Thermal Distributions are not the Full Picture… or Three Sides to Every Story

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Taking on your toughest technical problems

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Low Cycle Fatigue – Why Drums Crack

- Fatigue damage is present nearly everywhere in a delayed coke drum in cyclic service.
- Cracking failures are created from Low Cycle Fatigue in which the nominal yield strength of the material is exceeded repeatedly from thermal constraints.
- Defects, cracks, and attachments have specific stress concentrations that create local peak stresses in addition to nominal stresses.

Drum Cracking Examples

Drum Stresses Are Caused By:

- Conventional pressure vessel loading
- Shrinking and friction of drum walls at bulges and on coke bed interactions
- Hard coke (Myan and Venezuelan feeds produce harder coke). What is your HGI (Hargrove Grindability Index)?
- Thermal gradient caused by premature switching during the heat up of the skirt
- Thermal gradient by cooling steam/water rates inside drum wall during quench –local and global flow channeling which leads to thermal constraint stresses
- Shorter Cycle Times – coke not cooled, less time in oven, weak stiffness

Three Headed Problem

1. Fast Quenching can create non-uniform cooling of the coke matrix and mal-temperature gradients (Thermal Issue)
2. Coke stiffness can create friction and resistance to shrinkage of the steel envelope (Coke Issue)
3. Bulging can create stress multipliers – bending stress adds to membrane stress (Bulge Severity Issue)

Thermal Issue

(the first head of the problem)

- Fast Quench creates problems at internal tri-metal joint seams
- Local flows of hot vapor and cold water create self-constraint problems in drum wall and skirt
- Hot-Cold sides of drum create leaning – banana effect

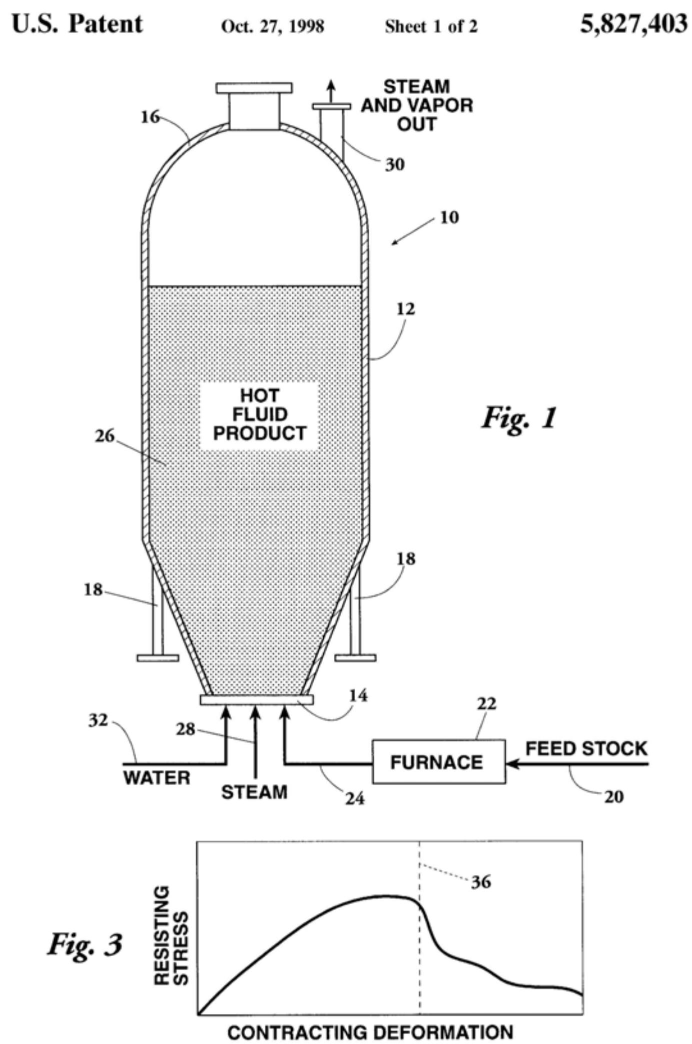
Three Inter-Related Thermal Issues

- Vertical and circumferential thermal gradients
  (detected by TC and Strain Gage)
- Rapid heating and cooling on inside wall
  (detected by TC)
- Coke bed interaction with drum wall
  (detected by Strain Gage)

Coke Stiffness Issue

(the second head of the problem)

- Coke can be hard or soft.
- Hard coke often bonds to wall.
  - Creates thermal insulation on inside wall.
  - Can create and maintain stable internal flow channels.
  - Resists radial and hoop shrinkage.
  - Resists vertical contraction.
- Soft (loose shot coke) coke cannot form or maintain stable flow channels within the coke bed matrix!
  - Internal flow channels collapse under self weight.
  - "Slushy" contents move around and shake structure.
  - Foaming and turbulence move the mass around inside the drum, similar to sloshing.



Coke Stiffness Illustrated in 1998 Citgo Drum Design Patent

- Hard Coke has a large resisting stiffness that collapses at peak compression.
- Radial and vertical resistance ceases when coke near wall collapses and ceases to grip the shell.

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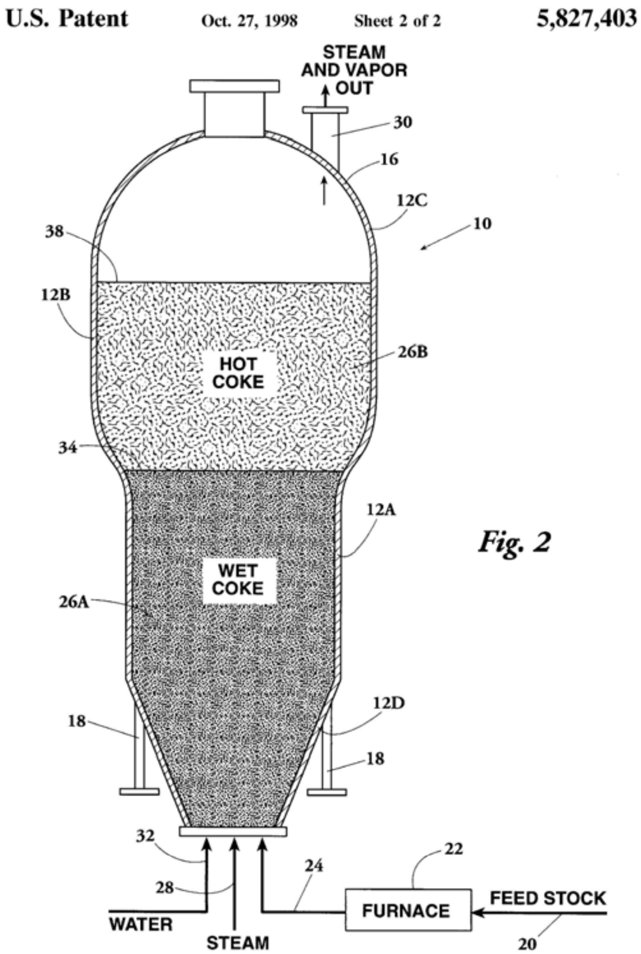


