



Waste Heat Boilers: FFS Case Histories

Session: Fitness for Service

API Inspectors Summit
Galveston Texas
January 27-30, 2009

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Presenter

Experience:

- Bachelor of Applied Science (Mechanical Engineering) from the University of British Columbia, Canada.
- 8.5 years in an Oilsand Upgrading plant in Northern Alberta, Canada.
 - 1.5 years as a project engineer
 - 3 years as a maintenance engineer
 - 3 years and the maintenance engineering team leader
 - 1 year as an associate engineer focused on failure analysis and fitness for service
- ~1 year with the Equity Engineering Group as a senior engineer in the fitness for service group.

Purpose of the Presentation

- Purpose:
 - To provide some examples of waste heat boiler (WHB) reliability issues, including a discussion of damage mechanisms and inspection techniques.
 - To highlight some of the common engineering analyses that are used for design and to assess Fitness for Service
 - To highlight the criticality of some basic design, maintenance, and inspection issues.
- Sources:
 - Personal previous experience (issues with 10 different WHB's over a number of years)
 - E²G historical job files

Presentation Overview

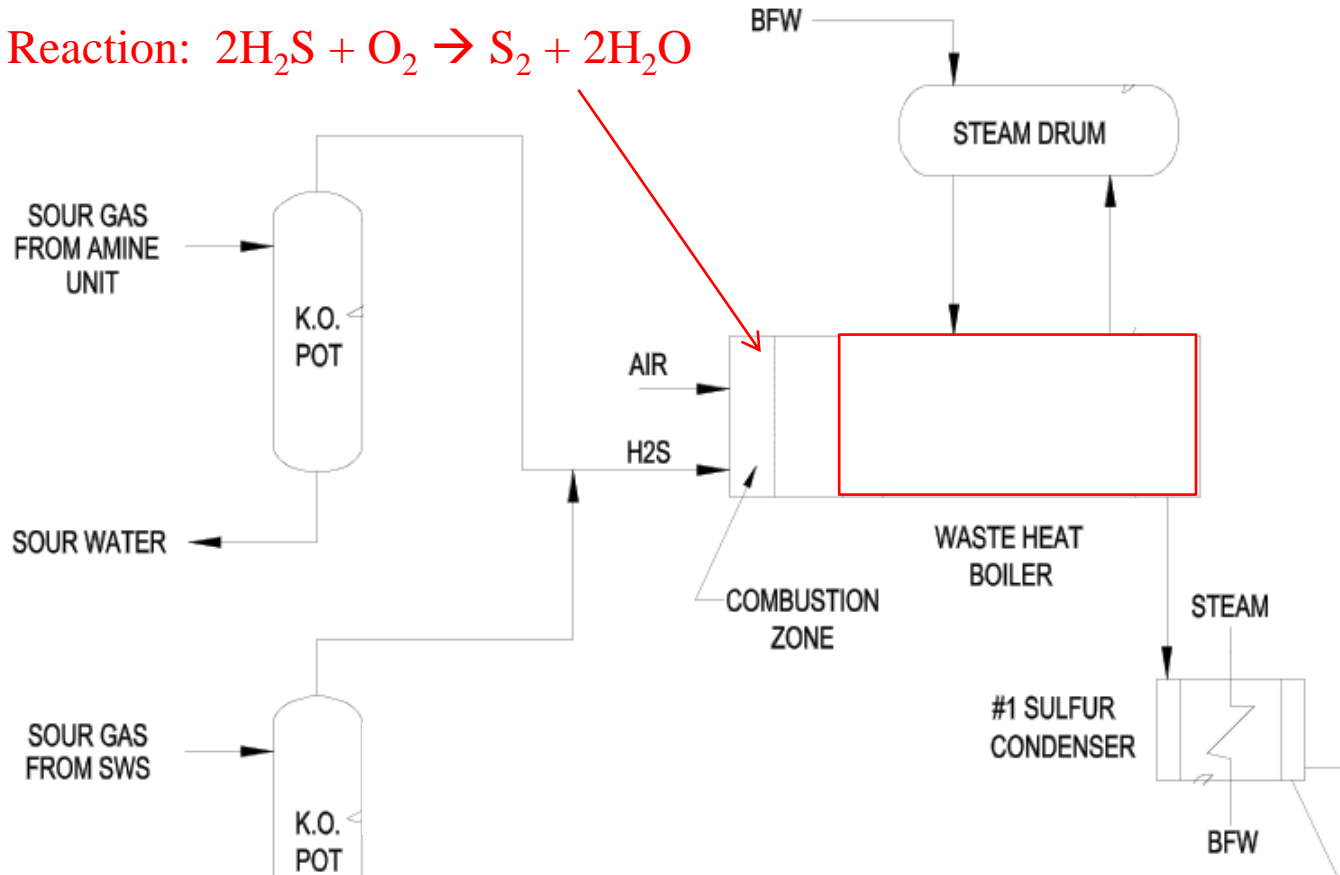
- Introduction
- Basic WHB overviews
- Damage Mechanisms
- Case Histories
- Fitness for Service Considerations
- Summary

