Fast quench problems and how they damage coke drums

Rio De Janeiro, Brazil • August 7, 2009
Presented by: Julian Bedoya
Julian.bedoya@stress.com

Prepared by: Richard Boswell
Richard.boswell@stress.com
Classic Drum Deformation For Low Alloy Drums

Weil and Murphy (Kellogg 1960, ASME)

- Permanent deformation pattern of vessels in cyclic service
- Skirt is attached to the cylinder by welding

Fig. 7 Deformation pattern of vessels in heavily cyclic service
Typical* Butt Weld Detail

- Welds fail from Low Cycle Fatigue
- Crack initiates often at edges of weld cap interface to clad
- Crack grows through base metal to leak hot oil in Circ crack

* Joint detail may vary
Some Key Points of the Coking Cycle

- The drum grows larger and taller when it is hot –
- It is filled with a lot of hard material as the hydrocarbon cracks and releases vapor
- Some cokes will bond to the wall, and flow channels develop within the coke bed
- Hot oil is stopped (diverted to other drum)
- Steam is used to remove volatile vapor
- Water enters from bottom to cool the coke bed, becomes steam and flows up the center or outside along the walls
- The coke drum shrinks in diameter and height as it cools
- Eventually water can form and fills the drum

Which way does the water go?
Discussion of the Flows during the Coking Cycle

- Traditional Analysis methods assume a uniform average flow of water upwards to remove heat from coke bed and shell at same time.
- Coke bed formation determines path of least resistance for water flow:
  - Flow channel area and friction
    - Plugging and channel collapse
  - Permeability
  - Porosity
  - Collapse strength of coke matrix
- Temperature measurements suggest fast quench with flow near wall is common.
- This creates greater stress in shell/cladding bond and skirt weld.
- This increases likelihood that hot zones remain in coke after quench.
Problem Circ Weld Seam* Cracking Is Common

4. Crack Initiation and Propagation

* Joint detail may vary
Cracking from ID at Weld Cap to Clad Junction
Drum Cracking Examples

Coke Drum Failed During Quench After Repair

Cracked Skirt to Shell weld - 5 Years
A NOTABLE COKER QUENCH
STRESS MEASURED ON SHELL O.D.
A Measured Cycle For In-Line Skirt Stress Response (OD)
Some Key points to describe the transient

1. Switch-In after Prewarm
2. Max temperature during Filling
3. Begin to cool from Coke Insulation Build-up
4. Begin Quench after Switch-Out and Steam Purge
5. Open drum, remove water and begin drilling

Skirt FE Analysis based on Measured Transients

What is the rate of Heating and Cooling?
Example of Cone Temperature

Temperature, °F

Elapsed Time, Hour

Cone

Skirt

Cone Peak Thermal Rate

Thermal Rate, °F/min

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35

0 10 20 30 40 50 60 70 80 90

0 10 20 30 40 50 60

0 5 10 15 20 25 30 35 40 45 50 55 60
During Quench - Skirt is Pushed and then gets Pulled by Knuckle

DISPLACED SHAPE AT THE END OF FILL

DISPLACED SHAPE 1 HOUR INTO QUENCH

( MAXIMUM STRESS DURING QUENCH OCCURS HERE)
Example Temperature Distribution During Quench

Skirt is still hot in “hot box” zone
Example
Bending
Stress
Distribution
Example In-Line Skirt Axial Stress During the Fill Transient

Note high bending stresses as hotter cone PUSHES Skirt Outward

Axial Bending Stress

Gap Radiation
Example Tangent Mount Axial Stress During the Quench Transient

Axial Bending Stress

Gap Radiation,

Gap Conductance active when in contact

Note high bending stresses as cooler cone PULLS Skirt Inward
FEA: Axial Stress transient at the top of the skirt ID is function of SCF at inside radius.
FATIGUE LIFE CALCULATION FOR A SKIRT IS MORE ACCURATE USING MEASURED THERMAL TRANSIENT

• Design (by others) predicted 152 years
• SES Transient analysis performed prior to T/A
• Maximum stress intensity range during transient = 143,430 psi
• Using ASME code Section VIII Division 2 fatigue design Table 5-110.1, UTS < 80 ksi, a fatigue life of 1228 cycles was obtained.

Finite Element Model vs Reality

After 5 years (~1369 cycles) cracks were discovered in all 4 drum skirts (no slots) prior to T/A
Thermal Cycles and Rates for Cone

Temperatures
Dec, 2000 - Jan 10, 2001

Temperature, °F

Temperature Rate, °F/min

ET Hrs

T1
T1 rate
Thermal Cycles and Rates for Skirt and Shell
Thermal Cycles and Rates for Skirt and Shell
Thermal Quench and Rates for Skirt and Shell
Thermal Rate Histogram for Shell

- **2003**
- **Max Rates for Quench 30 cycles 2003**
  - Frequency vs. °F per minute
  - TC2, TC3, TC4, TC5, TC6

- **2004**
- **Max Rates for Quench 48 cycles 2004**
  - Frequency vs. °F per minute
  - TC2, TC3, TC4, TC5, TC6
Does Fast Quench Shorten Cyclic Life?

- Where Does Fast Quench Hurt?
  - Skirt Attachment Weld
  - Shell Circ Seams
  - Cone Circ Seams

- Why Does Fast Quench Hurt?
  - Constraint created by components at different temperatures (i.e. thermal expansions)
  - Different Material Properties (Yield, Expansion, Conductivity, Diffusivity)
FEA Transient Analysis for ID Circ Seam

Base Metal
Cladding
Weld Overlay
Stress Distribution Across Weld During Quench for Linear Elastic Fracture Mechanics Evaluation

Stress Distribution Below the Weld
Just Below Weld Cap

High Stress At Interface of Cladding

Distance from ID (inches)
Example of Measured Cone Temperatures

Skin Temperatures approaching Inlet Temperature

Fast Quench

Coking.com
Fast Quench Issues

- *Traditional Analysis* methods assume a *uniform average flow* of water upwards to remove heat from coke bed and shell at same time, or *up thru central primary flow channel*.
- Coke bed formation determines path of least resistance for water flow
  - Flow channel area and friction
    - Plugging and channel collapse creates new flow paths
  - Permeability
  - Porosity
  - Collapse strength of coke matrix
- Temperature measurements suggest fast quench with flow near wall is common
  - Generally random and not necessarily aligned with Inlet Nozzle
- This creates greater stress in *shell/cladding bond* and *skirt weld*
  - Creates greater stress at circ seams tri-metal junction
- This increases likelihood that *hot zones remain* in coke bed after quench
What to do about Fast Quench?

• Change the way you do it
• Use Sensor Measurements (TC and HTSG) to guide you
• Use your Process Technology experts to address the possible procedures and maintain production
• Change the way drums are made
• Or, be prepared for continued problems....