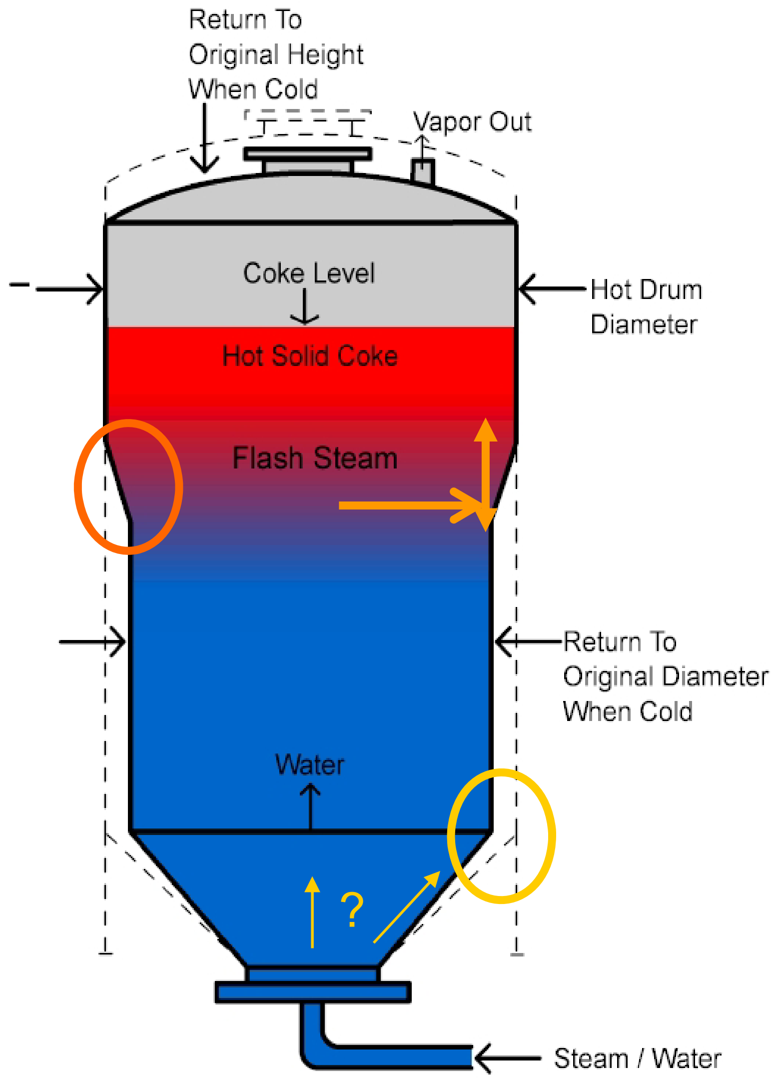
Fig. 2

Drum Vassing against coke bed is illustrated in Citgo 1998 patent

- Colder shell can shrink radially and vertically.
- Transition in wall between hot and cold zone is called vassing.
- Flexibility of cylinder allows compliant interaction with minimal stress in wall.

Some Key Points of 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 today (this decade).
- This creates greater stress in shell/cladding bond and in skirt weld.
- This outside flow near wall increases likelihood that hot zones remain in coke after quench.



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Drum Bulges – Severity Issue

(the third head of the problem)

- Corrugations cause non-uniform variation in the cyclic stress field.
- Bulge Severity is illustrated with Bulge Stress Concentration Factor Analysis which evaluates bending stress from internal pressure.
- Encourages Low Cycle Fatigue from bending stress amplification.
- Relationship to circ seams is critical.

The Full Solution for Three Headed Problem

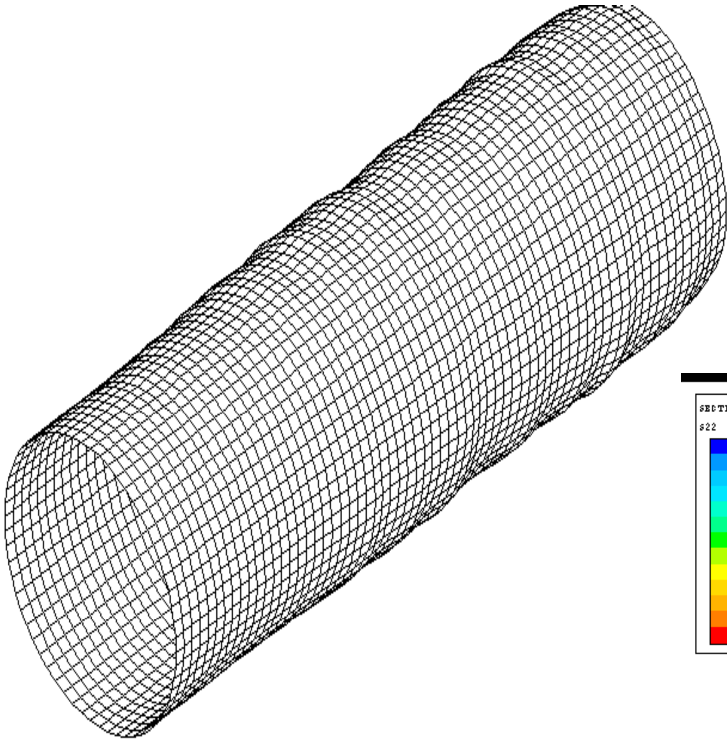
- Bulge Severity Analysis from Laser Scan.
- Install EHMS with strain gages and thermocouples.
- Determine fatigue and crack growth relative to other severe locations.
- Plan Inspection and Repair Strategy.
- Investigate methods to reduce stress and extend life.

