2017 CHEVRON COKER SAFETY & RELIABILITY

- Presention for REFCOM Conference – DELAYED COKER
- May 2017

- OVERVIEW

• Bottom unheading injury	Dan Plinski
• Furnace transfer line loss of containment	Carolyn Johnson
• Furnace transfer line cleaning – coke ignition	Ankur Amlani
• Furnace tube thinning investigation	Dale Wilborn

Coker Safety & Reliability

Discussion Topics

- Original Delayed Coker process design was extremely high risk – especially bottom and top unheading.
- Lower cycle times and different resid qualities may have introduced new issues and risks.

Agenda

- Top and bottom unheading risks greatly mitigated with slide gate valves. However, Chevron has still experienced 3 "line of fire" incidents even with Delta Valves.
  - ➢ One top unheading area
  - ➢ Two bottom unheading area
- Furnace transfer line erosion and cleaning incidents
  - ➢ Coke accumulation increases velocity, increased elbow erosion risk.
  - ➢ Coke in transfer line can ignite when opened for cleaning.
- Furnace tubes and return bends need to be inspected.
  >Erosion and thinning can occur.

Desired Outcomes

- Prevent coke drum "line of fire" personal exposure; prevent personal injuries.
- Prevent Coker furnace transfer line loss of containment and piping overheating incidents.
- Communicate unusual Coker furnace tube thinning; see if others have experienced anything similar or have any thoughts on damage mechanism, prevention, etc.

SAFETY : Coker Hot Water Incidents since Installation of top & bottom Delta Valves

- Bottom unheading device (BUD) using Delta Valve slide gate installed on all Chevron coke drums by 12/2003 (first 14 in industry).

- 2012 – Pascagoula transfer line inspection (opening port) after cut, trapped hot water.
- 2014 – El Segundo hot water on top of closed TUD, driller manually changing combo tool, ankle burn.
- 2016 – El Segundo coke drum fallout prior to drilling – serious injury

Previous Coke Drum Unheading

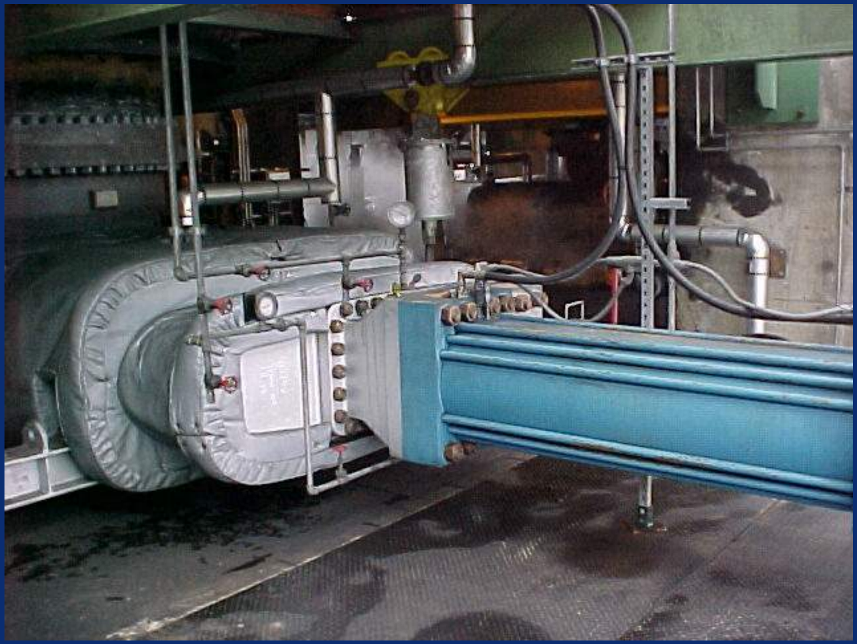
Originally: All manual.

Late 80's: Hydraulic lowering to head cart, hydraulic lift for chute.

Vulnerable to fall-out.

A number of serious injuries plus many burns, bruises, etc.

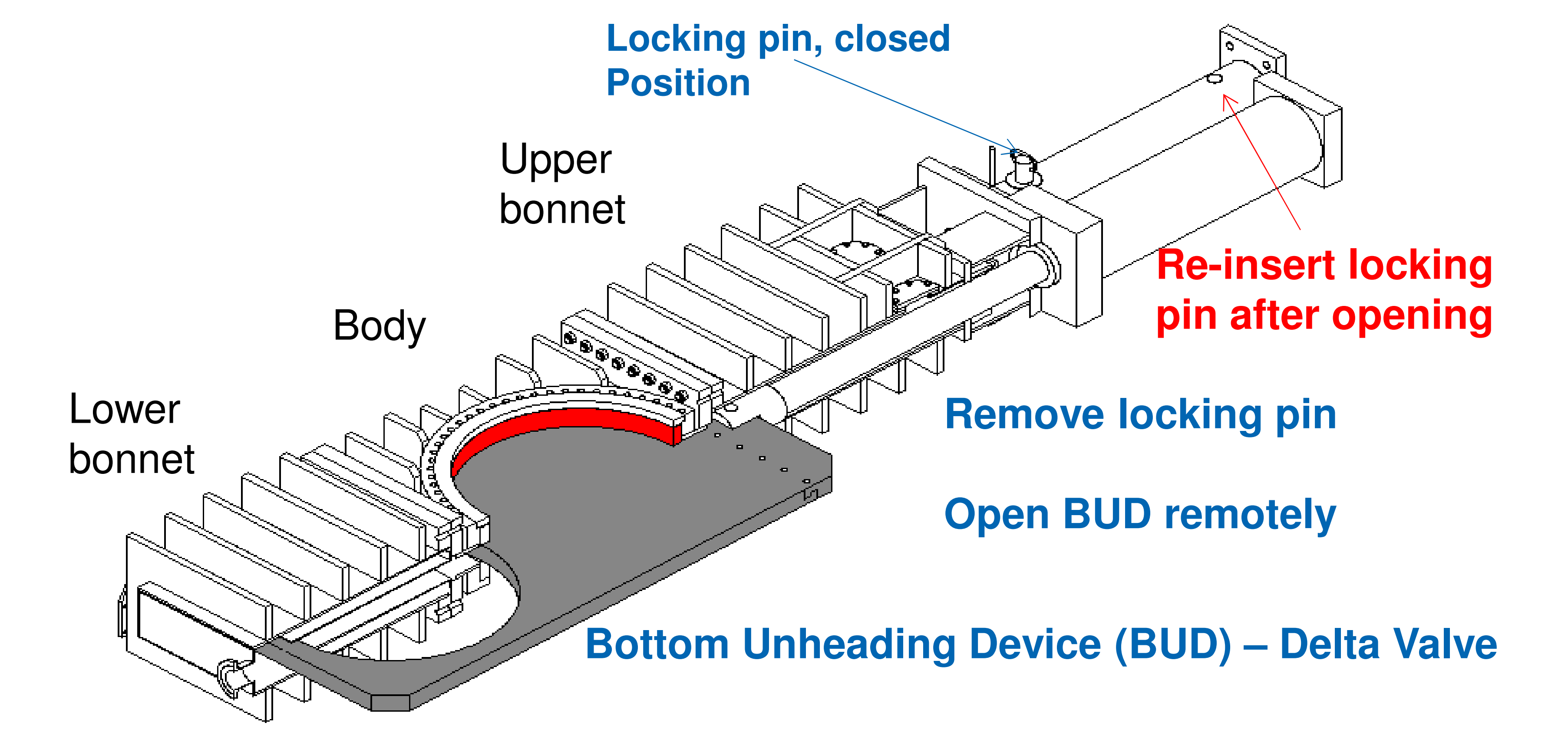
Automatic Bottom Unheading Device (BUD)



Remotely operated, hydraulically actuated slide gate valve manufactured by Delta Valve

- Side entry transition spool with "improved design" to solve the leaking flange issue encountered in 1st installation in Salt Lake.

Coker Design Safety Upgrade – Automatic Remote Unheading



Coker V-501A Fall-Out & Injury

- 6/1/2016 Coke Drum Sequence

- Feed
- Switch
- Steam strip to main fractionator
- Depressure to blowdown

- Quench - 157,000 gallons, good
  (V-510 condensed steam 33,000 gal, normal)
- Vent below 2.0 psig (normal)
- **Drain - poor, did not drain much water**
- Unhead – Opened BUD from remote location

- Normally water rushes out from 60” BUD opening if the drain has been poor.
- In this instance, coke bridged and held water and coke in the drum until….

Coker V-501A Fall-Out & Injury

… structure operator came down from blowdown (middle) deck to feed / unheading (bottom) deck to insert locking pin into the “valve open” position. (About 10 minutes after opening BUD).

The fall-out of coke and water occurred at that point in time. Coke and water overwhelmed the stationary chute into the pit, backed up and came out the ~ 6” gap between fixed chute and stationary chute.

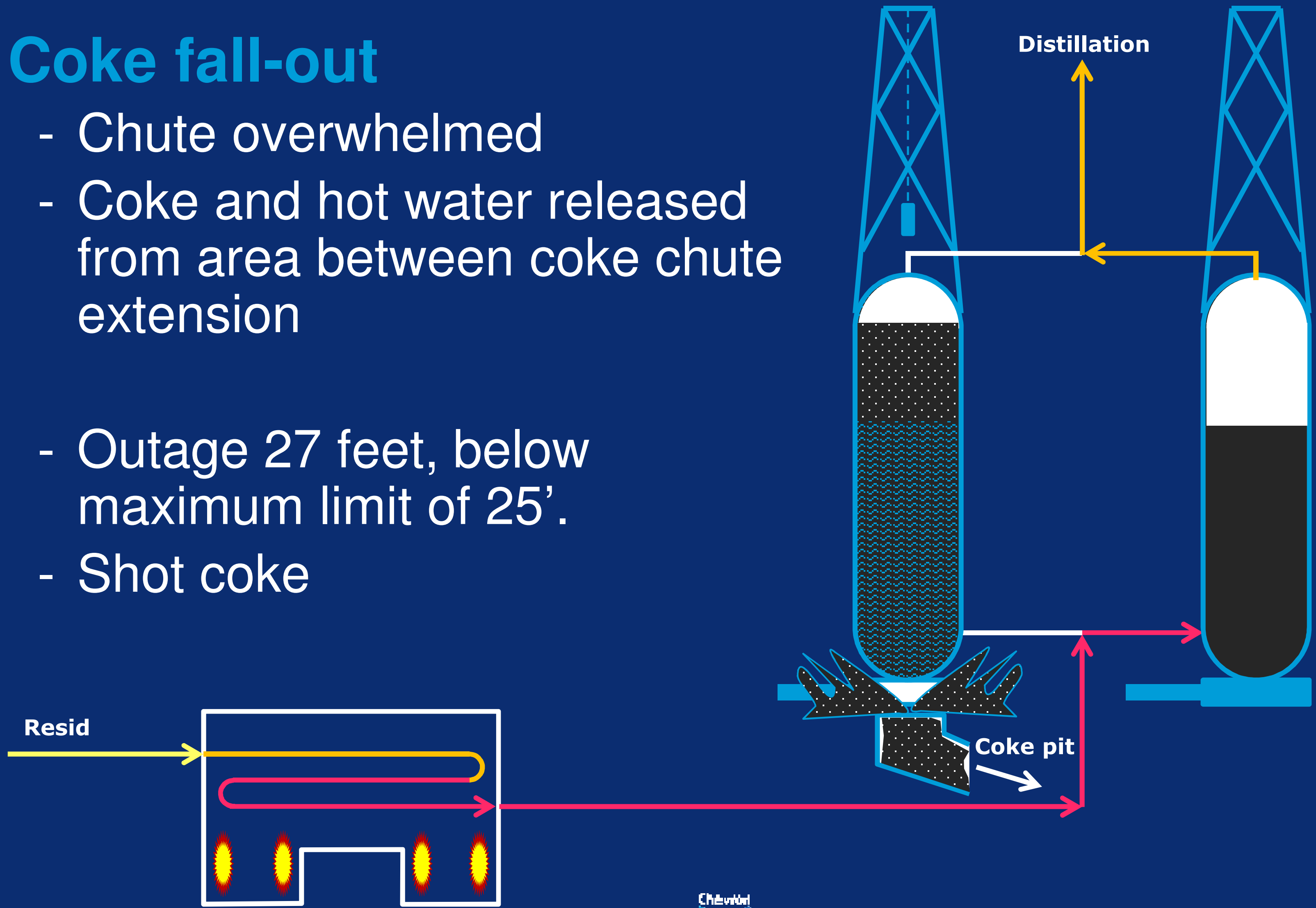
C-501A Coke Fall-Out & Injury

Coker Process at Time of Injury

Coke fall-out

- Chute overwhelmed
- Coke and hot water released from area between coke chute extension

- Outage 27 feet, below maximum limit of 25'.
- Shot coke



Coker V-501A Fall-Out & Injury

Original design: CS fixed chute to bottom flange of BUD. There were plates used to fill gap between bottom (feed) deck (72” opening).

New design (right picture) is stainless, two pieces with the intent to have a seal to prevent coke and water onto deck. New design developed and being implemented prior to incident.

Lessons Learned – Corrective Action

INJURY SEVERITY

Serious, hospitalization.

NOMEX does not protect against hot water or steam.

1. IMMEDIATELY STOP Re-INSERTING locking pin after opening BUD until after the energy source (coke & water) has been removed from coke drum. Recommend inserting after coke has been cut to verify that the BUD limit switch is in correct position, fully opening the gate. Verifies an edge of the gate will not be in path of falling coke and experience erosion during coke drilling operation.

2. Continue and complete the fixed chute replacement. Monitor new design performance; has it stopped coke back-up onto bottom unheading deck?

