Assessment of Bulging Severity

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&

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Coking.com Coke Drum Workshop
Calgary, Alberta
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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 $½ 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)

## 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>
</tr>
<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>
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<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>
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# BULGING INTENSITY FACTOR (BIF)

**Carbon steel**

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<tr>
<td>≥+2.5</td>
<td>SEVERE (End of Economic Life)</td>
<td></td>
</tr>
<tr>
<td>+2 to +2.5</td>
<td></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 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>
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</tr>
<tr>
<td>≤-2.5</td>
<td>SEVERE (End of Economic Life)</td>
<td></td>
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</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>
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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.
- Total data base: 80+ 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

![Diagram showing the relationship between BIF (maximum absolute) and Inside Diameter (feet).]
DATABASE

Maximum thickness versus BIF

[Graph showing the relationship between Maximum thickness (inch) and BIF (maximum absolute)]
DATABASE

Diameter over Minimum Thickness versus BIF

D / Tmin

BIF (maximum absolute)
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
Case Study (1)
Case Study (1)

“V. HIGH - SEVERE”
Almost through-wall crack
Case Study (2)
Case Study (2)

“SEVERE”
Multiple cracks: total 21 ft long

“HIGH”
2 cracks: 2.5 ft and 3 ft long
Summary

• The Bulging Intensity Factor (BIF) is a geometry-based technique for assessing the severity of coke drum bulges

• The method is designed to help in:
  • Planning maintenance outages, repairs, and replacement
  • Determining the frequency of laser scans
  • Quantifying the risk of failure
  • Prioritizing inspections and optimizing resource allocations

• So far, predictions seem to correlate well with cracking history
SUNCOR COKE DRUMS (14)

- 6 of C- 1/2 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

- 2 of 30’ dia – 1Cr-1/2 Mo
- Built 2007
- 6 of 32’ dia – 1Cr- 1/2 Mo (future)

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 Bulging Intensity Factor (BIF)
- Software analysis – in house
- Finite Element Analysis
- Probabilistic Crack Propagation calculations
- Strain Gage & temperature Measurements
- AET (Acoustic Emission Testing)
- Shear wave UT
<table>
<thead>
<tr>
<th>DRUM</th>
<th>Maximum BIF and severity ranking</th>
<th>Severity of last scan</th>
<th>Deterioration speed</th>
<th>Notable areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5C3</td>
<td>0.66~0.73</td>
<td>0.76~0.66</td>
<td>Marginally Medium</td>
<td>Slow</td>
</tr>
<tr>
<td>5C4</td>
<td>0.58~0.71</td>
<td>0.76~0.76</td>
<td>0.61~0.56</td>
<td>Low</td>
</tr>
<tr>
<td>5C5</td>
<td>0.77~0.61</td>
<td></td>
<td>Medium</td>
<td>Mild</td>
</tr>
<tr>
<td>5C6</td>
<td>1.66~1.02</td>
<td>1.59~1.08</td>
<td>1.82~1.10</td>
<td>Very high</td>
</tr>
<tr>
<td>5C7</td>
<td>0.68~0.75</td>
<td>0.46~0.71</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>5C8</td>
<td>0.68~0.89</td>
<td>0.77~0.60</td>
<td>0.75~0.64</td>
<td>Marginally Medium</td>
</tr>
<tr>
<td>5C50</td>
<td>1.06~0.64</td>
<td>1.14~0.69</td>
<td>High</td>
<td>Mild</td>
</tr>
<tr>
<td>5C51</td>
<td>1.10~0.73</td>
<td>High</td>
<td>N/A</td>
<td>Bottom of the fifth can</td>
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Crack Repair History on U1 Coke Drum Shells  Updated February 2009

Through Wall Crack

Bulge A

Bulge B

Bulge A

Bulge A

Bulge A

Bulge A

Bulge A

Bulge A

Bulge A

5C-8
5C-7
5C-6
5C-51
5C-50
5C-5
5C-4
5C-3


0 1 2 3 4 5 6 7 8

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### BIF Results

Suncor used SES’s BIF to evaluate bulge severity of the drum surface. Results 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>
<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>0.78</td>
<td>B</td>
<td>medium</td>
</tr>
<tr>
<td>20</td>
<td>0.76</td>
<td>B</td>
<td>medium</td>
</tr>
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</table>
BIF Bulge Severity Prediction for likelihood of Cracking

5C-6 BIF reached severe limit before 2006 and bulge repaired through weld overlay in 2008 T/A

BIF reaches severe limit on or before 2018 based on laser scan data up to 2005

5C-3, 4, 5, 7 & 8 BIF prediction based on laser scan data up to 2007

5C-3, 4, 5, 7 & 8 BIF prediction does not fit well but appears stable

BIF reaches severe limit on or before 2027 based on laser scan data up to 2007
CONCLUSIONS

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

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

• Suncor’s experience shows that the BIF correlates well with actual cracking history
Questions?

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Company</th>
<th>Email</th>
<th>Phone</th>
</tr>
</thead>
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<tr>
<td>Mahmoud Samman, Ph.D., P.E.</td>
<td>Stress Engineering Services, Inc.</td>
<td><a href="mailto:mms@stress.com">mms@stress.com</a></td>
<td>281-955-2900</td>
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