Introduction

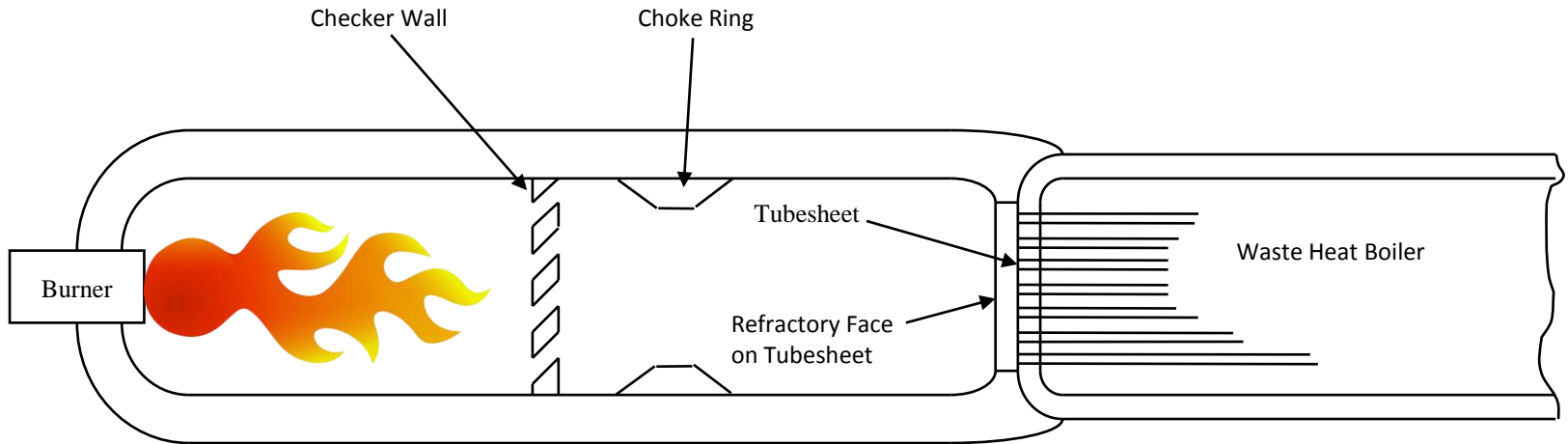
- So what about WHB's?
 - High process temperatures, 1400-2200 °F
 - Difficult thermal design considerations managed using multi-material refractory/ceramic systems
 - Rich hydrogen sulphide (H_2S) and hydrogen (H_2) environments.
 - Difficult to inspect due to refractory systems
- Plan to touch on 2 main types of WHB's:
 - Sulfur plant (Claus) reaction coolers
 - Hydrogen reformer, furnace outlet coolers

WHB Overview – Sulfur Plant

- Basic Claus Process Plant



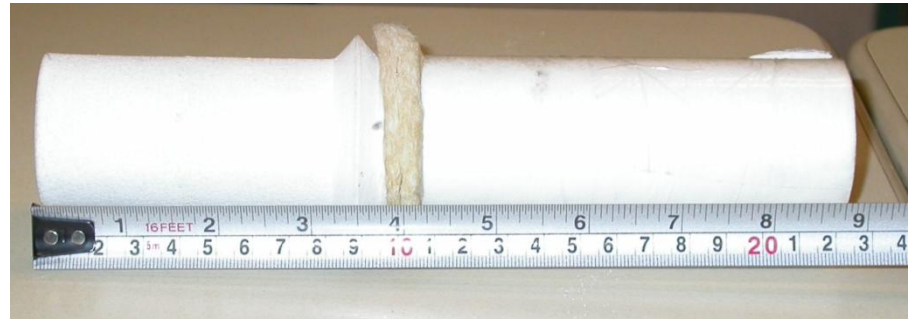
WHB Overview – Sulfur Plant



- Checkerwall in place to promote mixing, stabilize flame, and to prevent flame impingement to some degree.
- Choke ring in place to promote mixing

WHB Overview – Ferrule Types

- Hex head type versus ferrule and castable refractory.



