Coke Drum Life Extension Issues and Solutions for Inlet Nozzle Problems

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Fort McMurray

Taking on your toughest technical problems

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Three Headed Problem

1. Fast Quenching can create non-uniform cooling of the coke matrix and severe temperature gradients (Thermal Issue, detected by TC and Strain Gage).
   - Fast Quench creates problems at internal tri-metal joint seams and create severe thermal gradients.
   - Local flows of hot vapor and local flows of cold water create self constraint problems in drum wall and skirt – hot metal opposing cold metal displacement.
   - Hot-Cold sides of drum create leaning – banana.
   - Leaking of flanges.
2. Coke stiffness can create friction and resistance to shrinkage of the steel envelope (Coke Issue, detected by Strain Gage).
3. Bulging can create stress multipliers – bending stress added to membrane stress (Bulge Severity Issue, detected by Strain Gage and laser scan).

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Why is Shot Coke a Problem?

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- Shot coke consists of loosely bonded particles whose aggregate structural stability is much less than sponge or needle coke.
- Consequently they may pack tighter in the bottom of the drum due to hydrostatic pressure of the weight of the coke bed.
- Flow channels will be less stable and may not endure the full drum cycle.
- Coke bed content is less solid, more fluidized, with shifting masses causing vibration.
- Hence, all flows within the coke bed will become very random, and
- Flows most often found to be nearer the drum wall rather than centered and symmetric, especially with side inlets.

Shot Coke (Partially crushed to show shot structure)

Sponge Coke

Photos from Foster Wheeler

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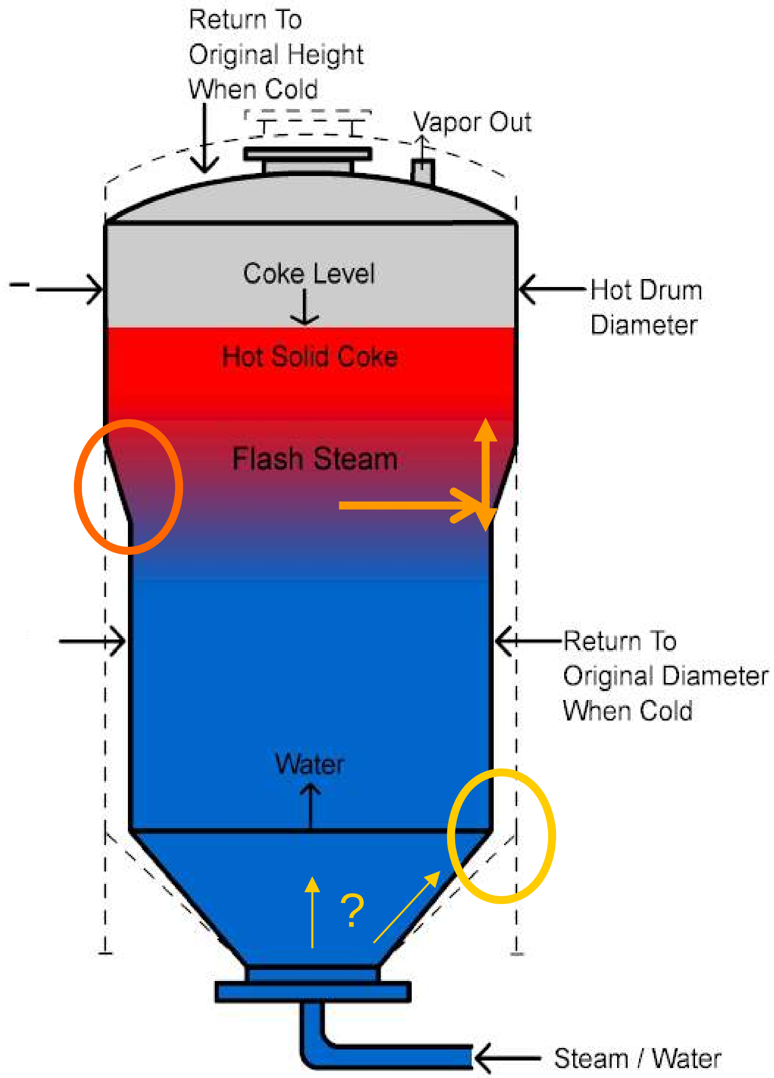
Some Key Points of the Coking Cycle

- 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). <u>Steel is Quenched</u>, Not Coke Bed! Coincide with Side Inlet Flows and Shot Coke.
- 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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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 flows ***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 with the use of side feed configured drums making shot coke.
  - **Generally random but not always aligned with Inlet Nozzle due to a general swirl effect that often favors one side of drum.**

- This creates greater stress in **shell/cone-cladding bond** and at **skirt weld.**
  - **Creates greater stress at circ seams tri-metal junction.**

- This increases likelihood that **hot zones remain** in coke bed after quench.

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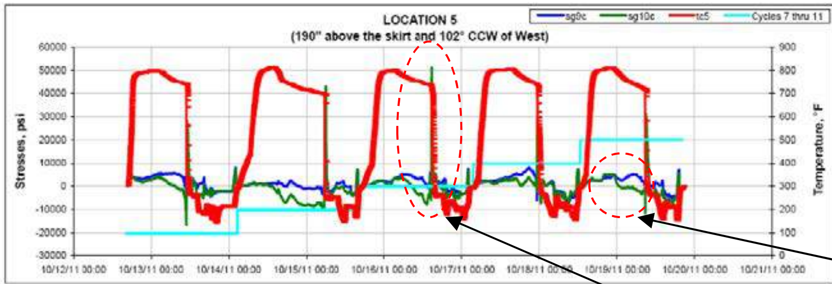
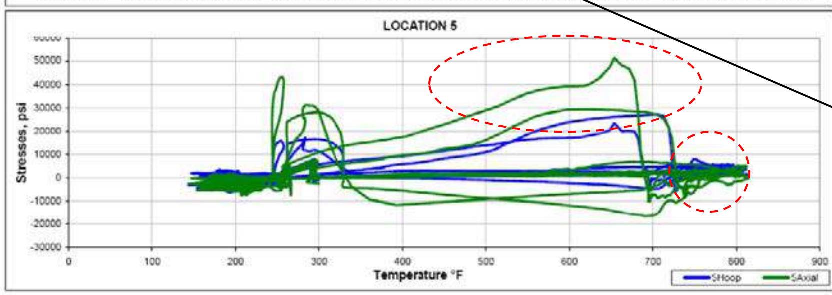
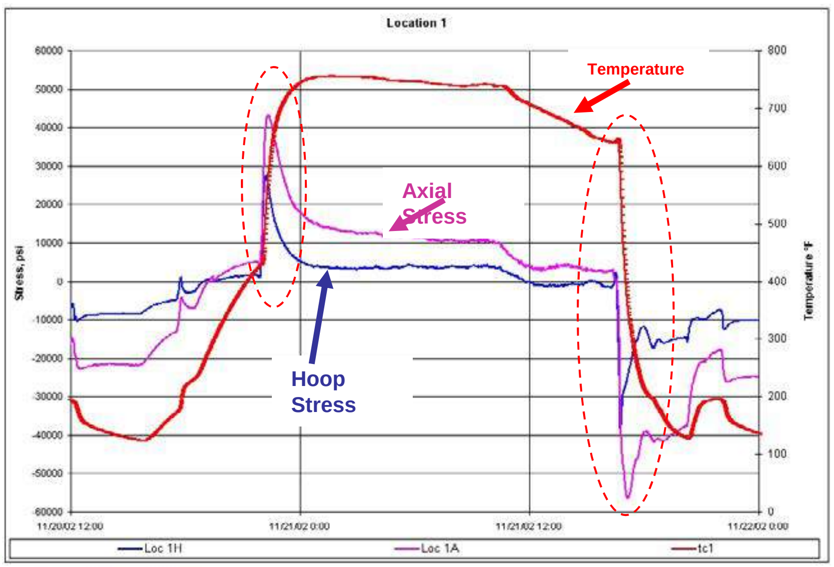
Drum Cylinder and Skirt are Stressed Differently







- During Filling, the drum is stressed like a pressure vessel.
- Drum Shell is transiently stressed during Quench.
- Local flow paths can quench one side of drum before the other.
- Drum Skirt is transiently stressed during Fill and Quench.
- Middle chart shows Stress vs Temperature for the 5 cycle trend in Top Chart.
- Top and Bottom Charts are Stress vs Time trend.

Weil and Rapasky (Kellogg 1958, API)

- **Problems with Bottom Head and Inlet Cracking**
- **Bottom cools within a couple of hours,**
- **But then begins to heat back up!**

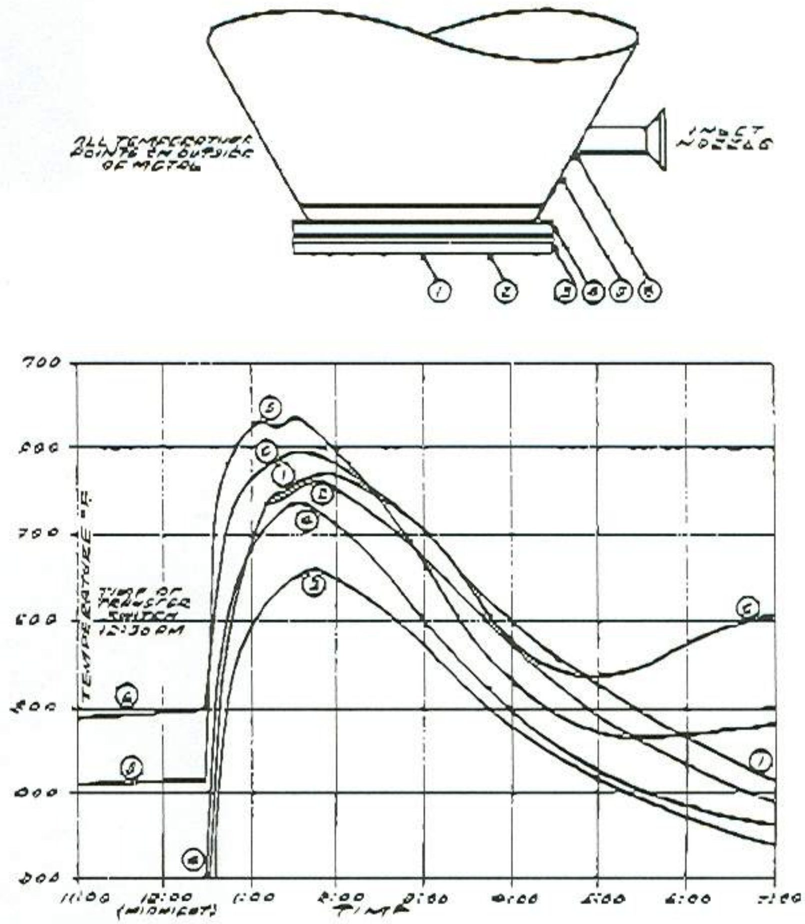


FIG. 10—Metal Temperatures at Bottom Head of Coke Drum During Transfer Switch.

