Safety Culture and Safe Sealing- Anacortes Refinery Explosion

Engineering Symposium in Rochester

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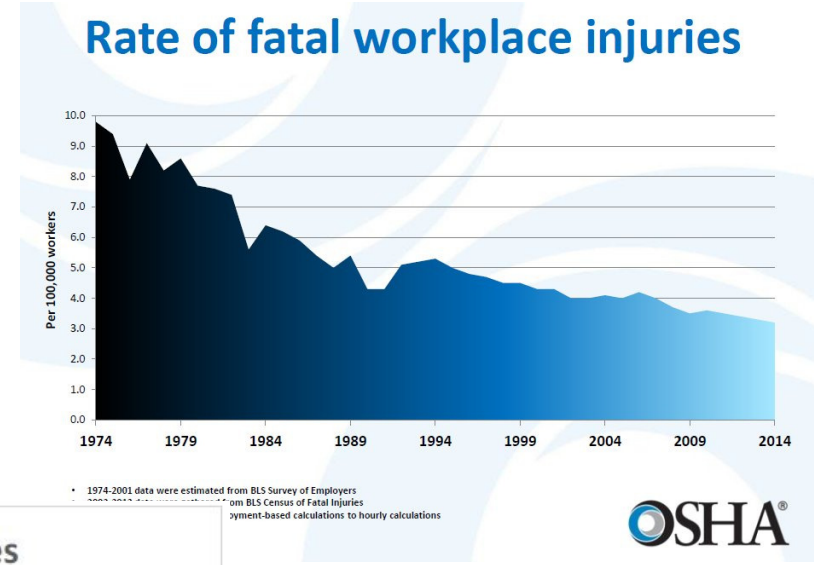
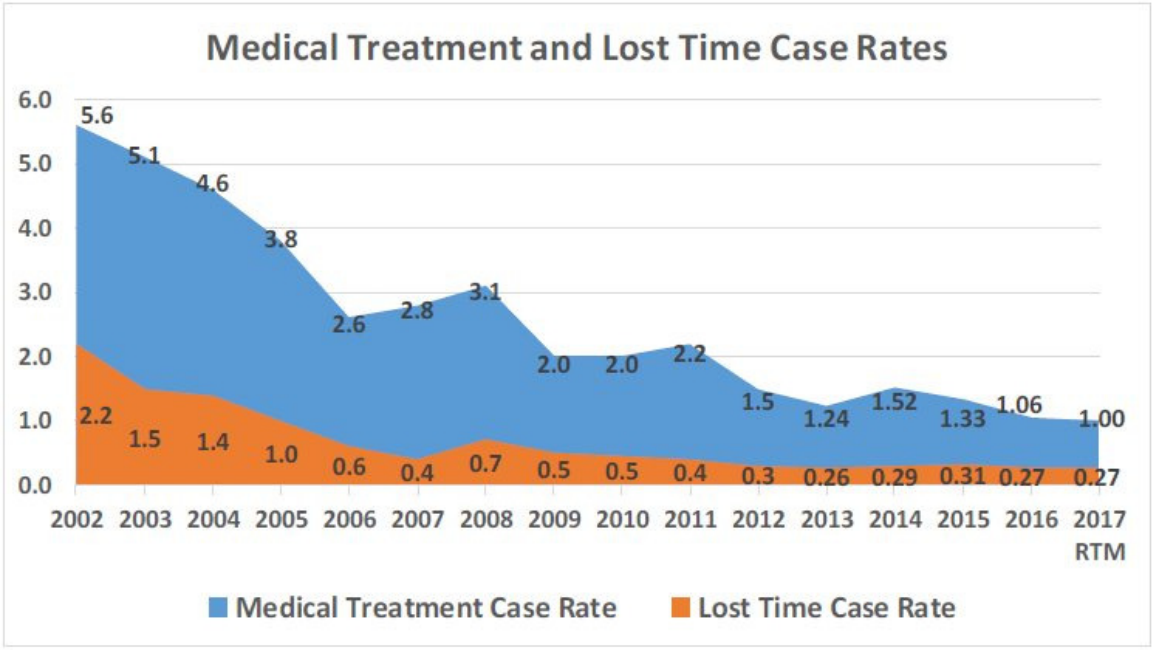
Safety - an ever present subject

- Daily meetings
- Posters
- Events
- Metrics





Safety Attitude

- OSHA compliance specialist statement –

  "…safety should not be a company priority. Priorities in an organization can and usually do change. Safety and health need to be a core values of the organization. Safety is really a case of values versus priorities."[1]

[1]"OSHA Update," a presentation given to the Monroe Professional Engineers Society on September 27, 2016 by Gordon DeLeys – OSHA Compliance Assistance Specialist

Safety and Sealing Devices

- Sealing applications
  - Dangers are many times overlooked
  - The case at Anacortes refinery shows how fatal consequences occur when leakage is accepted as normal

- Sealing products are…
  - Perceived as commodities
  - Low cost but high consequence