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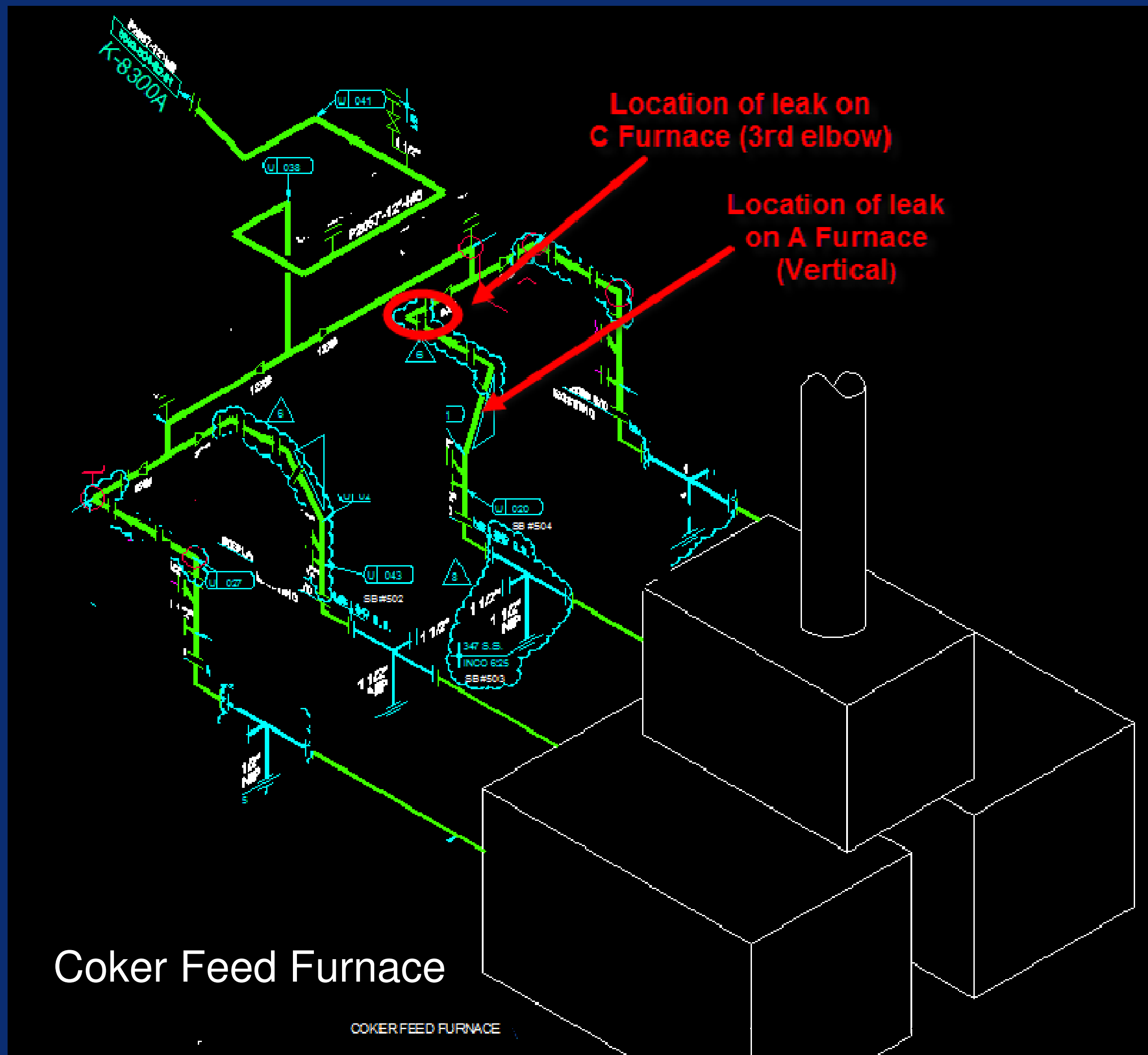
Incident Overview

Modified original FW transfer line geometry due to excessive coke accumulation in outlet barrel.



Incident Overview

- Initial leak on A furnace transfer line discovered after a spall.
- Second leak on C furnace transfer line discovered during spall.

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Incident Overview

- Drum was feeding for ~5hrs for the first leak and ~3hrs for the second.
- Immediately pulled feed & replaced with 100% velocity steam.
- Increased steam temperature to 1100ºF for 10 hours.
- Both instances, no “tarry drum” issues when quenching and cutting coke.

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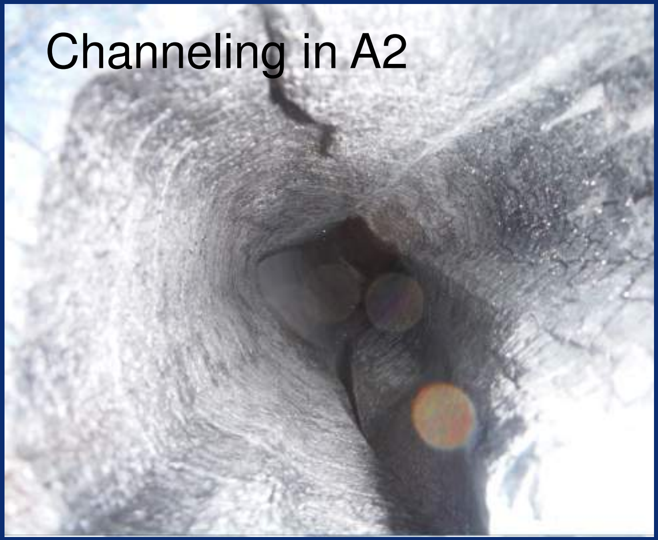
Investigation Key Findings

- Elevated coke build up in the transfer piping increased velocity of spalling steam/coke fines, accelerating erosion.
    - Condensate rates in the Spall Procedure were set at a previously inspected ID of 3.9”.
    - ID in C Furnace 6” piping ranged from 3-3.5”.
    - Spall velocity ranged from 500-600ft/s.

Investigation Key Findings

- Channeling in the coke due to a change in direction of the flow which targeted locations for erosion.
  - Apex of 90ºs.
  - Quench steam introduced perpendicular to flow.



Investigation Key Findings

- The time between open/clean/inspect opportunities had been lengthened on all furnace outlet piping due to more online spalling, fewer module bypass. This resulted in reduced opportunities to visually identify coke build up and potential wall thinning.
- Transfer line was last cleaned during the 2008 turn around. Several sections were replaced after.

2015 B1 leak during spall. Leak is opposite quench steam injection.

2011 B1 leak during spall

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Investigation Findings

- Found the erosion on the elbows to be ~12” away from top of flange.
- Pictures: C Furnace pass 1 - 1st elbow
  - Stellite/Inco breach
  - Thinned from ~ 0.5” to 0.140”

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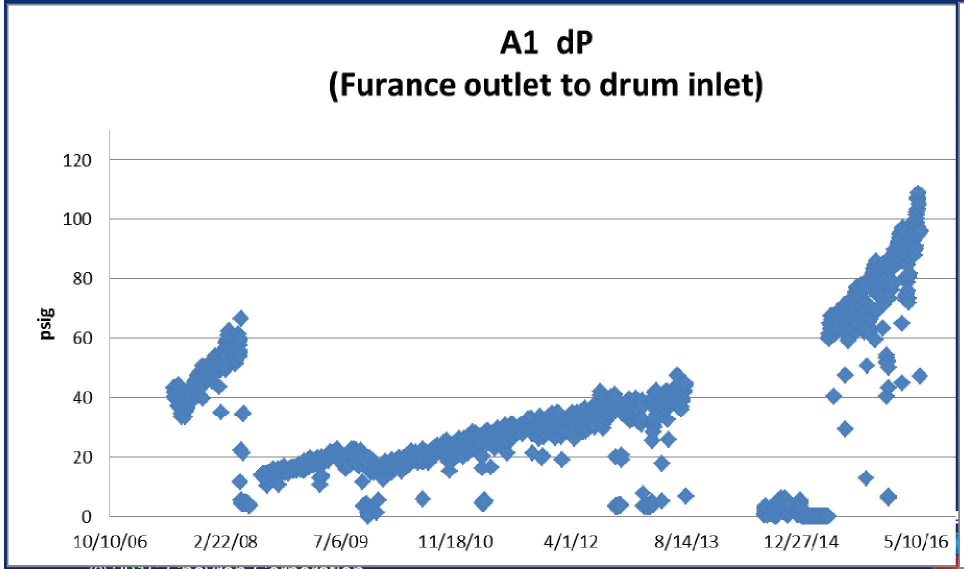
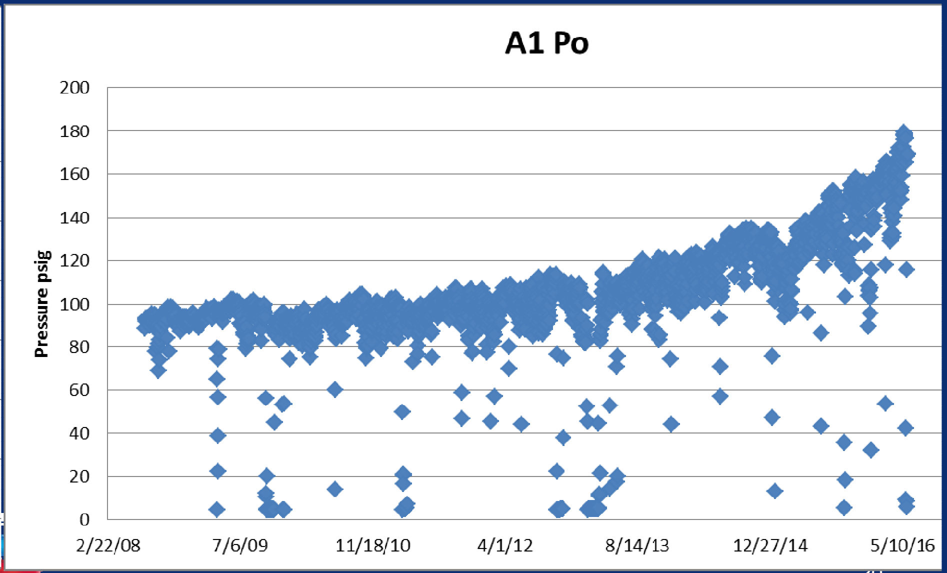
Transfer Line dP & Outlet Pressure

- dP in the furnace outlet piping has increased since the line has been replaced and/or hydroblasted.
- Increase is evident in all 3 furnaces (highest in A).
- Increases exponentially over time as would expect with dP correlated to diameter^5. Also no step change indicating it was not from a single event.
- Increase in pressure indicates increased coke formation.





Sample Analysis

- Volatile Combustible Matter (VCM) indicated C furnace transfer line coke was closer to Tar.
  - Coke drum: 9-10%
  - A Furnace: 4.5%
  - C Furnace: 35%
- Metals are more concentrated in Transfer line than coke drum.
- Limited feed metals analysis. However, Calcium was high for several months prior to incidents. Feed Iron also spiked.

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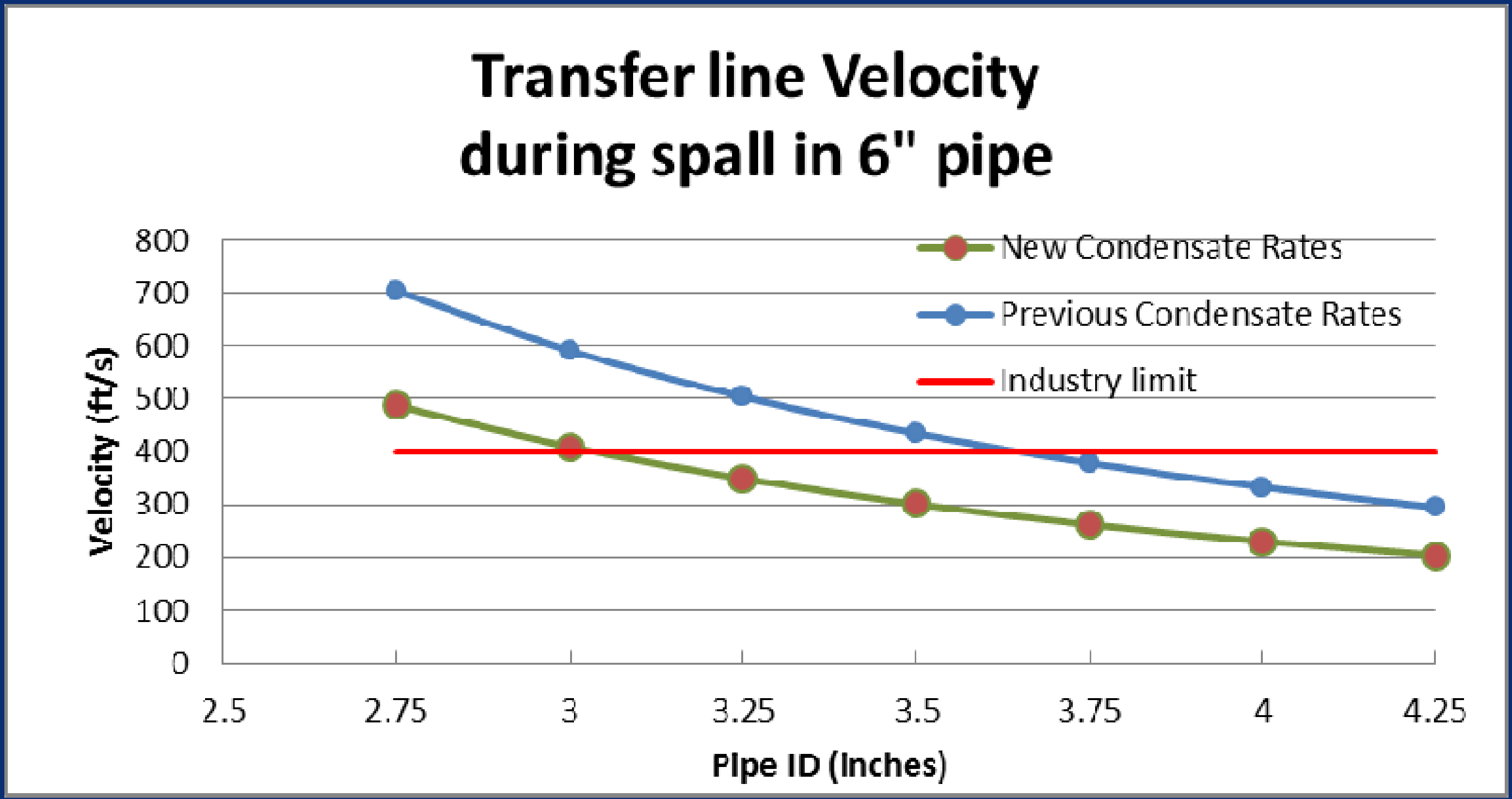
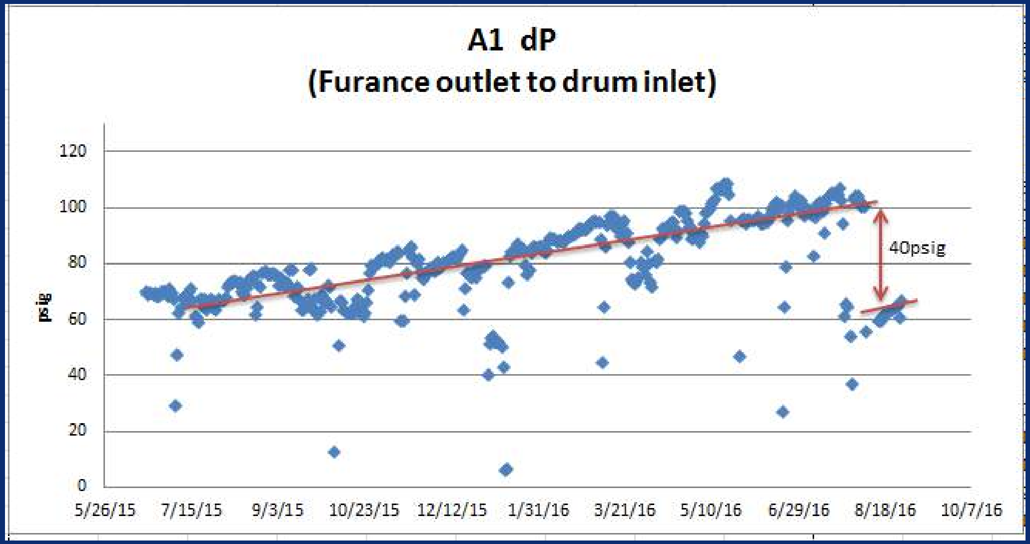
Investigation Recommendations

