Assessment of Bulging Severity

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2009 COKING.COM Meeting
Galveston, TX
March 2008
OVERVIEW

- Background
- Plant Experience
- Q&A
BACKGROUND

- Why does bulging occur?
- What are the consequences of bulging?
- Bulging magnitude versus cracking severity
- The Bulging Intensity Factor (BIF)
Why Does Bulging Occur?

- Resistance of coke (high nominal stresses)
- Material / thickness mismatch (mechanical ratchet or progressive distortion)
- Operation (cycle time, switch temperature, feed rate, ..)
- Flow patterns inside drums (cold / hot spots)
What are the consequences of Bulging?
What are the consequences of Bulging?

Hoop Stress For Bulged Drum at 324 deg Profile ('95)
Pressure = 38.4 psi + Hydrostatic

Axial Stress For Bulged Drum at 324 deg Profile ('95)
Pressure = 38.4 psi + Hydrostatic
What are the consequences of Bulging?

Higher nominal stresses

Accelerated bulging mechanism

Cumulative fatigue damage (cracks and fires)
Bulging Magnitude vs. Cracking Severity
Bulging Magnitude vs. Cracking Severity
Can we use API-579 Assessment?

Sure! Level 3 Assessment only
(plastic collapse, local failure, buckling, and fatigue analyses)

Requirements

(1) quantify both mechanical and thermal loads,
(2) simulate how these bulges were formed to account for residual stresses and plastic deformation in bulges (nonlinear model),
(3) use continuum elements to capture stress fields at sharp bulges,
(4) evaluate crack stability or growth if any exist or likely to form, and
(5) incorporate creep damage effects for Carbon steel drums.

Problems

Cost: A strain-gage monitoring system, a nonlinear continuum model, and a LOT of labor and computer time can cost $ \frac{1}{2} to 1 M

Feasibility: Requirement (2) above may not be achievable!
TOOL DEVELOPMENT

Cracking histories → Correlation → Geometric patterns → Pattern Recognition
Slicing the Bulge

Circumferential profile

Longitudinal profile
Geometric Parameters

Magnitude

Curvature

Frequency

Circumferential and longitudinal profiles

Cross correlation

BIF
The Bulging Intensity Factor (BIF)

From laser scans:

Identify and Rank
areas most susceptible to cracking

Prioritize & optimize inspections
# BULGING INTENSITY FACTOR (BIF)

Chrome Alloy Drums

<table>
<thead>
<tr>
<th>BIF</th>
<th>External Cracking Likelihood</th>
<th>Internal Cracking Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥+2</td>
<td></td>
<td>SEVERE (End of Economic Life)</td>
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<tr>
<td>+1.5 to +2</td>
<td></td>
<td>Very High</td>
</tr>
<tr>
<td>+1 to +1.5</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>+0.75 to +1</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>0 to +0.75</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>0 to -0.75</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>-0.75 to -1</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>-1 to -1.5</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>-1.5 to -2</td>
<td></td>
<td>Very High</td>
</tr>
<tr>
<td>≤-2</td>
<td></td>
<td>SEVERE (End of Economic Life)</td>
</tr>
</tbody>
</table>
# BULGING INTENSITY FACTOR (BIF)

Carbon steel and C-1/2 Mo Drums

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<thead>
<tr>
<th>BIF</th>
<th>External Cracking Likelihood</th>
<th>Internal Cracking Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq+2.5$</td>
<td>SEVERE (End of Economic Life)</td>
<td></td>
</tr>
<tr>
<td>+2 to +2.5</td>
<td>Very High</td>
<td></td>
</tr>
<tr>
<td>+1.5 to +2</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>+1 to +1.5</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>0 to +1</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>0 to -1</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>-1 to -1.5</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>-1.5 to -2</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>-2 to -2.5</td>
<td>Very High</td>
<td></td>
</tr>
<tr>
<td>$\leq-2.5$</td>
<td>SEVERE (End of Economic Life)</td>
<td></td>
</tr>
</tbody>
</table>
### BULGING INTENSITY FACTOR (BIF)

#### SEVERITY IMPLICATIONS

<table>
<thead>
<tr>
<th>Severity Grade</th>
<th>Cracking Pattern Related to Bulging</th>
<th>Recommended Laser Scanning Frequency</th>
</tr>
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<tbody>
<tr>
<td>Low</td>
<td>Rare</td>
<td>Every 3 years</td>
</tr>
<tr>
<td>Medium</td>
<td>Seldom</td>
<td>Every 2 years</td>
</tr>
<tr>
<td>High</td>
<td>Occasional</td>
<td>Every 1 year</td>
</tr>
<tr>
<td>Very High</td>
<td>Repeated</td>
<td>Every 1 year</td>
</tr>
<tr>
<td>SEVERE</td>
<td>Too frequent to operate economically</td>
<td>Consider partial or full shell replacement</td>
</tr>
</tbody>
</table>
DATABASE

• Calibration data base: 11 drums with known cracking histories.

• Application data base: 70+ scans.

• Carbon steel, Carbon-1/2Mo and 1 to 1¼ Chrome drums.
DATABASE

Age versus BIF
(Age shown does not account for any repairs or can replacements)
DATABASE

Diameter versus BIF

BIF (maximum absolute)

Inside Diameter (feet)
DATABASE
Minimum thickness versus BIF

![Graph showing the relationship between minimum thickness and BIF.](image-url)
DATABASE

Maximum thickness versus BIF

GRAPHIC: Scatter plot showing the relationship between maximum thickness (inch) and BIF (maximum absolute) values.