Q&A – 1 of 4

- Should safety be a priority or a core value?
  - Core value

- Why?
  - Priorities change core values do not

The Case of the Tesoro Refinery Explosion and Fire in Anacortes, WA

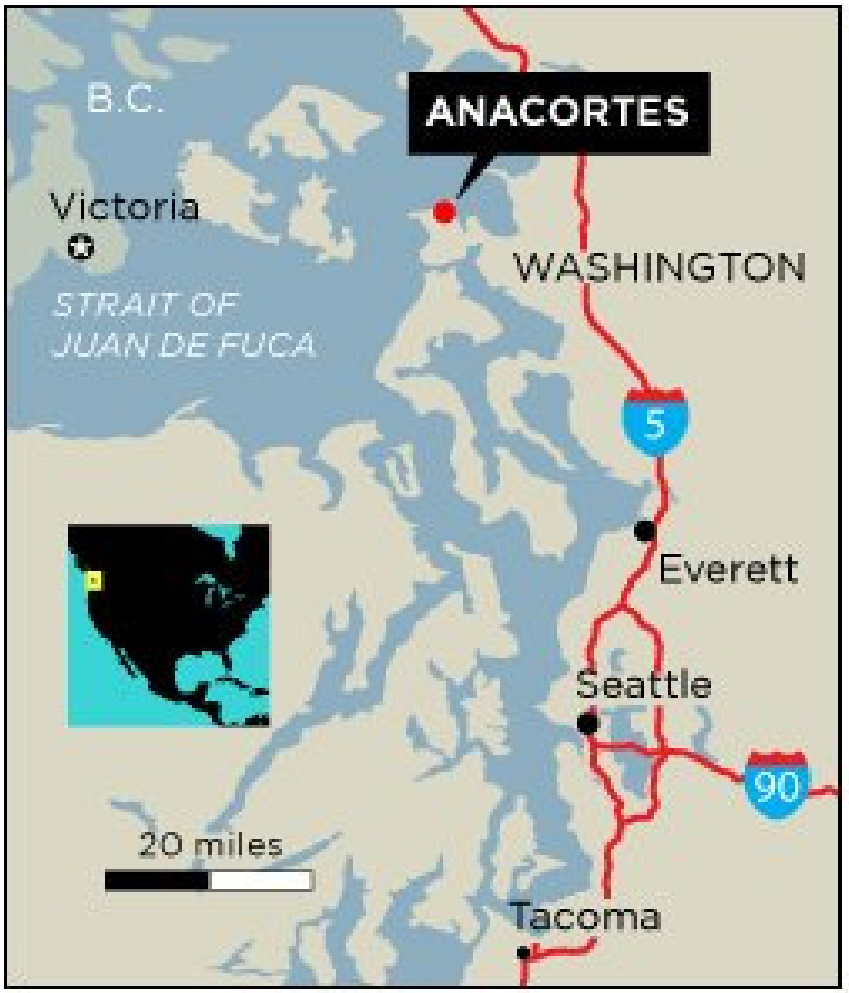
- Deadly accidents can occur when…
  - Safety risks are distorted and minimized
  - Hazardous conditions accepted as normal
  - Specific to this case - leakage is accepted as normal
- What happened? – CSB Video (01:10 to 05:20)
  - http://www.csb.gov/videos/behind-the-curve/

Naphtha Hydro-treater (NHT) Heat Exchanger - E-6600E

- Catastrophically ruptured at the Tesoro refinery at Anacortes, WA on April 2, 2010
- Hydrogen and naphtha at more than 500°F were released, ignited and exploded resulting in an intense fire lasting over three hours

Naphtha Hydro-treater (NHT) Heat Exchanger - E-6600E

- Fatally injured seven Tesoro employees
  - One shift supervisor and six operators
- All assisting with start-up in the immediate vicinity of the heat exchanger
- Why were they there?
- How does this relate to flange leakage?



Fire at heat exchanger bank

Top view of heat exchanger bank

Ruptured heat exchanger

Chemical Safety Board Major Findings[2]

- Technical Issues
  - Rupture due to high temperature hydrogen attack – HTHA
  - Inspection for HTHA is not reliable
- Organizational
  - Process Hazard Analysis failed to recognize HTHA or leaks as a hazard for
    - Documented from 1995
  - Difficult to operate manual valves required additional personnel
  - Management normalized hazardous conditions
  - Start up of the NHT heat exchangers accepted as hazardous and non-routine
  - Leaks and fires accepted as the norm
  - Use of six additional personnel to control fires accepted as normal procedure
- Codes and Standards
  - CSB judged API recommended practices to be too permissive with regards design criteria and HTHA
- Regulatory
  - Recommendations to California to improve the oversight of refineries
  - Safety was activity based (compliance) vs. goal based
    - Example – Tesoro discontinued its corrosion control program since it was not a legal requirement

[2]Report can be downloaded at the U.S. Chemical Safety Board website: http://www.csb.gov/tesoro-refinery-fatal-explosion-and-fire/