- Lower the condensate rate during spalls in the procedure, which lowers the velocity and erosion.
  - Spalls have been equally effective.



Open, Clean, and Inspect



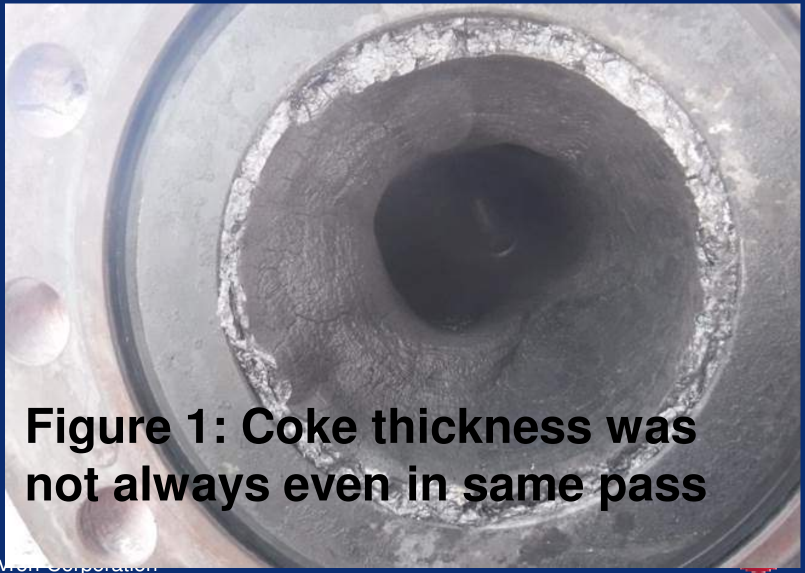


Figure 1: Coke thickness was not always even in same pass

Figure 2: Coke peeled from wall

Investigation Recommendations

- Set a limit on furnace transfer line dP which will trigger Operations to open, clean, and inspect the transfer line.
- Develop and implement an asset strategy plan on the Furnace transfer line.
- Eliminate and/or minimize the affect of quench steam in order to reduce channeling.
  - Install Cushion Tee's which avoid the 90 degree mixing point and impingement of coke fines during spall on first elbow.
  - Consider increasing transfer line temperature limit during spalls in order to eliminate quench steam.

GOAL: PREVENT LOSS OF CONTAINMENT FROM TRANSFER LINE

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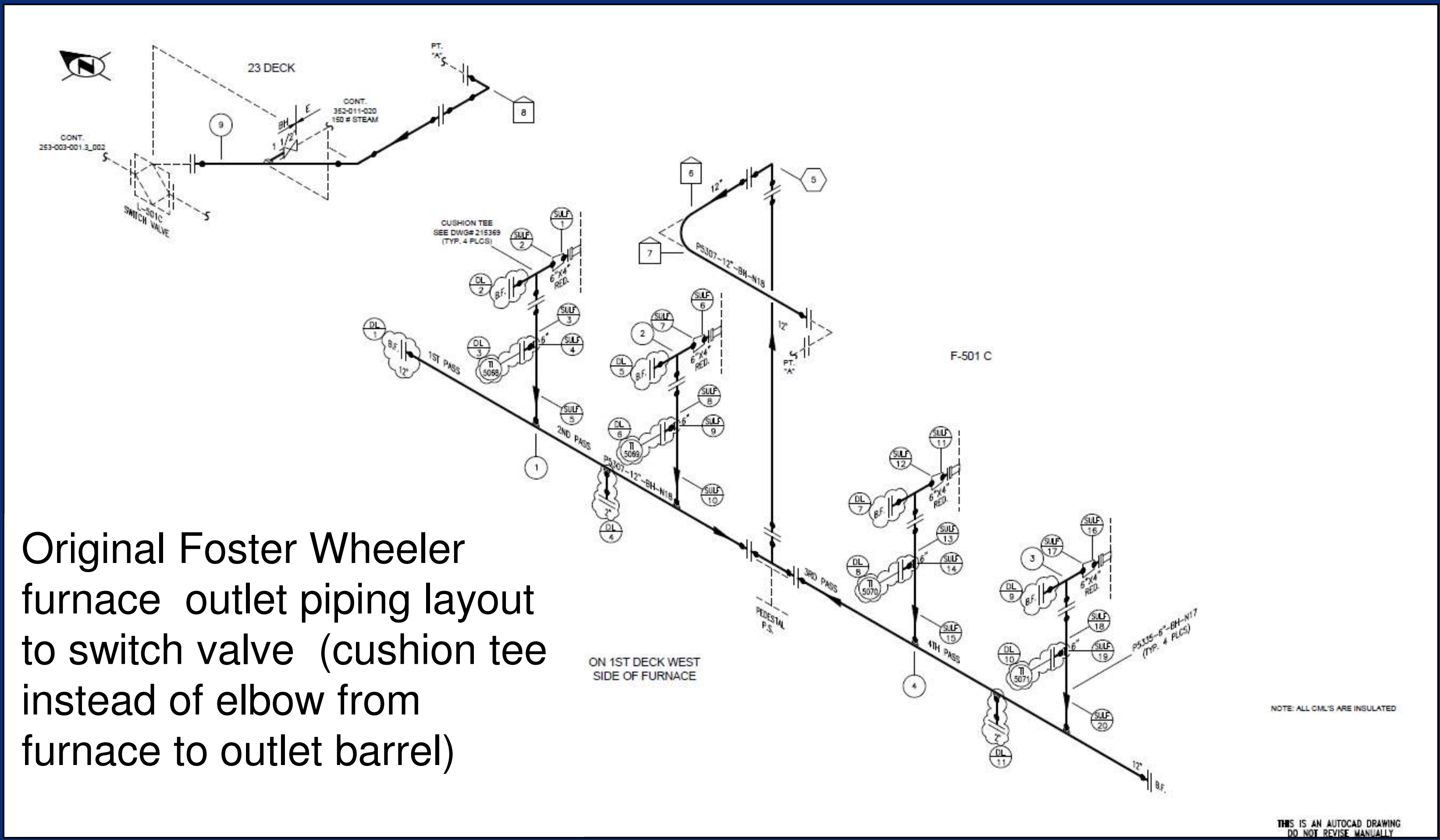
Incident Context

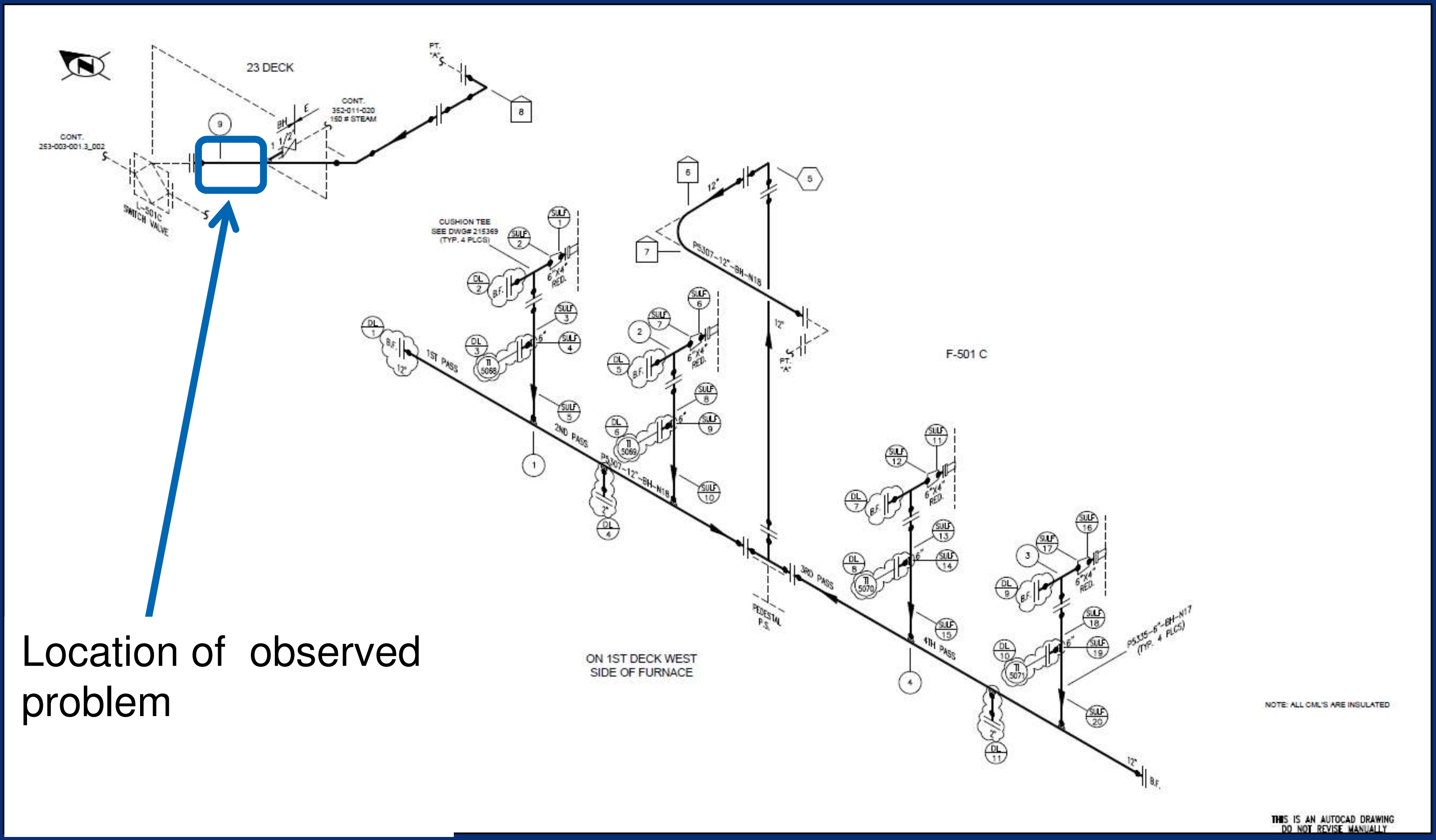
- C Module Coming Offline for Mechanical and Smart Pigging
- All necessary LOTO/cleanup completed
- Began breaking flanges as needed for:
  - Transfer line inspection and cleaning
  - Installation of pigging spools

ESE Transfer Line
5Cr 1/2Mo



Original Foster Wheeler furnace outlet piping layout to switch valve (cushion tee instead of elbow from furnace to outlet barrel)

