JUBCOR 2022
CONFERENCE & EXHIBITION

Tube Failure of Vertical Heat Exchanger

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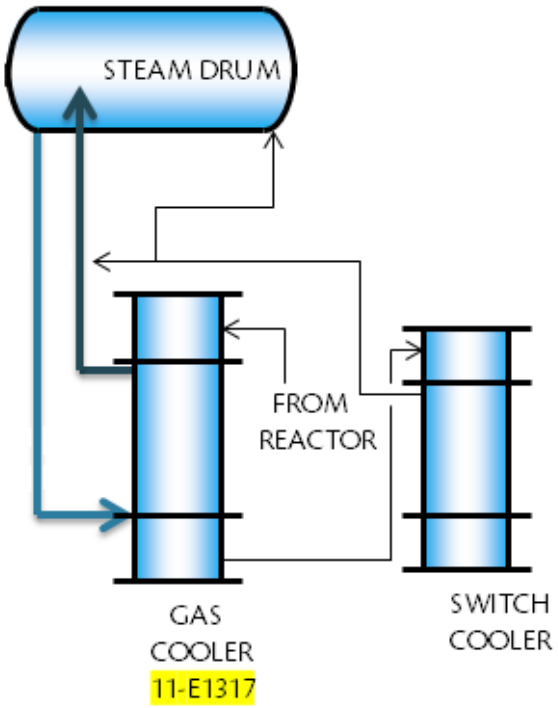
Outline

- Overview
- Timeline
- History of Failures
- Exchanger Modification
- Investigation
- Licensor and Consultant Feedback
- Conclusion
- Recommendations

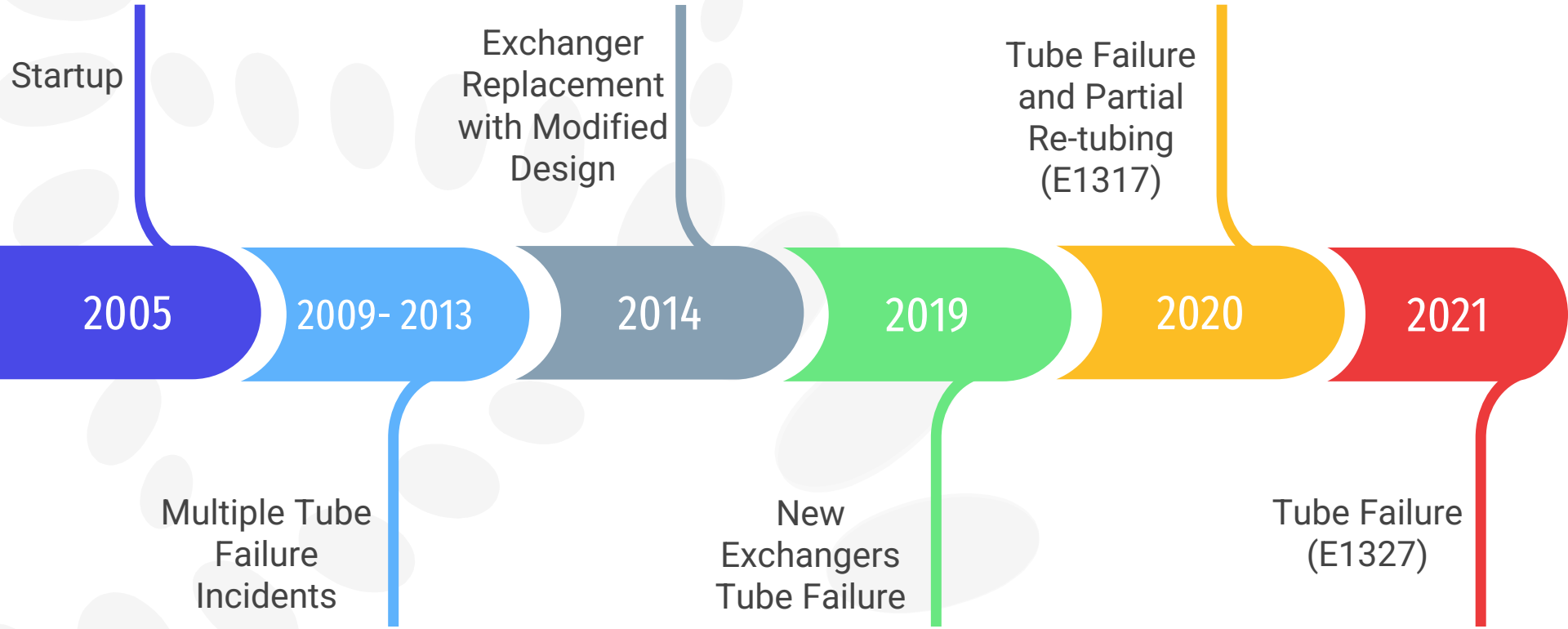
Overview

System Overview:

- The gas coolers are vertical shell and tube heat exchangers
- The Gas Coolers (11-E1317, 11-E1327) cool the reactor product gas.
- Hot Reactor Effluent gas gets cooled from 430 Deg C to 270 Deg C
- Product gas passes through the tubes
- Boiler feed water from the steam drums passes through the shells
- The boiling liquid leaves the shells of the coolers and returns to the steam drums
- BFW enters at the bottom and leaves at top by thermosyphon
- Total number of tubes is 3584 tubes in each exchanger



Timeline


Startup
2005
Multiple Tube Failure Incidents
2009- 2013
Exchanger Replacement with Modified Design
2014
New Exchangers Tube Failure
2019
Tube Failure and Partial Re-tubing (E1317)
2020
Tube Failure (E1327)
2021

Detail History of Failures

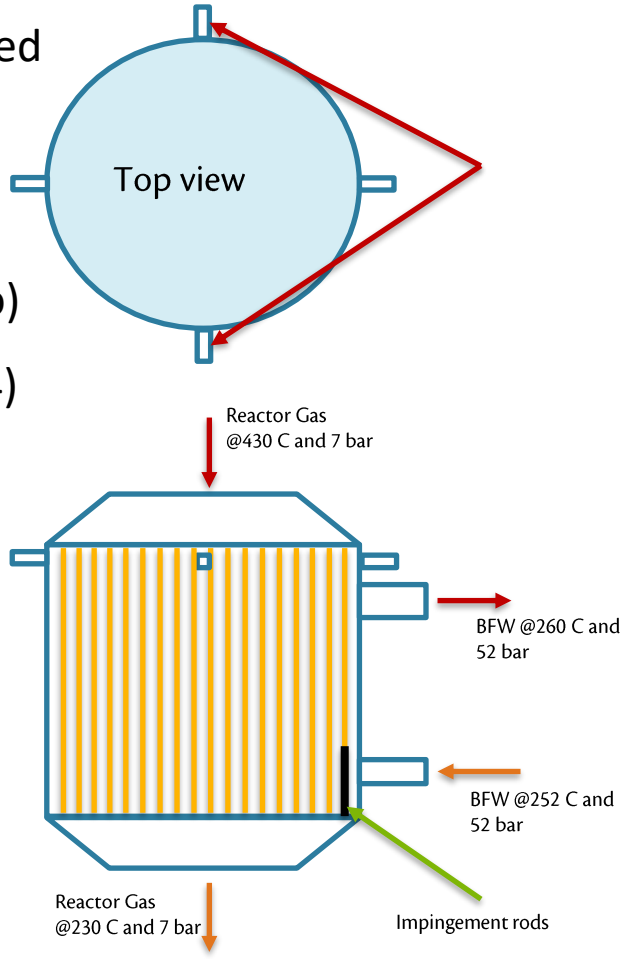
- **11-E1317:**
  - **Old Exchanger:** The exchanger was found leaking several times starting from 2009 to 2013, total number of tubes plugged is 227. Failures was observed on tubes near the inlet and outlet of BFW
  - **New Exchanger:** in 2019, 295 tubes we found leaking and have been plugged
  - **New Exchanger:** in 2020, More than 160 tubes were found leaking. Due to the number of old plugged tubes and high number of newly leaking tube, partial re-tubing was done for the most affected area (600 tubes)

- **11-E1327:**
  - **Old Exchanger:** The exchanger was found leaking several times starting from 2009 to 2013, total number of tubes plugged is 158. Failures was observed on tubes near the inlet and outlet of BFW
  - **New Exchanger:** Crack on the shell to top girth flange circumferential weld occurred two times in 2015, investigation showed that the PWHT was not done properly and the manufacturer confirmed it
  - **New Exchanger:** in 2020, 113 tubes we found leaking and have been plugged
  - **New Exchanger:** in 2021, 17 tubes we found leaking and have been plugged