HTHA

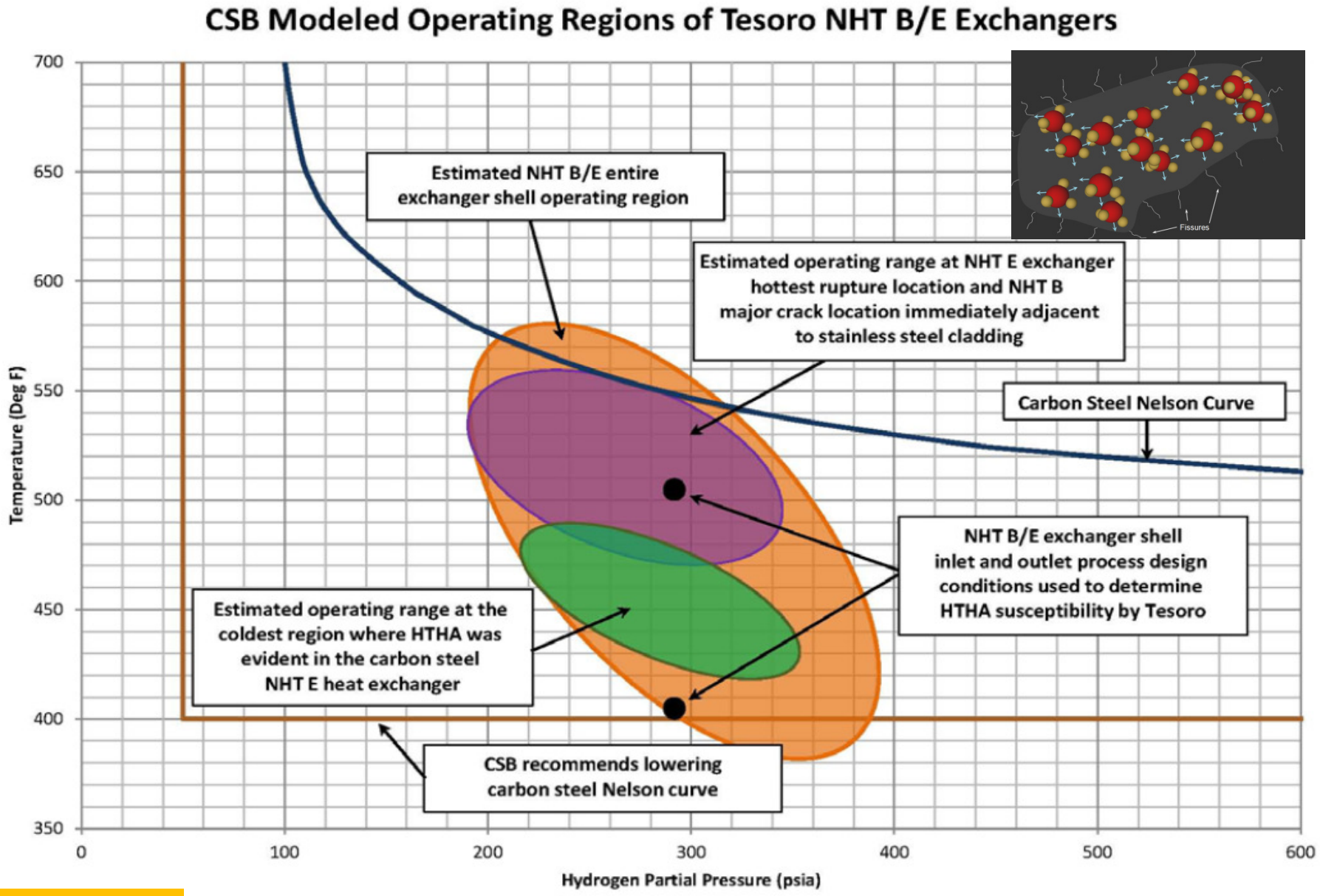


Figure 46. Estimated Operating Conditions of the B and E Heat Exchangers

From CSB report pages 29 and 136

What went wrong? Procedures and Design

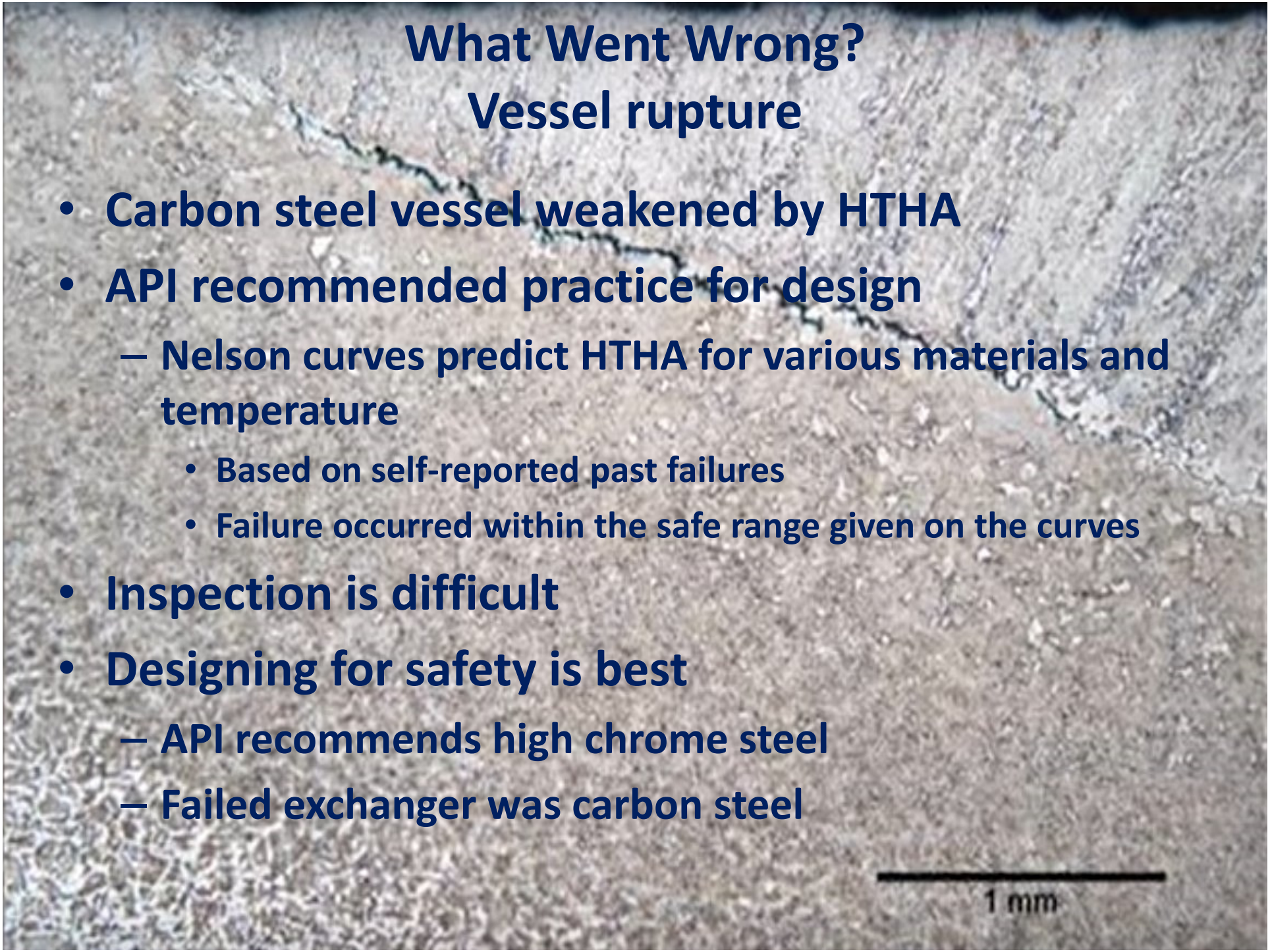
- Increased heat to shorten the heat-up time of the NHT
  - Contributing factor to the rupture
- Heat Exchanger Materials of Construction
  - Lack of preventive/conservative specification of the heat exchangers' MOC
  - Design norms of using Nelson curves to predict safe region of carbon steel judged flawed by CSB
  - Equipment operated at temperatures above the material safe range as dictated by the Nelson curves.
- Difficult to operate control components (valves) require human intervention
- Inspections favored over designing for mechanical integrity and safety
- Gaskets were routinely re-used
- Start up was categorized as a hazardous activity