ESE Transfer Line
5 Cr ½ Moly



Location of observed problem

Operator Observation
16 Hours after System Opened to Atmosphere

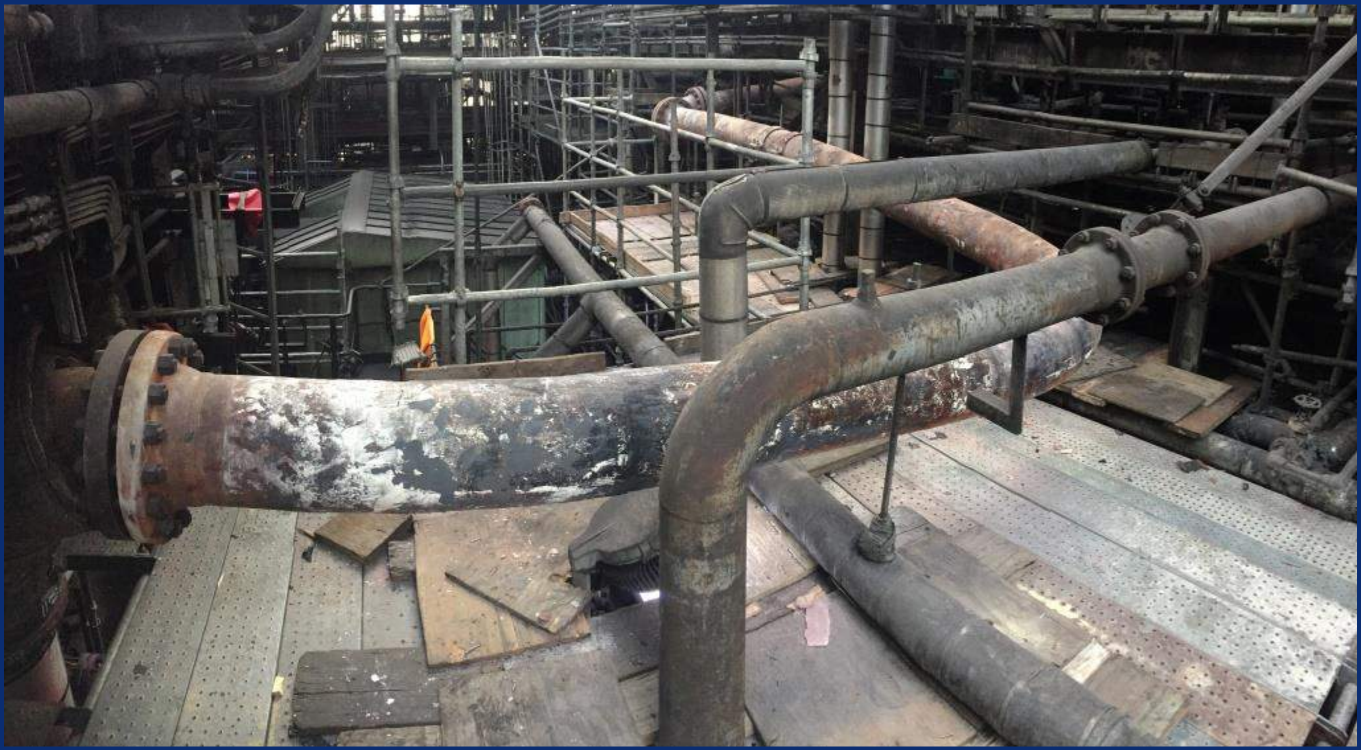
Coke combusting inside transfer line.

Response: Introduced 150# steam to cool the line.

Photos of Transfer Line Post-Incident

Observed sagging elbow.

Photos of Transfer Line Post-Incident



Stripped insulation for inspection and fitness for service evaluation.

Fixed Equipment / Mech. Engineering Actions

- Performed hardness testing
  - Showed tensile strength slightly above 60-85 ksi (ASTM A387 spec for 5Cr class 1 plate)
  - Concluded no considerable damage re: mechanical properties. Line deemed fit for service.

- Stress Calcs:
  - Caesar modeling showed 2-3 ksi max stress.
  - API 579 calcs - exposure temp was ~1500-1600F to yield/creep at 2-4 ksi
  - Recommended a new pipe support to eliminate potential for future damage due to creep/yield.

Additional Takeaways

- Procedural changes to ensure adequate purging/cooling with steam prior to opening to atmosphere.
  - Acceptance criteria still being determined.
- Addition of steam connection (and PI) on transfer line to allow for introduction of cold steam when taking line out of service for cleaning.
- Addition of PI at inlet to transfer line to measure pressure drop increase over time. Develop DP increase limit to trigger open / clean / inspect.
- NOTE: A module transfer line experienced coke build-up and thinning in elbow from increased velocity similar to Pascagoula.
- GOAL: PREVENT TRANSFER LINE LOSS OF CONTAINMENT

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Executive Summary

PROBLEM:

First inspection of 347H SS Coker F-501B furnace tubes in 2016 since installation in 2008 using spot UT revealed unexpected thinning of the "flame side" between 4:00 and 7:00.

Chevron ETC Failure Analysis

- Identified carburization as the damage mechanism, occurring at elevated temperatures during <u>normal operations.</u>

Furnace Expert and Burner Supplier site visit

- No consistent poor flame pattern or flame impingement; one area with hot spot.
- Opportunity to use Infrared camera to verify skin TI readings.

What is confusing about identified damage mechanism:

- **No skin TI indication of elevated temperatures**
- **Subsequent smart pig inspection showed thinning throughout furnace, not worse thinning in the lower tubes the govern EOR coke removal.**
- **Quest metallurgist attributed thinning to sulfidation, possibly TAN.**

El Segundo Coker Furnace History

1991	F-501A/B/C	Conversion to balanced draft, low NOX burners
1995	F-501C	Radiant furnace re-tube, 347H stainless steel
2000	F-501C	1st return bend loss of containment after steam: air decoke
2001	F-501C	Design upgrade, replace convection, raise radiant roof
2008	F-501B,A	Design upgrade, convection, radiant re-tube to 347H SS from 9 chrome, flatback return bends.
~2012	**F-501C**	**Inspection of 347H SS radiant tubes, NO WALL LOSS.**
2016	F-501B	Tube 30, ~ 38% wall loss (0.225 – 0.14) in short section of tube. Other tubes in furnace exhibited wall loss.
2016	F-501B	SMART PIG. General wall loss, Pass 3 tube 18, 0.138”.
2016	F-501A	SMART PIG. General wall loss, Pass 3 tube 33, 0.159”.
2016	F-501C	SMART PIG. General wall loss, 0.170” minimum.

NOTE 1: **Chevron maintained the 1200 F tube metal temperature (TMT)** coke removal trigger from previous 9 chrome metallurgy so F-501C would operate the with the same guidelines as F-501 A &B. After 2008, maintained 1200 F because of concerns with return bend erosion during coke removal process. (Higher TMT = more coke to be removed)

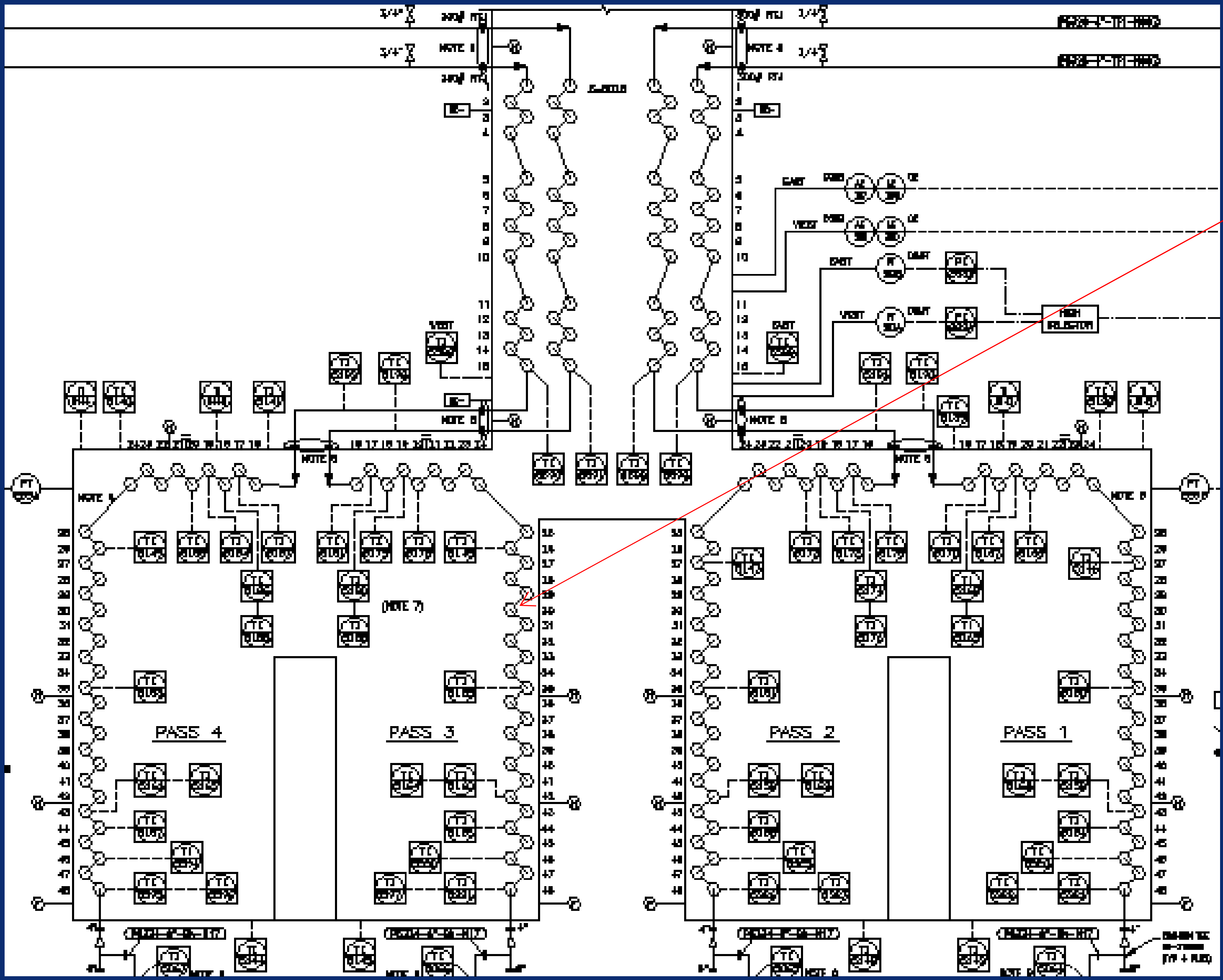
Coker F-501C Design

U-bend
hole

Top: Convection finned tubes with inspection & cleaning lane
Top Center: Bottom row convection tube 15, 4 passes
Top right: Radiant roof and wall

- Raise radiant roof tubes to eliminate "suspended brick" design.
- Initial rounded U-bend replacement with flatback.

Coker Tube Layout



Tube 30
Pass 3
F-501B

Spot UT inspection

Thin, removed for metal Analysis

Radiant 347H SS

F-501B Pass 3 Tube 30

Tube 30 : Removed for metallurgical analysis.
Very localized, maybe 6 feet in length, down to 0.14”.

Length wise, thin section is in the middle. Both ends had some loss in thickness, from 0.226 down to 0.180. Limited spot UT data.

Circumferentially, damage is only 4:00 – 7:00, the tube side that “sees flame reflected from wall”. Back side of tube is nominal, 0.226”.

Tube 30 – F-501B Pass 3

Wall side

Flame side

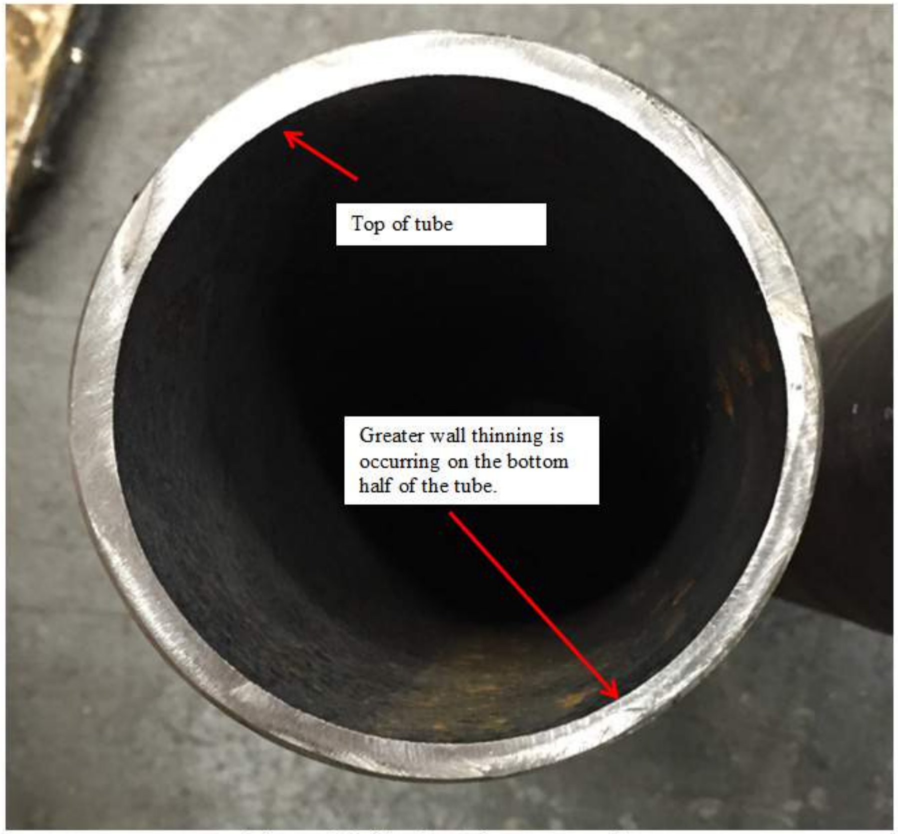


Figure 2: Thinning tube cross section

The thinner side corresponds to the bottom half of the tube, roughly the 4 to 7 o'clock position. The thinnest area is at the 7 o'clock position on the fire side, also known as the "sunny side" (Figure 3).

Chevron Engineering Technology Center (ETC)

- Confirmed 347 SS tubes.
- The H for high carbon grade was not confirmed.
- Dark spots indicate higher presence of carbides.
- Carbides forming within individual grains towards the inner surface.

- CARBURIZATION damage is occurring toward the inner surface during normal operation.
- THINNING occurs by spalling off carburized metal during temperature cycling in coke removal process.