- X-axis: Maximum Thickness (inch)
- Y-axis: BIF (maximum absolute)
- Data points indicate variability in thickness values across different BIF levels.
BIF Output

- Two-dimensional color contour plots
- Three-dimensional surface maps
- Ranking of most severe locations
- Multiple scans:
  - Statistical analysis
  - Growth rate analysis
  - Future cracking projections
SUNCOR COKE DRUMS

- 6 of C- /2 Mo Drums
  - ID = 26’, T-T = 66’
  - Built 1966
  - Completed 8200 Cycles

- 2 of 1Cr - 1/2 Mo Drums
  - ID = 26’, T-T = 66’
  - Built 1979
  - Completed 5,500 Cycles

- 4 of 1Cr- 1/2 Mo
  - ID = 29’, T-T = 94’
  - Built 2001
  - Completed 1800 Cycles

- Upcoming Cokers
  - 2 of 30’ dia – 1Cr--1/2MO (Installed)
  - 6 of 32’ dia – 1Cr- 1/2MO

Suncor Portion of this presentation is compiled with the contributions received from Projects, Reliability, Process and Operations Group.
Special Thanks to: Vrajesh Shah- Sustainable Projects, Charles Stephens & Aaron Johnson - Reliability Engineering
OBJECTIVES

• How severe is the Bulging in the Drums?
• How should we prioritize the drum inspection needs?
• When will the bulging result in Cracking?
• When should we replace the coke drums?
• How soon do we need to rescan the drum?
• How to minimize unplanned outages?
• What will be the total crack repair cost 5 to 10 years from now?
Evaluation Techniques

- Laser scans
- Bulge Severity and Growth Analysis using Bulge Inspection Factor (BIF)
- JIP CokerCola software analysis
- Finite Element Analysis
- Probabilistic Crack Propagation calculations
- Strain Gage Measurements
- AET (Acoustic Emission Testing)
1. Search for bulging and evaluate it.
2. Search for cracking.
3. Determine actual cyclic stress in shell and skirt.
COMPARE 1996 AND 2000 BULGES
COMPARE 2002 AND 2004 BULGES
1967: 5C-3~8 started up
4 Thru wall cracks in Drum 6
1 crack in Drum 5
(April 2001)
1981: 5C-50/51 started up
1 Crack in 5C50
June 1998
3/4/7/8 never cracked

Cracked August 2002 causing a fire hazard

Through wall crack along upper edge of circ. weld
Outward bulge at several inches centered on circ. weld
Bulges change over time

Suncor tracks the progress of the BIF of a certain bulge and predict when it may reach a critical value (BIF > 1.5)

BIF map of 1996 scan

BIF map of 2004 scan
BIF Results

Suncor used SES’s BIF to evaluate bulge severity of the drum surface. Result were intended as a guide to rank bulges for inspection priority as a function of their likelihood to encourage cracking.

<table>
<thead>
<tr>
<th>Rank</th>
<th>BIF</th>
<th>Zone</th>
<th>severity</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1.82</td>
<td>A</td>
<td>very high</td>
</tr>
<tr>
<td>2</td>
<td>1.54</td>
<td>A</td>
<td>very high</td>
</tr>
<tr>
<td>3</td>
<td>1.49</td>
<td>B</td>
<td>high</td>
</tr>
<tr>
<td>4</td>
<td>1.23</td>
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<tr>
<td>5</td>
<td>1.19</td>
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<td>6</td>
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<td>7</td>
<td>1.10</td>
<td>B</td>
<td>high</td>
</tr>
<tr>
<td>8</td>
<td>1.06</td>
<td>B</td>
<td>high</td>
</tr>
<tr>
<td>9</td>
<td>1.03</td>
<td>A</td>
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<tr>
<td>10</td>
<td>0.94</td>
<td>B</td>
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<tr>
<td>11</td>
<td>0.93</td>
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<tr>
<td>12</td>
<td>0.91</td>
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<tr>
<td>13</td>
<td>0.85</td>
<td>B</td>
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</tr>
<tr>
<td>14</td>
<td>0.84</td>
<td>C</td>
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<tr>
<td>16</td>
<td>0.83</td>
<td>C</td>
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<tr>
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<td>0.76</td>
<td>B</td>
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Changes in BIF for Bugle A and Bulge B

Increase in the BIF over the years.

Changes in BIF Bugle A

Changes in BIF for Bulge B
### BIF RESULTS - ALL DRUMS

<table>
<thead>
<tr>
<th>Drum</th>
<th>Maximum BIF and severity ranking</th>
<th>Rate of deterioration</th>
<th>Areas of Concern</th>
</tr>
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<tbody>
<tr>
<td>3</td>
<td></td>
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</tr>
<tr>
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<tr>
<td>6</td>
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<td>1.66</td>
</tr>
<tr>
<td></td>
<td>v. high</td>
<td>v. high</td>
<td>v. high</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
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<tr>
<td>50</td>
<td>0</td>
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<td>1.06</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>51</td>
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</table>
Crack away from weld (BIF=1.82)

THROUGH WALL CRACK August 2005

Bulge A is expected to have a “severe” likelihood of cracking between May/2005 and June/2006.

Bulge B- The bulges in shell course #5, is expected to remain stable at the “very high” likelihood of cracking for the next few years.
CONCLUSIONS

• The BIF is a valid method for evaluating the severity of bulging in coke drums

• The BIF is used for identifying and ranking the most severe locations on a drum and finding cracks before they go through wall

• Suncor used this technique along with other available tools to make future predictions of drum inspection needs and projected life

• Suncor’s experience shows that the BIF correlates well with actual cracking history
Summary of Benefits

- **Operators:** planned maintenance outages
- **Owners:** quantify the risk of failure and plan drum repairs and replacement
- **Inspectors:** prioritize work and optimize the allocation of resources
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