What went wrong?
Safety Culture

- Unsafe conditions accepted as normal
  - "...long history of frequent leaks and occasional fires during this startup activity..."
- Focus on fire suppression instead of fire prevention
  - Required additional persons during start up
- Hazard elimination not pursued; Hazardous conditions accepted as normal
- Required proof that a practice was harmful or dangerous to justify corrective action
- Not the norm to prove that a process/activity was safe
- Working to achieve regulatory compliance as a basis for safety management rather than reduction of risks to as low as reasonably practicable (ALARP)
  - CSB finds that this is not specific to the Anacortes site
- Improvements and implementation of improvements to flange joint integrity were not institutionalized

What Went Wrong?
Vessel rupture

- Carbon steel vessel weakened by HTHA
- API recommended practice for design
  - Nelson curves predict HTHA for various materials and temperature
    - Based on self-reported past failures
    - Failure occurred within the safe range given on the curves
- Inspection is difficult
- Designing for safety is best
  - API recommends high chrome steel
  - Failed exchanger was carbon steel



Q&A – 2 of 3

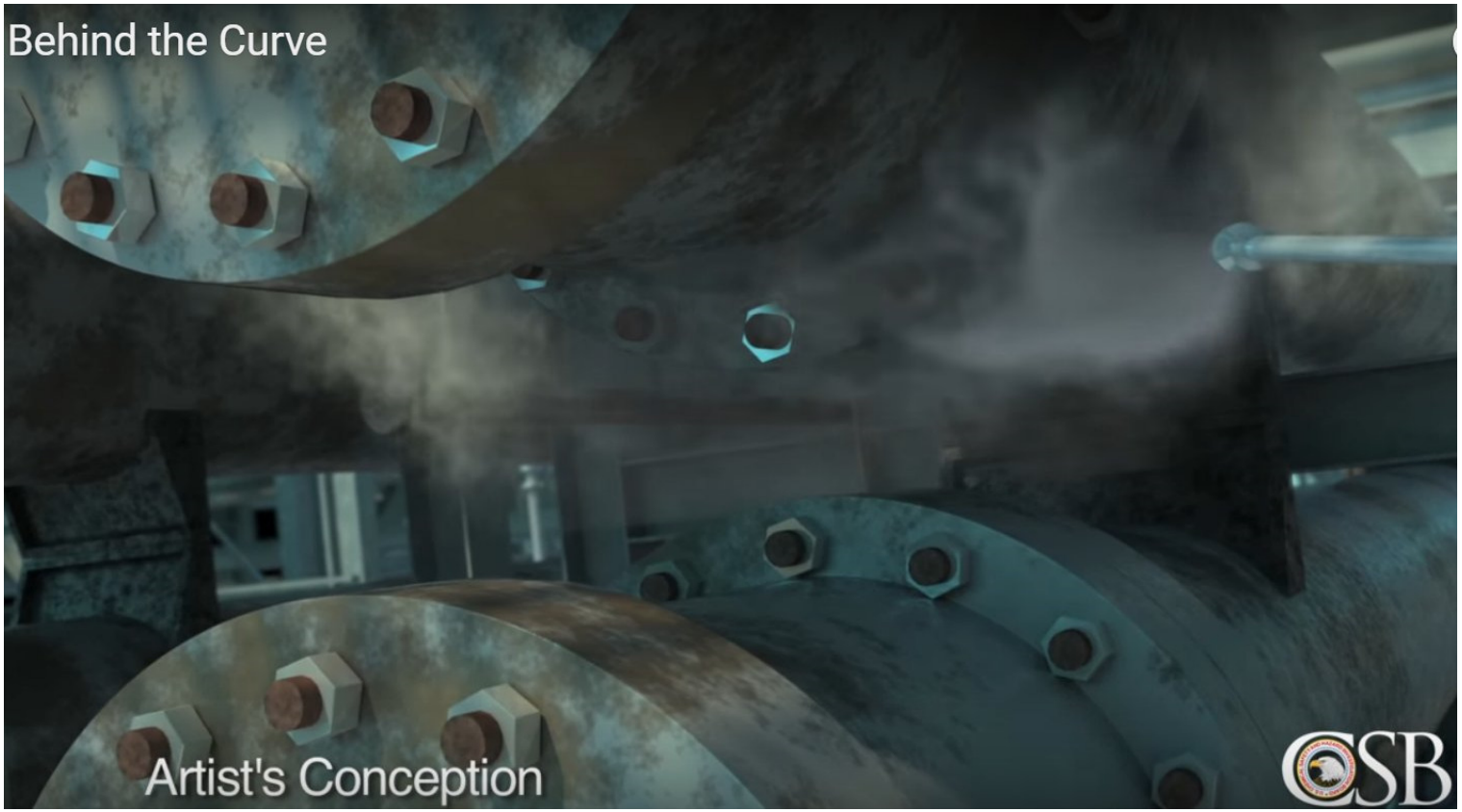
- What mechanism caused the heat exchanger rupture?
  - High Temperature Hydrogen Attack – HTHA
- What are some of the things that went wrong? There are a number answers, name some -
  - Increased heat to speed up start up
  - Nelson design curves found to be unreliable
  - Carbon steel not best
  - Inspections favored over better design
  - Gaskets reused
  - Hazardous/unsafe conditions accepted…"it's normal, it's always been that way."
  - Did not institutionalize improvements