Tube wall loss from inside of tube

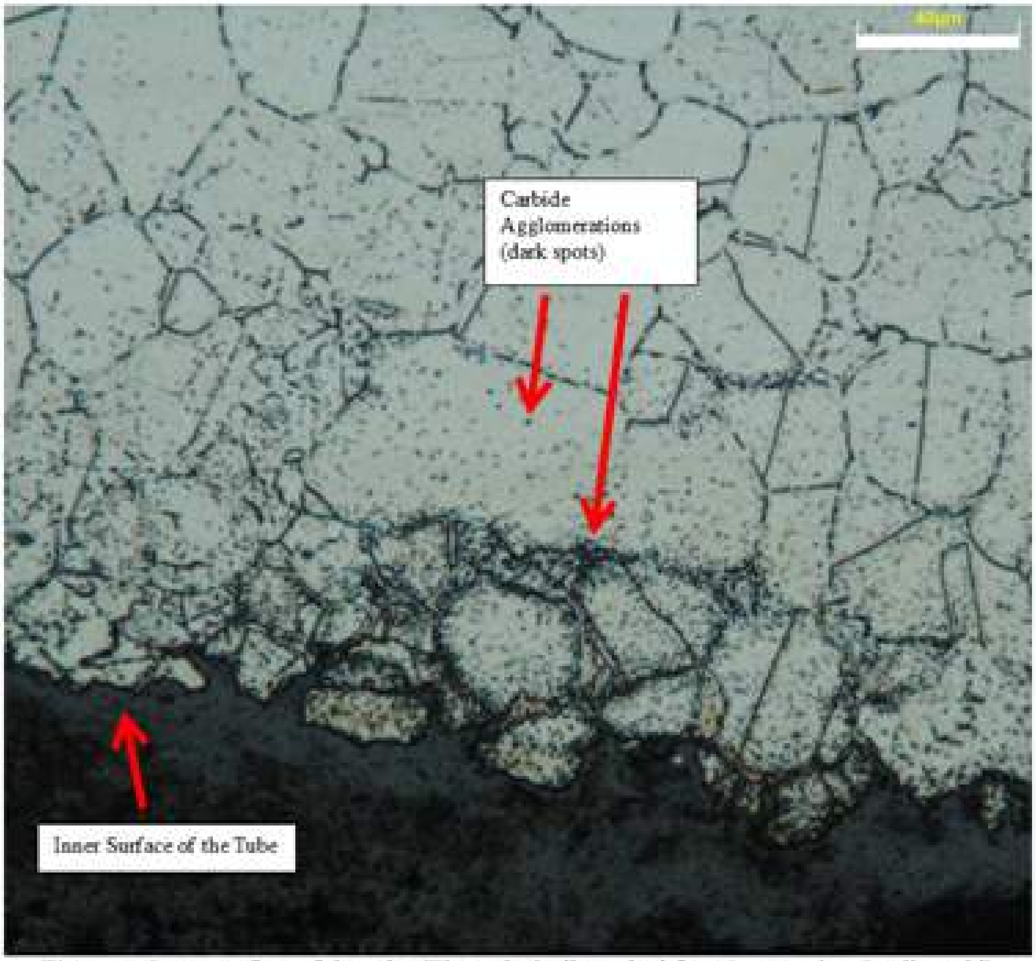
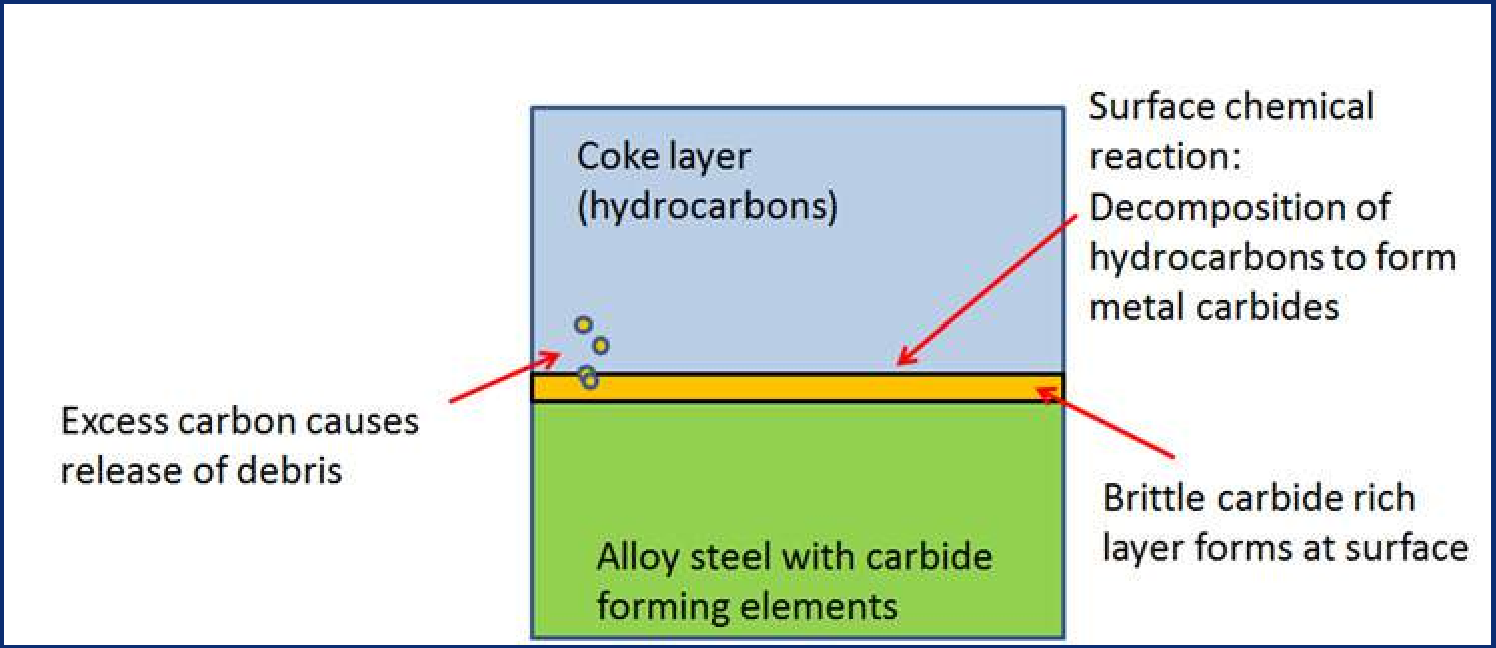


Figure 4: Inner surface of the tube (Electrolytically etched for 10 sec. using Oxalic Acid)

ETC: What is CARBURIZATION ?



- CARBURIZATION is caused by continuous diffusion of carbon into the tube metal due to the breakdown of hydrocarbons at the metal surface.
- For stainless steel, CARBURIZATION occurs over 1100 F. (DWW – No evidence of carburization in F-501C radiant tubes for first 15 years of operation. What changed?)

Coker 347 SS Industry Experience

- Initial Chevron 347H SS guidelines allowed 1372 F maximum TMT as limited by creep. High temperature corrosion (ie carburization) was not considered a viable damage mechanism.

- Company 1
  - Site 1- TMT to 1360F, replaced a couple of radiant roof tubes from carburization & flame pattern.
  - Site 2 - TMT to 1450F, tube damage due to carburization / sulfidation. At 1380 F, no issues.

- Company 2 - operated to 1350 – 1400 maximum TMT, experienced carburization and tube failures.

- Company 3 - Operated to 1400 F TMT. Four lower convection tube failures from sulfidation. Actual temperatures with fins ~ 1450 F

Furnace Expert Visit

Field visit with Chevron Furnace Expert and John Zink

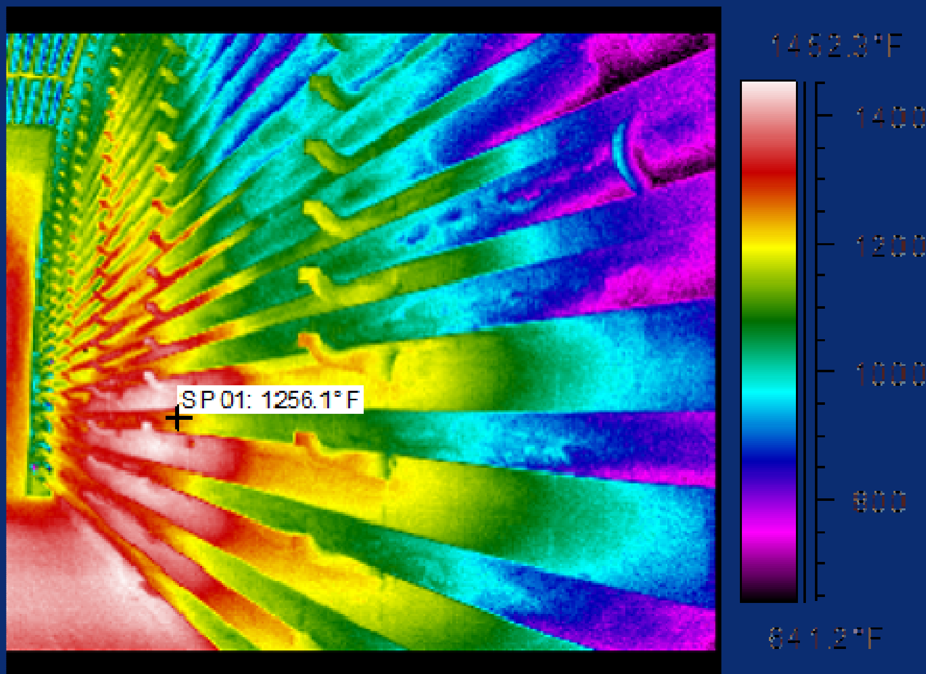
Summary

- Overall acceptable flame pattern and air flow
- Hot spot noted on F-501 C (Pass 1)
- Discussion of burner tiles and effects on air to fuel mixing; not the primary “root cause”.

Factors Discussed

- Flue gas flow recirculation (baking soda test)
- Flame impingement due to occasional burner problems
- Potential after-burn / flame-impingement due to incomplete combustion, periodic high CO.
- Over-firing due to inaccurate outlet TI, coke.
- Tube skin TI indication may not be representative of highest TMT.
- Unknown corrosive components in feed?

Coker F-501C Pass 1 Hot Spot



+ is on refractory, supposed to be on tube. Initial report of 1300 F revised to 1256 F. Visibly tubes 45, 46,47, 48 for a section of tube are much hotter than rest of same tubes.

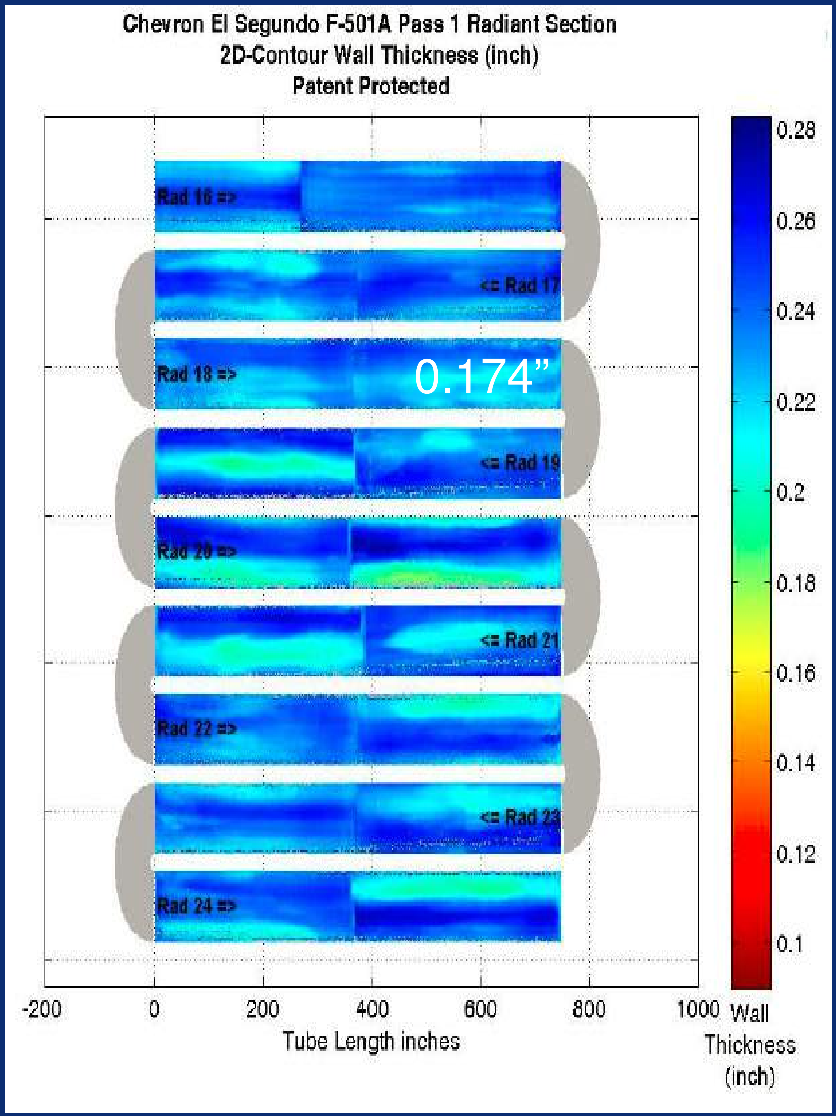
F-501C pass 1, July 7, 2016. Burner 12 was out of service. Tube and refractory across from burner 8,9, 10 was extremely hot, about 15 foot width. Tube skin TI for same tube was 1120 F. The 136 F difference does not mean the skin was incorrect; **it means the heat release in the firebox was not uniform.** Burner 8, 9, 10 could have had higher fuel rates due to other burners plugged or out of service.