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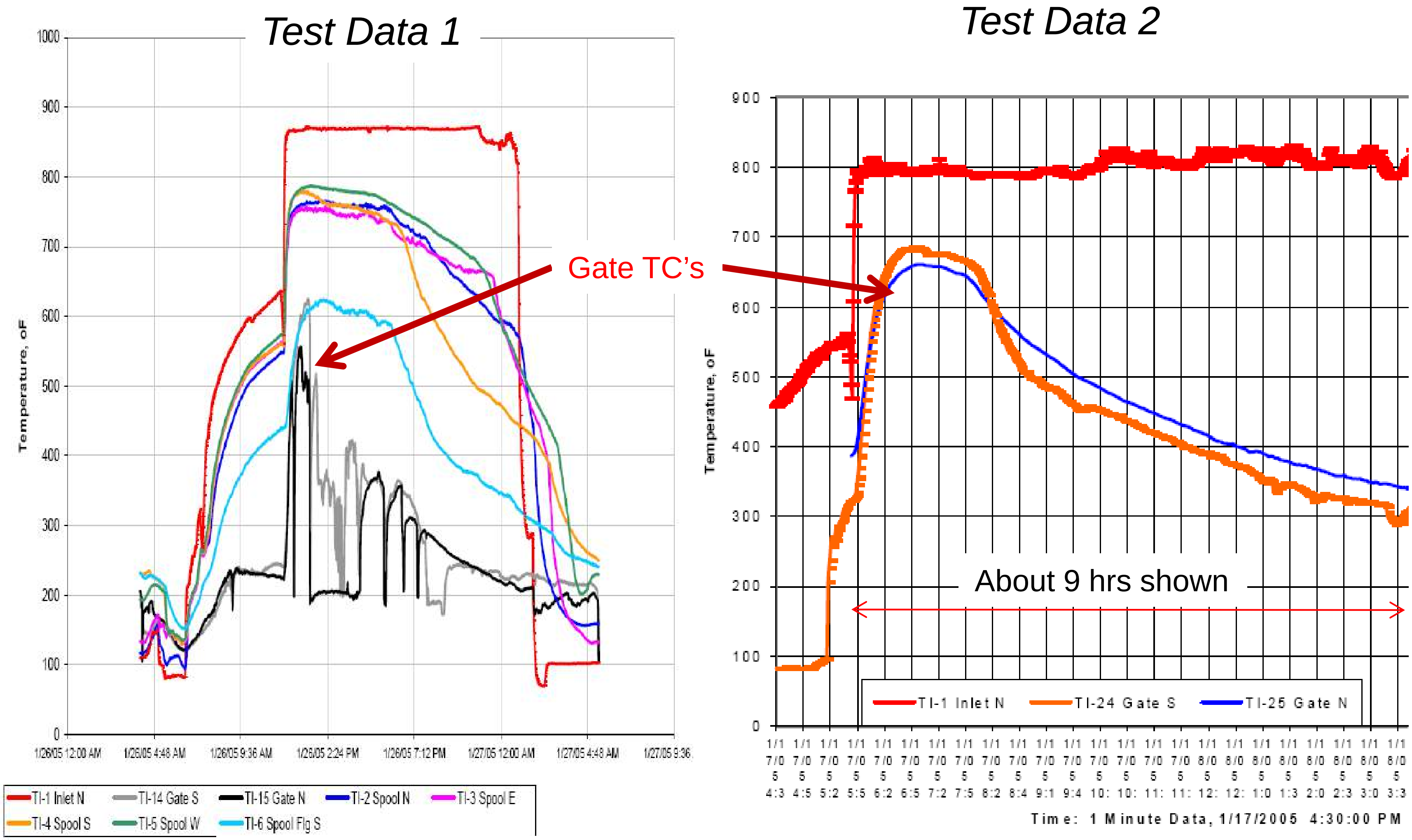
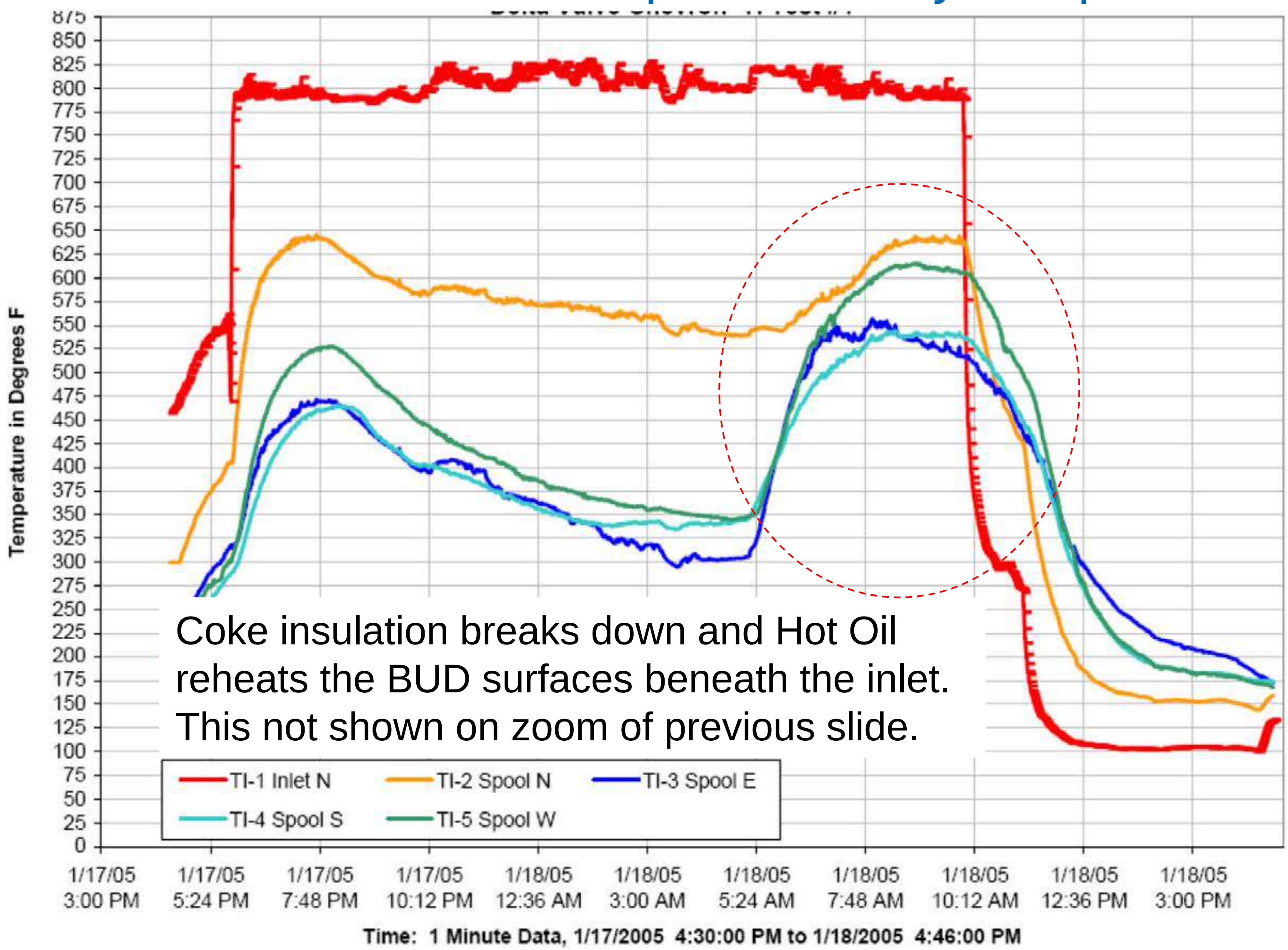
Thermocouple Data for Spool and Un-Header Gate
with Side Inlets from Two Independent Coke Drums with Different Feed Stock and Procedures



The peak temperature at the bottom of the gate is in the range of 600-700 ºF. Although the resid stays at over 800+ ºF for 12 hours, a coke insulation layer on the top of gate results in the temperature drop.

Test Data Site 2 : Complete First Cycle Spool Trends



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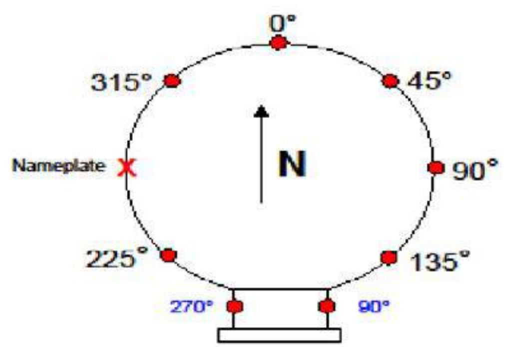
Examples of Measured Thermal Gradients : Locations on Drum with Side Feed Nozzle

POST – INSTALL:

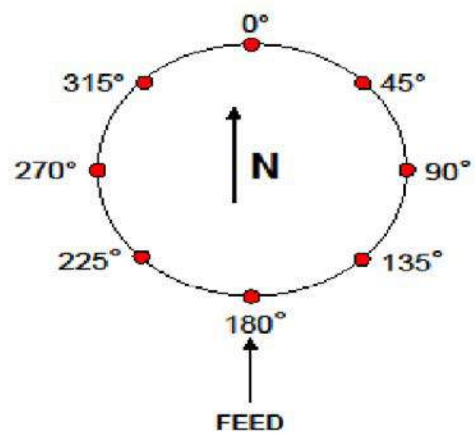
SPOOL ELEVATION
1512 Locations

No thermocouple installed at 270° due to nameplate.

Inlet locations are ≤ 5" from the spool body.

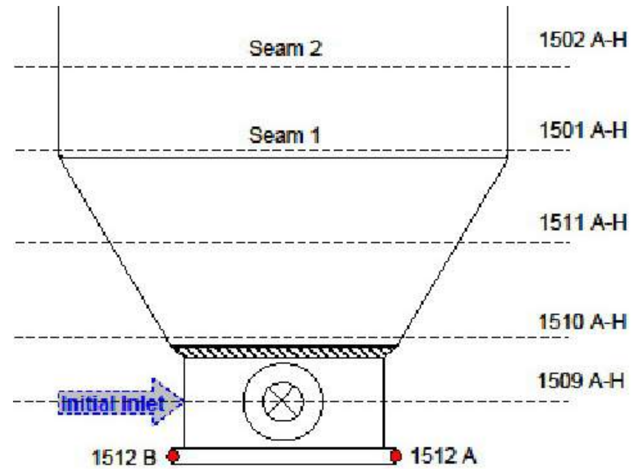


CONE ELEVATIONS
1510/1511 Locations



Coke Drum

1 1/4 Cr 1/2 Mo		ID= 27 ft
1994		thickness t
top	Course 8:	1.125"
	Course 7:	1.000"
	Course 6:	1.000"
	Course 5:	1.000"
	Course 4:	1.125"
	Course 3:	1.125"
	Course 2:	1.125"
bottom	Course 1:	1.250"



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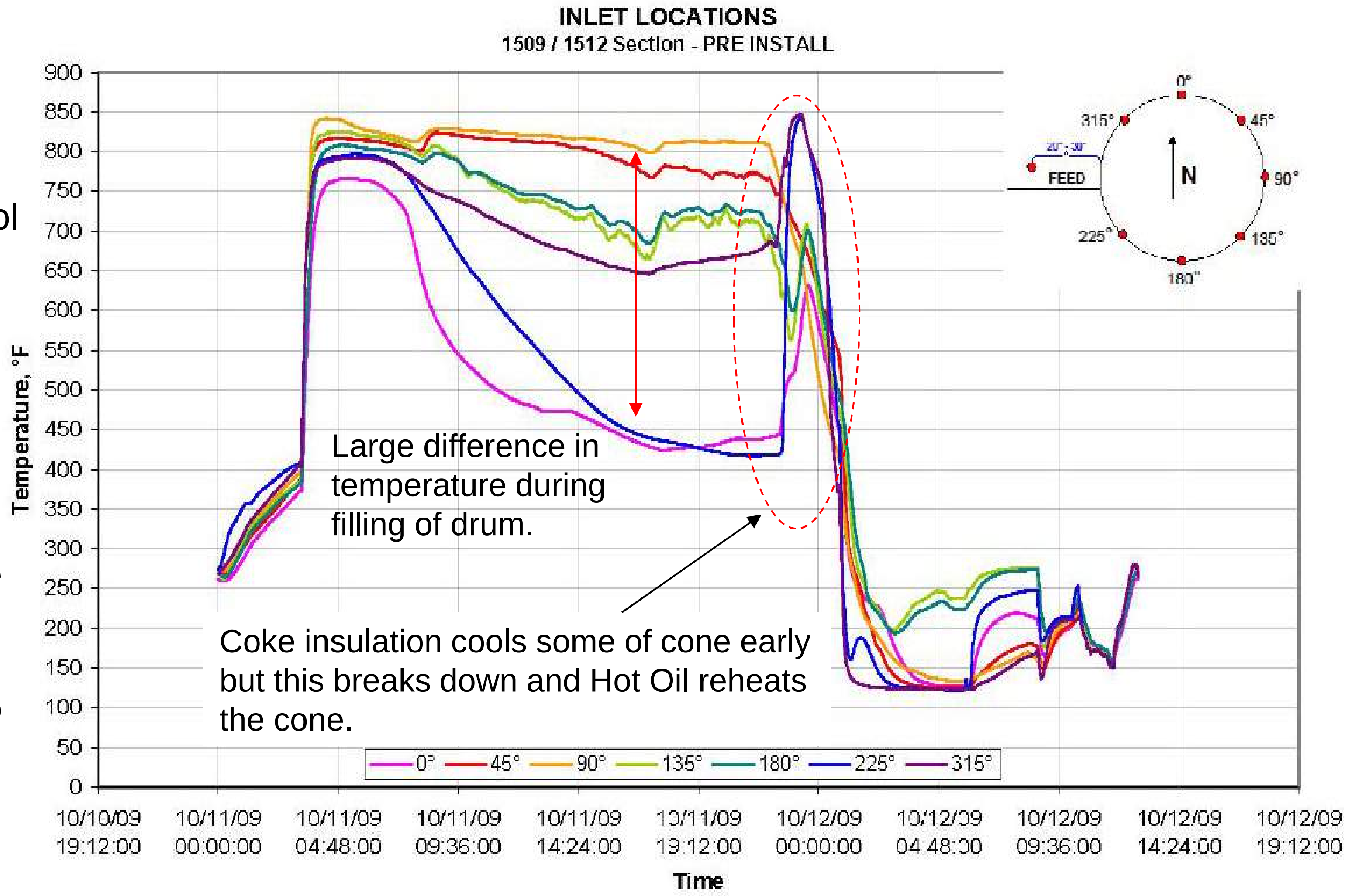
Temperature Trends with Side Feed Inlet Nozzle

Trends with existing side Inlet show cool down and reheat with large differential temperatures.

Some of cone has coke insulation and other parts do not.



