Assessment of Bulging Severity

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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 Bullging?

- 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
# 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>
</tr>
<tr>
<td>0 to +0.75</td>
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<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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</table>
# BULGING INTENSITY FACTOR (BIF)

## Carbon steel

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

Inside Diameter (feet)

BIF (maximum absolute)
DATABASE
Maximum thickness versus BIF
DATABASE
Minimum thickness versus BIF
DATABASE

Diameter over Minimum Thickness versus BIF

![Graph showing the relationship between Diameter over Minimum Thickness (D/Tmin) and BIF (maximum absolute) with data points distributed across various values of D/Tmin and BIF.](image-url)
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

- 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 Bulging Intensity 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.

Approach for Remaining Life

- SES
  - BIF (Bulging Intensity Factor)
- CIA
  - Laser Scans
- Suncor
  - In house crack prediction analysis
- Economic Evaluation
- Strain Gage Shell + Skirt
- AET
  - Drum Remaining Life
COMPARE 1996 AND 2000 BULGES
COMPARE 2002 AND 2004 BULGES
CRACK HISTORY – ALL DRUMS

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 of 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. 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>
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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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<td>5</td>
<td>1.19</td>
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<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>
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<td>high</td>
</tr>
<tr>
<td>9</td>
<td>1.03</td>
<td>A</td>
<td>high</td>
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<tr>
<td>10</td>
<td>0.94</td>
<td>B</td>
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</tr>
<tr>
<td>11</td>
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<tr>
<td>14</td>
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<td>0.76</td>
<td>B</td>
<td>medium</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>
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<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
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<tr>
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<td>0</td>
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<td>1.66</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
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</tr>
<tr>
<td>50</td>
<td>0</td>
<td></td>
<td>1.06</td>
</tr>
<tr>
<td>51</td>
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BIF Bulge Severity Prediction for Likelihood of Cracking

5C6-A BIF Prediction - reaches Severe Limit before Jan 1, 2006

5C6-A Crack June 2002 and August 2004

5C6-A Fire 1999 causes buckles and dents

5C6-B BIF does not Curve fit well but appears stable

5C50: BIF (3 Points) and 5C-51 (1 point)

5C-03, -04, -05 BIFs (1 scan each in 2002)

5C-03, -04, -05 BIF Prediction - quadratic polynomial (same as 5C-06)

5C50 & 51 - BIF Prediction reaches Severe Limit about Jan 1, 2017

5C50 and 51 BIF Prediction exponential function


BIF Bulge Severity
Plant Experience

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

• 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?

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