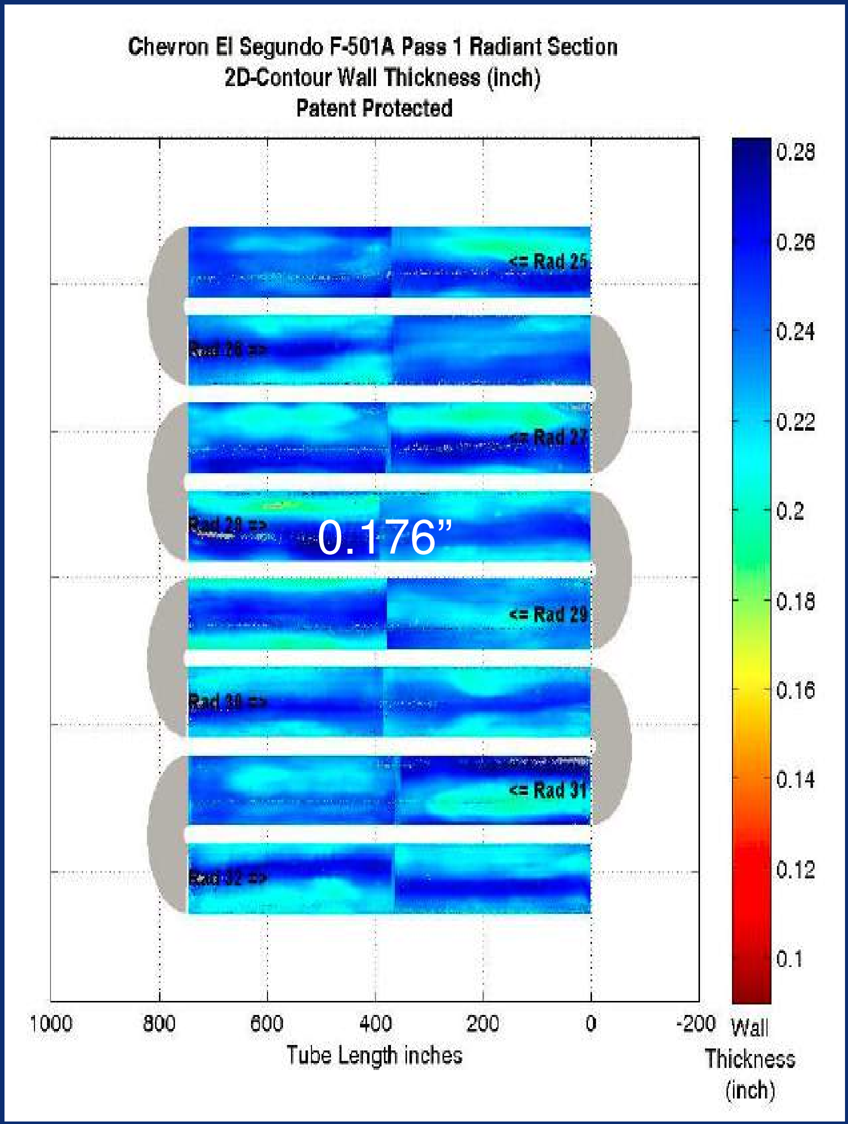
PIG (CEDA) and SMART PIG (QUEST)

CEDA (Terry Rehn) was able to navigate flat back return bends and remove all the coke as verified by Quest.

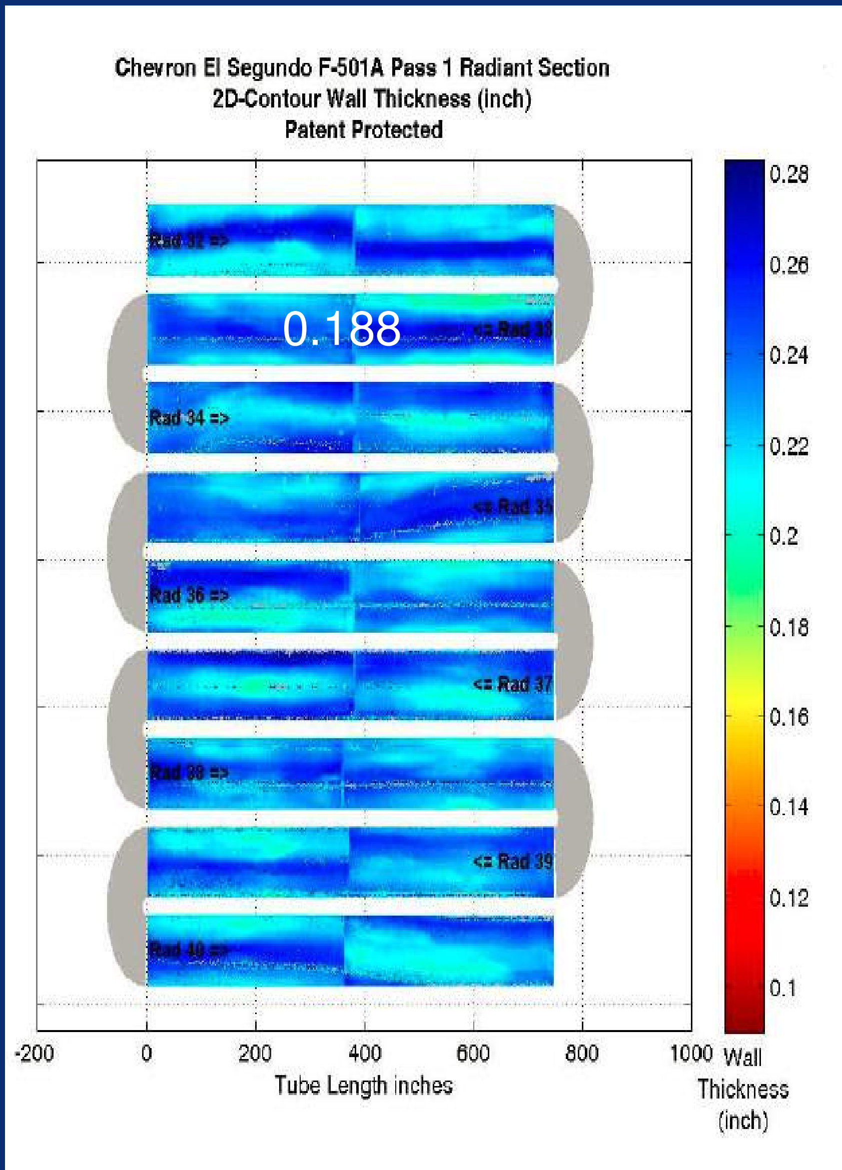
- SMART PIGGING by QUEST. Pig pushed using CEDA set-up.
- Previous attempt to smart pig resulted in damaged and stuck pig. Could not negotiate the flat back return bend.
- Sent a test rig to Quest to develop technique to navigate flat back return bends. Required a “tugger” in front of the smart pig.
- * Successful SMART PIG data for all three furnaces.