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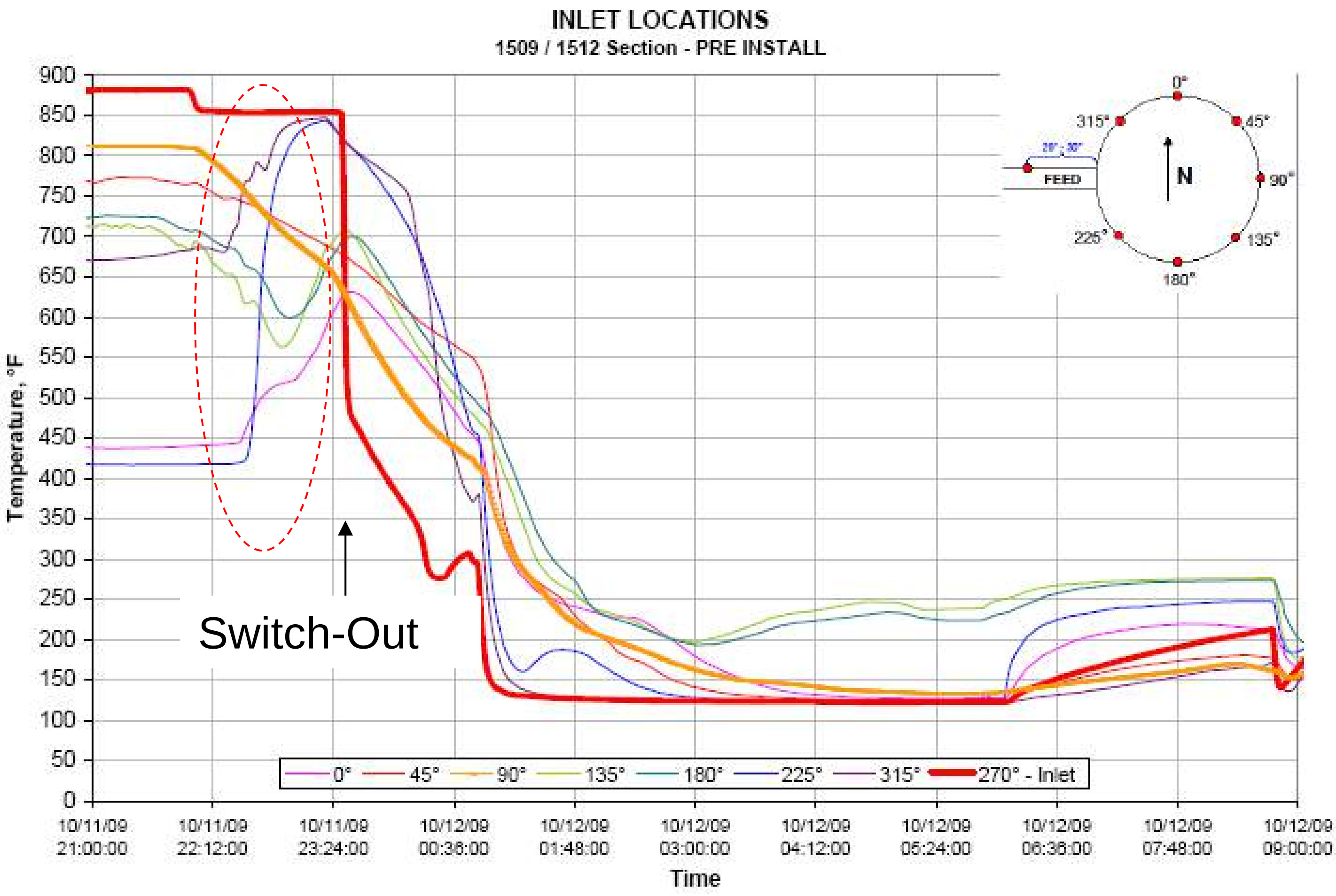
Zoom of Quench from Previous Slide

Zoom of previous slide Quench Trend with existing Side Inlet show cool down and reheat prior to Switch-Out and large differential temperatures.



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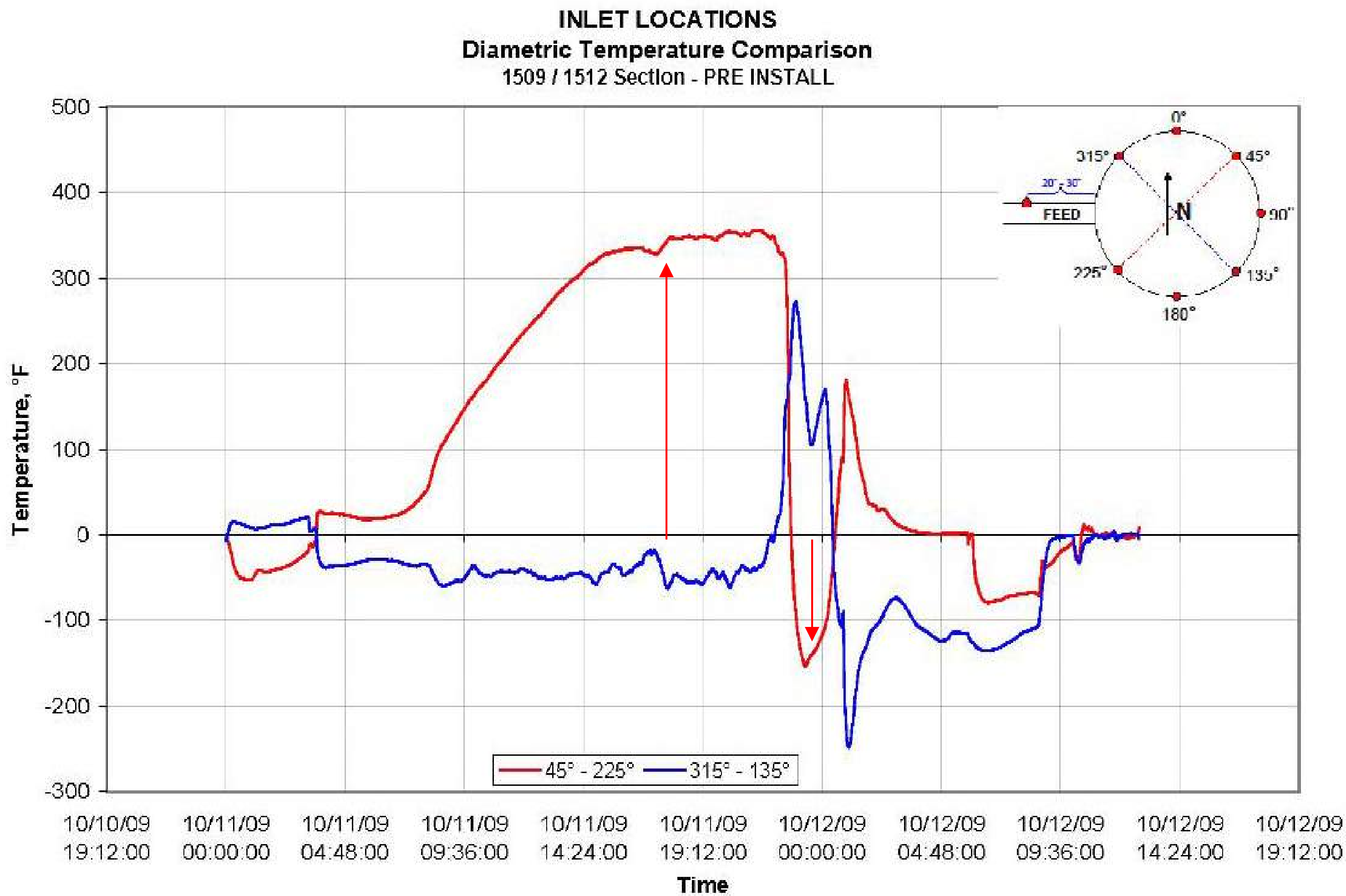
Temperature difference across cone from trend on previous slide.

Diametric temperature difference with existing Side Inlet show cool down then reversal during reheat prior to Switch-Out .



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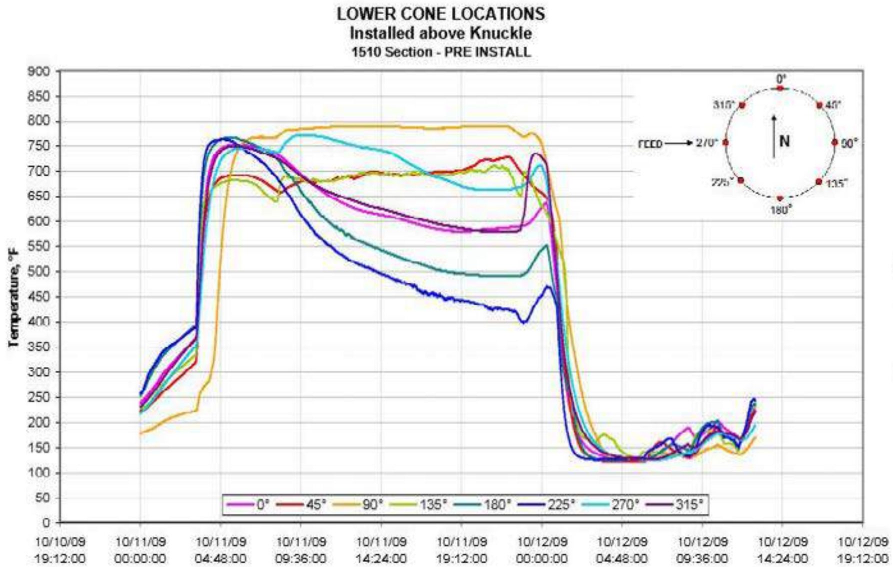
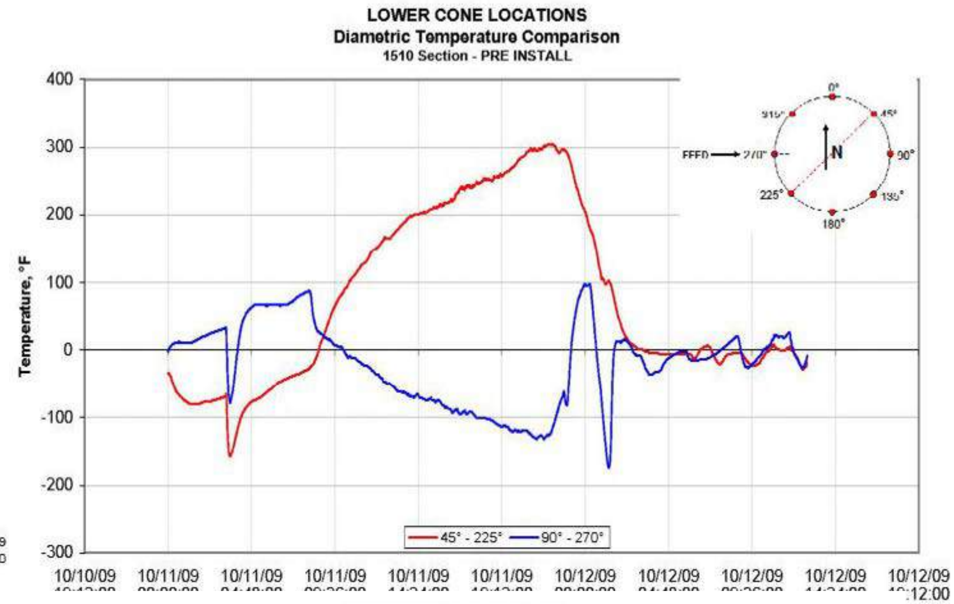
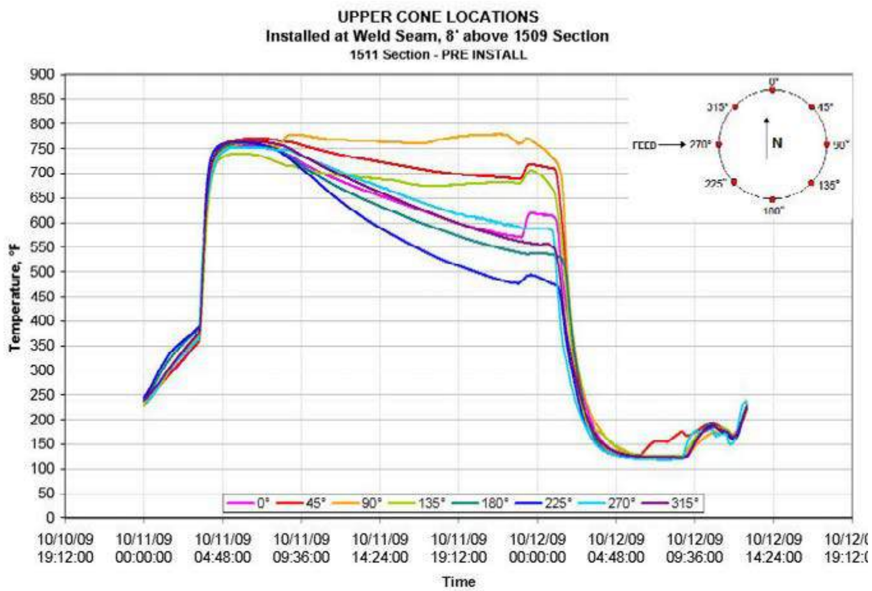
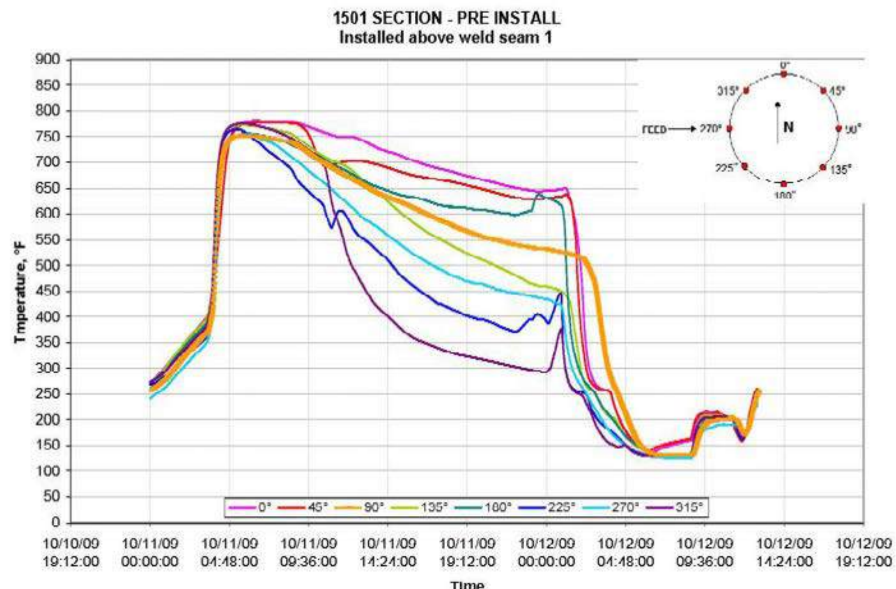




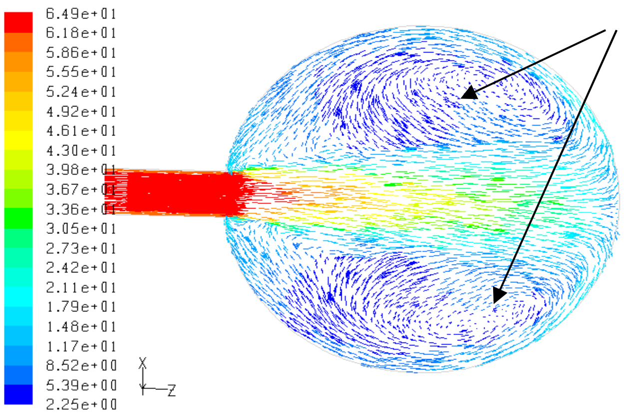




Additional Temperature and Diametric Difference trends (same cycle) with existing Side Inlet nozzle.

