Fatigue Life & Reliability Consideration During Field Repair of Coke Drum & Piping

2017 Refcomm Presentation at Galveston, Texas
May 8-12, 2017

Anand Umakanthan
Senior Vice President
Head- Reliability Fixed Equipment & Piping

Tej Chadda
Director, Technology Technical Services
Fatigue Life and Reliability Considerations during Field Repair of Coke Drum & Piping

OVERVIEW

► Introduction to RIL DCU & (16)-Coke drum / Piping System
► Repair Consideration
► Fatigue Life & Reliability Consideration
► Field Repair Execution (Solid Skirt ; Vapor Line)
► Routine Inspection & Monitoring
► Thermal Operation & Gradient Optimization
► Q & A
Introduction to RIL DCU & (16)-Coke drum / Piping System

AmecFW DCU Process Licensor and DEC

Coker # 1
► Coker # 1 with (8)-coke drums / bottom feed / started in year ’99
► Basis of original process design – 24 hr coking cycle
► Coking cycle reduced to 14 hrs few years after commissioning

Coker # 2
► Coker # 2 with (8)- drums / single side feed / started in year ’09
► (4) coke drums modified to dual feed inlet in year ’13
► Basis of original process design – 13 hr coking cycle
► Coke drum design “duplicate” of Coker # 1 except “uniform” wall
Introduction to RIL DCU & (16)-Coke drum / Piping System (cont’d)

► Skirt Junction weld cracks continued to be monitored and repaired “on-line”
► Vapor line weld cracks continued to be monitored and repaired
► Thermal Gradient and operation optimization performed by plant operators in year 2007 with assistance from AmecFW
► Routine Inspection and monitoring programs for coke drum & piping welds implemented by RIL reliability team per recommendation and assistance from AmecFW
► Current goal is field repair of coke drum / piping considering also fatigue life and reliability improvement
► Current modification to coke drums include the use of Center Feed Injection Device
(Operational results will be shared in future)
Field Repair & Fatigue Life / Reliability Improvement Consideration

► Can existing design be upgraded to be fatigue resistant?
► Can existing fabrication practice be upgraded to be fatigue resistant?
► Can existing thermal operation be further optimized to reduce thermal gradient after switch to coking and during water quench?
► Can Delta T between drum / Vapor line be reduced during quench?
Fatigue Life & Reliability Consideration (cont’d)

Weld build-up skirt junction crack, typical Locations & Fatigue Resistant Consideration:
Can thermal B.M. / Stress be reduced at skirt crotch area by redesign?
Fatigue resistant design change during field repair to reduce moment / stress. Repair performed during shutdown using shop fabricated slotted skirt panel, field welding & PWHT.
Fatigue Life & Reliability Consideration (cont’d)  
(During coke drum field repair)

Key Factors to be considered during the field repair of aging coke drum:

► The original design, fatigue life basis, stress riser and fatigue resistance of the coke drums.
► The original fabrication and stress risers of coke drum.
► Coke drum temperature monitoring data using skin TI’s, Thermal gradient and Thermal Operation history of coke drum
► Coking cycle history
► Operating thermal operation parameters including preheat, drum temperature at switch to coking, switch operation and water quench.
► Past inspections and repair history of shell / cone and critical welds, crack, bulge and detailed mechanical integrity assessments
► Stress riser and the quality of corner intersections (chamfering / radiused) between slots and keyholes especially at the upper keyhole
Fatigue Life & Reliability Consideration (cont’d)
(Modification of coke drum solid skirt to slotted skirt)

**FEA of solid and slotted skirt, thermal gradient & estimated fatigue life**
A comparative stress study of skirt modification was performed. The results are tabulated below.

<table>
<thead>
<tr>
<th>Skirt Description</th>
<th>Skirt Slot</th>
<th>Thermal Gradient</th>
<th>Estimated Fatigue Life (Inner Crotch)</th>
<th>Estimated Fatigue Life (Upper Keyhole)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original / Solid</td>
<td>None</td>
<td>8H@500F/10Q</td>
<td>2100</td>
<td>N/A</td>
</tr>
<tr>
<td>Original / Solid</td>
<td>None</td>
<td>12H@500F/20Q</td>
<td>1200</td>
<td>N/A</td>
</tr>
<tr>
<td>Modified/Slotted</td>
<td>WITH SLOTS</td>
<td>8H@500F/10Q</td>
<td>&gt;7000</td>
<td>&gt;7000</td>
</tr>
<tr>
<td>Modified/Slotted</td>
<td>WITH SLOTS</td>
<td>12H@500F/20Q</td>
<td>4800</td>
<td>8900</td>
</tr>
</tbody>
</table>
Fatigue Life & Reliability Consideration (cont’d)
Operating thermal gradient review & optimization