WHB Overview – Sulfur Plant Details

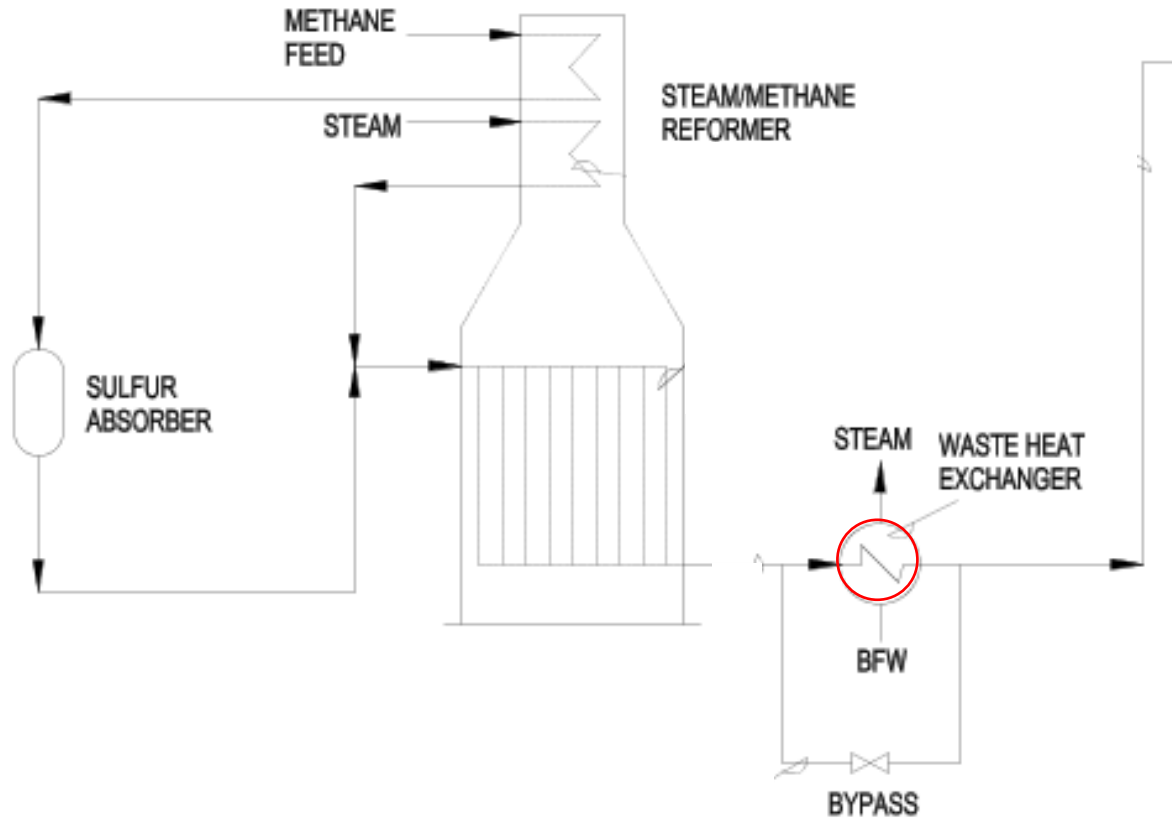
- Air/Tailgas mixture burned at 2100-2200 °F (1150-1200°C)
- 2 main types: watertube and firetube
- Reaction furnace usually coupled directly to WHB (flame “sees” the WHB tubesheet.)
- Usually carbon steel construction
- Waste heat generally used to generate steam
- Internally protected with refractory and brick
- Tubesheet usually employs a refractory/ferrule system

WHB Overview – Sulfur Plant

Damage Mechanisms

- Sulfidation:
 - Corrosion of steel at elevated temperatures from reaction with sulfur compounds.
 - Generally at temperatures above 500°F.
- Refractory Degradation:
 - Failure of the ferrule system is of particular concern as it enables hot gases to get to the tubesheet.
- Oxidation:
 - Corrosion in the presence of oxygen creating an oxide scale.
 - For carbon steel, becomes significant >1000°F.
 - For stainless steel, becomes significant >1500°F.