Flow Simulation Results – Straight Side-entry Nozzle, Flow Condition #2 for high flow rate

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

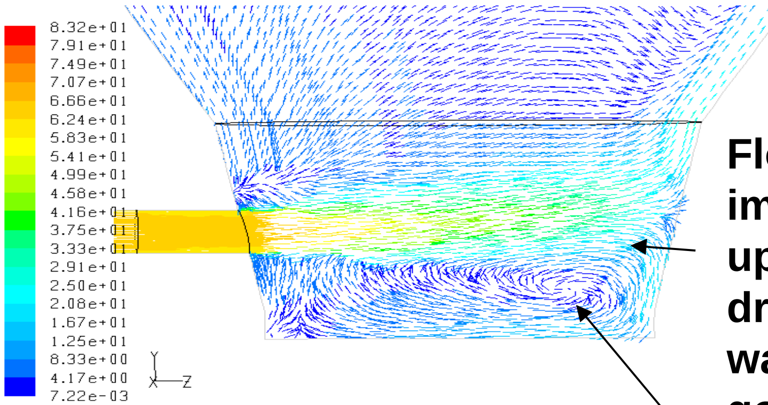


Non-symmetrical recirculation regions around the inlet

Impingement region

Close up view of flow in the inlet region

Velocity (m/s) (on horizontal plane through the inlet; viewed from above)



Close up view of flow in the inlet region

Flow impinges upon the drum wall and goes up

Velocity (m/s) (on Plane 1)

Non-symmetric recirculation region beneath the inlet will encourage non uniform coke insulation to form on gate and components

The feed rate was a furnace feed of 54,600 BPD (~2.0 API)

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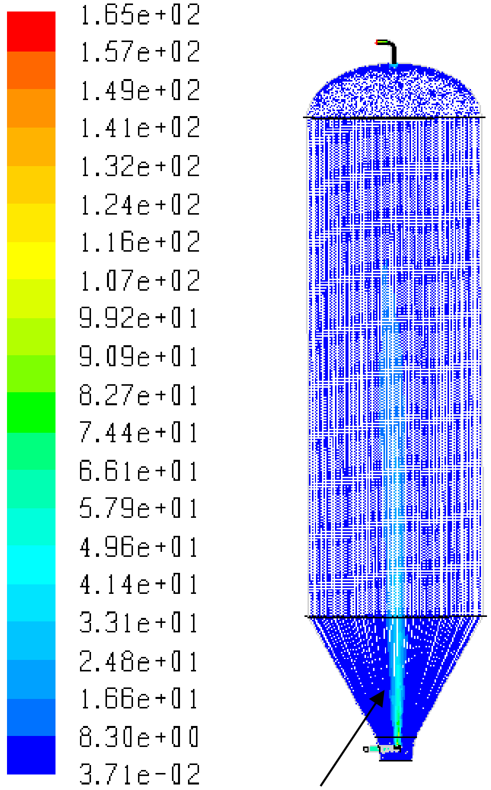
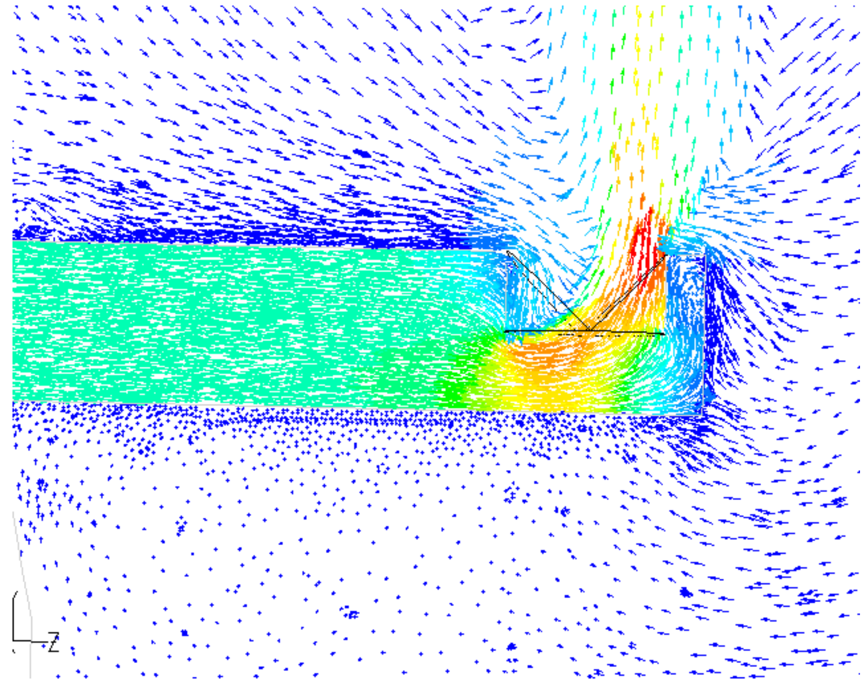
Flow Simulation Results – Early Centered Insert Nozzle (Flow Condition #2)

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum



Velocity (m/s)

Vertically directed flow at the center of the drum is generated by the inlet



Close up of inlet region

- Goal is to restore symmetrical flow patterns to drum for hot oil feed and water quench, and encourage insulating coke buildup on gate with minimum pressure loss.
- Encourage a central vertical flow of quench water that quenches the coke bed and not the drum.
- Increase remaining cyclic life of the coke drum

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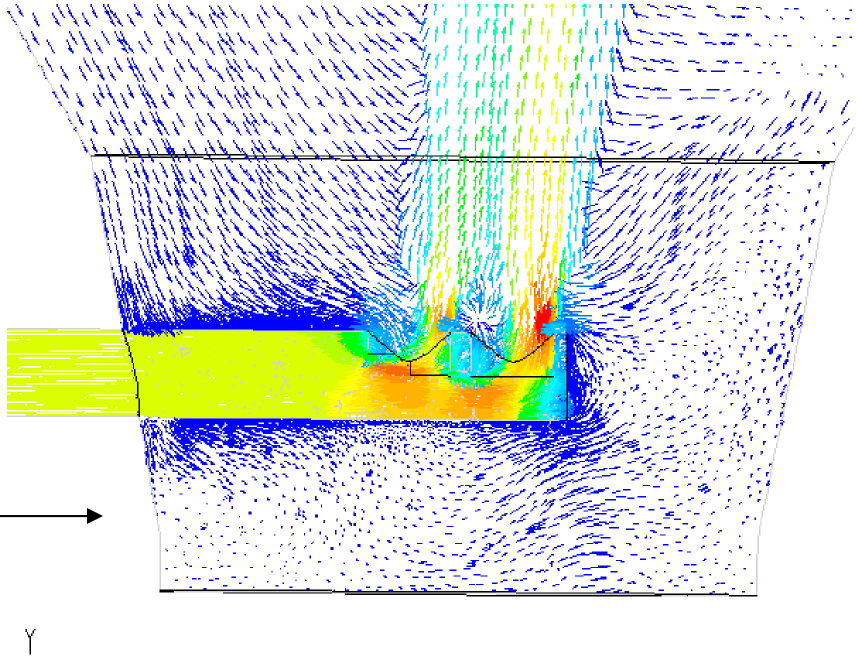
Flow Simulation Results – Modifications to Centered Insert Nozzle, Flow Condition #2

The simulations represent the beginning of the coking process when VRC vapor is injected into an empty drum

Alternate concept modification #4

(This is not final design because flow is slightly tilted.)

Note low circulation beneath nozzle on top of gate will encourage coke insulation to form above gate.



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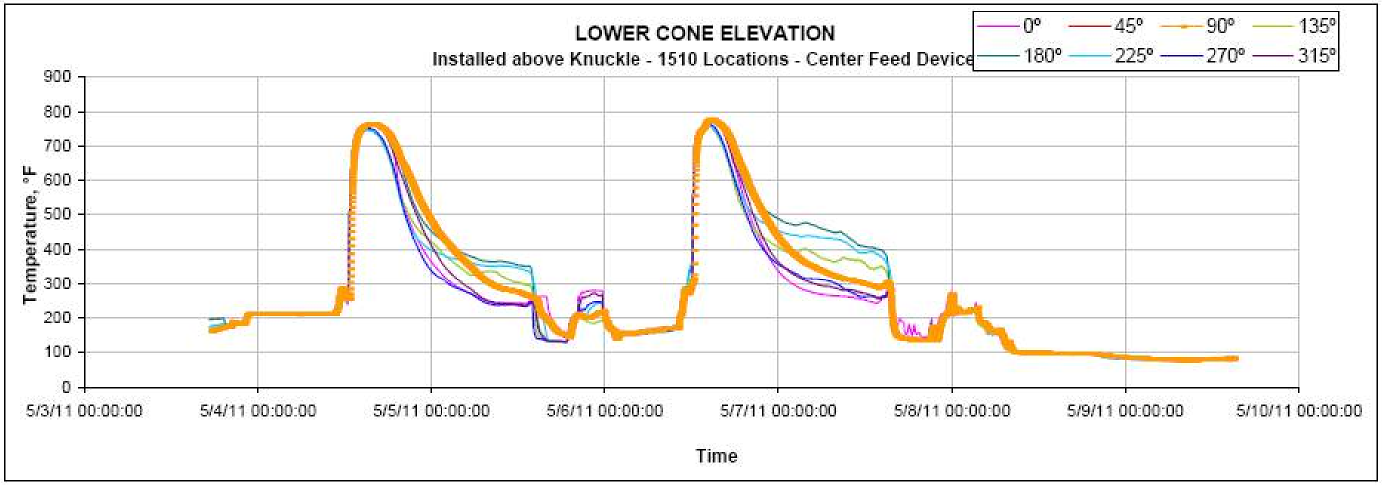
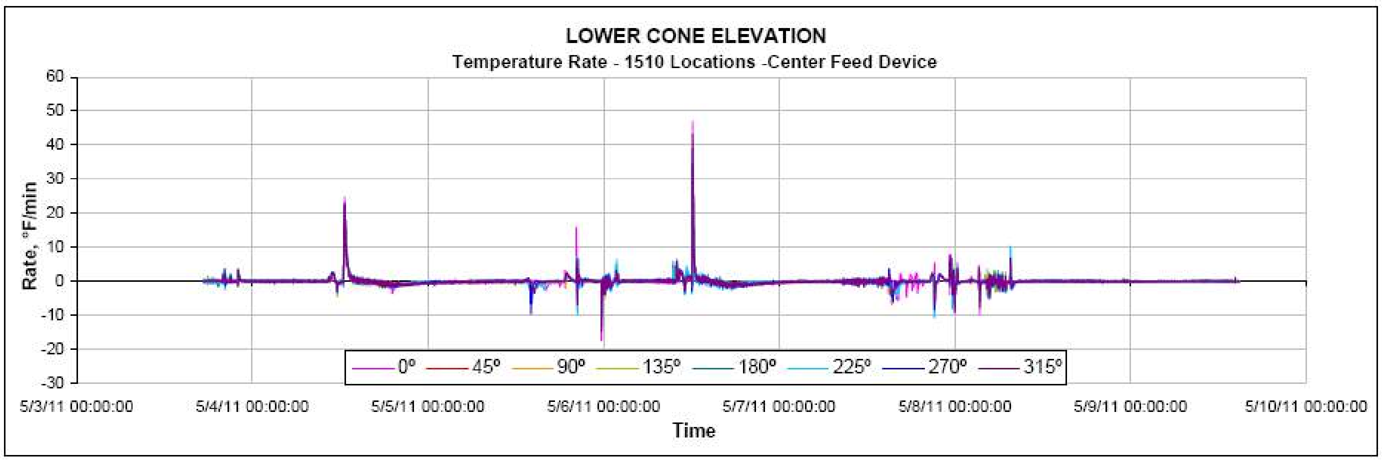
New CF Device First Cycles on Operating Drum May 2011