Bulge Severity Analysis

(Solution Part 1)

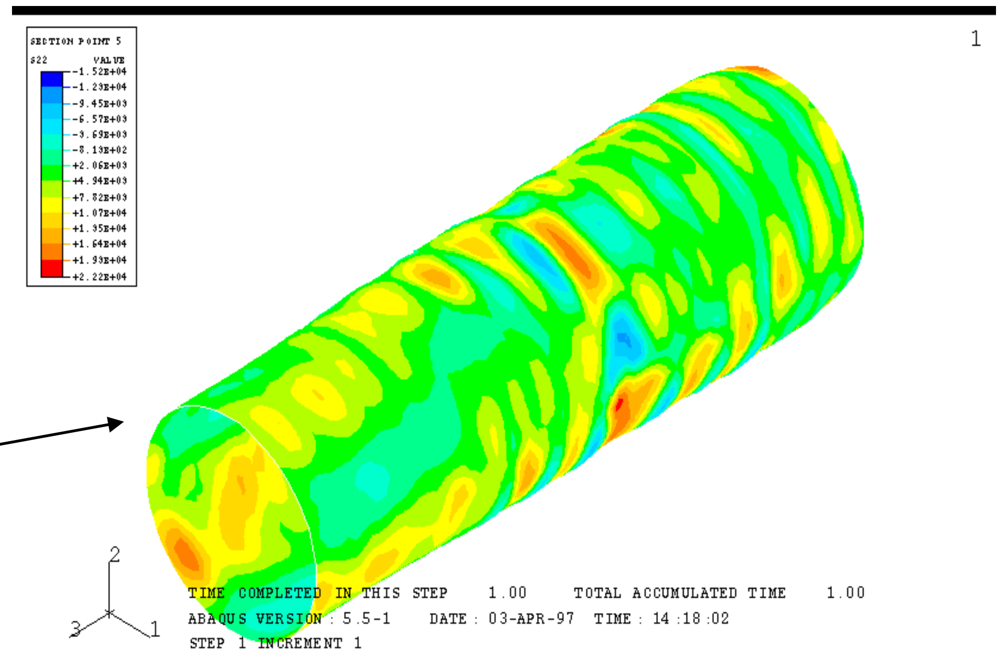
- Bulges grow slowly each cycle since yield stress is often exceeded.
- Exact cause is difficult to calculate or illustrate.
- The shapes of the bulges can be gradually rounded, sharp, local, or fully around the circumference.
- Bulge peaks can align with circ seams, as can bulge valleys.
- Bulges increase the surface stress on inside and outside of the wall.
- Pressure Loading is used to evaluate the geometric effect created by bulging with no thermal effects.

Bulging Creates Additional Stress in Wall



3-D Finite element model using laser scan results

3-D Finite element model calculates stress from internal pressure.



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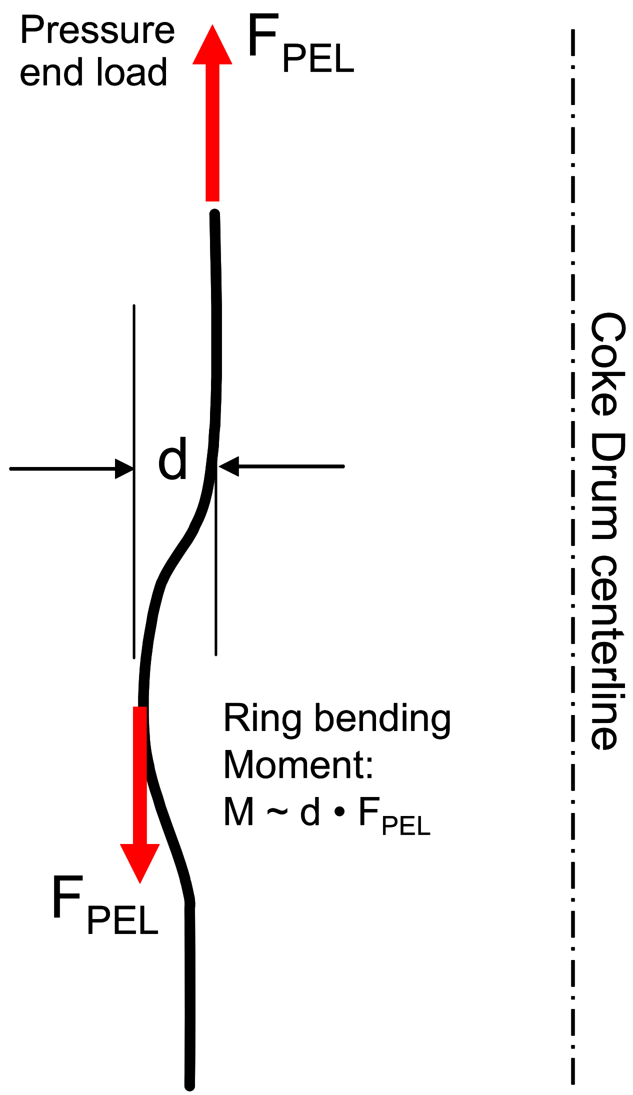
Bulges Increase the Surface Stress by Bending

- Axial Membrane Forces are not at same diameter.
- This creates an axisymmetric Bending Moment.
- Creates Hoop Stress and Axial Bending Stress.
- At “peak” there is compression on outside and tension on inside
- At “valley” there is tension on outside and compression on inside.
- Simple calculations for singular bulge relate vertical height to radial depth.
- On corrugated drum, it is more accurate to do this with finite element model.