WHB Overview – H₂ Reformer



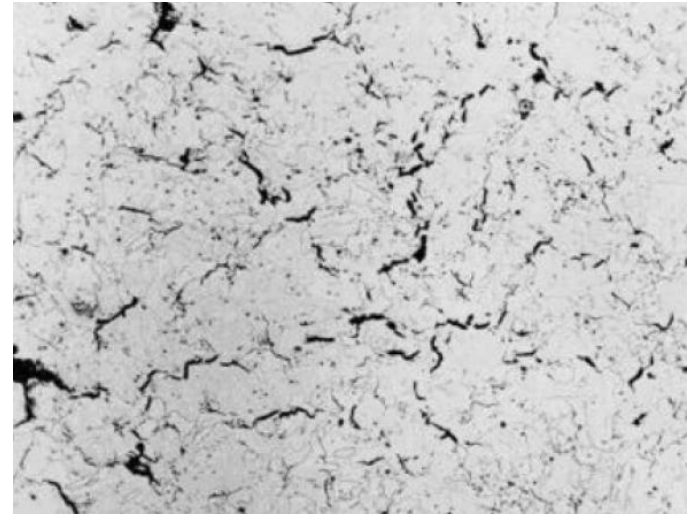
WHB Overview – H₂ Reformer Details

- Methane gas, steam mixture reacted at >1400 °F (760°C). Get H₂, CO, and steam.
- First exchanger on furnace outlet recovers waste heat, generally for steam production.
- Usually carbon steel construction
- Internally protected with refractory and brick
- Tubesheet usually employs a refractory/ferrule system

WHB Overview – H₂ Reformer

Damage Mechanisms

- High Temperature Hydrogen Attack (HTHA):
 - HTHA results from exposure to hydrogen at elevated temperatures and pressures.
 - Hydrogen reacts with carbides in steel to form methane (CH₄) which cannot diffuse through the steel.
 - For a specific material, HTHA is dependent on temperature, hydrogen partial pressure, time and stress. Service exposure time is cumulative.
 - Can “look” similar to creep damage



Case History #1- Sulfer Plant WHB

- New firetube style WHB, roughly 3.5 years old
- Sulfur plant shutdown for regular inspection and maintenance.
- Internal inspection of reaction furnace found the checkerwall down, no other significant indication of damage.
- New WHB tubesheet ferrules and refractory appeared to be in good condition
- Upon restart of the unit, attempting PSV lift tests, could not get the boiler pressure to ~200 psig...must be a water leak?
- After re-entry into the reaction furnace...

