Failure Modes and Inspection Needs of Coke Drums

Mahmod Samman, Ph.D., P.E.
President
Houston Engineering Solutions, LLC
(832)512-0109
mms@hes.us.com
Overview

• Introduction
• Overview of common failures
• Skirt failures
• Shell failures
• Inspection and monitoring needs
• The big picture
• Summary
Introduction

• Profitable unit
• Failure-prone
  – Batch process
  – Excessive loads
    • Thermal
    • Mechanical
  – Randomness
    • Flow channels
    • Feed type
  – Human factors
Common Failure Modes

• **Skirt failures**
  – Cracks
  – Buckling
  – Bolt failures

• **Shell failures**
  – Bulges
  – Cracks
  – Tilting (banana)

• **Piping Failures**
  – Blow-down line
  – Nozzles
  – Pipe supports

• **Vibration-induced failures**

• **Structural concrete failures**
Skirt failures
Skirt Failures

• **Cracking in attachment weld**
  – Common in conventional welded skirts
  – Potential consequences
  – Drum replacement

• **Buckling**
  – Uncommon
  – Potential consequences

• **Anchor bolt failures**
  – Drum movement and “jumping”
  – Typically recurring
  – Becoming more common
  – Overload, fatigue, corrosion
  – Thermal gradients, vibrations, falling boulders, corrosion
Conventional Skirts

Variations:
• Slots
• Weld details
• Scallop
• Forged ring

Damage:
• Joint cracks
• Keyhole cracks
• Bulges
• Bolt failures

In-line

Lap-joint
<table>
<thead>
<tr>
<th>Description</th>
<th>Location</th>
<th>Percent Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking at Weld</td>
<td>A, B, C</td>
<td>56%</td>
</tr>
<tr>
<td>Cracking into Shell</td>
<td>A</td>
<td>43%</td>
</tr>
<tr>
<td>Cracking from Skirt OD</td>
<td>B</td>
<td>63%</td>
</tr>
<tr>
<td>Cracking From Skirt ID</td>
<td>C</td>
<td>26%</td>
</tr>
<tr>
<td>Cracking at Slots / Keyholes</td>
<td>D</td>
<td>76%</td>
</tr>
<tr>
<td>Total Cracking in Skirts</td>
<td>A, B, C, D</td>
<td>78%</td>
</tr>
</tbody>
</table>
Skirt Stresses

Temperature

Skirt Stress
Temperature Animation Close-Up
Axial Stress Animation
Skirt Attachment Experience

• API 1996 Survey:
  – 23% replaced skirt => 45% cracked again.
  – 54% ground-and-rewelded => 50% cracked again.

• Typical design life of conventional welded skirts under today’s transients:
  – 500 – 1500 cycles
  – 2 - 6 years

• Observed cracks in recent conventional welded skirts is 3 to 5 years.
Recap on Skirt Failures

• Skirt failures are common in conventional welded skirts especially attachment weld cracks.

• Drum design, fabrication, and operation influence skirt life.

• Neither skirt repairs nor replacement are typically effective in ending attachment weld cracking.
Shell failures and inspection needs
Shell Failures

• **Bulging and cracking**
  – Common
  – Consequences
  – Drum replacement

• **Tilting**
  – Becoming more common
  – Uneven drum heating or cooling
  – Single-sided inlets
  – Consequences (Functional vs. structural)
Shell Bulging & Cracking

• Classic
• Constrained balloon

Weil and Rapasky (1958)

Courtesy CB&I
## Cycles to First Bulge / Crack

### Cycles to First Bulge

*(Cycles to First Through Wall Crack for Reference)*

<table>
<thead>
<tr>
<th>Material</th>
<th>Average Number of Cycles to First Bulge</th>
<th>Minimum Number of Cycles to First Bulge</th>
<th>Maximum Number of Cycles w/o Bulge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td>3023</td>
<td>183</td>
<td>7057</td>
</tr>
<tr>
<td>Carbon ½ Moly</td>
<td>2504</td>
<td>346</td>
<td>(9386)*</td>
</tr>
<tr>
<td>Chrome Moly</td>
<td>2978</td>
<td>1286</td>
<td>(4745)*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Average First Through Wall Crack</th>
<th>Minimum Cycles to First Through Wall</th>
<th>Maximum Cycles without Crack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Steel</td>
<td>5968</td>
<td>3650</td>
<td>5749</td>
</tr>
<tr>
<td>Carbon ½ Moly</td>
<td>3968</td>
<td>1286</td>
<td>(9386)*</td>
</tr>
<tr>
<td>Chrome Moly</td>
<td>3570</td>
<td>2025</td>
<td>(5994)*</td>
</tr>
</tbody>
</table>