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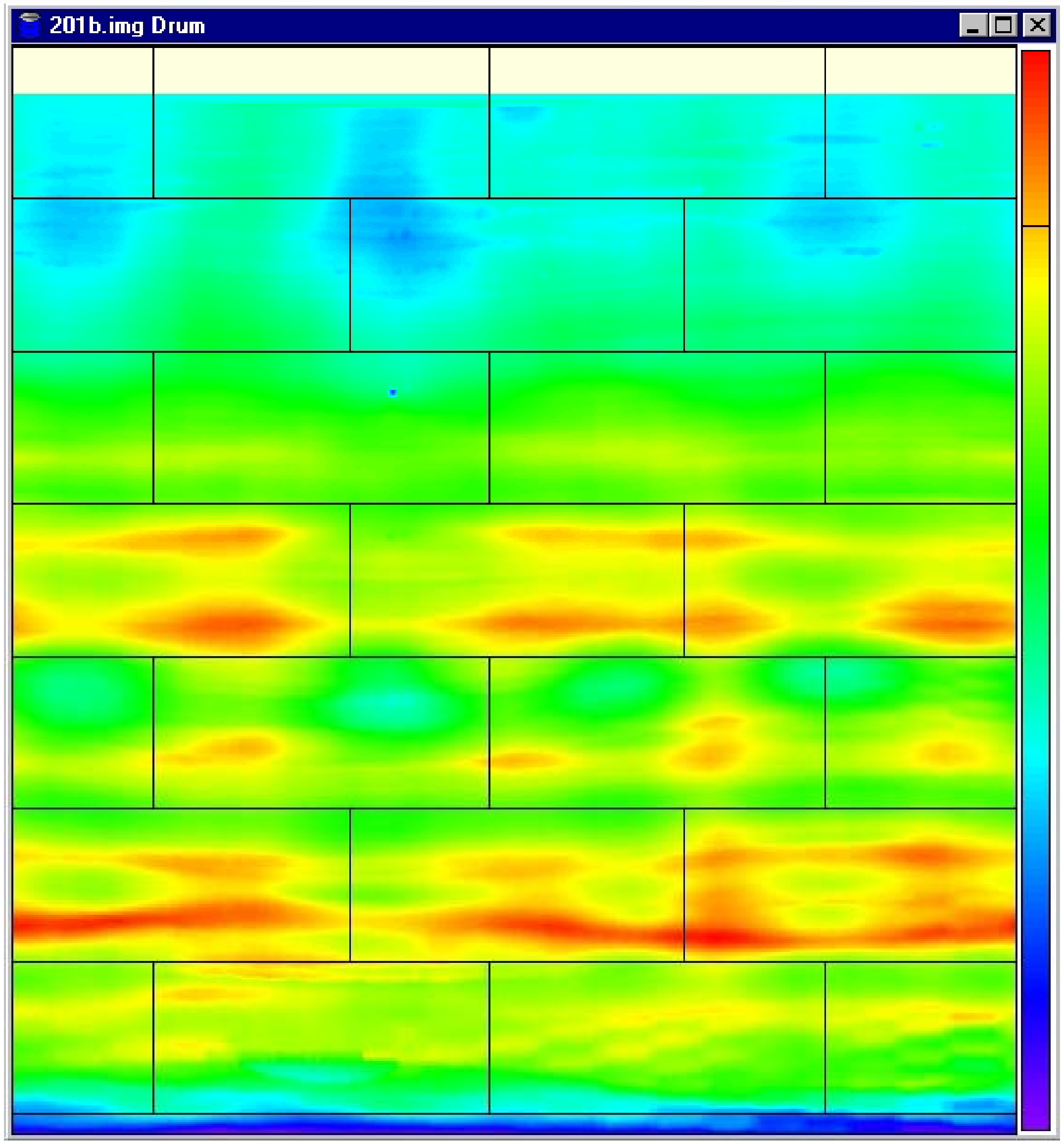
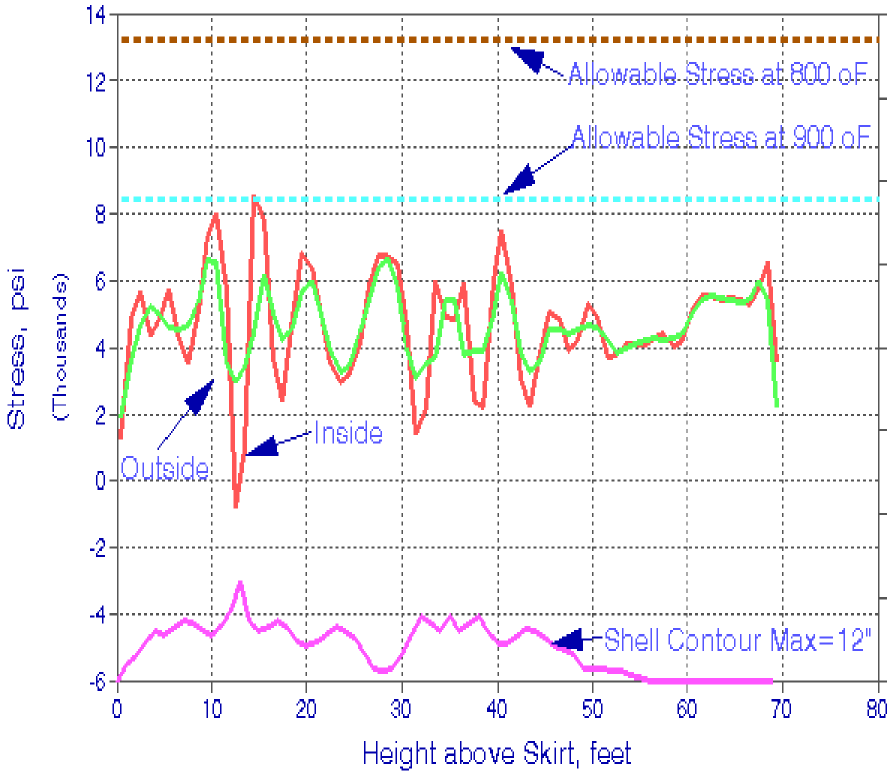
1995 Citgo Coker I F201B Drumview Scan

- F-201 B Nominal inside radius = 126”
- November ‘94 survey : 8.4% bulge
- May ‘95 survey : 9.5 % bulge
- **“How Bad IS Bad?”**
- How much growth can be allowed?
- How much severity is allowed?
- This was the first time this was addressed.



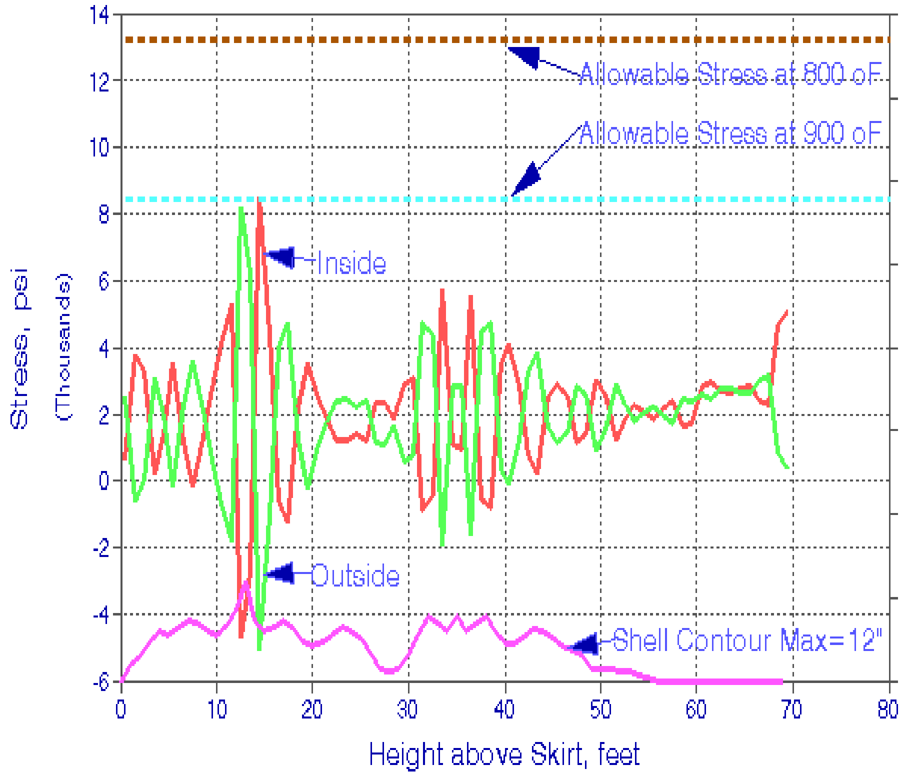
What are the consequences of Bulging Pressure Vessel?

