Bulging Assessment of Coke Drums

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

Ediberto B. Tinoco
Fábio C. Marangone
Hezio R. Silva
Petrobras, Brazil

Coking.com Conference
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Introduction

• Very common.
• Known for decades.
• Potential serious consequences.
• Premature drum replacement.
• Despite design improvements, still a problem.
Historical Bulging Pattern

Weil and Rapasky paper (1958): The constrained balloon.
Consequences of Bulging

• PRIMARY: Excessive strain
• SECONDARY: Increase in nominal stress
• Leaks and fires
Possible Causes of Bulging

- **Progressive non-uniform radial growth.**
- **Radial growth:**
  - Quench stress.
  - Strength of base metal.
  - Type of feed.
- **Non-uniform:**
  - Mismatch.
  - Imperfections.
  - Side inlet.
  - Random channeling.
  - Local post weld heat treatment (PWHT)
- **Progressive (ratcheting)**
Shell Cracks

- Bulging-induced cracks
- Weld cracks
- Combination
Bulging-Induced Cracks
Bulging Assessment per API-579 / ASME-FFS

• Level 1: N/A to coke drums
  – Fabrication tolerance.
  – Not for cyclic service.

• Level 2: N/A to coke drums

• Level 3: Infeasible and costly process
  – Lack of proper load definition.
  – Costly to obtain data.
  – Prohibitive to simulate bulging.
  – Research work.
Industry Practice

• Stress analysis
• Geometric analysis
• Strain analysis
Stress Analysis

• High stress concentration correlates with severity.
• Linear elastic finite element analysis.
• Drum is built with bulges (no plastic strain).
• Apply design / unit loads.

• Advantages
  – Simple

• Disadvantages
  – Unrealistic model.
  – Susceptible to several error sources (e.g. ovality, bulge shape, ..)
  – Excludes primary cause of bulging failure.
Strain Analysis

• High strain correlates with severity.
• Plastic Strain Index (PSI)™ uses failure limit of API 579/ ASME FFS

• Advantages:
  – Focuses on primary mode of failure.
  – Excellent correlation with bulging cracks.
  – Uses failure limits of industry standard.

• Disadvantages:
  – Relatively new.
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>
PSI Trending
Case Study

- Four sister drums commissioned in 1994.
- Inside diameter: 6.400 meters (21 ft).
- Tangent-to-tangent length: 22.6 meters (74 ft).
- Material: 1Cr - 1/2Mo with stainless steel clad (SA-240 TP405).
- Variable wall thickness: 12.5 to 25 mm (0.492 to 0.984 inch) with 3 mm clad.
- Nominal 48 hour full cycles (24 hour fill).
- Compare stress and strain analysis techniques.
Radius Map

Various degrees of ovality circled

Excessive cracking

Localized Bulge

Cracking
Stress Concentration Factor
(axial SCF @ outside surface)

Ovality-based
High stress concentrations highlighted

Highest SCF

Negligible severity at crack site
### Stress Concentration Factor

**Summary**

#### Axial Stress - Inside Surface

<table>
<thead>
<tr>
<th>Drum</th>
<th>Max Positive</th>
<th>Max Negative</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>5.7</td>
<td>-2.4</td>
</tr>
<tr>
<td>B</td>
<td>6.7</td>
<td>-3.6</td>
</tr>
<tr>
<td>C</td>
<td>7.8</td>
<td>-3.5</td>
</tr>
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<td>6.4</td>
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#### Hoop Stress - Inside Surface

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<tr>
<td>A</td>
<td>4.2</td>
<td>-1.0</td>
</tr>
<tr>
<td>B</td>
<td>3.1</td>
<td>-0.6</td>
</tr>
<tr>
<td>C</td>
<td>4.0</td>
<td>-2.1</td>
</tr>
<tr>
<td>D</td>
<td>3.9</td>
<td>-0.7</td>
</tr>
</tbody>
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#### Axial Stress - Outside Surface

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Plastic Strain Index (PSI)

Negligible impact of ovality on PSI results

High Severity at crack sites
Plastic Strain Index (PSI)  
(Summary)

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<tr>
<td>Maximum PSI (inside surface)</td>
<td>+51.5%</td>
<td>+67.0%</td>
<td>+80.8%</td>
<td>+76.1%</td>
</tr>
<tr>
<td>Minimum PSI (outside surface)</td>
<td>-28.0%</td>
<td>-33.2%</td>
<td>-41.0%</td>
<td>-47.3%</td>
</tr>
<tr>
<td>Surface of highest severity</td>
<td>inside</td>
<td>inside</td>
<td>inside</td>
<td>inside</td>
</tr>
<tr>
<td>Severity level</td>
<td>Concern</td>
<td>Danger</td>
<td>Failure</td>
<td>Danger</td>
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Conclusions from Case Study

• Stress and strain analysis techniques produce significantly different results.
• Stress analysis appeared to be susceptible to several error sources such as drum ovality and bulge shape.
• PSI has correlated well with bulging-induced cracks.
Summary

• Bulging is a common and recurring problem in coke drums that is linked to their design, fabrication, and operation.
• Stress analysis of bulging is based on the assumption that stress concentration is an indication of severity. The method uses unit or design loads to calculate stress concentrations.
• The Plastic Strain Index (PSI) is a strain assessment method based on failure limits of API 579/ASME FFS.
• An example assessment of four coke drums revealed that:
  – Stress and strain analysis techniques produce significantly different results.
  – Stress analysis appeared to be susceptible to several error sources such as drum ovality and bulge shape.
  – PSI has correlated well with bulging-induced cracks.