Case History #1, Con'd

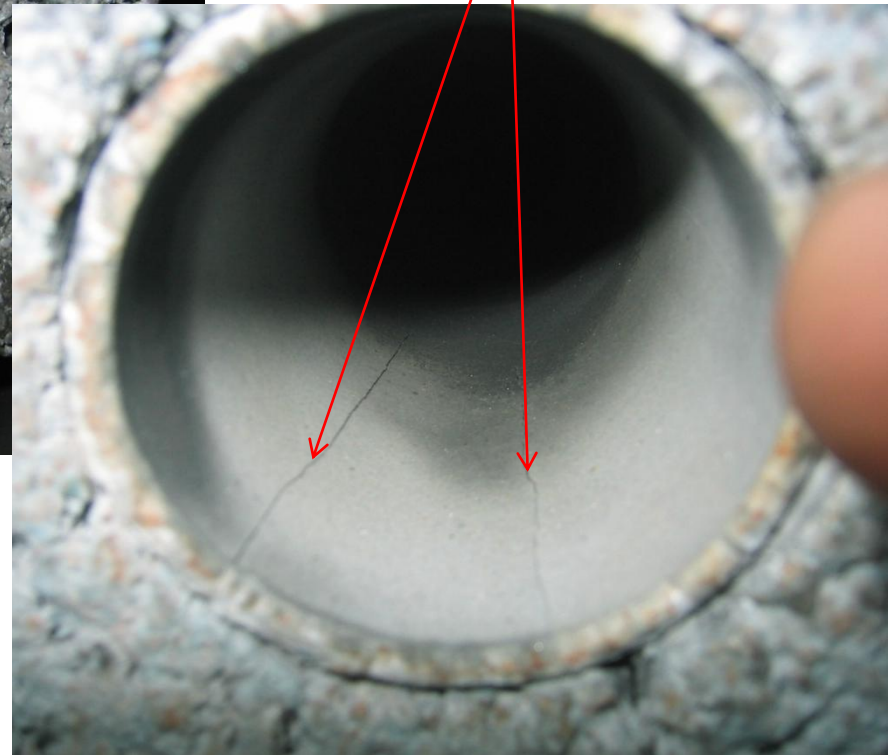
Staining from Leaking Tubes



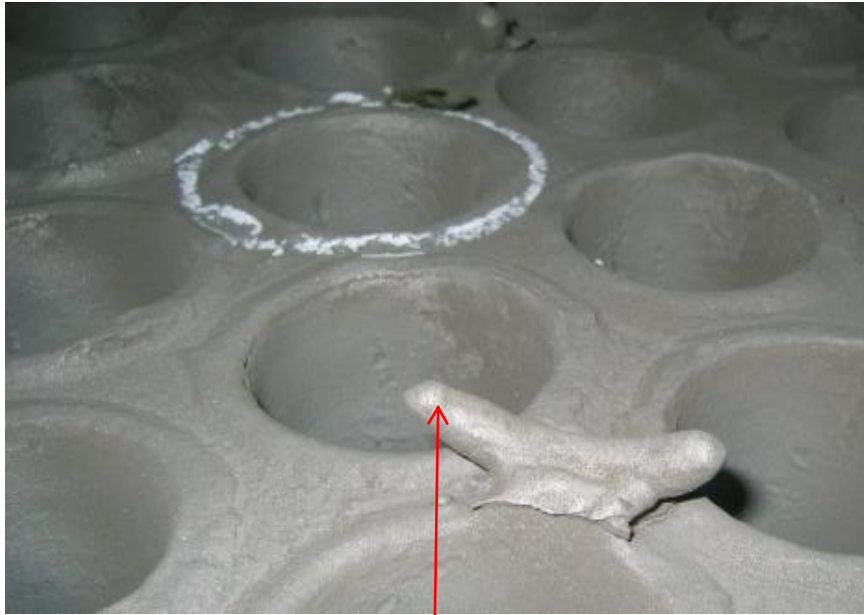
Case History #1, Con'd



Longitudinal Cracks

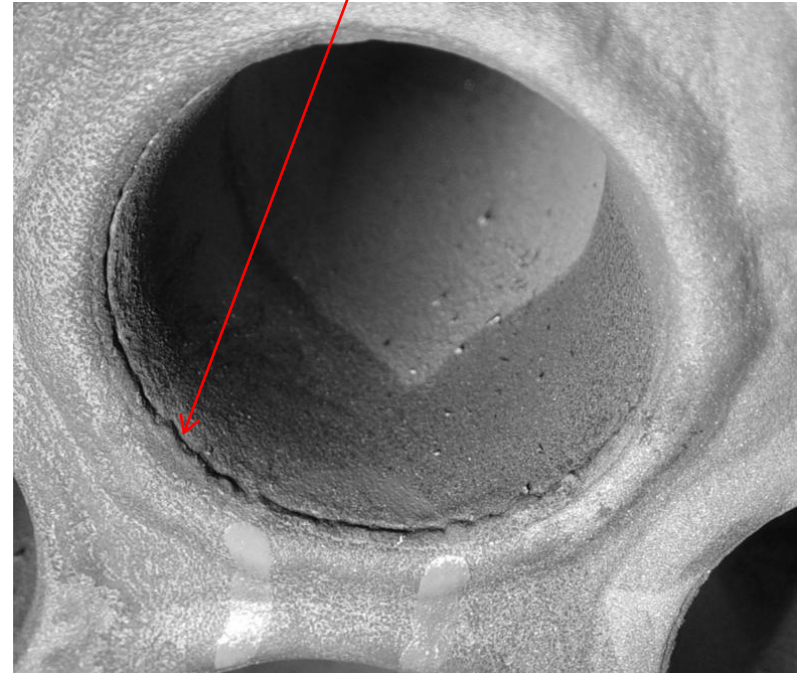