Hoop Stress For Bulged Drum at 324 deg Profile ('95)
Pressure= 38.4 psi + Hydrostatic



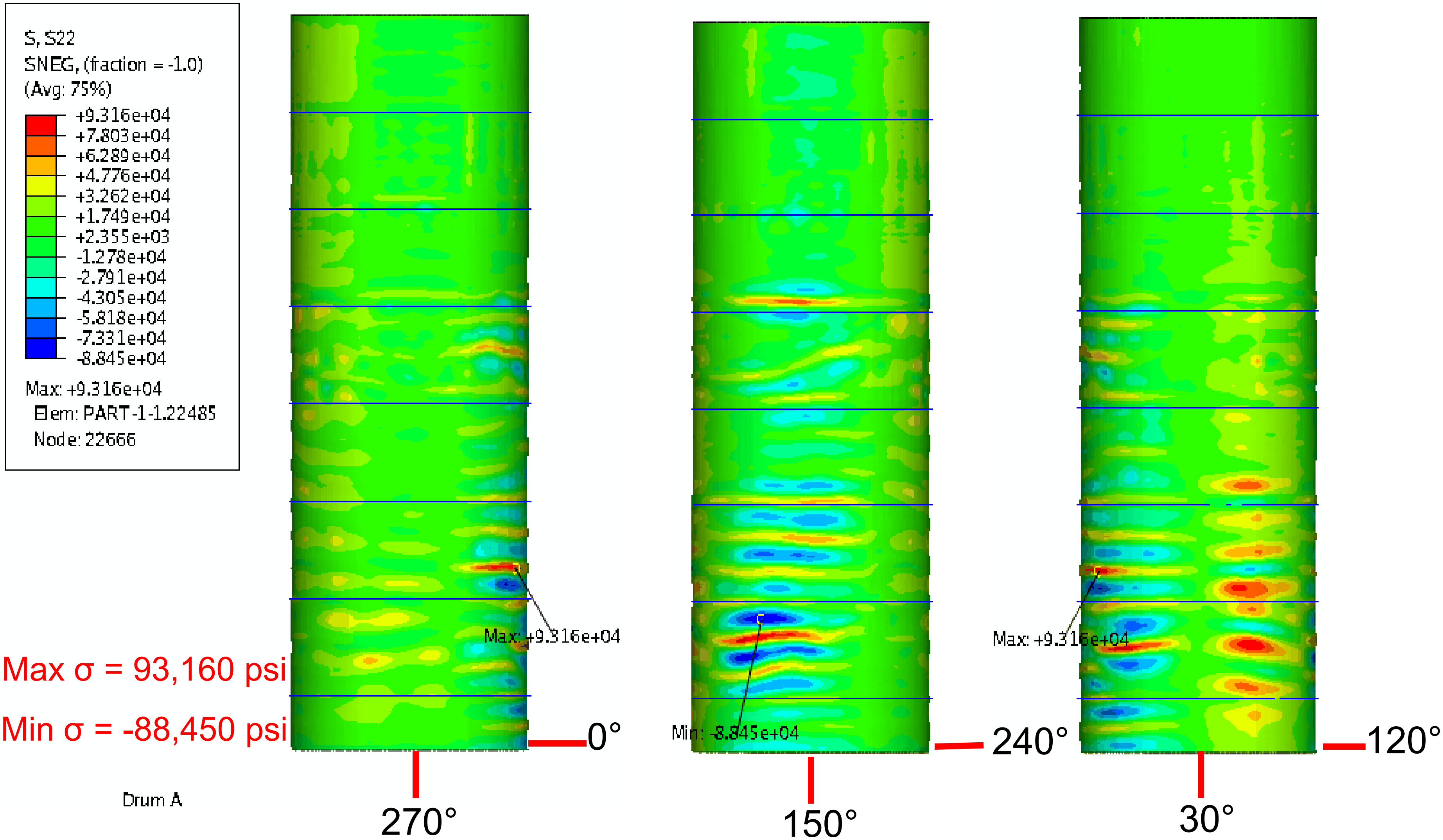
HOOP SCF = 2

Axial Stress For Bulged Drum at 324 deg Profile ('95)
Pressure= 38.4 psi + Hydrostatic



AXIAL SCF = 4

Contemporary Example : Axial Stress Drum A (ID)



Max σ = 93,160 psi

Min σ = -88,450 psi

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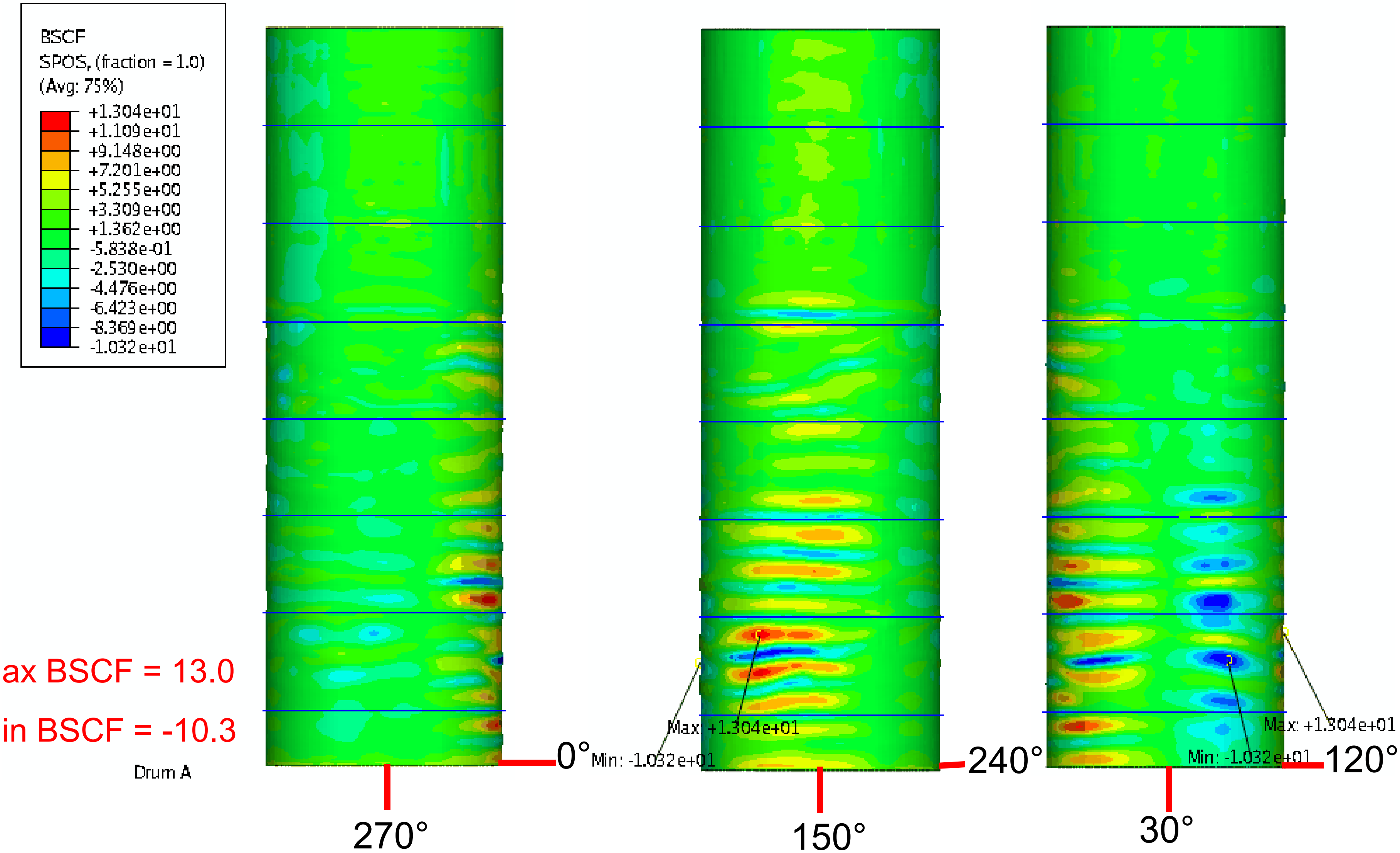
BSCF Axial Drum A (OD)