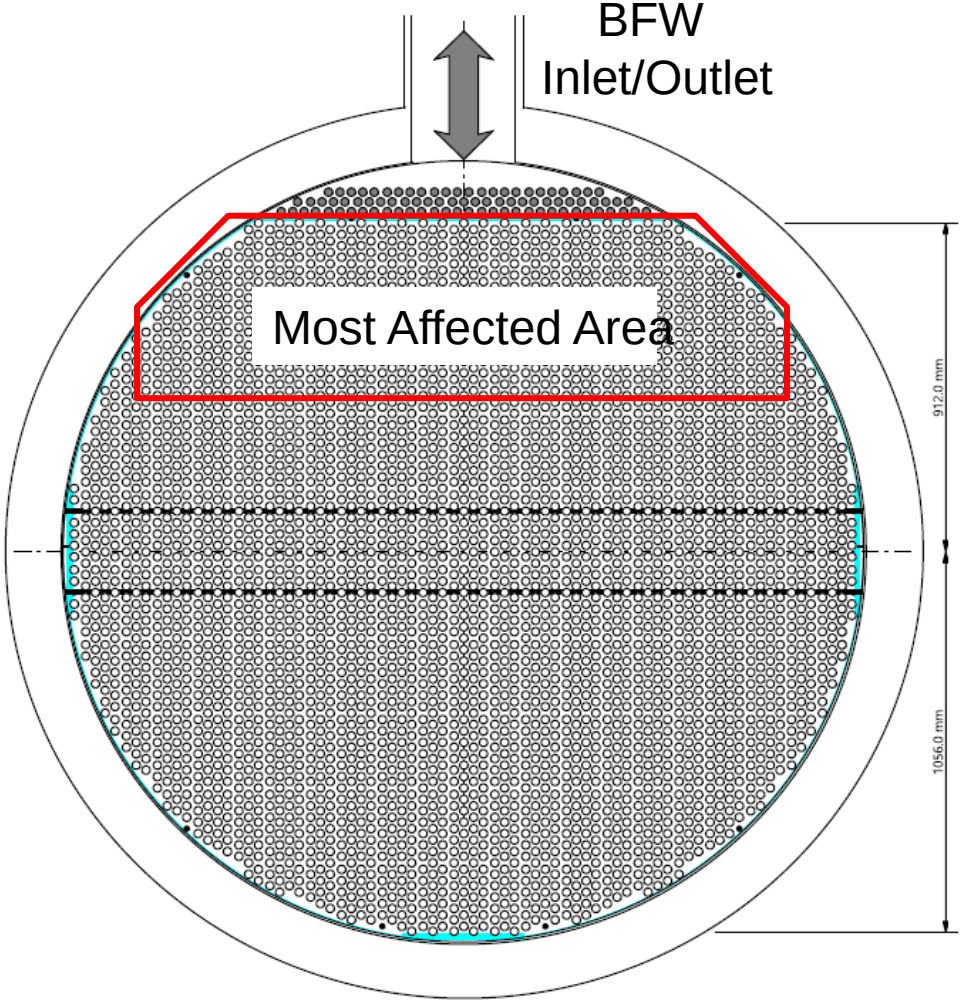
Modification on New Exchangers (2014)

The Below modification were done for the new exchanger installed on 2014 after consulting with the licensor and HTRI:

- Upgrade the MOC (tubes with higher Chromium “Cr”)
  Old: SA209-T1 (0.5% Mo), New SA213 T11 (1.25% Cr, 0.5% Mo)
- Adding vent points (nozzles) on the top (increased from 2 to 4)
- Add rods impingement instead of plate impingement
- Reduce the number of tube 4008 to 3584 (remove the tubes near the BFW Inlet nozzle).
- Maintain the BFW chemistry within the specifications.
- BFW outlet nozzle was repositioned to be closer to top tubesheet



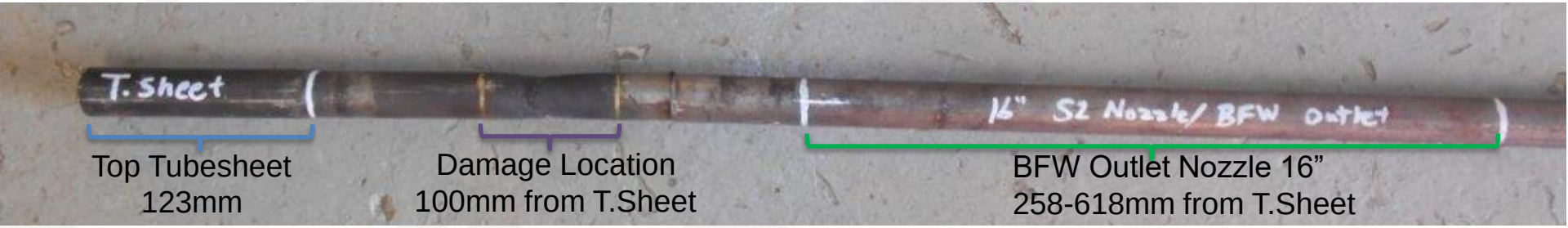
Tube Failure Investigation (2019)