Case History #1, Con'd

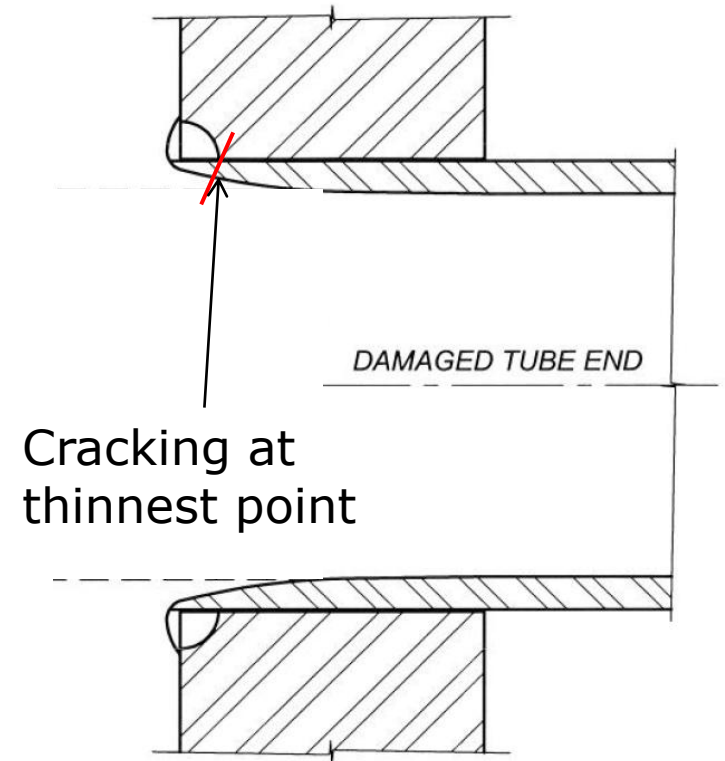


Refractory "V" anchors were 3 inches long.

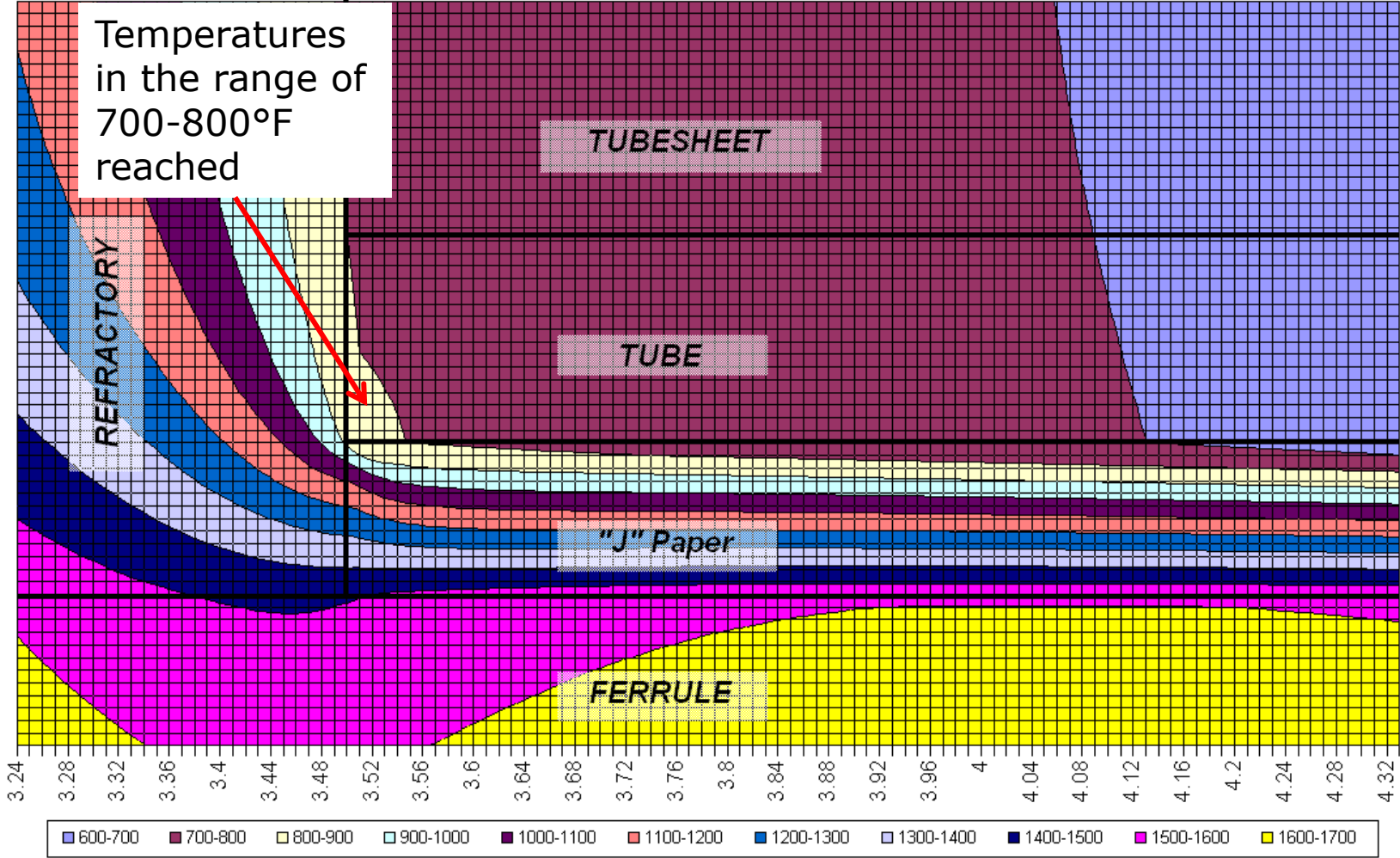
- Cracking at thinned point
- Tubes are 2.25" OD, 8 BWG