Max BSCF = 13.0

Min BSCF = -10.3

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Comments on BSCF Analysis

- Pressure Loading is used to evaluate the geometric effect created by bulging. This is not a fatigue or thermal analysis of the bulges.
- Coke drums are not usually operated at their design pressure, but they do have daily thermal/pressure cycling. These frequent transient thermal loadings have been found in some cases to be 10 times the design pressure.
- As the drum quenches from a hot, expanded diameter to a colder, less expanded diameter, the drum wall flexes as the cooling progresses from the bottom to the top of the drum.
- Corrugations will also flex and this vassing-like action creates bending stress alternating from tension to compression. Nominal, perfect cylinders typically manage this without much damage. Corrugations increase and amplify this thermally created stress in proportion to their severity and sharpness (i.e. shape). This fatigue stress is not specifically included in this analysis.
- This analysis does not assure that cracking is present, only that geometric conditions are present to encourage fatigue and crack growth.

Discussion of Bulge Severity

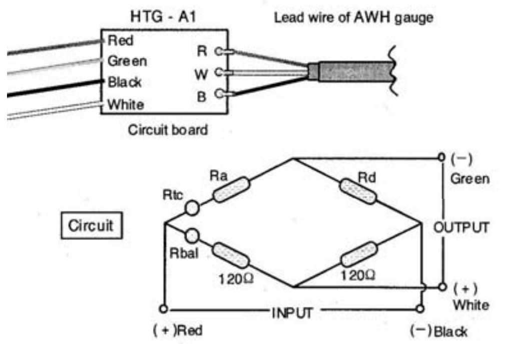
- Comparison to previous scans may indicate a trend of severity and rate of severity growth.
- When BSCF increases, the bulge shape is becoming sharper and bending increases.
- When BSCF decreases, the drum has either grown to meet the bulge, or the vertical height (width) my have increased to make the bulge more rounded.
- Circ Seams usually crack first, but there are known instances of cracking at bulge peaks in between seams such as example Citgo's Drum A.
- Positive values of BSCF are likely to have large tensile stress that propagate crack growth.
- Drum crack repairs can also reduce the BSCF.

Three Inter-Related Thermal Issues

- Thermal gradients going vertically and circumferentially
  - detected by TC and Strain Gage
- Fast heating and cooling on inside wall
  - detected by TC on outside
- Coke bed interaction
  - detected by Strain Gage

A Thermocouple by itself does not equal a Strain Gage. <u>Both are required for the whole story!</u>

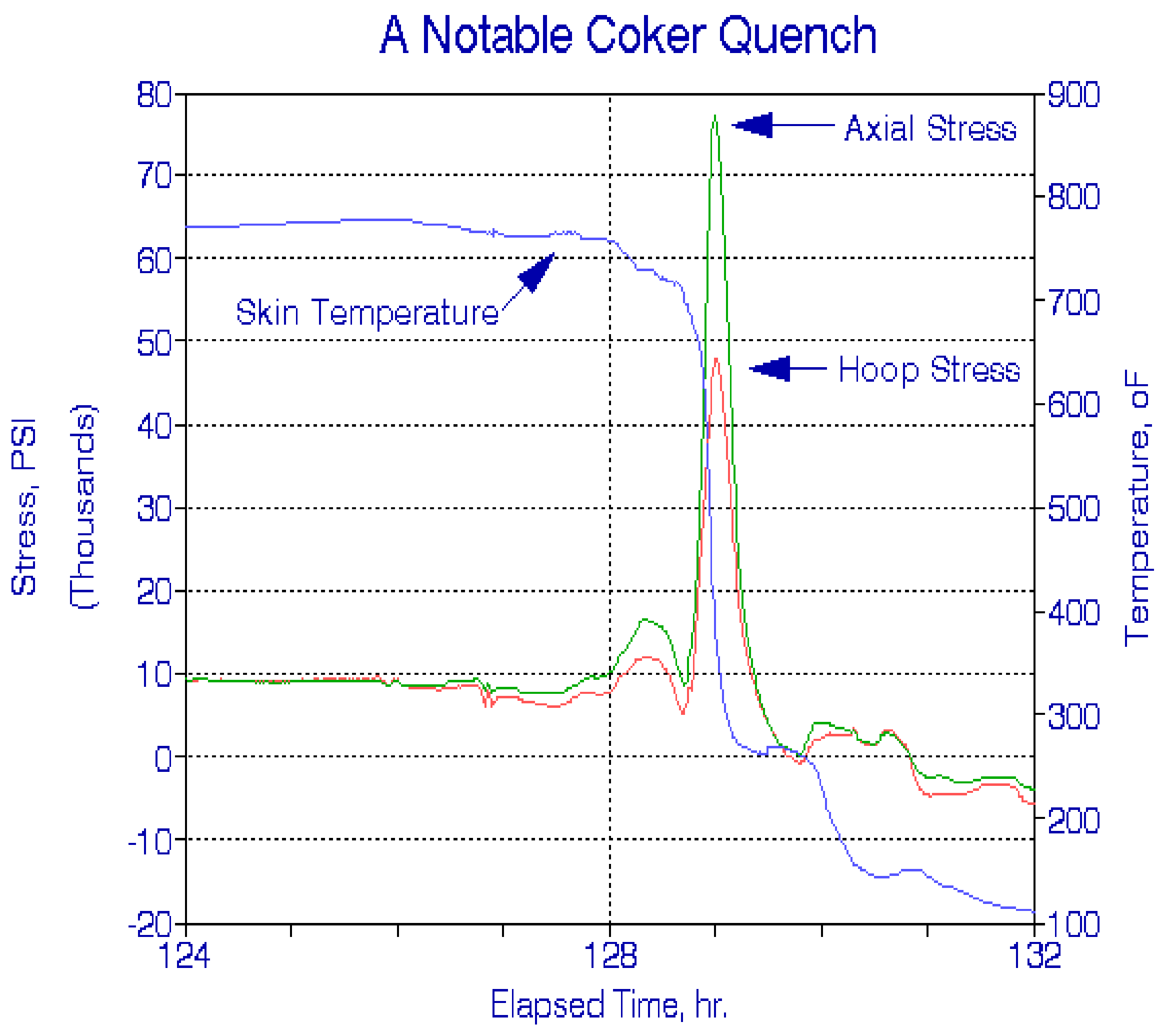
High Temperature Strain Gage with Intrinsically Safe Instrumentation



Designation of HTG-A1 Bridge and Color Code of lead Wires

1100 °F Max

A NOTABLE QUENCH STRESS MEASURED ON SHELL O.D.