Flange Leakage – Complacency

- CSB report, “The NHT heat exchangers frequently leaked flammable hydrocarbons during startup, sometimes resulting in fires…. management had been complacent about these hazardous leaks and did not always investigate the cause of the leaks.”
  - E-6600E’s flanges had been leaking for many years
- Corrective action process failed so reactive actions were taken

Flange Leakage – Complacency

- Use of steam lances to spray on the leaking flanges during start-up to mitigate fires
  - Cause of the fires not corrected
  - This action required additional personnel to be in close proximity to the NHT heat exchanger
- Use of clamps and active leak repair masked the sealing problem



NHT Heat Exchanger Flange Leakage Issues and Actions

- Technical issues
  - Engineering design – flanges, bolts, surfaces, materials
  - Maintenance
  - Sealing devices
- Attempted actions made to prevent the leaking of the NHT heat exchangers
  - Gasket modifications
  - Changes to torque and bolting practices
  - Resurfacing of flange surfaces
  - Installation of warm-up piping to smooth the equipment's transition from cold to hot during startup

Good Gasket Practices Pursued But Not Institutionalized

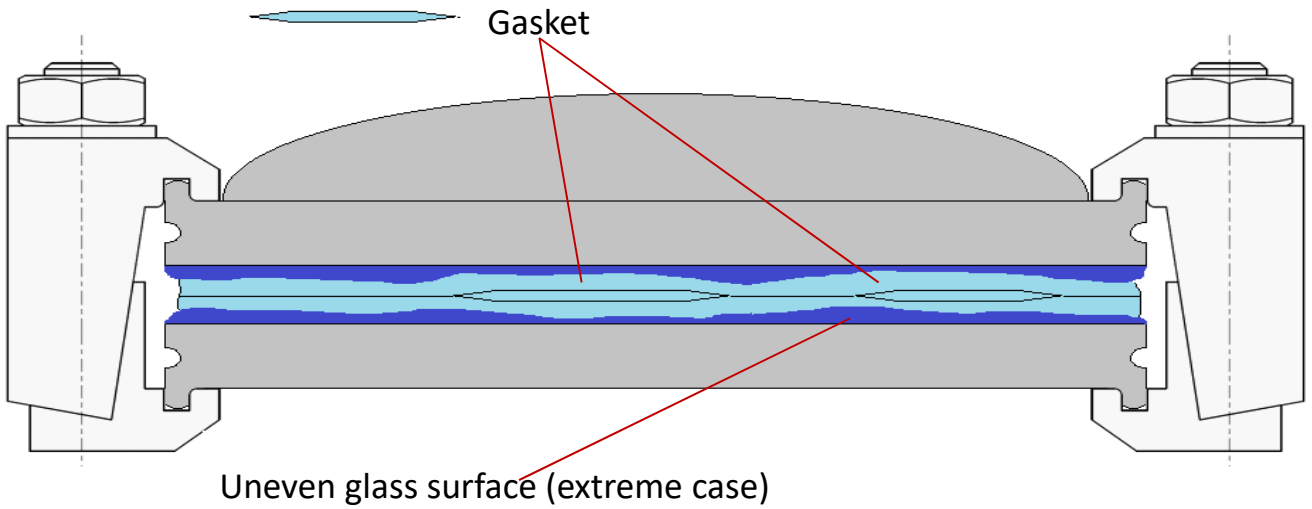
- March 2009 startup
  - Several severe leaks from the heat exchangers
  - Following August installed a different type of gasket
    - Startup that followed resulted in no leaks from the heat exchangers
  - Problem re-appeared during the next clean-out-startup cycle
    - Gasket was the re-used
- Documents indicate that the heat exchanger gaskets were allowed to be re-used after flange disassembly at cleaning cycles
- Seal manufacturer and industry best practice is that gaskets are never to be reused
  - Lack of knowledge in use of sealing devices
  - The Fluid Sealing Association has a recently updated gasket manual
    - See website www.fluidsealing.com

Q&A – 3 of 4

- Why were so many people in the vicinity of the heat exchanger?
  - To manage fire
  - Also, person needed to actuate troublesome manually operated valve(s)
- Why were there fires?
  - Poor sealing practices

