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?

Hoop Stress For Bulged Drum at 324 deg Profile (95)
Pressure = 58.4 psi + Hydrostatic

Axial Stress For Bulged Drum at 324 deg Profile (95)
Pressure = 58.4 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

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

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**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>SEVERE (End of Economic Life)</td>
<td>Very High</td>
</tr>
<tr>
<td>+1.5 to +2</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>+1 to +1.5</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>+0.75 to +1</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>0 to +0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 to -0.75</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>-0.75 to -1</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>-1 to -1.5</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>-1.5 to -2</td>
<td>Very High</td>
<td></td>
</tr>
<tr>
<td>≤-2</td>
<td>SEVERE (End of Economic Life)</td>
<td></td>
</tr>
</tbody>
</table>
BULGING INTENSITY FACTOR (BIF)

Carbon steel and C-1/2 Mo Drums

<table>
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<tr>
<th>BIF</th>
<th>External Cracking Likelihood</th>
<th>Internal Cracking Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥+2.5</td>
<td>SEVERE (End of Economic Life)</td>
<td>Very High</td>
</tr>
<tr>
<td>+2 to +2.5</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>+1.5 to +2</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>+1 to +1.5</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>0 to +1</td>
<td></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>≤-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>
</thead>
<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

DATABASE

Minimum thickness versus BIF
DATABASE
Maximum thickness versus BIF

- 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)
Approach for Remaining Life

1. Search for bulging and evaluate it.
2. Search for cracking.
3. Determine actual cyclic stress in shell and skirt.
4. Develop Long Term Operation, Inspection, Repair and Replacement Plans

SES
- BIF (Bulging Intensity Factor)
- FEA (Finite element Analysis)
- Strain Gage Shell + Skirt

CIA
- Laser Scans

Suncor
- In house crack prediction analysis
- Economic Evaluation

Cold Eyes Review

AET
- Drum Remaining Life

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 SC50
- June 1998
- 3/4/7/8 never cracked

CRACK HISTORY – ALL DRUMS
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 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>
</thead>
<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>
<td>A</td>
<td>high</td>
</tr>
<tr>
<td>5</td>
<td>1.19</td>
<td>A</td>
<td>high</td>
</tr>
<tr>
<td>6</td>
<td>1.12</td>
<td>A</td>
<td>high</td>
</tr>
<tr>
<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>
<td>high</td>
</tr>
<tr>
<td>10</td>
<td>0.94</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>11</td>
<td>0.93</td>
<td>E</td>
<td>medium</td>
</tr>
<tr>
<td>12</td>
<td>0.91</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>13</td>
<td>0.85</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>14</td>
<td>0.84</td>
<td>C</td>
<td>medium</td>
</tr>
<tr>
<td>15</td>
<td>0.83</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>16</td>
<td>0.83</td>
<td>C</td>
<td>medium</td>
</tr>
<tr>
<td>17</td>
<td>0.80</td>
<td>D</td>
<td>medium</td>
</tr>
<tr>
<td>18</td>
<td>0.79</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>19</td>
<td>0.76</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>20</td>
<td>0.76</td>
<td>B</td>
<td>medium</td>
</tr>
</tbody>
</table>
Changes in BIF for Bugle A and Bulge B

Increase in the BIF over the years.

Changes in BIF for 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>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.73 low</td>
<td></td>
<td>Fifth-cans and the south side of the lower four circumferential welds</td>
</tr>
<tr>
<td>4</td>
<td>0.71 low</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.77 Medium</td>
<td></td>
<td>Circumferential weld between the fourth and fifth cans</td>
</tr>
<tr>
<td>6</td>
<td>1.66 high, 1.59 high, 1.62 high</td>
<td>1.82 High</td>
<td>Northeast side of the middle of the third can and the bottom of the fifth can</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1.06 high, 1.1 high</td>
<td>1.14 high</td>
<td>Mild, Bottom of the fifth can</td>
</tr>
<tr>
<td>51</td>
<td>1.1 high</td>
<td></td>
<td>Bottom of the fifth can</td>
</tr>
</tbody>
</table>
Crack away from weld (BIF=1.82)

**Plant Experience**

**BIF Bulge Severity Prediction for Likelihood of Cracking**

- **Maximum BIF (A)**:
  - Bulge A is expected to have a "severe" likelihood of cracking between May/2005 and June/2006.
  - Bulge B: The bulges in shell course #6, is expected to remain stable at the "very high" likelihood of cracking for the next few years.

**Through Wall Crack August 2005**
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
<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Company</th>
<th>Email</th>
</tr>
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<tbody>
<tr>
<td>Mahmod Samman</td>
<td>Ph.D., P.E.</td>
<td>Stress Engineering Services, Inc.</td>
<td><a href="mailto:mms@stress.com">mms@stress.com</a></td>
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<tr>
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