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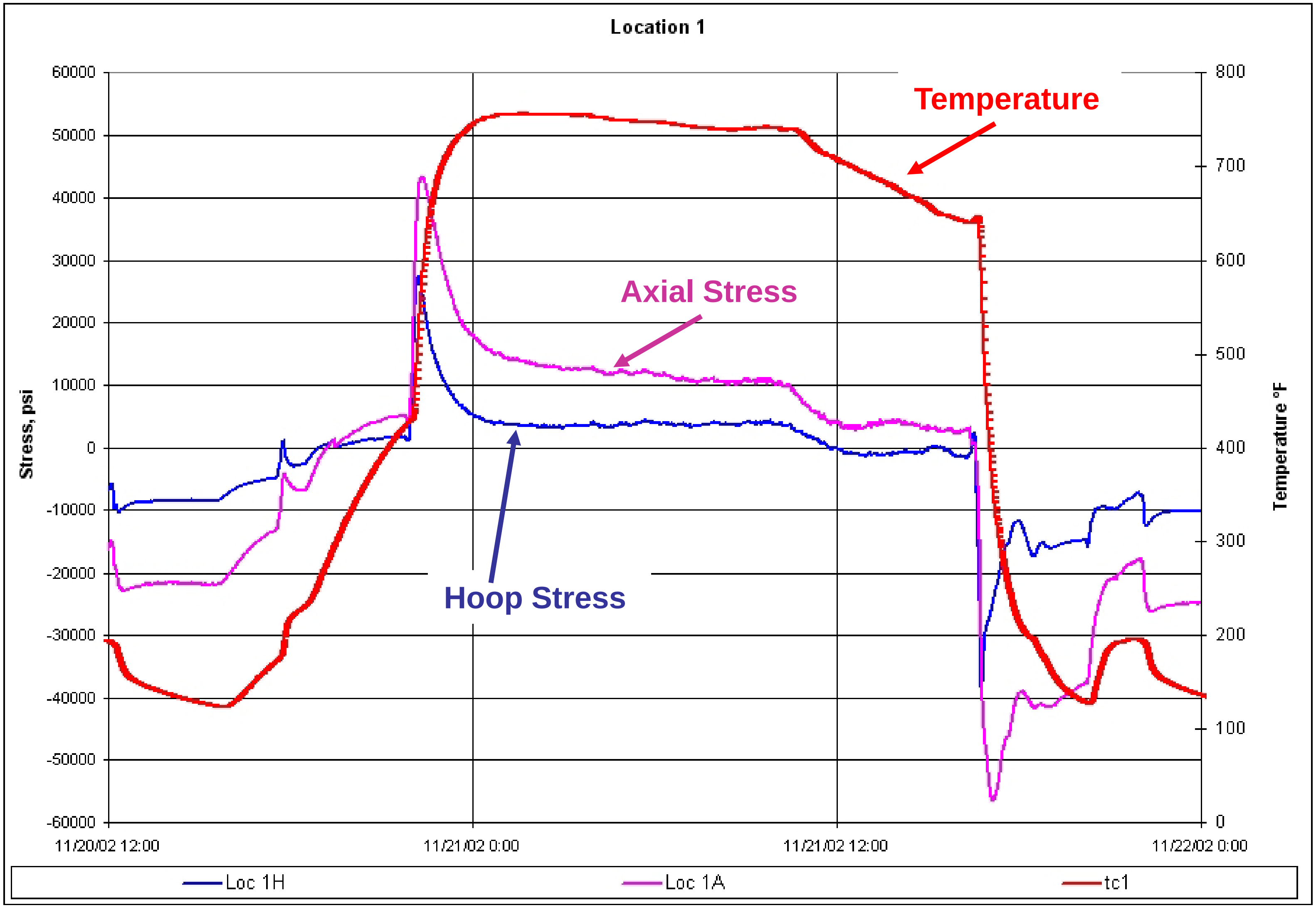
A Measured Cycle For In-Line Skirt Stress Response (OD)



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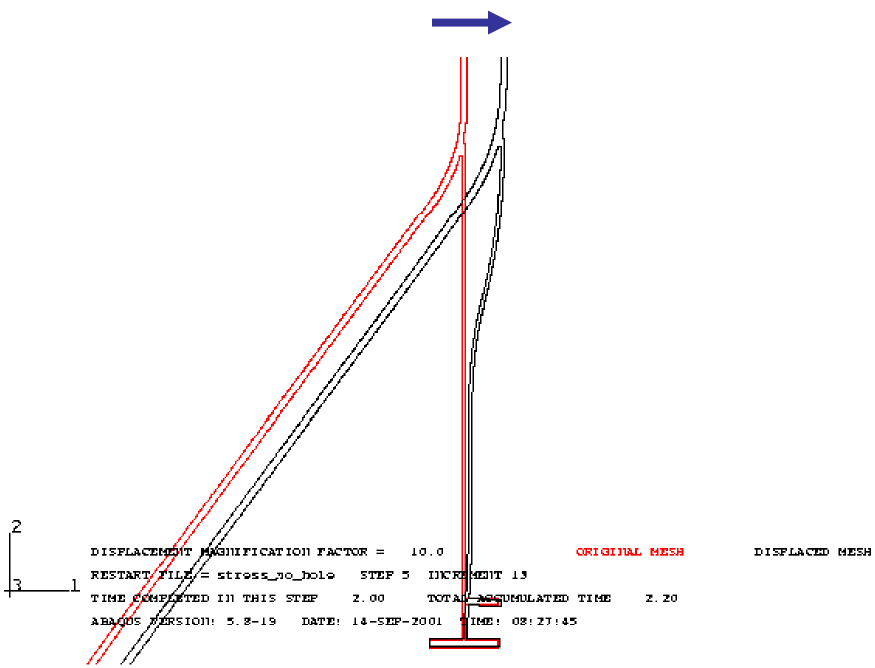
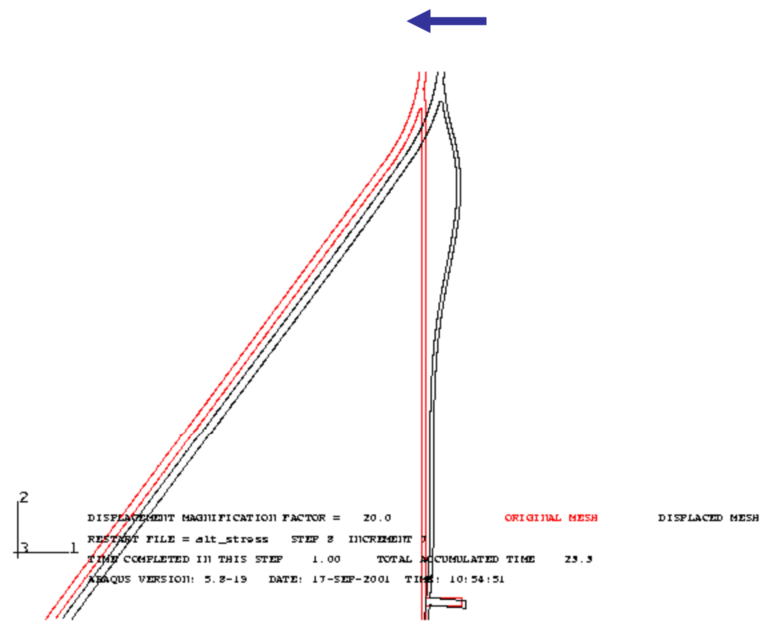
During Quench - Skirt is Pushed and then Pulled by Knuckle