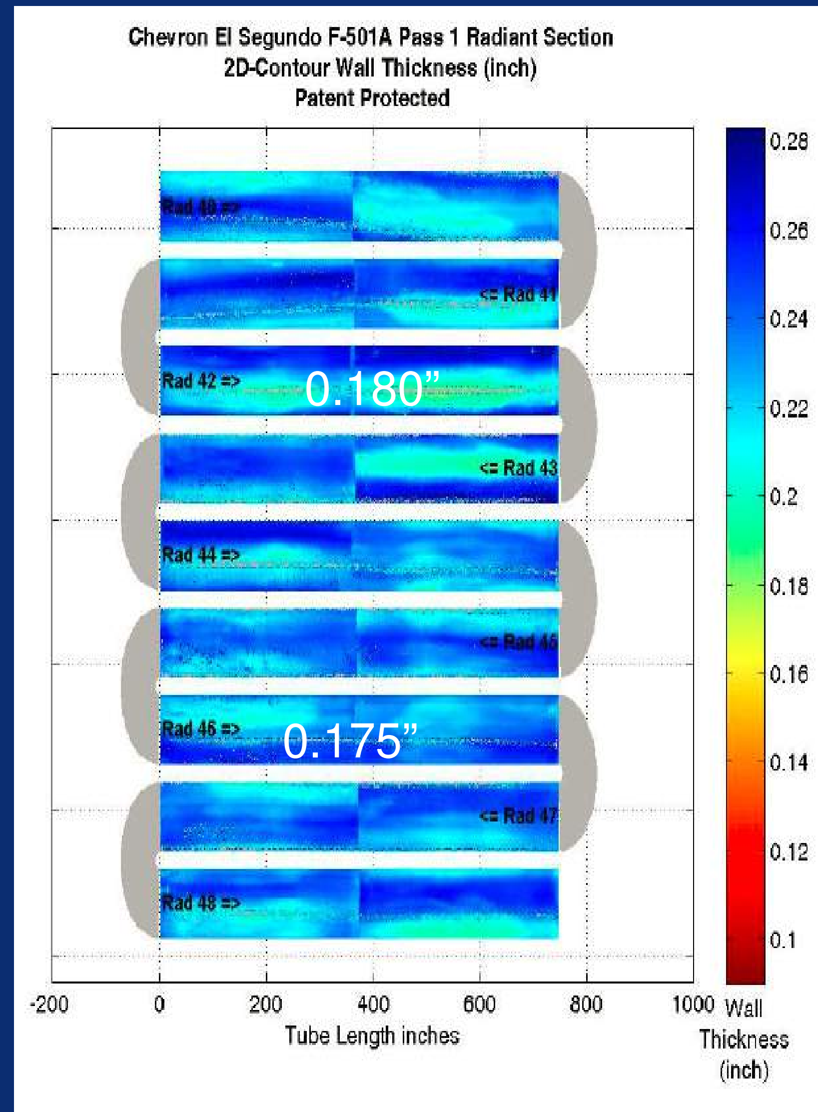
F-501A Radiant Pass 1 Tubes 16-32



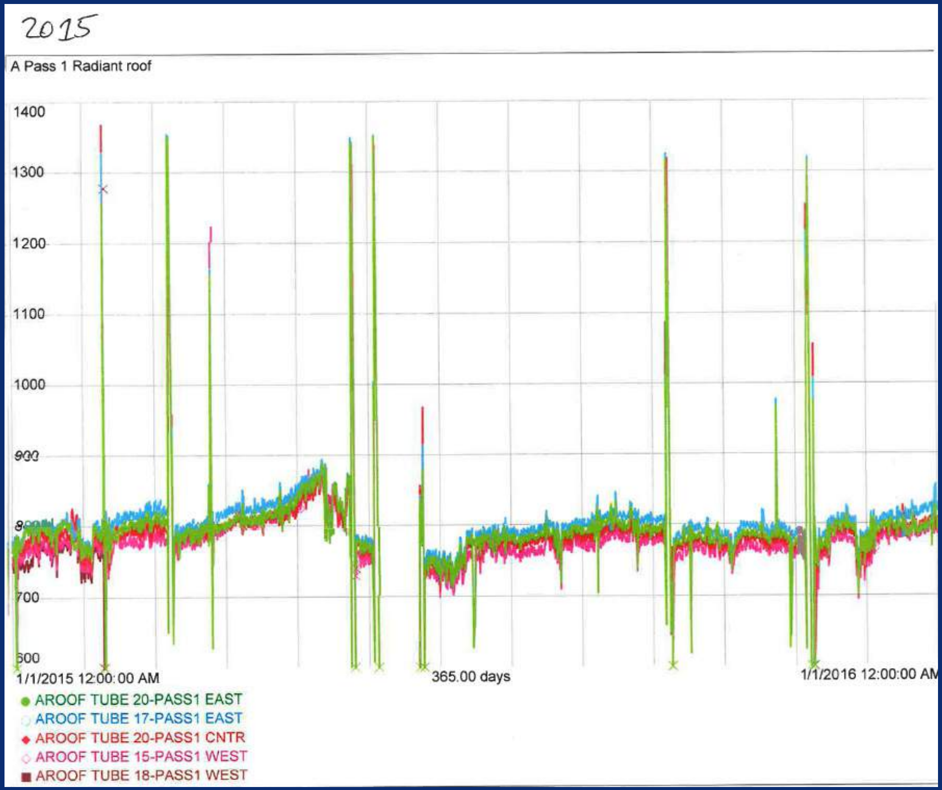


F-501A Radiant Pass 1 Tubes 32-48





F-501A Pass 1 Radiant Roof Tubes

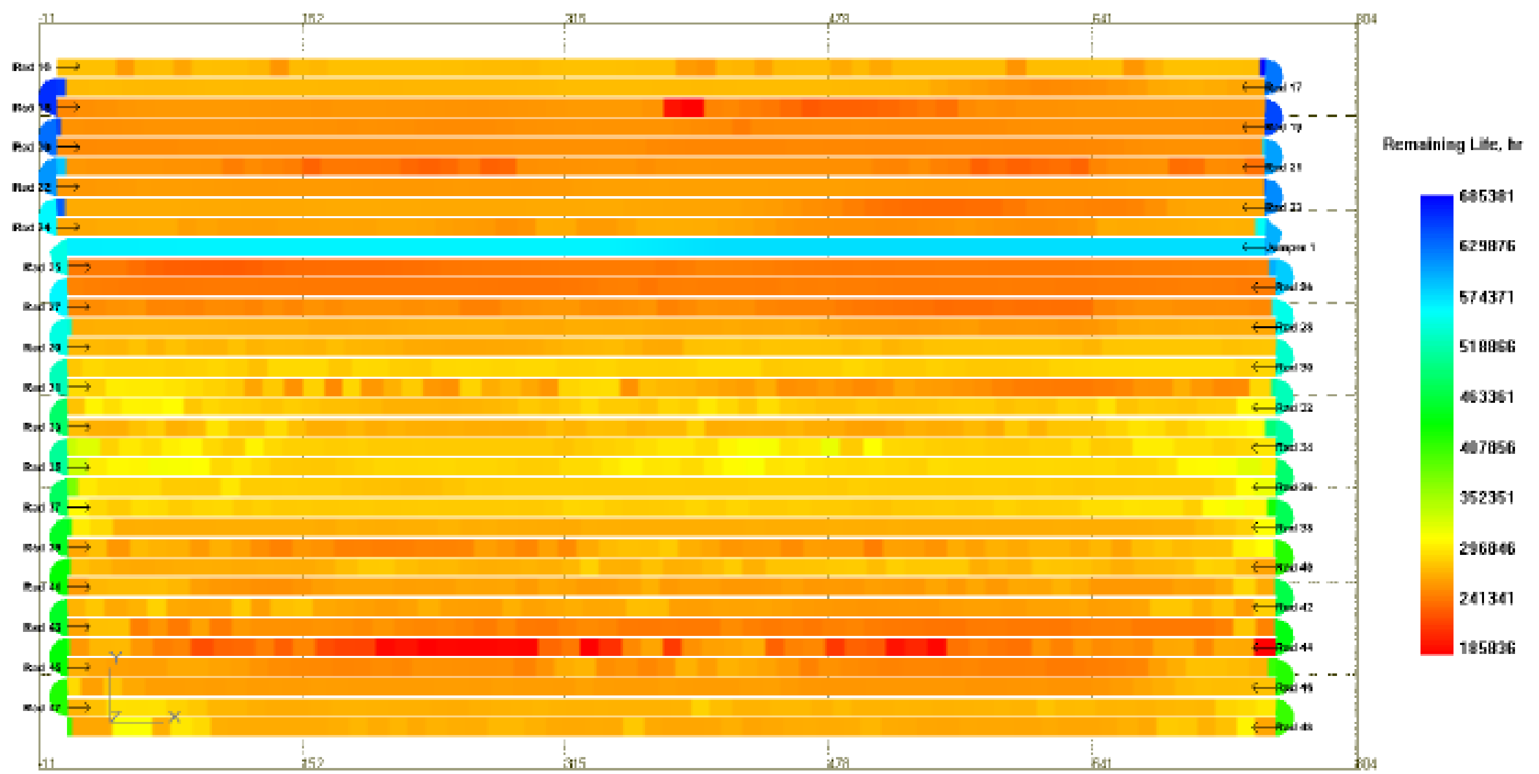


Short duration spikes are during coke removal.

F-501A/B/C roof tubes have maximum TMT under 1000 F. No convection section TI excursions. Tube wall loss is similar for radiant roof and radiant wall, which runs at much higher skin temperatures. Radiant roof temperature is well below temperature where CARBURIZATION is expected.

QUEST: F-501B Radiant Pass 3

Figure 1. Failure Remaining Life for Pass 3 Radiant Tubes



DWW: Furnace tube remaining life pretty uniform; not longer for roof radiant tubes which have not seen high temperature. Furnace tube thinning seems to be independent of skin temperature??

QUEST INTEGRITY Analysis – F-501B

- Fitness For Service - Level 3 Assessment
- Used FTIS (smart pig) inspection data
- Tube 30 material testing by Quest metallurgist
- Reviewed operating history including skin temperature data

The Radiant tube metal loss rate was significantly higher than expected based upon the material (347H stainless steel) and the sulfur content of the feed. Chevron had reported the elevated metal loss rate was due to carburization damage, but the Quest Integrity metallurgical evaluation and the operating TMT assessment did not support this conclusion. The metal loss rate is most likely the result of the high temperature sulfidation mechanism. The elevated rates could be due to various reasons, such as naphthenic acid content of the feed, frequency of descaling operations, etc. It is also possible that localized hot spots may contribute to the metal loss damage rate, although these hot zones have not been reported in the infrared monitoring. Chevron should further investigate the Radiant metal loss damage rates and take appropriate actions to reduce or manage the damage rates.

No creep damage in the form of diametrical growth, bulging or swelling was detected in Radiant and Convection tubes. The operating equivalent tube metal temperatures must have been below the creep regime threshold temperatures of 1236°F and 1314°F, respectively for the 9Cr and 347H materials, during the past operating history.

Coker - WHAT HAS CHANGED?

Furnace Tube Thinning: WHAT IS THE DAMAGE MECHANISM?

ETC	**Carburization – high temperature damage mechanism**
QUEST	**Sulfidation, possibly TAN**

Regardless of actual damage mechanism, something changed in last 3-5 years to cause tube thinning. Damage has not been happening since 347H SS tubes installed in F-501C in 1995.

What else has changed in Coker?

1. **Increased resid TAN from SJV crude.**
2. **Increased resid preheat exchanger fouling .**
3. **Furnace convection section fouling.**
4. **Increased rate of radiant skin temperature fouling.**

High Acid Crude

- Total Acid Number (TAN) is a measure of the naphthenic acid content. TAN in whole crude is distributed primarily to the diesel – heavy gasoil stream.

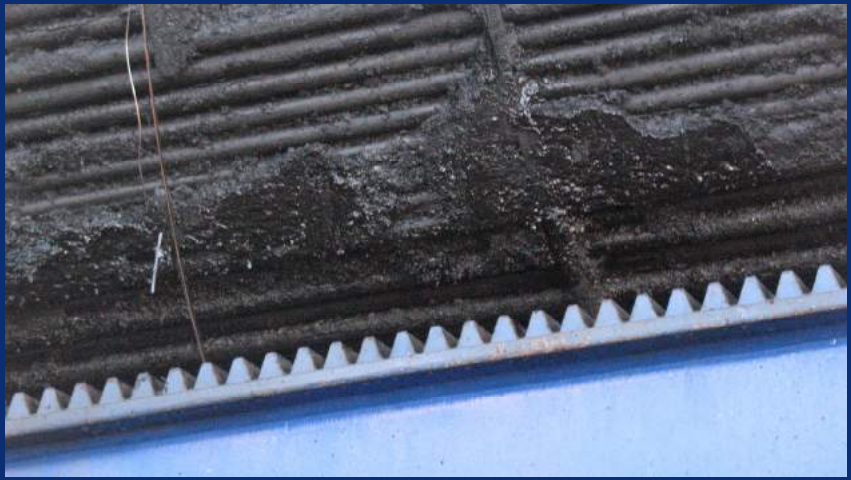
- Chevron has developed the ability to measure TAN in resid in the last 3-4 years. The concentration has been higher than expected, above 1.0 TAN, for resid from our high acid crude unit. No. 2 CU uses 317L SS metallurgy in many locations, but not offplot resid rundown piping.

- SJV crude rate has increased in last 3-4 years to utilize available Coker capacity.

- In 2015, 2 CU processed SJV 100 % for first time. Historically blended 10-15% of a lower acid crude with SJV.
    - No. 2 CU Resid TAN increased from ~ 1.3 up to 1.7. Assumes normal cutpoint. Dropping higher TAN gasoil into resid can raise TAN further.
    - San Joaquin Valley (SJV) is a blend of many fields; oil blend quality could also be changing.

Resid Preheat Exchanger Fouling

- E-535 fouling has increased in the last 3-4 years.

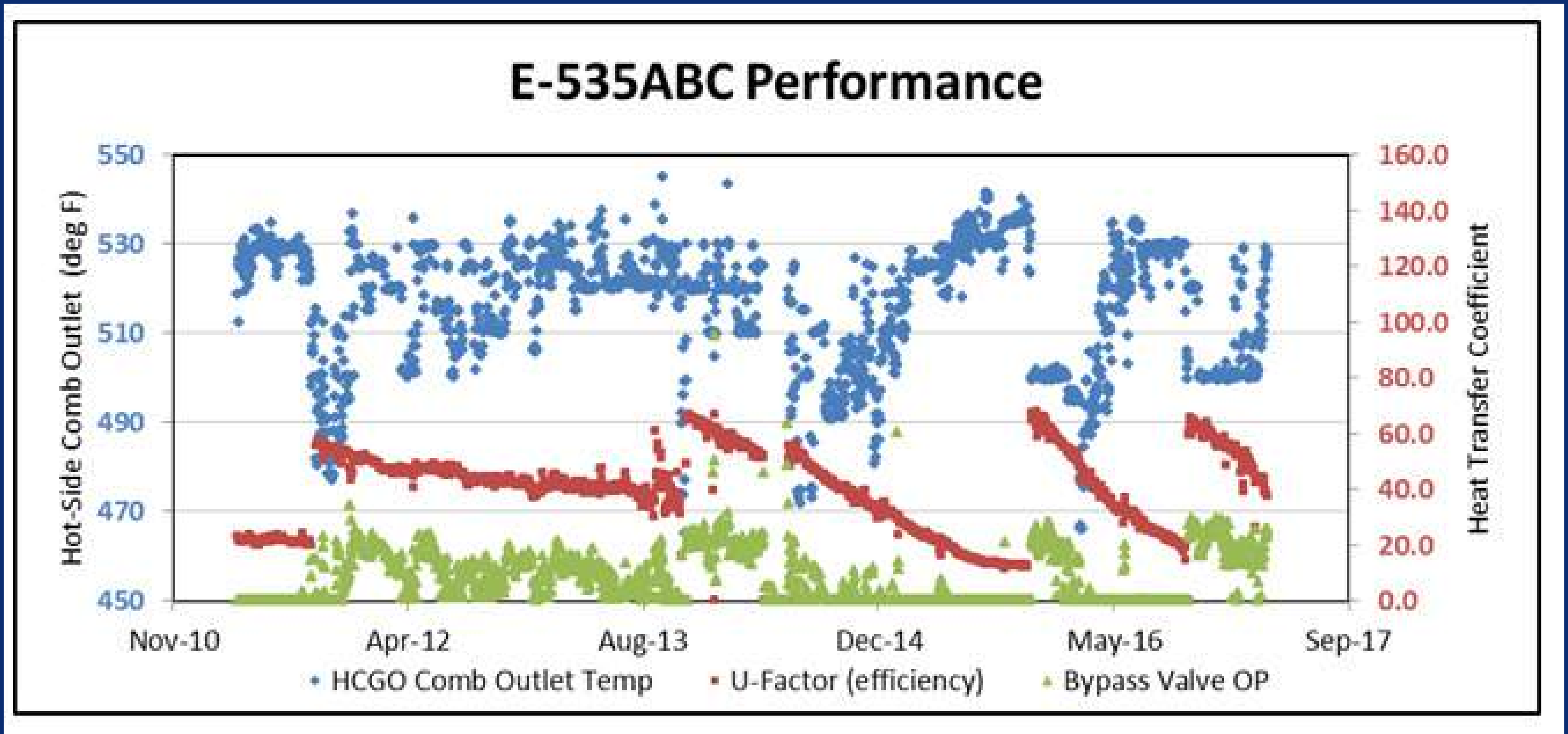


Asphaltene
material at bottoms

Packed with of Iron sulfide scale
at top of bundle (E-535B)

Coker HCGO – resid exchangers use to achieve a 3 year run before cleaning was required. Cleaning frequency has been every year recently. Exchanger acting as a filter for iron sulfide scale collection.

Resid Preheat Exchanger Fouling



Coker HCGO – Resid exchanger heat transfer U-factor has had step change since 2013, dramatic increase in fouling rate.

Lower heat transfer causes lower furnace feed temperature, higher furnace fired duty.

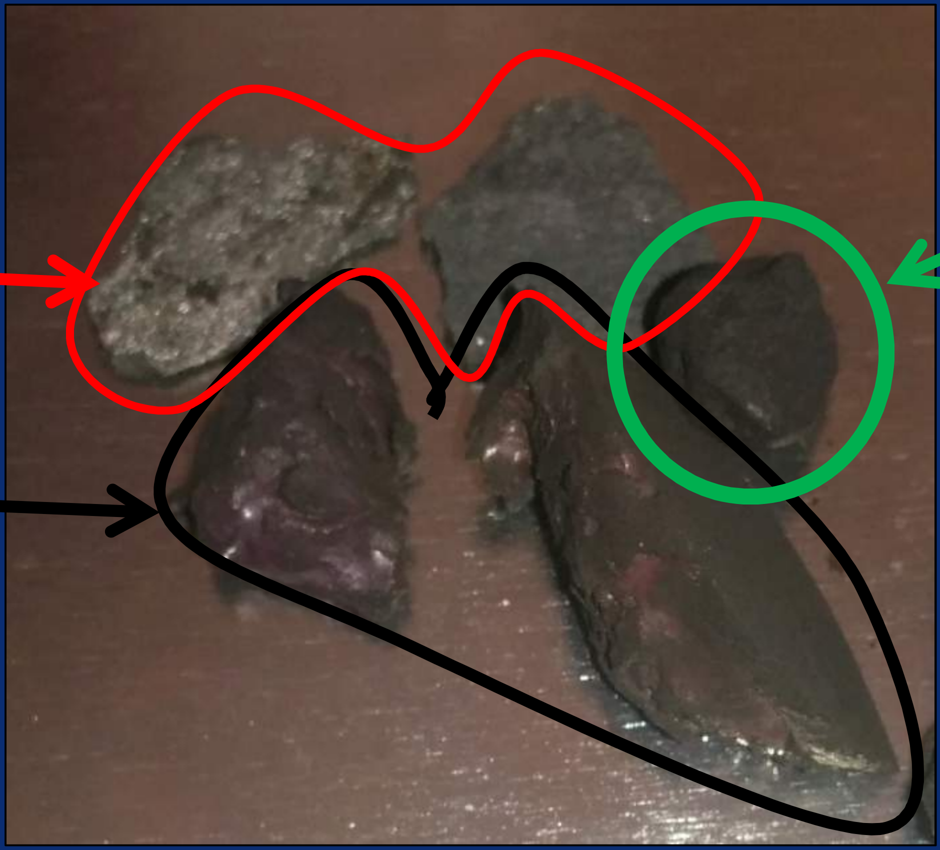
Convection Section Fouling

- Furnace convection section performance is a challenge to monitor.
- Convection outlet to radiant inlet has some variation; resid feed temperature also has variation.
- Pigging removed coke deposits from inside tubes. No known historical issues with deposit accumulation. First time pigging furnace, no reference point.
  - Coke deposits analyzed, showed high calcium and silicon??
  - CONVECTION section fouling would shift furnace duty to radiant firebox. Higher radiant firebox heat flux could cause higher radiant fouling.