Thermal Gradient Review of Skirt Junction and Optimization of Coke drum Thermal Operation
Optimization of thermal Operation & gradients:

Key operational parameters depending on the design and fatigue life basis:

► Pre-heat temperature of coke drum prior to switch to coking
  (290 deg C is preferred but should be a minimum of 260 deg C)
► The duration of the switch to coking to avoid thermal shock (generally a 2-step switch targeting a 15 minute interval).
► The transient thermal gradients after switch to coking (generally in the target range of 4 – 7 deg C/min)
► The transient thermal gradients during water quenching (generally in the target range of 8 – 12 deg C/min)
► Optimize the quench rate and schedule to accomplish the above targets and guidelines
Fatigue Life & Reliability Consideration (cont’d)
Critical High Stress Piping Weld, Crack & Repair

Overhead Piping Critical High Stress Weld, Crack & Repair Consideration
- Thermal Fatigue & Vibration Induced Fatigue Consideration
- Original design, whether fatigue resistant
- Weld quality impacts on fatigue life and Fatigue Strength Reduction Factor consideration
- Components for which ASME B31.3 Code does not provide equation to calculate Stress Intensification Factor (SIF)
- SIF for Pipe or Pipe Fitting to Pipe Thickness mismatch
- SIF for pipe to reducer
- SIF for pipe to flange
- SIF of the above weld junctions require detailed FEA for further use
Enhanced fabrication, examination and inspection in addition to the typical welding and NDE procedures, specifically:

- The final weld pass on the ID and OD is to be ground smooth and flush to remove any weld cap.

- Any offset between thicknesses to be ground to 10:1 taper or use thickness transition spool.

- 100% visual inspection of both OD and ID is required.

- For carbon and low alloy steel materials, perform 100% inspection of the root pass and final pass (ID as well as OD) after grinding smooth and flush.

- 100% RT of the final weld.

- Acceptance criteria for welds per B31.3 Table 341.3.2 for severe cyclic service.
Fatigue Life & Reliability Consideration (cont’d)
Effect of banana movement, BE & piping stress

Coke Drum Banana Movement Estimate

- Consider temperature difference between the hot side and the cold side of coke drum shell during operation, especially during quench
- Estimate the banana movement, (BE), of the coke drum
  \[ BE = 1.2 \left( R + 0.5D \right) \left( 1 - \cos \left( \alpha \right) \right) \]
  \[ \alpha = 57.2956 \gamma (Th-Tc) \left( 1 + \gamma x Tc \right) \pi / (180D) \]
- Perform overhead piping system stress analysis
- Perform repair assessment considering cyclic thermal stress level:

Legend

D  Coke drum nominal diameter
L  Coke Drum Height, Bottom Tangent Line to Top Tangent Line
Th Shell Hot Side Temperature
Tc Shell Cold Side Temperature
\( \gamma \) Coefficient of thermal expansion
Fatigue Life & Reliability Consideration (cont’d)
Calculation of SCF at thickness mismatch using FEA

FEA MODEL - 2D AXISYMMETRIC
@ Pipe / Fitting Wall Thickness Mismatch

FEA STRESS RESULTS & SCF

Stress Intensity
Type: Stress Intensity
Unit: MPa
Value: 2.53

Stress Concentration Factor (SCF) = 2.53
Fatigue Life & Reliability Consideration (cont’d)
Calculation of “Delta T” between Coke drum & OVHD line

Temperature Profile for TI's @ Various elevations of coke drum (DFI)
Consideration for Skirt Repair / Modification

![Diagram of WELD DEPOSIT and OUTSIDE with labels]

![Bar chart showing Crack Resurfacing data since commissioning]

- 1ST CRACK: 36 months after commissioning
- 2ND CRACK: 13 months
- 3RD CRACK: 12 months
- 4TH CRACK: 8 months
- 5TH CRACK: 6 months
Consideration for Skirt Repair / Modification

Historically, crack has been observed at this location.

First instance where the crack has propagated at the toe of the weld.

Location of the crack at the toe of the skirt to cone weld joint.