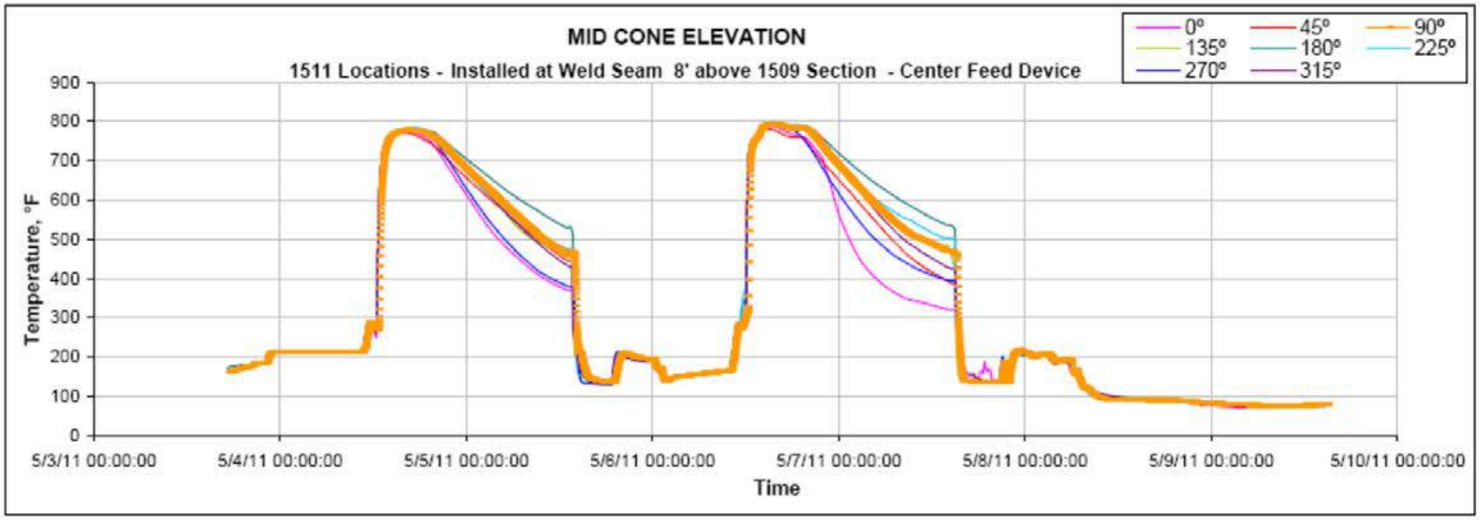


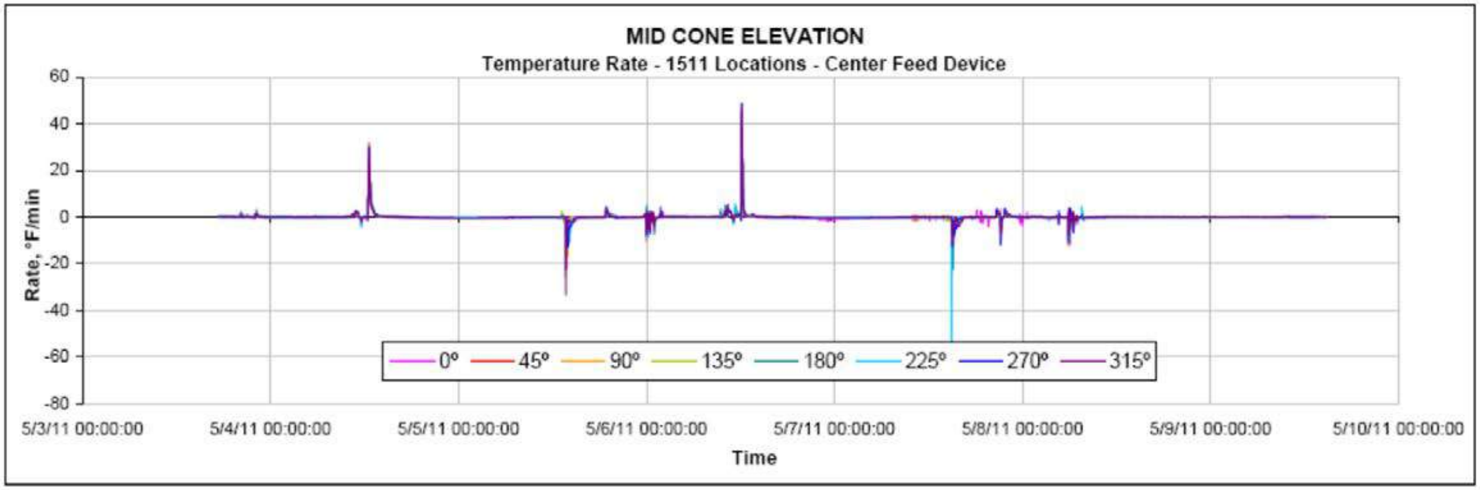


This and the following plots illustrate the effectiveness of the center feed nozzle.

Temperature in the sections are tracking closely and suggest coke insulation on cone and spool greatly reduces temperature at quench. This reduces stress in drum and skirt.

New CF Device First Cycles on Operating Drum May 2011





Temperature in the sections are tracking closely and suggest coke insulation on cone and spool greatly reduces temperature at quench.

This reduces stress in drum and skirt.

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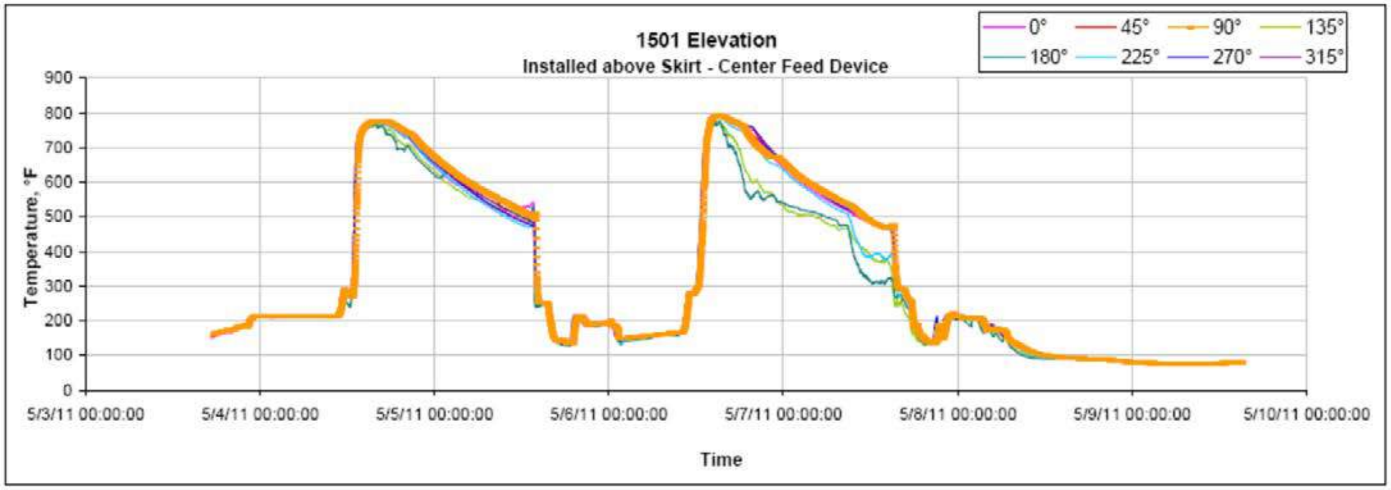
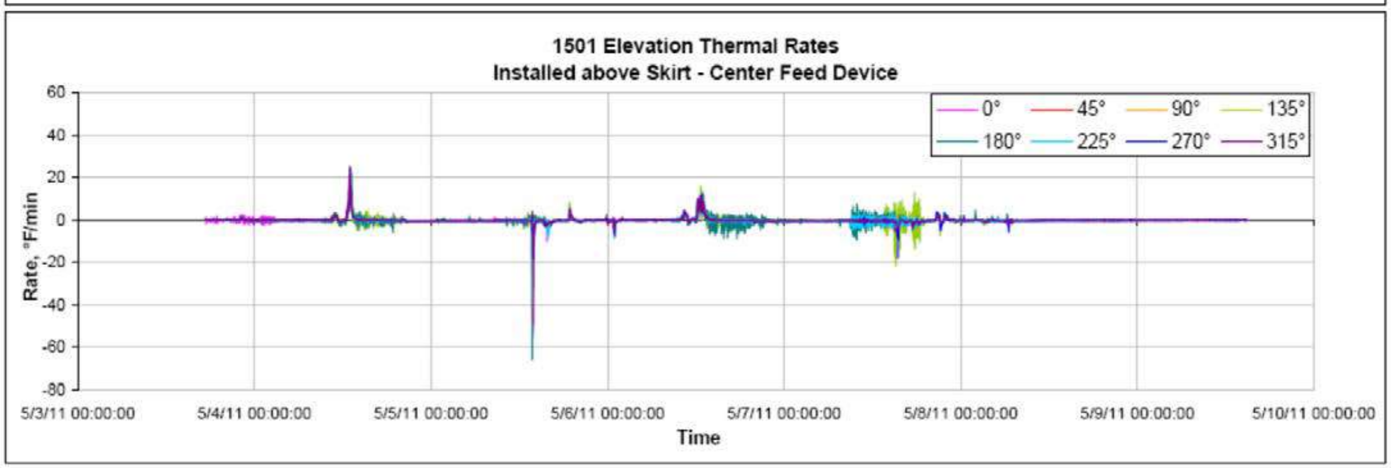
New CF Device First Cycles on Operating Drum May 2011

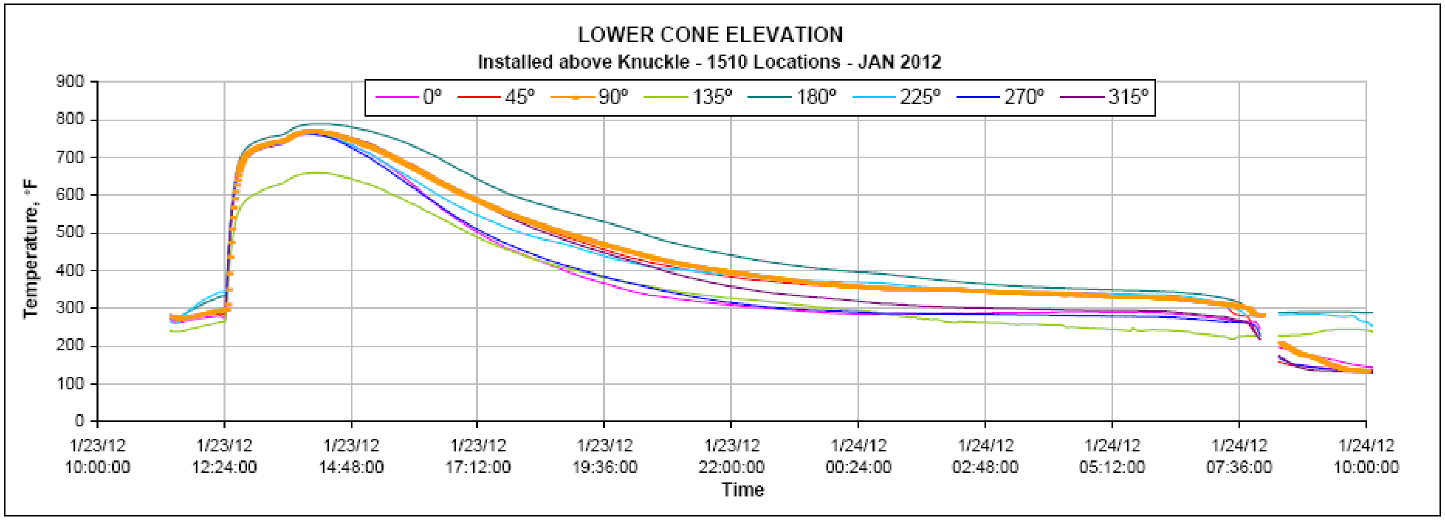


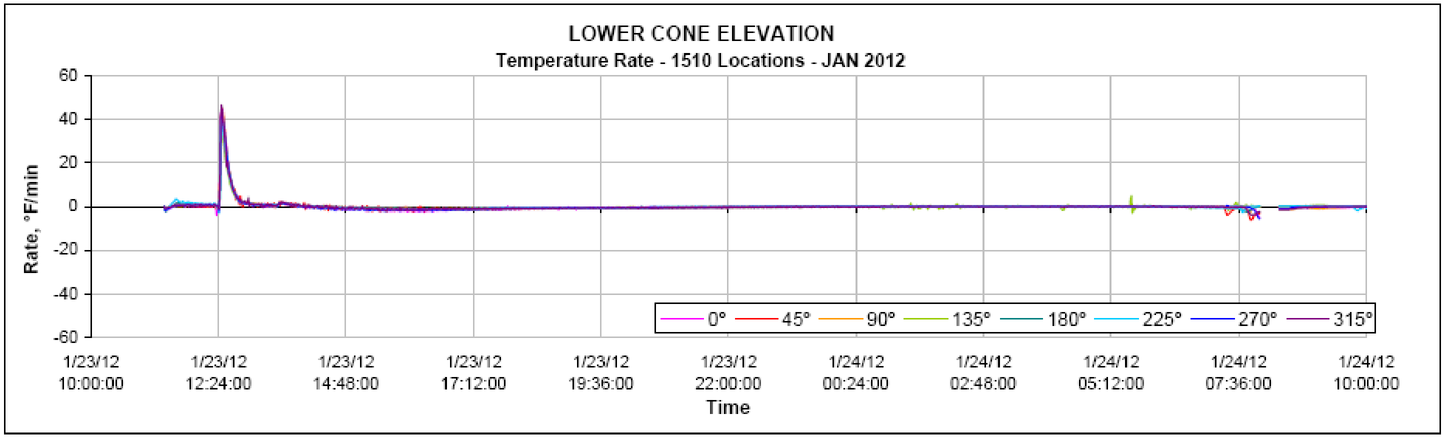


Temperature in the section above the skirt are tracking closely and suggest coke insulation on cone greatly reduces temperature at quench.

This reduces stress in drum and skirt.

Later Cycles on Operating Drum with CF Device January 2012





Temperature in the lower cone section closely and suggests coke insulation on cone greatly reduces temperature at quench.

This reduces stress in drum and skirt.

Quench Water Flow with Center Feed Device

- The highly focused jetting can keep quench flow centered in coke bed.
- This will decrease the likelihood that quench water will flow along the sides of the cone and drum and quench steel instead of coke.
- Quench stress will be less severe.
- Stress measurement on skirt and shell showed that fatigue damage decreased 37% and this extends the life of the skirt by 60%.

Conclusions with Center Feed Device

- Flow through a custom designed nozzle has been simulated for hot oil vapor after switch-in to an empty drum.
- Analysis and Measurement show the temperature distributions to be more uniform at each elevation.
- Different inlet types were compared, and the CFD nozzle optimized for performance.
- The volume between the nozzle and the gate will have low circulation. Coke will accumulate and bond to the walls creating an internal insulation with uniform temperature.
- These insulated components include gate, seals, and bolting which will cool exponentially during the cycle so that quenching effects are minimal.

Quench Conclusions with Center Feed Device

- The greatest benefit of this design may be expected during water quench into a fully coked drum.
- The focused central jet of water is expected to encourage a central flow path through the bed, and discourage flow outside of the bed.
- This will decrease the likelihood that quench water will flow along the sides of the cone and drum and quench steel instead of coke.