Material From A3/A4 Convection

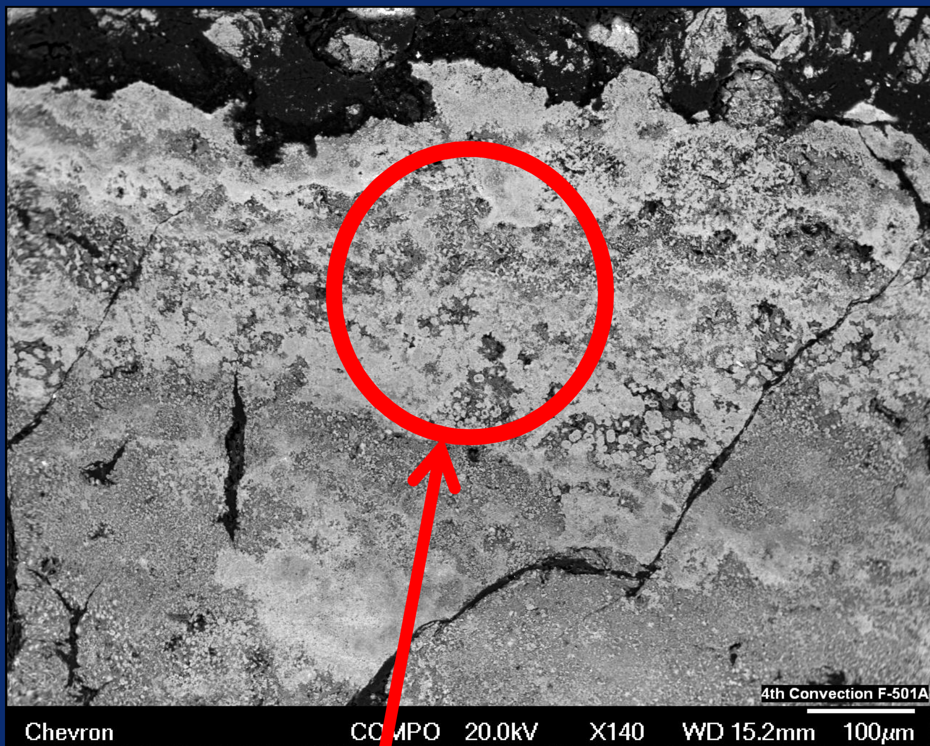
Grayish rock-like material

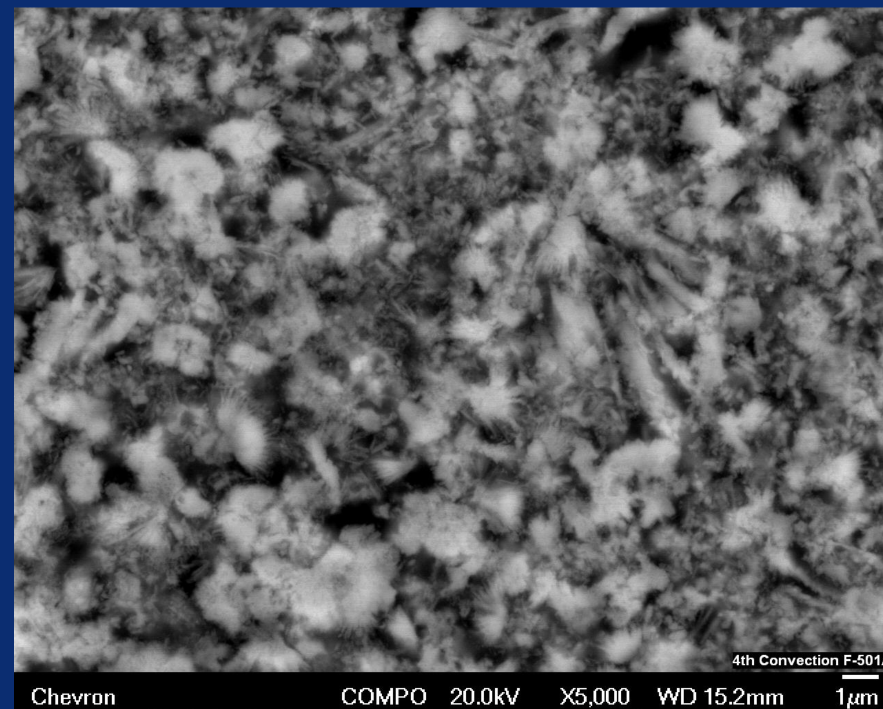
Pig Chunks (Ignore)



Coke

Analysis of Grayish Rock-Like Material





Lighter areas have high calcium content

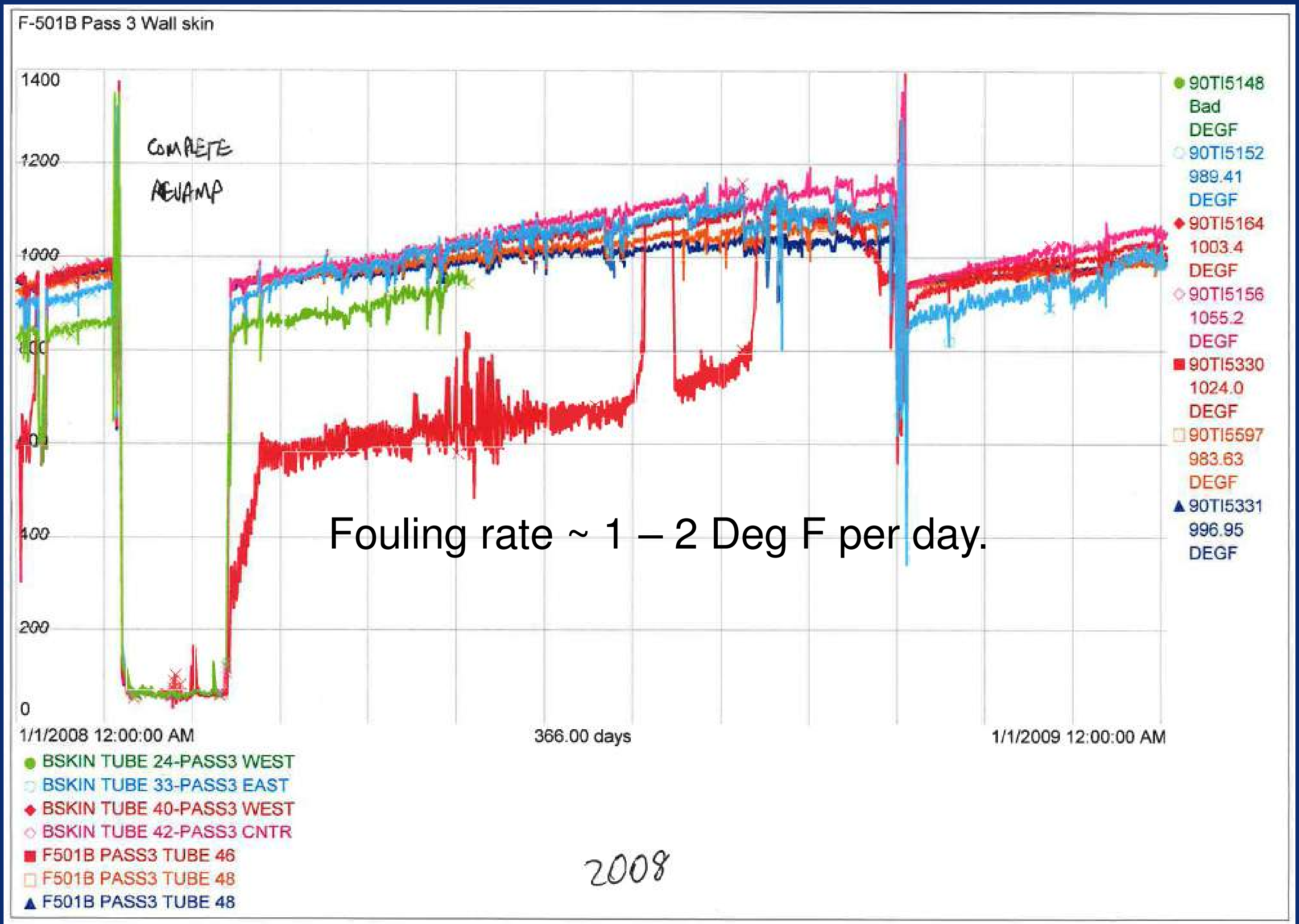
Fuzzy crystals, inorganic deposit,

- ETC: “Hard deposit, rich in Si-Ca.” “Very hard.”
  - Calcium from difficult to desalt crudes, maybe Napo, Ecuador?
  - Silicon used in crude (antifoam?). Why is it in convection deposit?

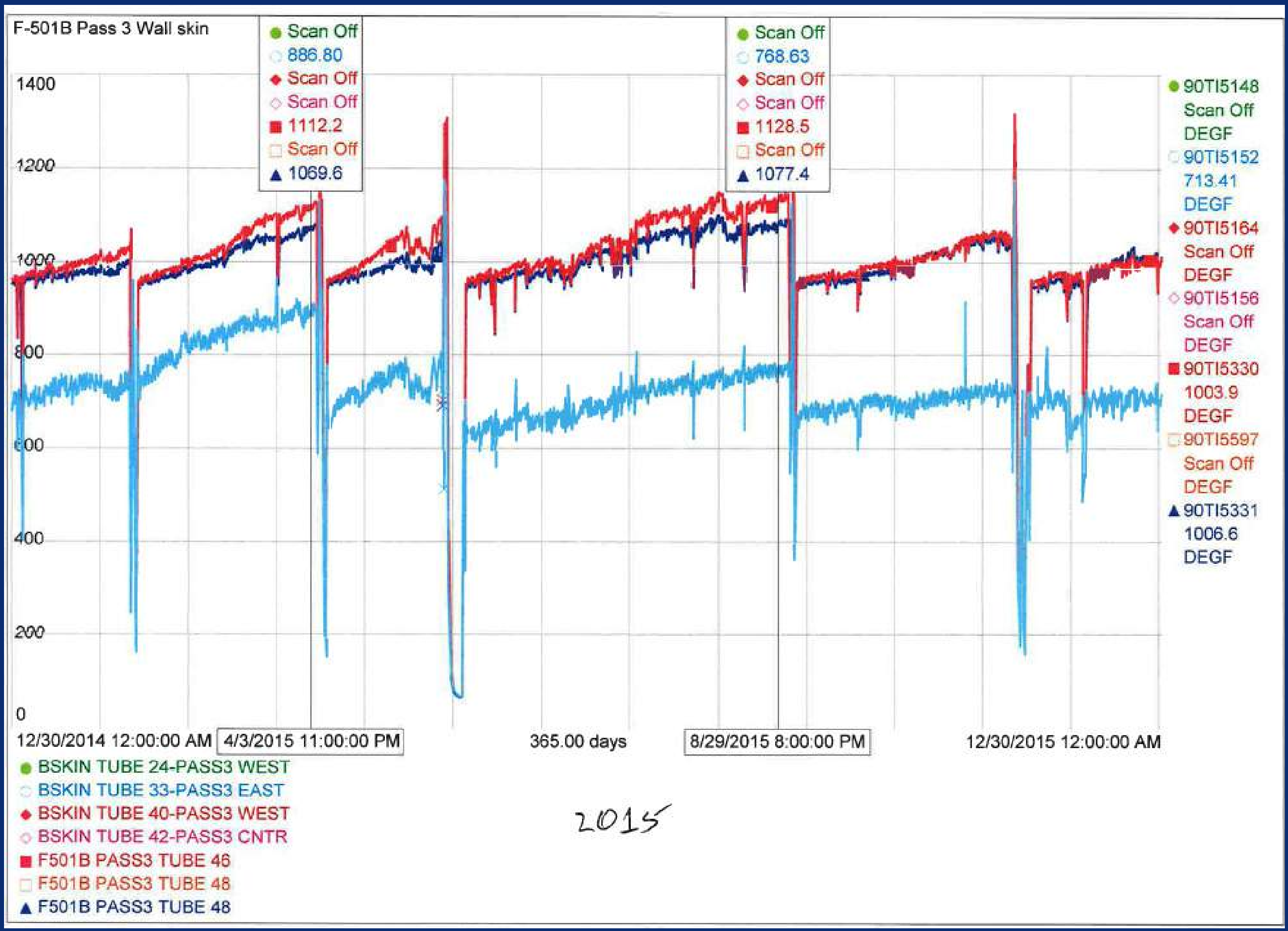
Radiant Section Fouling

- Key process monitoring by Engineering / Operations is the increase in Coker furnace tube skin temperatures.
- Many factors can affect furnace fouling rate, especially with a balanced draft design.
- There has been a marked increase in coke removal frequency from 2014-2017 compared to 2008 – 2011.
- After coke drum replacement in 2014, Coker feed rate & operating factor increased – no drum cracks. Annual furnace rate has increased but operating day rate has not changed significantly.

Furnace Fouling Rate: F-501B in 2008



Furnace Fouling Rate: F-501B in 2015



Fouling rate 3-5 Deg F per day. Lower radiant wall triggers coke removal.

SUMMARY

- The “root cause” for 347H SS tube wall loss has not been proven.
  - Carburization, Sulfidation and TAN are the primary suspects.

SMART PIGGING allowed a more complete wall thickness map. Future smart pigging will allow a better handle on wall loss rates.

Coker furnace operation to minimize fouling rates is an ongoing challenge, especially when feeding a wide variety of crudes.

? Has anyone else experienced unusual or difficult to explain Coker furnace tube wall loss?

Thanks DALE Wilborn wilb@chevron.com