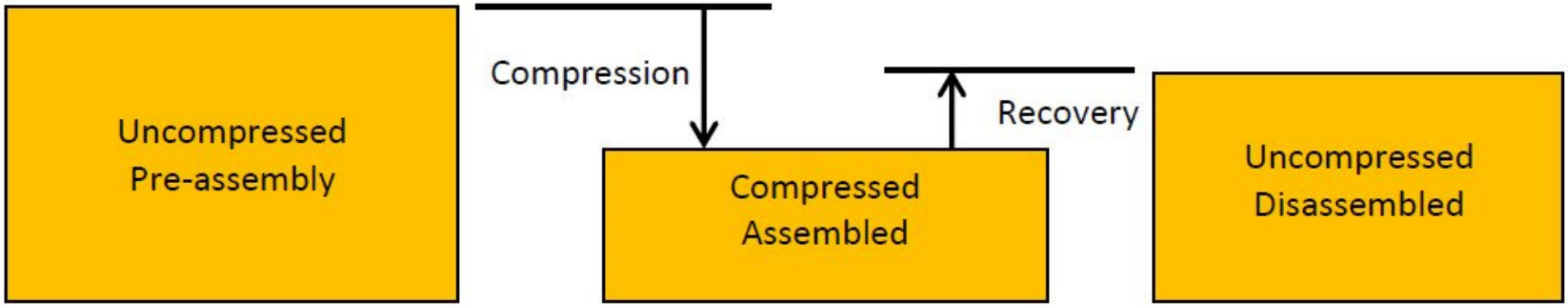
Why can’t a gasket be reused?

- The design intent of a gasket is to conform to the flange face and seal
- If the gasket were 100% elastic, it could be used again but it’s not!
- Only case of gasket reuse is rubber at ambient temperatures and moderate compressive loads



Why can’t a gasket be reused?

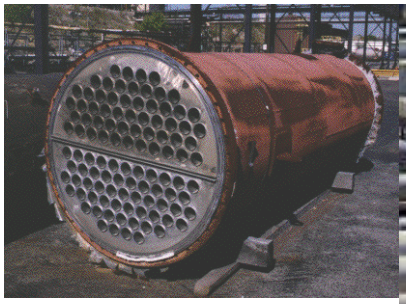
- When gaskets are installed they are compressed and take a set.
- Gaskets made of compressed fibers, inert fillers with rubber binders, PTFE or metal with flexible graphite filler/laminate are irreversibly densified when compressed
- When the compressive load is released it does not return to its original shape.
- Can be measured using ASTM-F36 test procedure



Why can't a gasket be reused? Gaskets Exposed to Heat

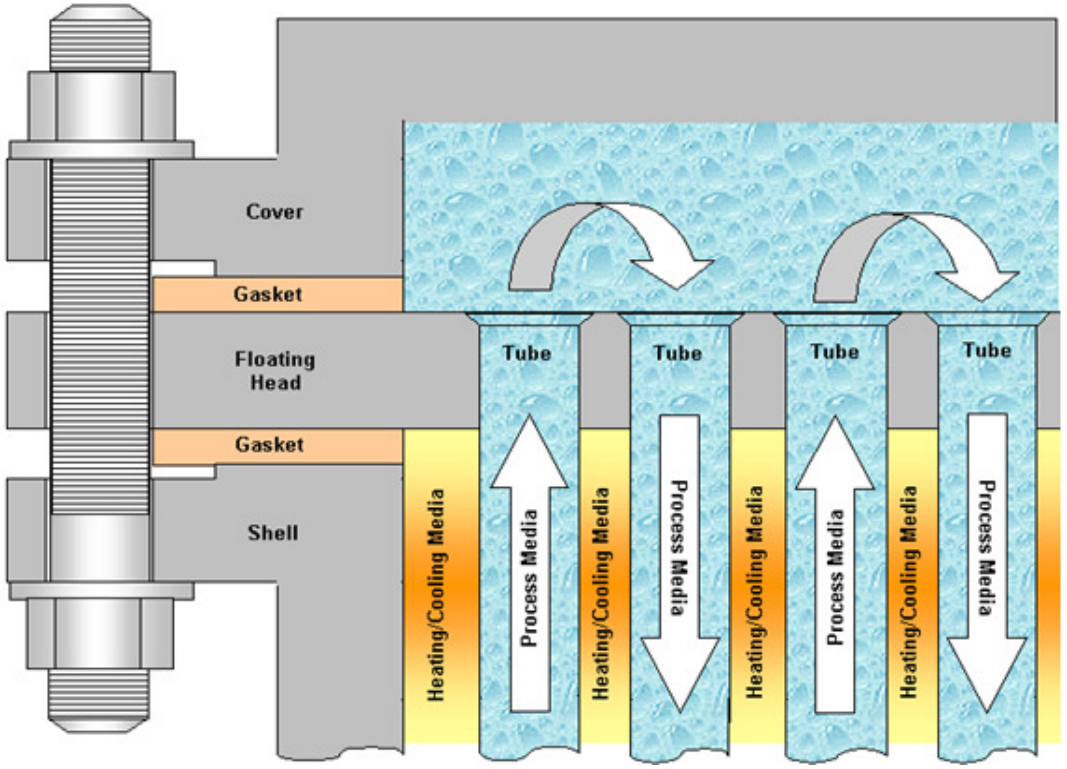
- Heat changes the form and properties of non-metallic gasket material
  - Cure and harden gasket materials that contain rubber
    - Becomes brittle
  - Accelerates creep
    - ASTM F38 and DIN 52913
- Metal in metal gaskets can be subject to reduction of yield point
  - Elevated temperature will alter stress vs. strain characteristics taking the material out of the elastic region, causing permanent deformation and a reduction or elimination of resilience.