Tube Failure Investigation (2019)

- For the purpose of analysis, 2 tubes were pulled and sent for failure analysis

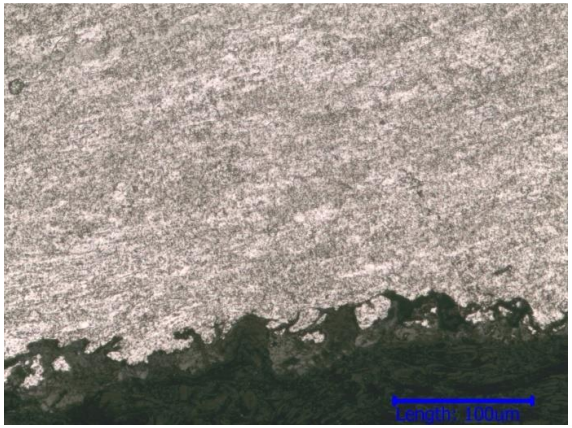
- **Tubes Condition:**
  - Tubes were sheared during pulling indicating a weak area and found the tube near the sheared location to have external damage (deep grooves).
  - The damage is located around 100mm from the top tube sheet.
  - No apparent damage observed on the plane of BFW inlet



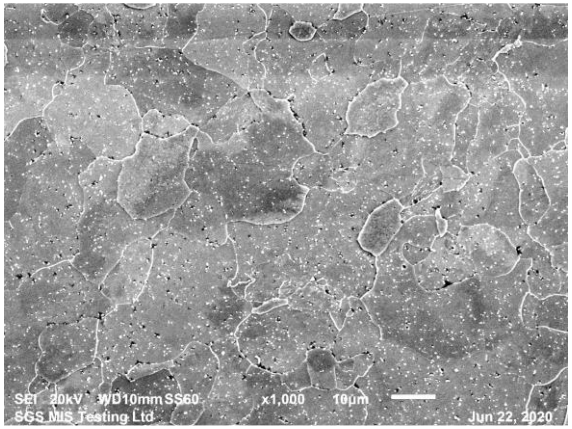
Tube Failure Investigation (2019)

Lab Failure Analysis:

- **Visual Examination:**
  - Tubes were sheared due to tensile overload caused by localized external damage
  - External pitting around sheared area
  - No internal degradation observed
- **Metallographic examination (SEM):**
  - External pitting caused by corrosion
  - The examination shows abnormal condition of the microstructure attributed to possible improper or lack of heat treatment (normalizing & tempering),
    - Expected: ferrite and bainite
    - Observed: ferrite with fine, spheroidized carbides
- **Chemical analysis, EDX and Hardness:**
  - No Significant findings



Pitting Damage



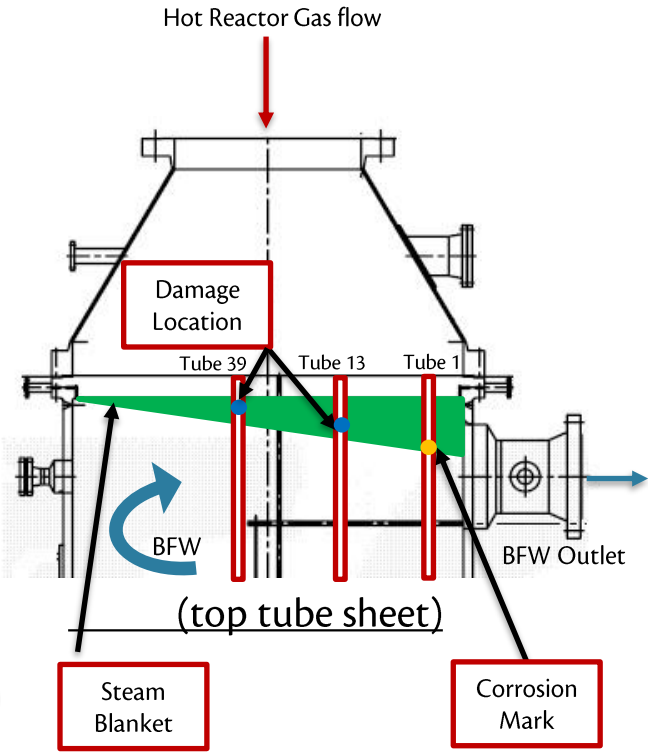
Microstructure

Tube Failure Investigation (2020)