A review of ExxonMobil Dual Inlet Patent 2010 for Uniform Temperature

(12) **United States Patent**
Chen et al.

(10) **Patent No.: US 7,736,470 B2**
(45) **Date of Patent: Jun. 15, 2010**

(54) **COKER FEED METHOD AND APPARATUS**

(75) Inventors: **Te-Hung Chen**, Vienna, VA (US); **Christopher P. Eppig**, Vienna, VA (US); **Timothy M. Healy**, Centreville, VA (US); **Scott F. Massenzio**, Houston, TX (US); **Robert W. Mosley**, Beaumont, TX (US); **Rutton D. Patel**, Arlington, VA (US)

(73) Assignee: **ExxonMobil Research and Engineering Company**, Annandale, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 554 days.

(21) Appl. No.: **11/716,634**

(22) Filed: **Mar. 12, 2007**

(65) **Prior Publication Data**

US 2008/0179165 A1 Jul. 31, 2008

Related U.S. Application Data

(60) Provisional application No. 60/897,242, filed on Jan. 25, 2007.

(51) **Int. Cl.**
C10B 57/04 (2006.01)

(52) **U.S. Cl.** **201/25**; 201/28; 208/131; 202/239

(58) **Field of Classification Search** 201/25, 201/28; 202/239; 208/131; 196/155
See application file for complete search history.

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Primary Examiner—N. Bhat
(74) *Attorney, Agent, or Firm*—Malcolm D. Keen; Glenn T. Barrett

(57) **ABSTRACT**

Described herein are methods and mechanisms for laterally dispensing fluid to a coke drum in a predictable and maintainable manner that alleviates thermal stress. In one embodiment, the methods and mechanisms utilize a split piping system to dispense fluid through two or more inlets into a spool that is connected to a coke drum and a coke drum bottom deheader valve. A combination of block valves and clean out ports provides a more effective means to clean the lines and allows fluid to be laterally dispensed in a controllable and predictable manner. The fluid is preferably introduced to the spool in opposing directions toward a central vertical axis of the spool at equal but opposing angles ranging from minus thirty (−30) to thirty (30) degrees relative to a horizontal line laterally bisecting the spool. Alternatively, however, fluid can be introduced to the spool tangentially.

16 Claims, 4 Drawing Sheets

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ExxonMobil Dual Inlet Patent 2010

4.0 SUMMARY OF THE INVENTION

Described herein are methods and mechanisms for laterally dispensing fluid to a coke drum in a predictable and maintainable manner that reduces drum/vessel thermal stress. The methods and mechanisms utilize a split piping system to dispense fluid through two or more inlets into a spool that is connected to a coke drum. The use of a combination of block valves and clean out ports provides an effective means to clean the lines and, thereby, allows the fluid to be laterally dispensed in a more controllable and predictable manner. The fluid may be introduced to the spool in opposing directions toward a central vertical axis of the spool at any angle between minus 30 degrees and 30 degrees relative to horizontal or, less preferably, tangential to the sides of the spool. The combination of opposing feed entry and angled feed entry using the split piping system is especially advantageous in reducing the total thermal stress connected with side introduction of heated fluid to the spool. By using the embodiments described herein, refineries can avail themselves of the safety and cycle time benefits provided by coke drum bottom

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deheader valves that require side fluid entry without incurring significant thermal stress problems in the vessel (e.g., recurrent plastic deformation of the coke drum bottom, leaks in nearby gasketed joints, metal fatigue and cracks in the drum). These and other features of the invention are set forth in more detail below.

Alternatively, but less preferably, the fluid streams may be dispensed into the interior of the spool tangential to the inside surface of the spool wall. By uniformly splitting the feed, and directing the feed into the coker bottom inlet plenum via two nozzles arranged to create a tangential flow, a circular flow pattern is established, and this can also result in a more uniform temperature distribution in the bottom plenum of the coke drum relative to a single feed inlet.

In either case, substantial reduction in thermal stress is achieved relative to a single horizontal feed inlet. This translates into a reduced incidence of leaking flanges, and a longer time between cracks in the vessel walls.

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ExxonMobil Dual Inlet Patent 2010

Nozzles near bottom with small angle to create uplifting circular flow.

Theta is +/- 30 deg

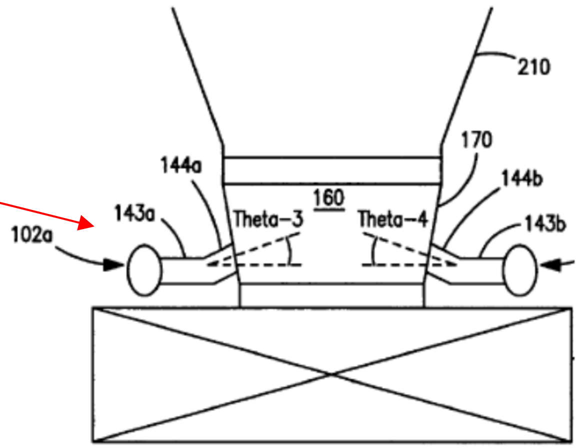

FIG. 2

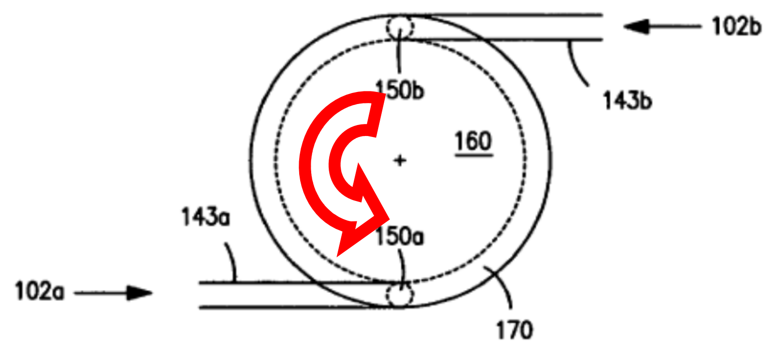

FIG. 3

Circular flow pattern established near bottom with tangential nozzles.

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ExxonMobil Dual Inlet Patent 2010

Turbulent mixing and diffusing to transform radial flow and create Circular flow pattern established near bottom.

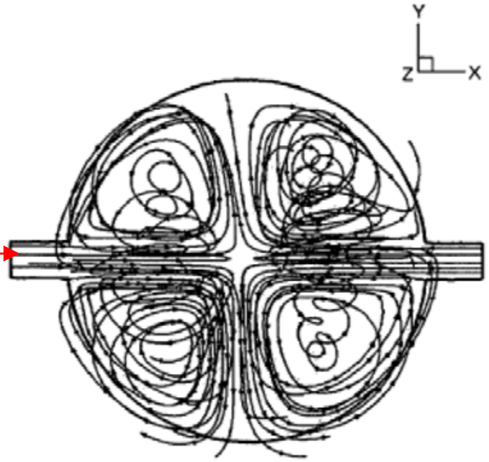

FIG. 4A

Diffuse flow eventually moves up and down the drum walls and then upwards as a diffuse central column.

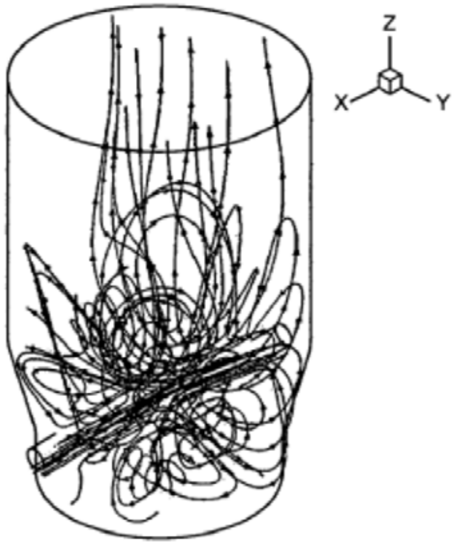

FIG. 4B

- Bottom would remain very clean, as well as uniformly hot during Fill.
- Because bottom is not filled with coke, a significant slump event may occur between hot oil and water stages.
- If slump event happens, water flow may be very difficult to inject due to plugging and constricted flow paths.
- If slump does not happen, Unheader components will be quenched suddenly and severely.

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CFD Nozzle Flow Animations

- SES has created high quality flow animations of different Inlet Nozzle configurations for comparison to **C**enter **F**eed Insert **D**evice.
- Simulations and performance suggest that coke will form below the nozzle and insulate the flanges, gate and internal components from rapid quenching and will encourage uniform temperature distributions.
- Simulations show dual/single side feed inlets encourage fluid flow along drum walls.

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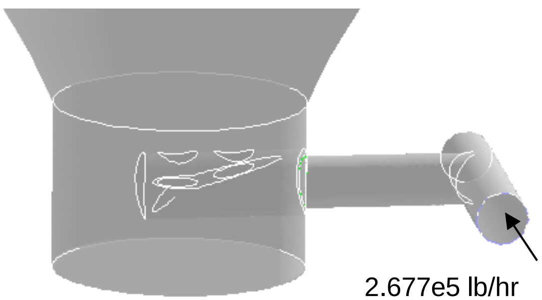
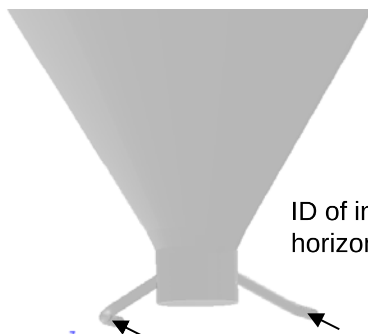
Nozzle Analysis Models

The time dependent flow behavior for four inlet configurations of the coke drum is simulated;. The total inflow feed stream flow rate is the same for all four configurations (2.677e5 lb/hr).



2.677e5 lb/hr flow rate specified

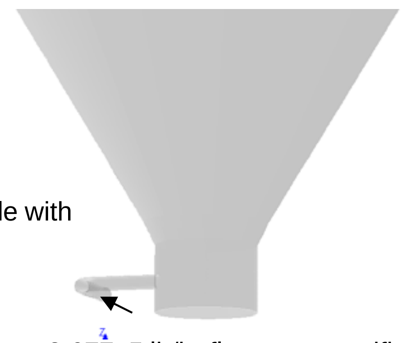
DV, CFD inlet



ID of inlet pipe is 8”; angle with horizontal is **30 degrees**

Equal flow rate into each nozzle, 2.677e5 lb/hr total flow rate split equally between the two inlets.

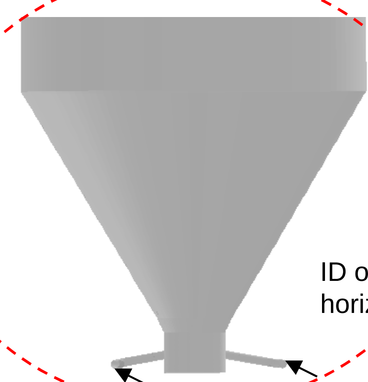
Dual side entry inlets



2.677e5 lb/hr flow rate specified

Single side entry inlet

Previously analyzed configurations



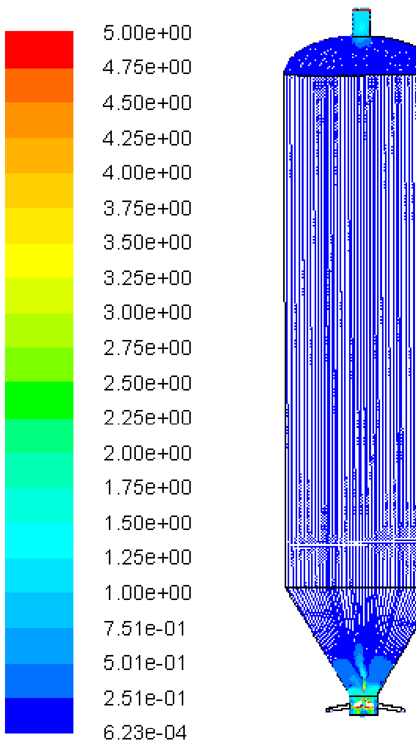
Dual side entry inlet configuration analyzed and discussed in this report

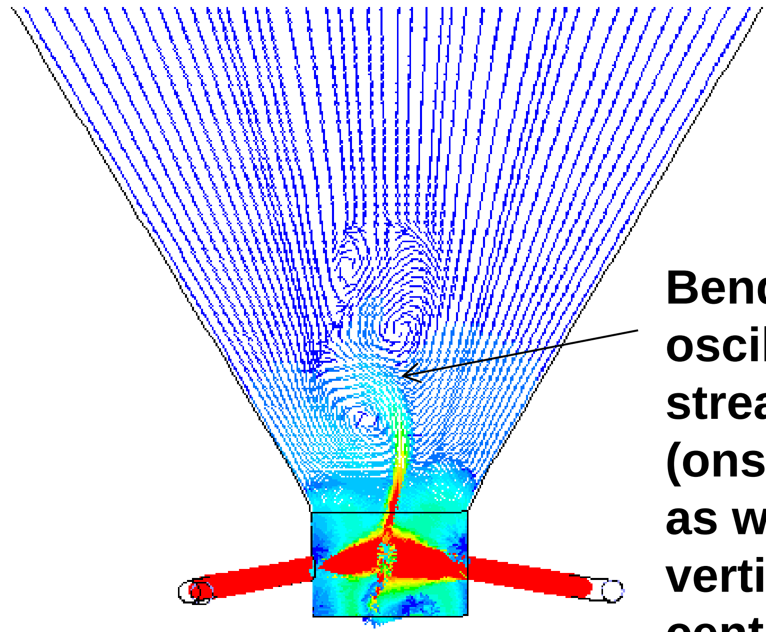
ID of inlet pipe is 8”; angle with horizontal is **10 degrees**

Equal flow rate into each nozzle, 2.677e5 lb/hr total flow rate split equally between the two inlets.

