – Carbon steel drums bulged far more extensively than C-Mo drums before giving through-wall cracks.

• 1996 Survey:
  – 97% said cracks were primarily circumferential.
  – 57% reported shell bulging. Of the drums that bulged, 87% cracked.
Bulging Types

There are different types of bulges that are created by different mechanisms and should be treated differently:

• Circumferential welds (especially w/ thickness change)
• Middle of drum
• In plates away from welds
Bulging-Induced Cracks

• Bulging-only
• Combination of bulging and weld defect
• Combination of bulging and weld-base mismatch
Bulging-Induced Cracks
Consequences of Bulging

• PRIMARY: Excessive strain
  ➢ Local failure
  ➢ Initiation of bulging cracks
  ➢ Strain age embrittlement.

• SECONDARY: Increase in nominal stress
  ➢ More fatigue damage
  ➢ Accelerated propagation of cracks

• Leaks and fires
Bulging Assessment per API-579 / ASME-FFS

• Level 1: N/A to coke drums
• Level 2: Does not exist
• Level 3: Infeasible and costly process
Industry Practice

• Stress analysis (1\textsuperscript{st} generation)
• Geometric analysis (2\textsuperscript{nd} generation)
• Strain analysis (3\textsuperscript{rd} generation)
Strain Analysis

• Plastic Strain Index (PSI)™
• Based on failure limit of industry standard API 579/ ASME FFS
• Focuses on primary mode of failure.
• Excellent correlation with bulging cracks.
PSI Analysis

- Four-tier severity system: Design, Concern, Danger, and Failure.
- Used to determine likelihood of bulging-induced cracking and frequency of laser scanning.
- Can be used for other pressure vessels with bulges of similar failure modes.

<table>
<thead>
<tr>
<th>PSI magnitude</th>
<th>Severity Grade</th>
<th>Likelihood of Bulging-Induced Cracks</th>
<th>Recommended Frequency of Laser Scanning</th>
</tr>
</thead>
<tbody>
<tr>
<td>80% to 100%</td>
<td>Failure</td>
<td>Likely</td>
<td>6 months to 1 year</td>
</tr>
<tr>
<td>60% to 80%</td>
<td>Danger</td>
<td>Probable</td>
<td>1 year</td>
</tr>
<tr>
<td>40% to 60%</td>
<td>Concern</td>
<td>Possible</td>
<td>1 to 2 years</td>
</tr>
<tr>
<td>0 to 40%</td>
<td>Design</td>
<td>Unlikely</td>
<td>2 to 3 years</td>
</tr>
</tbody>
</table>
Radius Map

Various degrees of ovality circled

Excessive cracking

Localized Bulge Cracking
Plastic Strain Index (PSI)

Negligible impact of ovality on PSI results

High Severity at crack sites
PSI Trend => Repair Need

Inside surface indications

Outside surface indications
Common Types of Bulge Repairs

• Window replacement
• Can replacement
• Weld overlays
  – Internal
  – External
  – Sandwich
Window Replacement

• Advantages
  – Simplest
  – Least expensive

• Disadvantages
  – Fit-up stresses
  – Two-way material mismatch
  – Short-term repair
Can Replacement

• Advantages
  – Better than window replacement
  – Effective solution for
    • Diagonal bulging
    • Extensive widespread cracking
    • Remote locations

• Disadvantages
  – Fit-up stresses
  – One-way material mismatch
  – Medium-term repair
Advantages of Weld Overlay Repair

• Advantages:
  – Lower nominal stresses under mechanical loads.
  – Favorable residual stresses on application surface.
  – Possible reduction of bulging severity.
  – Most effective and longest-lasting repair, if designed and applied properly.

• Disadvantages:
  – Need good automated procedure.
  – Unfavorable low tensile residual stresses.
  – Need proper engineering to handle potential for:
    • Instability / buckling
    • Excessive distortion.
    • Impact of transition stress riser on fatigue life.
    • Excessive thermal expansion stresses from repaired zone expanding differently from rest of wall.
    • Ratcheting in thinner wall that could result in generation of new bulges.
Buckling / Local Failure
Non-symmetric Distortion
Repair Implementation
Time History

• 08 coke drums commissioned in 1998
• Drums are 1.25Cr0.5Mo/SS410 clad

• Shell bulges monitoring since 2001
• Bulges >3” since 2007
• First shell crack: Apr2009 (2500cycles)
• First throughwall crack: Feb2010 (2740cycles)
• BOL repairs started: June2010
• Approx cycles: 3650 Oct13
Scope of Repairs

- Total repairs with Controlled-Deposition Welding (CDW, without PWHT)

- Total Surface Area BOL repairs: 3350sqft

- Max size single location BOL repairs: 663sqft (2.2m x 28m)
Inspection requirements

Preparatory

• Repair specific PQR: Hardness, Toughness, Microstructure
• Mock-up with approved WPS/PQR: I, V, S

Site execution

• Mapping+Marking
• Clad layer removal – Cu Sulfate test (A380)
• Thickness check, Base line diameter measurements
• BOL as per approved WPS: Surface finish at edges/interface, PMI, Thk, Fluorescent DPT, Distortion measurements, Taper edges 10:1, hardness limits for overlay/interface/HAZ
Challenges

- Overall process safety, Planning and scheduling for drum-pair repairs, with other drums in line.
- WPS/PQR: CDW with 3 layers min, hardness control
- Quality welders/operators specific to CDW requirements
- Working crew within one single confined space
- Simultaneous repairs for multiple locations in a drum
- Mapping/marking on drum wall
- Distortion measurements
- Controlling WPS parameters during execution at site
- Prediction of subsequent bulge growth
- Residual stress control
- Expected life post repairs, esp due to shake-down effect
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Photographs

Typical Shell Map with repair areas on shell courses

Typical Shell cross section: as-is/post-repairs

TYPICAL Shell/Clad configuration

TYPICAL Internal Shell Weld overlay repair (after 410SS clad cut-back)
Photographs

Typical bulge overlay repairs inside of the coke drum

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Performance

• Bulge growth under control, steady.