Why can’t a gasket be reused?
Shell & Tube Heat Exchangers
Flange Joint Dynamics

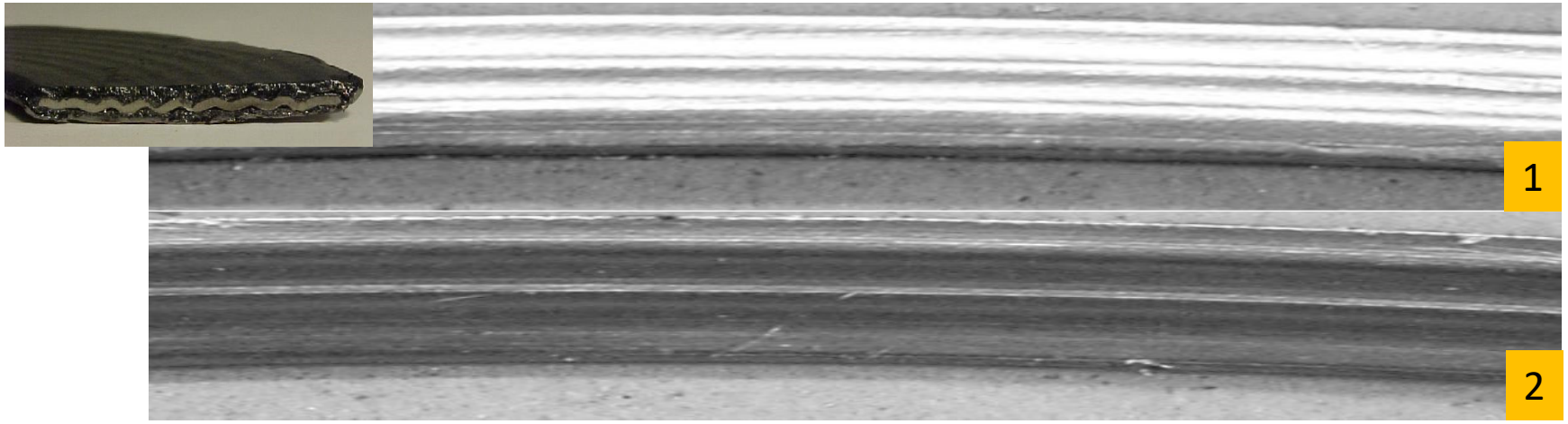


Heat Exchanger
Flange Joint Reaction to Thermal Transients

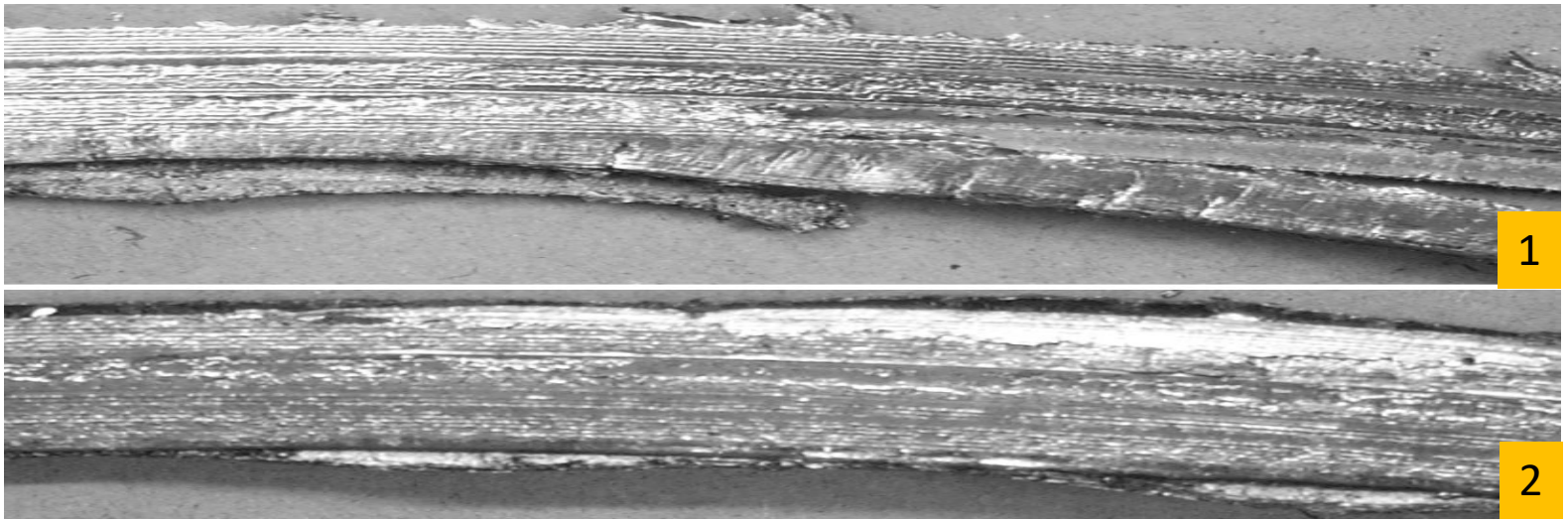
- When process equipment goes from ambient to elevated temperature
  - Flange joint components are subject to thermal growth and movement.
  - Head flanges, tube-sheets, bolts and gasket grow at different rates
    - This upsets the flange-gasket interface
  - Change in stress on the gasket
    - Can cause leaks
- Thermal growth
  - Bolts, flanges, tube-sheets and gasket are different masses and materials so grow at different rates
  - Bolts, flanges and tube-sheet grow axially and radially
    - Axial growth can cause compressive stresses on the gasket beyond those applied at assembly
    - Radial growth causes the flange surfaces to shear across the gasket upsetting the gasket-flange interface promoting leak paths