Flow Simulation Results – Dual Side Entry Inlets at 10 degree

The evolution of flow inside the coke drum using dual side entry inlets with time is depicted.





Bending and oscillation of flow stream is observed (onset of instabilities) as well as lower vertical velocity in center

Close up view of flow in inlet region on Plane 1

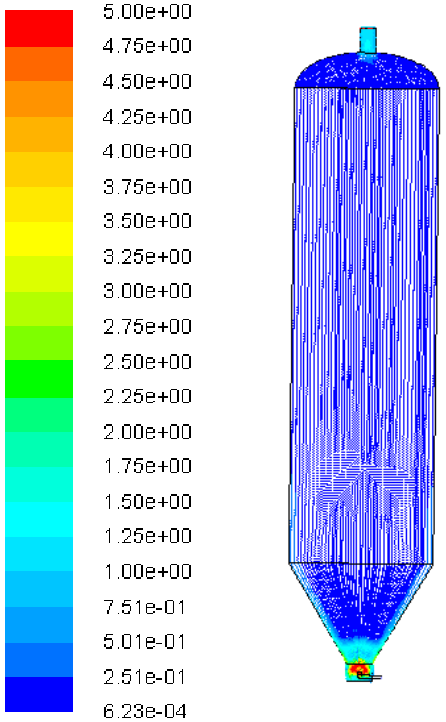
Velocity vectors colored with speed (m/s) are depicted on Plane 1.
Red color denotes speed of 5m/s or higher

Time=40 seconds

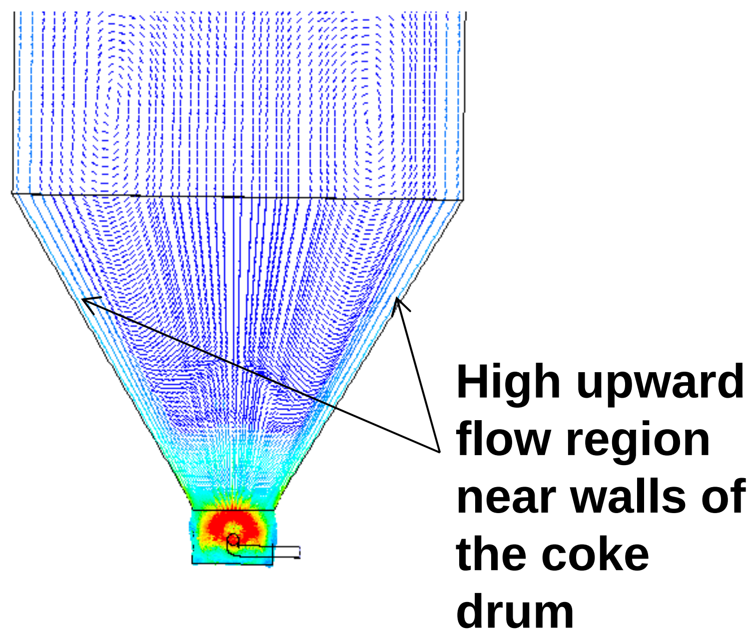
The analysis shows bending and oscillation of flow stream due to flow instabilities. However, **unlike the 30 degree** dual entry inlet, complete biasing of flow towards one-side is not observed.

Flow Simulation Results – Dual Side Entry Inlets at 10 degree

The evolution of flow inside the coke drum using dual side entry inlets with time is depicted.



Velocity vectors colored with speed (m/s) are depicted on Plane 2.
Red color denotes speed of 5m/s or higher



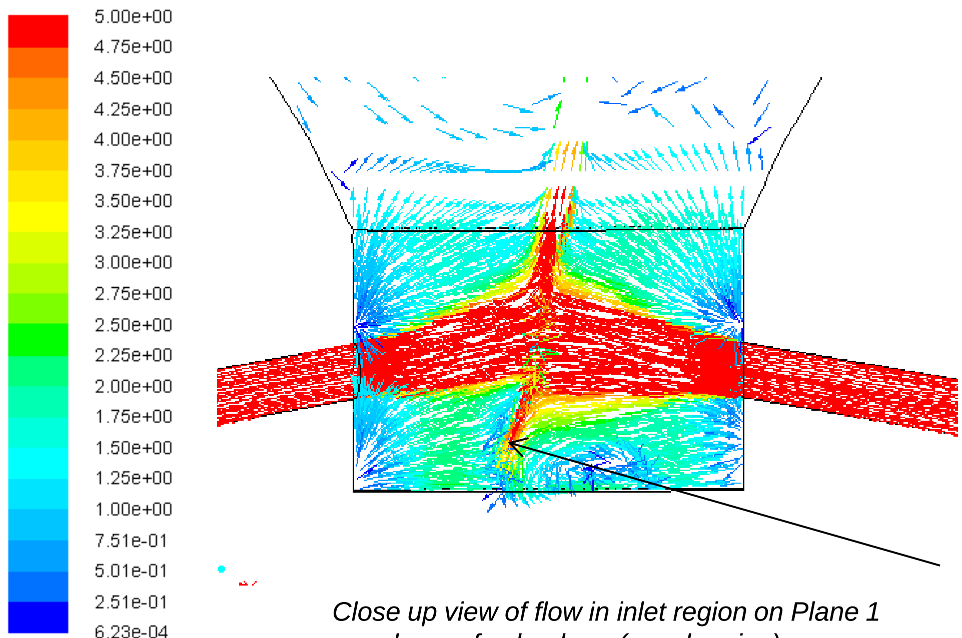
Close up view of flow in inlet region on Plane 2

Time=40 seconds

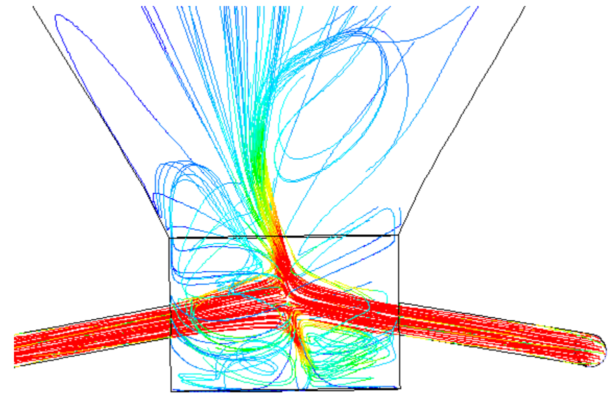
The analysis shows the formation of a region of upward moving flow near the walls of the coke drum.

Flow Simulation Results – Dual Side Entry Inlets at 10 degree

The flow behavior in the coke drum using dual side entry inlets is depicted.



Close up view of flow in inlet region on Plane 1 near base of coke drum (spool region)



Pathlines show downward flow in the spool region

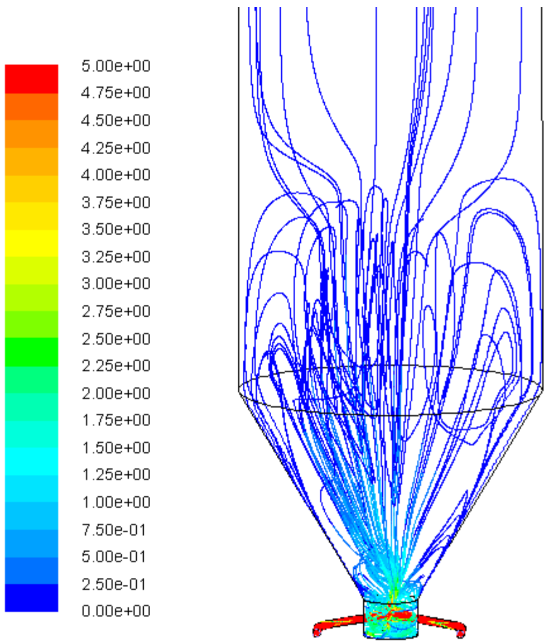
The analysis shows that some of the flow is diverted towards the bottom of the spool

Velocity vectors colored with speed (m/s) are depicted on Plane 1.
Red color denotes speed of 5m/s or higher

Time=40 seconds

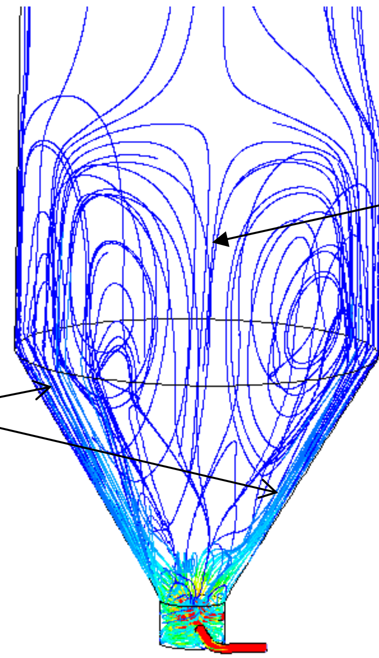
Flow Simulation Results – Dual Side Entry Inlets at 10 degree

The flow behavior in the coke drum using dual side entry inlets is depicted.



Path lines colored with speed (m/s) are depicted. Red color denotes speed of 5m/s or higher

Higher density of path lines shows higher flow along walls. This region is at 90 degrees to the plane in which the inlets are located



Note downward flow in center of drum

Alternate view along plane at 90 degrees to inlets

Time=40 seconds

The analysis shows that the fluid jets from the two inlets impact each other and the flow spreads out across a plane at 90 degrees to the plane containing the inlets. This results in higher upward flow near the walls of the coke drum along a region at 90 degrees to the inlet plane.

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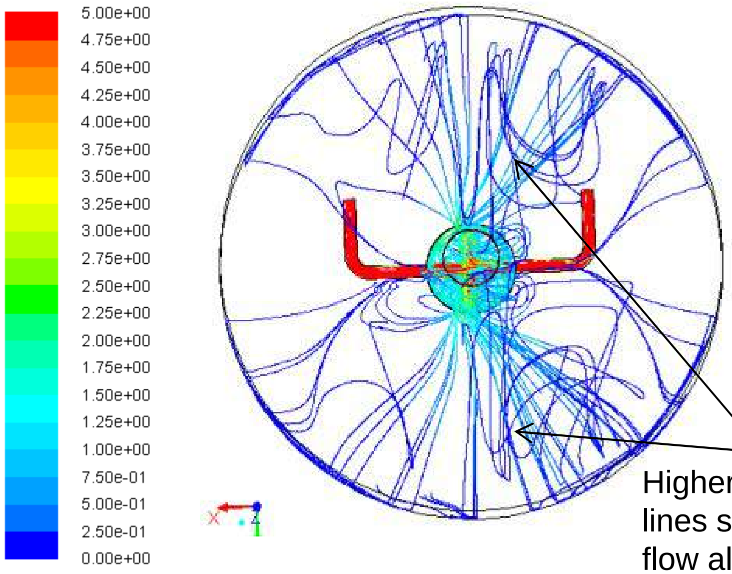
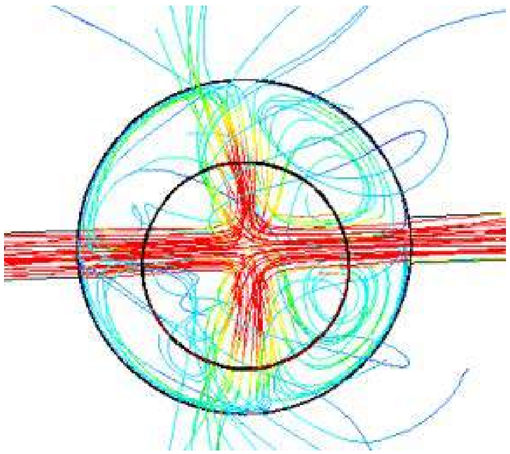
Flow Simulation Results – Dual Side Entry Inlets at 10 degree

The flow behavior in the coke drum using dual side entry inlets is depicted.



View from above

Higher density of path lines shows higher flow along this region



Close up view of spool region

Path lines colored with speed (m/s) are depicted. Red color denotes speed of 5m/s or higher

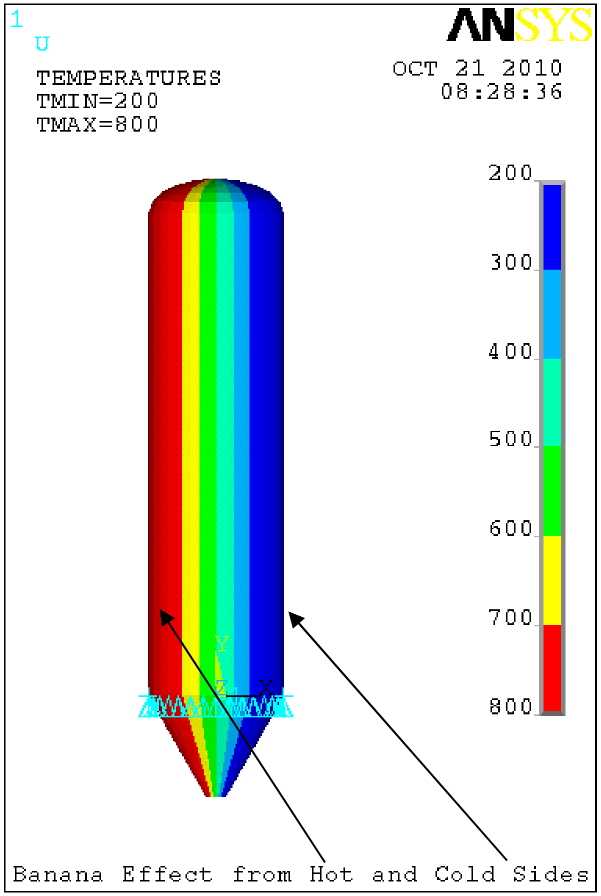
Time=40 seconds

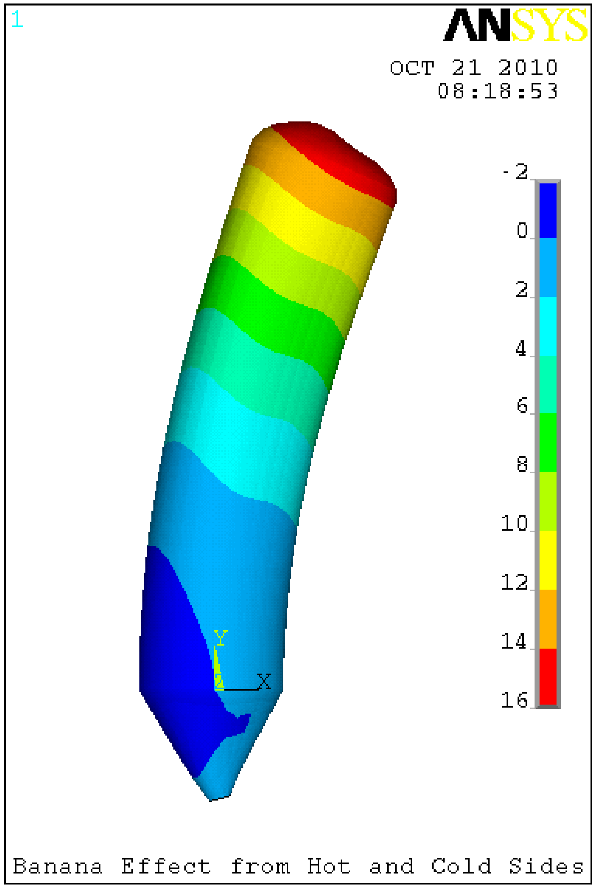
The analysis shows spreading of flow along a region at 90 degrees to the inlet plane.