Location of the cracks historically observed.
Consideration for Skirt Repair / Modification
Field Repair Execution: Case # 1
(Solid Skirt Modification to Slotted Skirt)

“On-Line” fabrication Of Mock-up Sample.
New Methodology for Skirt Slot & Keyhole cutting & Chamfering with radiused & smooth corner finish (both Inside & Outside Surfaces)
Field Repair Execution: Case # 1 (cont’d)
Mock-Up Sample Preparation of Slotted Skirt with Keyhole

Deburring/Chamfering done on the inside surface of the skirt, using the tool from outside.
**TYPICAL INSPECTION/MONITORING FOR KNUCKLE/SKIRT**

<table>
<thead>
<tr>
<th>Coke Drum</th>
<th>Date</th>
<th>Location</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH1</td>
<td>07.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td>RH2</td>
<td>05.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>NA</td>
</tr>
<tr>
<td>RH3</td>
<td>05.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>RH4</td>
<td>06.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>RH5</td>
<td>09.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>RH6</td>
<td>05.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>RH7</td>
<td>09.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>RH8</td>
<td>09.01.2012</td>
<td>Skirt joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Knuckle joint</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

**Legends**
- **OK**: No visual indication of any crack
- **MLC**: Fair line crack line indication visible
- **NI**: Not inspected this time due to improper cutting of glass wool/obstruction of all drain line or scaffolding pipe
- **NA**: Not available
- **"x" in last inspection indicates increased with last inspection
- **"x" in second last inspection indicates decreased with last inspection
- **"x" in third last inspection indicates no changes with last inspection**

**CD summary**
- **Skirt**: no. of donors
- **Knuckle**: no. of donors

<table>
<thead>
<tr>
<th>Indications</th>
<th>Skirt</th>
<th>Knuckle</th>
<th>No. of donors</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MLC</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NA</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
FIELD REPAIR CASE # 2: Vapor Line Weld Crack at Thickness Mismatch (Fitting to Pipe)

- 30° dia 90 deg LR elbow
- Circumferential crack near elbow to flange weld interface (towards elbow) at 6 o'clock position
- 30° dia WFlange

Failures in vapor line welds

- Cyclic operations
- Thickness mismatch between piping, fittings, flanges
- Workmanship
- Inherently high stress
FIELD REPAIR CASE # 2: Vapor Line Weld
Crack at Thickness Mismatch (Fitting to Pipe)

- Refurbish weld, Put higher schedule flanges
- Provide short transition piece, Procure short pipes
- Refurbish weld
- Refurbish weld
FIELD REPAIR CASE # 2: Vapor Line Weld Crack at Thickness Mismatch (Fitting to Pipe)

New methodology of vapor line weld crack repair using taper thickness transition spool to minimize stress riser
Routine Inspection & Monitoring (cont’d)
Coke Drum Critical Piping Welds

High Stress Welds and Nodes

NOTE: Node no. 366 lies between Nodes 390 and 410 and rests with PTFE.
<table>
<thead>
<tr>
<th>Skirt</th>
<th>On line</th>
<th>Off line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 window inspection lanes (Visual monthly inspection)</td>
<td>Visual / MPI / PA UT (during pigging)</td>
</tr>
<tr>
<td></td>
<td>Anchor bolts (Visual, UFD once in 2 years)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature data monitoring (six monthly)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shell</th>
<th>On line</th>
<th>Off line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Banana movement</td>
<td>Ext PAUT @ strategic circ welds (every pigging)</td>
</tr>
<tr>
<td></td>
<td>LASER scans / Bulge mapping / Bulge assessment (condition based)</td>
<td>Ext PAUT @Nozzles (every shutdown)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Piping</th>
<th>On line</th>
<th>Off line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supports (visual 3 - 5 years)</td>
<td>High Stress Nodes</td>
<td></td>
</tr>
</tbody>
</table>
Coke Drum Thermal Operation / Thermal Gradient Optimization

TYPICAL SKIN TXI LOCATIONS, MONITORING

8x4 eq dist TXI's
Coke Drum & Piping Monitoring, Assessment, Repair for Fatigue Life and Safety Improvement

PLANT OPERATION & RELIABILITY

COKE DRUM & PIPING FATIGUE LIFE, RELIABILITY AND SAFETY

AFW / STRESS ANALYSIS, FEA

AFW / PROCESS & OPERATION
Fatigue Life & Reliability Consideration
During Field Repair of Coke Drum & Piping

Thank you