Results of Radial Shear
Example - Corrugated Metal with Flexible Graphite



Before



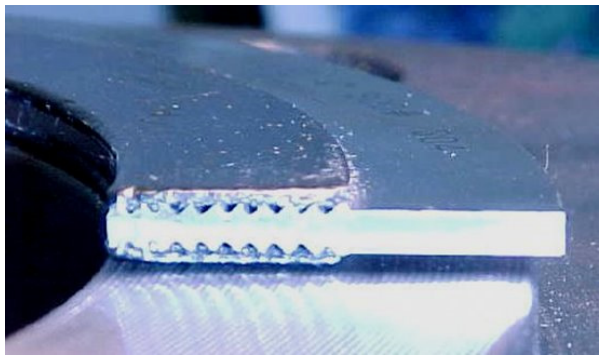
After

Common High Performance Gaskets for Heat Exchangers

- Gaskets such as corrugated or grooved metal with flexible graphite laminates, handle this shearing service better than others

Corrugated metal gasket

Price for 36”ID x 40”OD ~ $200



Kammprofile gasket

Price for 36”ID x 40”OD ~ $350

Qualification Test for Heat Exchanger Gaskets

- Radial Shear Tightness (RAST) Test developed by the now defunct Tightness Testing Research Laboratory of the University of Montreal evaluates performance

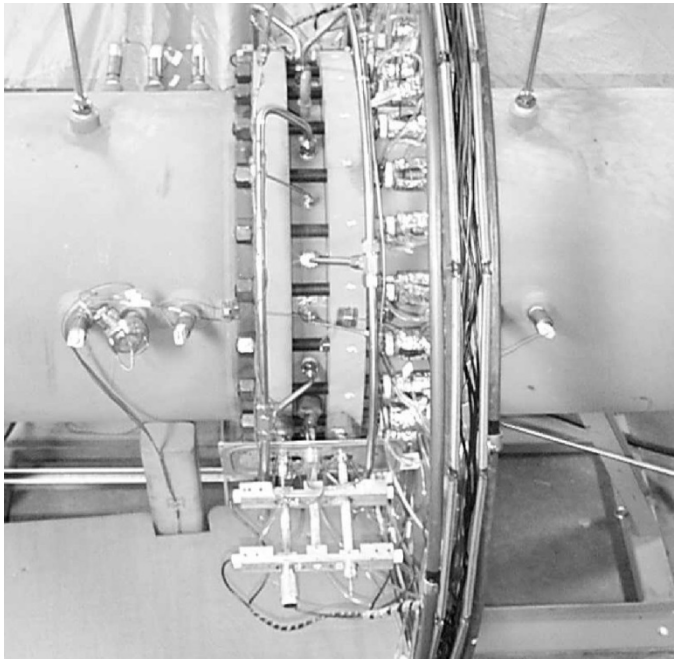
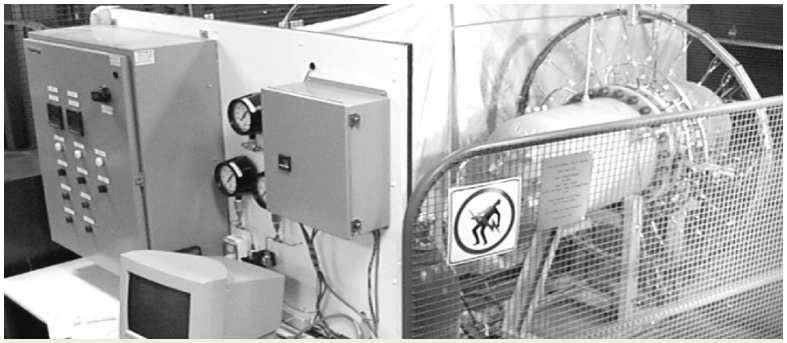


Photo courtesy of Matt Wasielewski of Yarmouth Research, North Yarmouth, ME



Courtesy of Warren Brown, Integrity Engineering Solutions Pty. Ltd., Dunsborough, Western Australia, TTRL Test Report, “Radial Shear Tightness Test Results”, November 1, 2001

Final Q&A – 4 of 4

- Can a gasket be reused?
  - NO!
- Why?
  - It's not the same material anymore. It won't compress and gain a seal as it did when it was used.

Conclusions

- The explosion at Anacortes in 2010 was not the result of poor gasket application
- The NHT heat exchanger vessel ruptured due to HTHA
- Poor gasket application was responsible for the number of lives lost
  - Safety complacency allowed heat exchanger leaks during start up requiring additional personnel to manage fire from leaks which led to the tragic loss of life
- Technology and know-how are available to assure safe sealing so we all get home at the end of the day safe and sound

Credits and References

- "Improper Selection or Installation of Gasketed Joints Can Be Deadly," by Drago and Frisard, *Pumps & Systems* magazine *FSA Sealing Sense* column, March 2017, http://www.pumpsandsystems.com/gaskets/march-2017-improper-gasketed-joints-can-be-deadly

- U.S. Chemical Safety And Hazard Investigation Board (CSB) Investigation, Catastrophic Rupture Of Heat Exchanger (Seven Fatalities) Tesoro Anacortes Refinery, Anacortes, Washington, April 2, 2010, Report 2010-08-I-WA May 2014

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