Case History #1, Con'd



Case History #1, Con'd



Case History #1 – Con'd

- Metallurgical analysis confirmed tubesheet temperature in the range of 700-800°F.
- The refractory anchors may have been on the order of 1000°F.
- The tubes were repaired/replaced and the tubesheet was weld built as required.
- The refractory system was modified to improve the thermal protection.

Case History #1 – Con'd

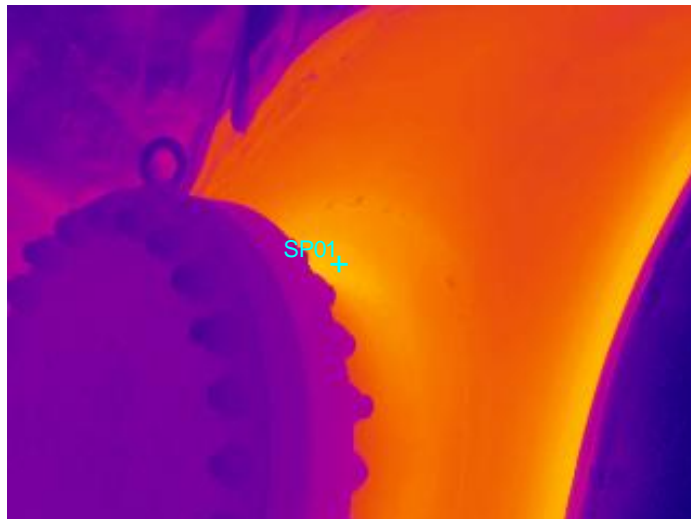
- Root Cause:
 - Poor thermal design for the tubesheet
 - Convection
 - Radiation (Very important)
- Consider:
 - No indication during operation of a problem
 - No significant indication of a problem upon internal inspection
 - Thermal protection design is very critical and should consider radiation.
 - Inspection should include rigorous inspection of the tubesheet refractory system.