Discussion

Design Issues – Direct Cause

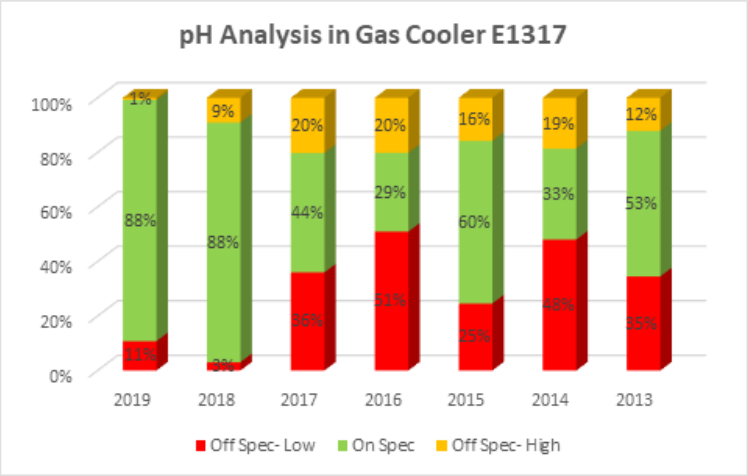
- The manifestation of the steam blanket is an inherent design issue that will persist as long as the exchanger orientation is vertical
- The location of the BFW outlet nozzle makes it impossible for the BFW level to be full up to the top tube sheet
- All corrosion (pitting) occurred on the tubes external surface at the interface between the steam and the BFW.
- The damage is localized and more sever at BFW outlet

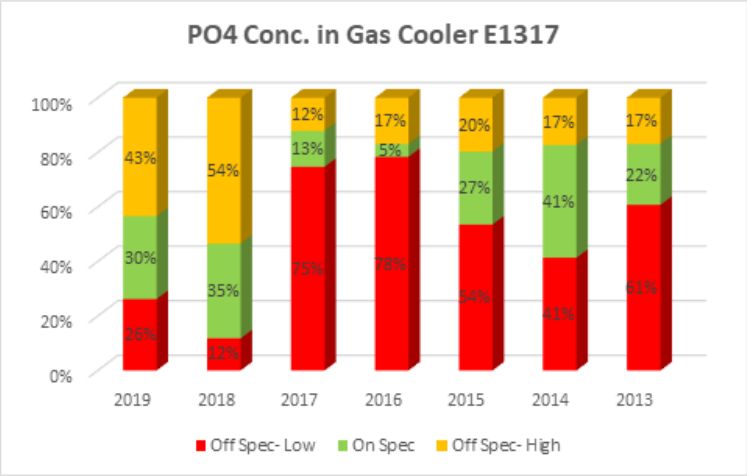


Discussion

Consequences of Boiler Feed Water (BFW) Quality :

- Off-spec of Phosphate and pH was observed for extended time
- Having low values of pH will remove the protective layer (Magnetite) and make the surface vulnerable for general or localized corrosion.
- Having high level of chemicals will form deposits at the interface between steam and BFW over the tube surface and start under deposit corrosion.





Discussion

Description of Damage

Localized corrosion due to the concentration of caustic or alkaline salts that usually occurs under evaporative or high heat transfer conditions.

Affected Materials

Carbon steel, low alloy steels and 300 Series SS.

Appearance of Damage

- Typically characterized by localized metal loss which may appear as grooves
- Localized gouging may result along a waterline where corrosives concentrate. In vertical tubes, this may appear as a circumferential groove

Prevention / Mitigation

- Proper design
- Damage can be minimized by reducing the amount of free caustic
- by ensuring adequate water flooding and water flow

Licensor: Huntsman Exchanger History & Feedback

- The original Gas Coolers were replaced after 23 – 25 years of service in the years 2006 – 2007
- The original exchangers were replaced due to tube leaks as have been experienced at Sipchem
- With the replacement exchangers there have been two incidents of tube leaks, of the same mechanism as the Sipchem exchanger. The first two rows of tubes were plugged since then the exchangers are running fine
- Steam blanketing is unavoidable. BFW chemicals near the Water / Steam interface deposit on the surface of the tube and cause under deposit corrosion.
- BFW , BW, Make up and condensate water spec maintenance is very important to avoid tube failures.

Conclusion

- Despite the fact of the new modified design, the exchangers have a major deficiency in its performance that will continue to create future failures in the tubes.

- Boiler Feed Water (BFW) parameters; pH & Phosphate showed off-spec readings though out the past years (2016 was the worst), which have accelerated the failure

Recommended Actions

- Strict control of Boiler Feed Water (BFW) Chemistry, it shall be maintained always within the specifications.
- Explore the possibility to install ceramic sleeves at the top tubesheet reduce the heat below the tubesheet and minimize the steam blanket
- Explore the possibility to replace the exchanger with horizontal design to eliminate the presence of the steam blanket

Thank You

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