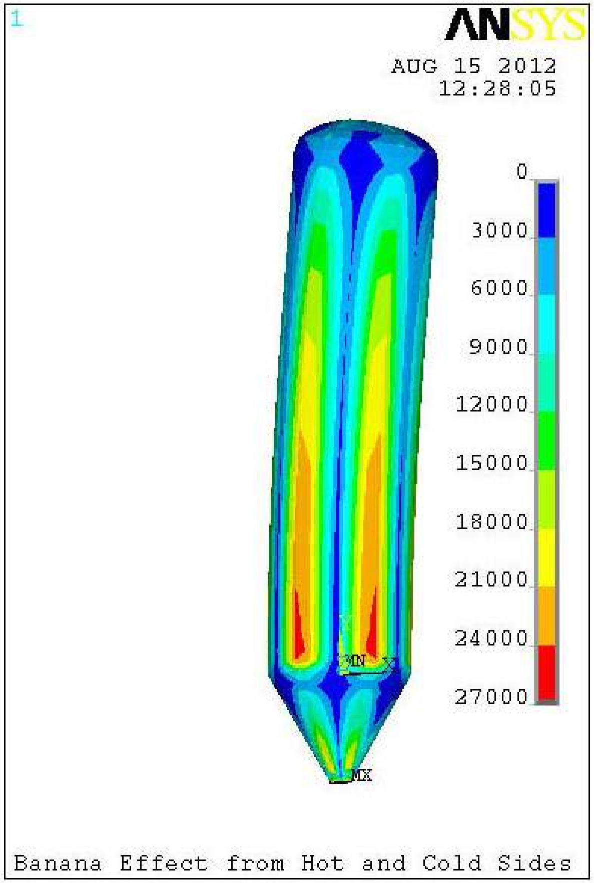
Comments on Dual Flow Inlets

- Greater pressure loss expected compared to single nozzle.
  - Creates Turbulent Diffusion and Mixing.
  - Attempts to create a uniform flow upward over a much larger area.
  - Radial flow energies can not completely cancel or be equal between nozzles.
- Vertical flow velocity in drum is less.
  - Overall swirl is encouraged and this can encourage fast quench rates on shell.
  - Higher flows near walls are expected, with low flow in center.
- Bottom would remain very clean, as well as uniformly hot during Fill.
  - This eliminates formation of insulating coke and encourages severe quench.
- Because bottom is not filled with coke, a significant slump event may occur between hot oil and water stages.
- If slump event happens, water flow may be very difficult to inject due to plugging and constricted flow paths.
- If slump does not happen, Unheader components will be quenched suddenly and severely.

Coke Drum Banana Shaping
from Hot and Cold Sides During Quench







Contour plot of temperature

Contour plot of deflection

Contour plot of stress

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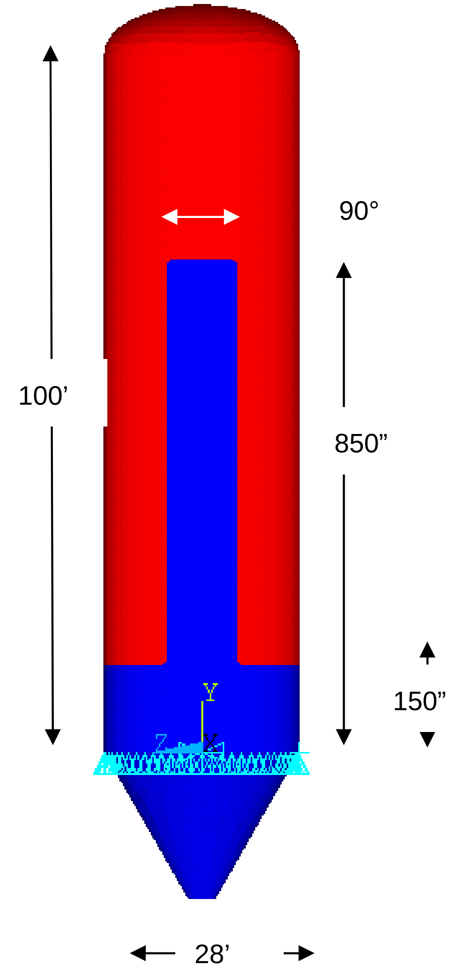
Sample Cold Zone Drum to Evaluate

- Diameter 28 feet
- Height (TL to TL) 100 feet
- Shell Thickness 1.75 inches
- Head Thickness 1.75 inches
- Cone Thickness 1.75 inches
  - Knuckle not modeled for simplicity

- Internal Pressure 50 psi
- Exaggerated Quench Temperatures
  - Hot Zone 800 °F
  - Cold Zone 400 ° F



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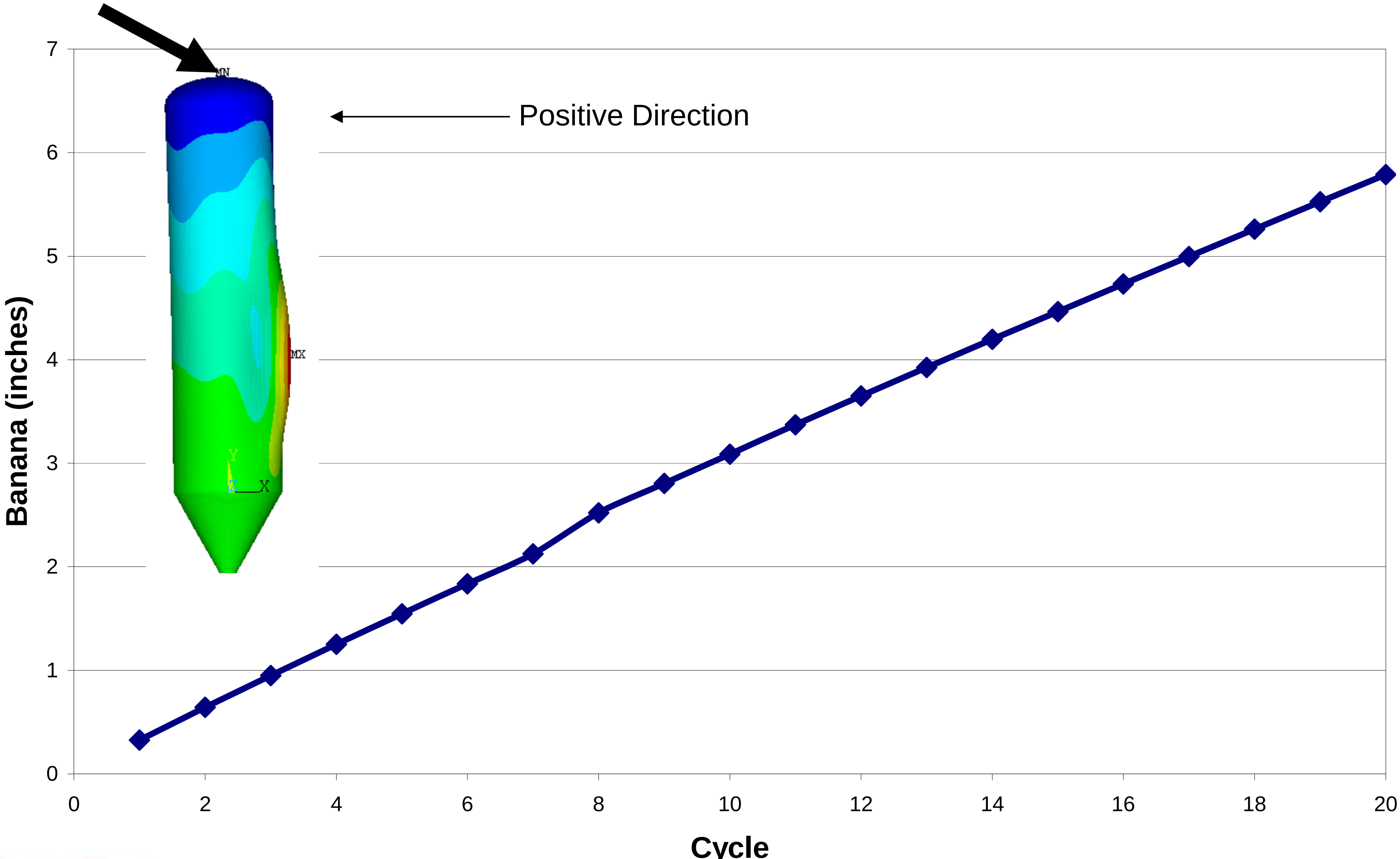
Banana at top of Drum after Quench



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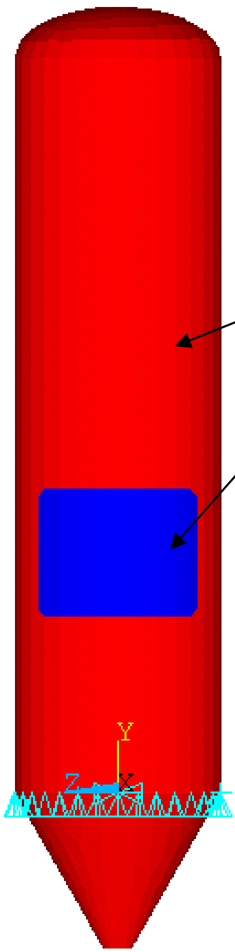
Bulge Growth Model with Cold Zones



Temperature distribution at quench

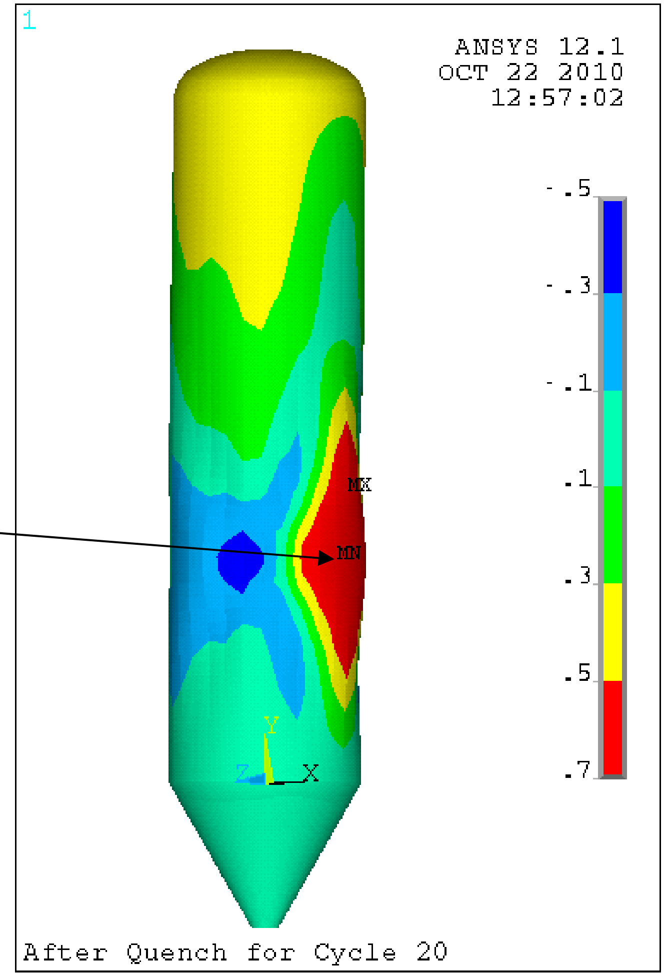
Hot zone: 825 °F

Cold zone: 200 °F

Bulge after 20 cycles (0.7 inches)

Bulges can form on drum walls as a result of local hot/cold spots.

Flow Channel are not friendly to drums.



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Summary of Fatigue and Inlet Nozzles

- 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 along drum walls.
- Fast quenching can create severe gradients.
- Severe thermal rates create multiple problems.
- Center Feed Inlet Device improves thermal gradients during Fill and Quench and reduces fatigue damage.
- Hard or Soft coke create different problems and these can change with feed stocks and recipes.
- Skirt is stressed during Fill and Quench, and the drum Cylinder/Cone is stressed during Quench.
- Awareness starts with appropriate EHMS.

- <u>Knowing your problem lets you solve your problem and extend drum cyclic life.</u>

Project Coke Drum

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