* - note, still operating without a bulge.
### Bulge Dimensions

**API 1996 Survey**

<table>
<thead>
<tr>
<th>Question</th>
<th>Maximum Answer Range</th>
<th>Average Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Vertical Length</td>
<td>3” to 620”</td>
<td>65”</td>
</tr>
<tr>
<td>Average Vertical Length</td>
<td>2” to 50”</td>
<td>23”</td>
</tr>
<tr>
<td>Maximum Circumferential Length</td>
<td>5.5” to 1,074”</td>
<td>547”</td>
</tr>
<tr>
<td>Average Circumferential Length</td>
<td>4” to 1,074”</td>
<td>408”</td>
</tr>
<tr>
<td>Maximum Radial Bulge</td>
<td>.31” to 6”</td>
<td>3”</td>
</tr>
<tr>
<td>Average Radial Bulge</td>
<td>¼” to 6”</td>
<td>2.1”</td>
</tr>
</tbody>
</table>
Locations of Bulges and Cracks

Histogram of Bulge and Crack Distribution

API 1996 Survey
Possible Causes of Bulging

• Radial growth:
  – Stress vs. strength
  – Type of feed
• Non-uniform:
  – Stiffness mismatch
  – Imperfections
  – Random channeling
  – Local heat treatment
• Progressive
• Patterns
  – Circumferential welds
  – Mid-plate
  – Mid-drum
Relatively Similar Bulging Pattern

Identical design and operation
Dissimilar Bulging Pattern

Identical design and operation
Consequences of Bulging

• Primary damage
• Secondary effects
• Can lead to leaks and fires
Shell Cracks

• Bulging-induced cracks
• Weld cracks
  – Defects
  – Weld-base boundary
  – Clad boundaries
• Combination
Bulging-Induced Cracks

INTERIOR

EXTERIOR
Bulging Severity

• Stress analysis
• Geometric analysis
• Strain analysis
Plastic Strain Index (PSI)

- Failure limits from API 579/ASME FFS
- Outcome:
  - Bulging-induced cracks:
    - Likelihood
    - Ranking
    - Locations
  - Frequency of laser scanning
- Correlates well with history of failures

<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>
Example
Identical design and operation

- Ovality
- Excessive cracking
- Localized bulge cracking
PSI Severity Maps

High Severity at cracking sites
PSI Trending
Recap on Shell Failures

• Shell failures are common.
• Several factors contribute to creating bulges.
• Bulging magnitude and severity are different.
• PSI analysis assesses the severity of bulges and provides directions for prioritizing inspection needs and optimizing resource allocations.
• Premature drum replacement can be avoided and bulges can be effectively managed with proper engineering, inspections, and repairs.
Inspection and monitoring needs
Overview

• Laser scanning
• Conventional nondestructive testing methods
• Acoustic emission testing / monitoring
• Temperature monitoring
• Strain monitoring
Laser Scanning

• Available laser scanning techniques

• Advantages
  – Bulge sizing and characterization
  – Some provide video surveying / photos

• Disadvantages
  – Significant differences in techniques / accuracy
  – Incomplete without engineering assessment
Conventional NDT Methods

• Advantages
  – Sizing of defects
  – Robust methods with physical record

• Disadvantages
  – Scaffolding and removal of insulation
  – Some require shutdown
  – Time-consuming / costly for entire drums
  – Too many indications
Acoustic Emission Testing

• Advantages
  – Detect active cracks only
  – Through-insulation
  – No shutdown

• Disadvantages
  – No size information
  – Human factors
Temperature Monitoring

• Advantages
  – Robust
  – Inexpensive
  – Commonly used and specified for new drums
  – Easily incorporated in control process

• Disadvantages
  – Incomplete without engineering analysis
  – Data management
Strain Monitoring

• Advantages
  – Measure of damage
  – Research / verification

• Disadvantages
  – Cost
  – Scaffolding / removal of insulation / wiring
  – Data management
  – Data scatter
Inspection/Monitoring Recap

• Most common inspection tools:
  – Visual
  – Laser scans
  – Liquid Penetrant
  – Ultrasonic testing techniques

• Valuable additional inspection/monitoring tools:
  – AET
  – Temperature monitoring
The Big Picture

• An effective mechanical integrity program:
  – Inspection
  – Assessment
  – operations
  – Repair
  – Replacement

  Integrally related
Summary

• Skirt and shell failure modes that are common in coke drums can lead to leaks and fires.
• Drum design, fabrication, and operation influence coke drum life.
• Premature drum replacement can be avoided and common failures can be effectively managed with proper analysis, assessment (PSI), inspections, and repairs.
• Most common inspection tools are visual testing, laser scanning, Liquid Penetrant, and Ultrasonic Testing techniques. Additional recommended tools include acoustic emission and temperature monitoring.
• Inspection needs are effectively fulfilled when inspections are performed as part of an inter-dependent mechanical integrity program.
QUESTIONS?

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