Case History #2 – H₂ Reformer

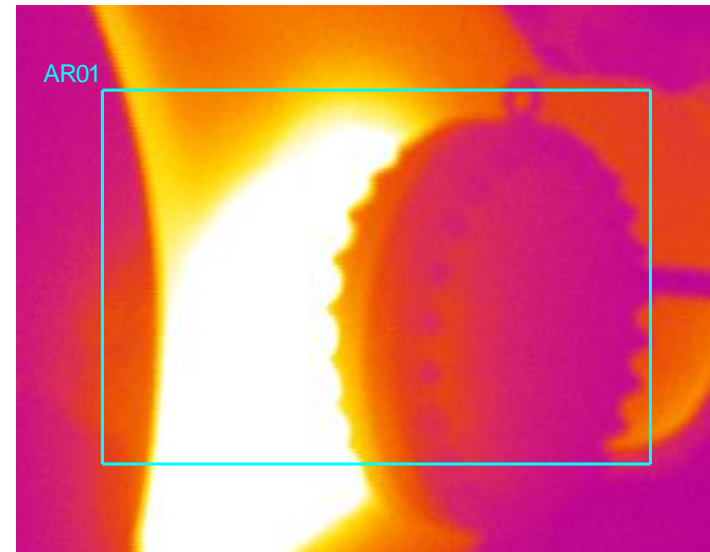
- Waste Heat Exchanger (WHE) receives hot gas (H₂, CO, Steam) from outlet of reformer furnace at temperatures >1400°F.
- 2 units that each service one side of the furnace.
- Exchanger is 26 years old, SA204-B (C-1/2 Mo) material
- Unit in regular operating mode.
- Routine thermal scanning of the furnace and surrounding equipment (performed twice a year)
- Thermal scanning of the 2 WHE reveals the following...

Case History #2 – Con'd

- The "A" unit exchanger is operating with metal temperature around 437°F (225°C)



- The "B" unit exchanger is operating with metal temperatures around 1094°F (590°C)!



Case History #2 – Con'd

- At most, based on the inspection schedule, the hot spot could have been present for ~ 6 months.
- The temperature was controlled to roughly 527°F (275°C) using air and steam hoses pointed at the hot spot.
- Subsequent ultrasonic backscatter (AUBT) inspection of the region about 4 months later did not find any damage.
- 3 months later the unit was shutdown again for repairs. Wet fluorescent magnetic particle inspection (WFMPI) was performed on the ID of the channel with no indications found.

Case History #2 – Con'd

- API 941 with 1100°F and 170 psia hydrogen partial pressure predict potential for HTHA
- Modeling and assessment of HTHA damage for the purposes of a fitness for service (FFS) assessment is difficult as there is limited data.
- Work is still ongoing within industry to better model this damage to the point of being able to predict failure, and remaining strength.

Case History #2 – Con'd

- NDE methods will find damage when it is fairly advanced (similar to creep)
- In general, for the purposes of FFS, if no damage is found, it is assumed that the damage exists to the extend of the error margin of the inspection technique.
 - For instance, if the inspection method can only find damage if it extends more than 0.25 inches in the material; it is assumed that the entire 0.25 inches is affected with HTHA.
 - A conservative model assumes the damaged material has no strength and fissuring and voids are sufficiently formed to greatly reduce the fracture toughness.

Case History #2 – Con'd

- FFS assessment deemed the vessel fit for temporary service with limitations on shutdown and start-up temperatures.
- Subsequent to this assessment, a sample was removed from the affected location and no HTHA was found!
- HTHA has a “sweet spot” temperature.
 - Too high, hydrogen is mobile enough to go right through
 - Too low, not mobile enough for diffusion

Fitness for Service Considerations

- FFS (and even design) work includes modeling of the components, especially the tubesheet and inlet channels. The modeling includes:
 - Thermal modeling including steady operation and transient operating cases.
 - In the case of HTHA, hydrogen diffusion based on the partial pressure, stress, and metal temperature are also performed.
 - Models that include and combine the effects of applied pressures and loads, temperature profiles, and varying material properties are constructed to determine the stresses for determination of component fitness for service.

Fitness for Service Considerations

- For any assessment, field testing or sampling is a good idea to justify the FFS analysis.
 - Case #1- Metallurgical analysis confirmed model results...can now change design to improve conditions.
 - Case #2- While the analysis did show fitness for service, subsequent sampling showed no damage. Some things are hard to model

Summary

- Sulfur WHB's:
 - Thermal design is critical and should consider all thermal components
 - Inspection should consider rigorous inspection of tubesheet thermal system. May even want to do periodic tearout to confirm condition.
- Reformer WHE's:
 - Condition of refractory is critical
 - HTHA, when found with NDE, is already fairly advanced
 - HTHA affects strength and toughness

Questions?



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