DISPLACED SHAPE AT THE END OF FILL





DISPLACED SHAPE 1 HOUR INTO QUENCH

(MAXIMUM STRESS DURING QUENCH OCCURS HERE)

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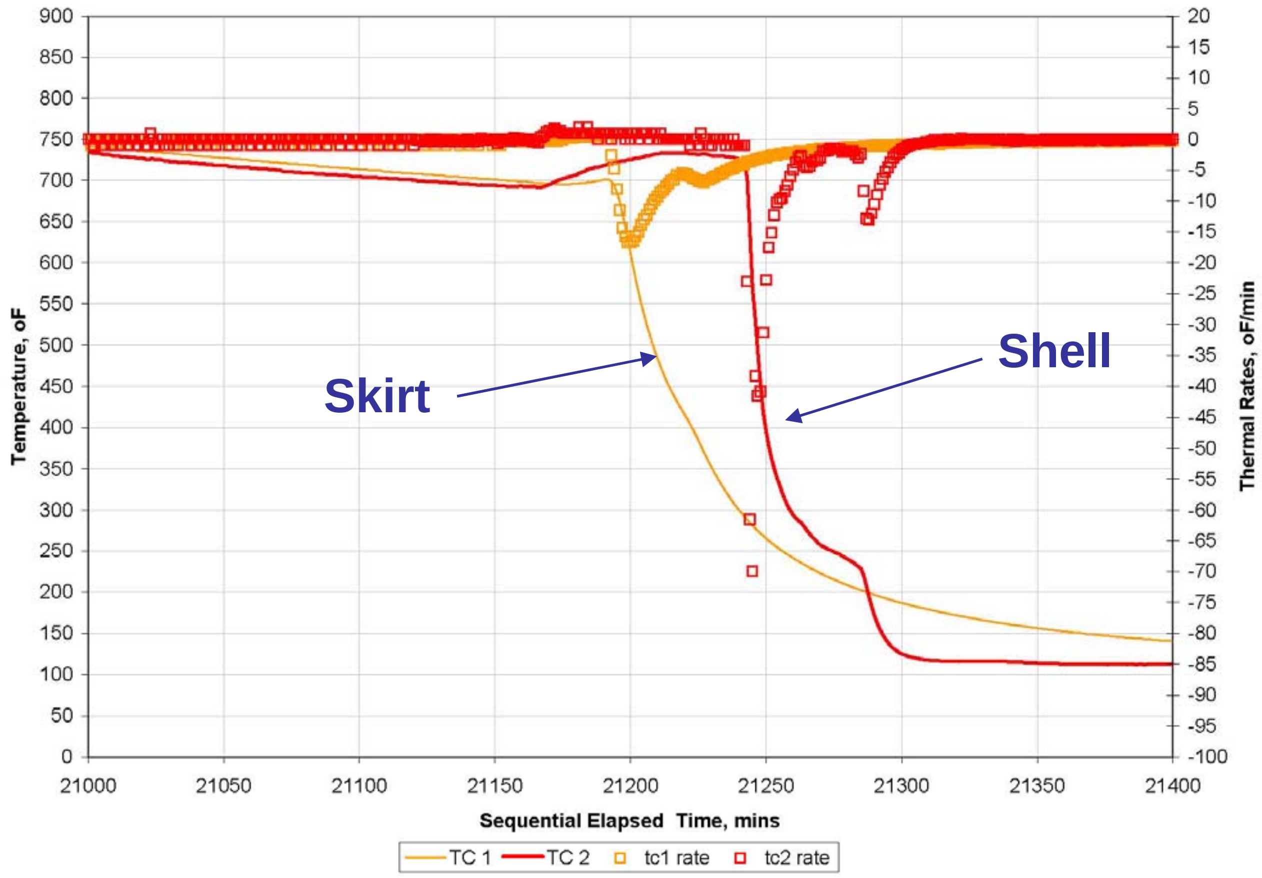
Thermal Quench and Rates for Skirt and Shell



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Conclusions

- Coke drums suffer fatigue damage from several causes which can be accelerated if not managed properly and these can lead to premature and repetitive cracking.
- Solutions focused on a single cause may overlook the other contributors today or tomorrow.
- Severe thermal gradients are the result of other conditions such as global flow channeling.
- Fast quenching can create severe gradients.
- Severe thermal rates create multiple problems.
- Hard or Soft coke create different problems and these can change with feed stocks and recipes.
- Awareness starts with appropriate EHMS.
- Knowing your problem lets you solve your problem and extend drum cyclic life.

Recommendation for Life Extension Procedures

- Use Acoustic Emission Testing to identify active crack growth and rank inspection areas.
- Review BSCF severity history from previous scans to determine if trends suggest a rate of growth.
- Install EHMS (Strain Gages and TC) to guide changes in quench procedure to reduce fatigue damage, and to input stress histogram to fracture mechanics calculation for crack size and growth.
- Consider selective weld overlay to strengthen bulge peaks.
- Repeat Scan and BSCF routinely as before.
- Prepare plans for replacement, repair, and life extension until replacement is available.

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