Hydrogen Piping Experience in Chevron Refining

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Outline

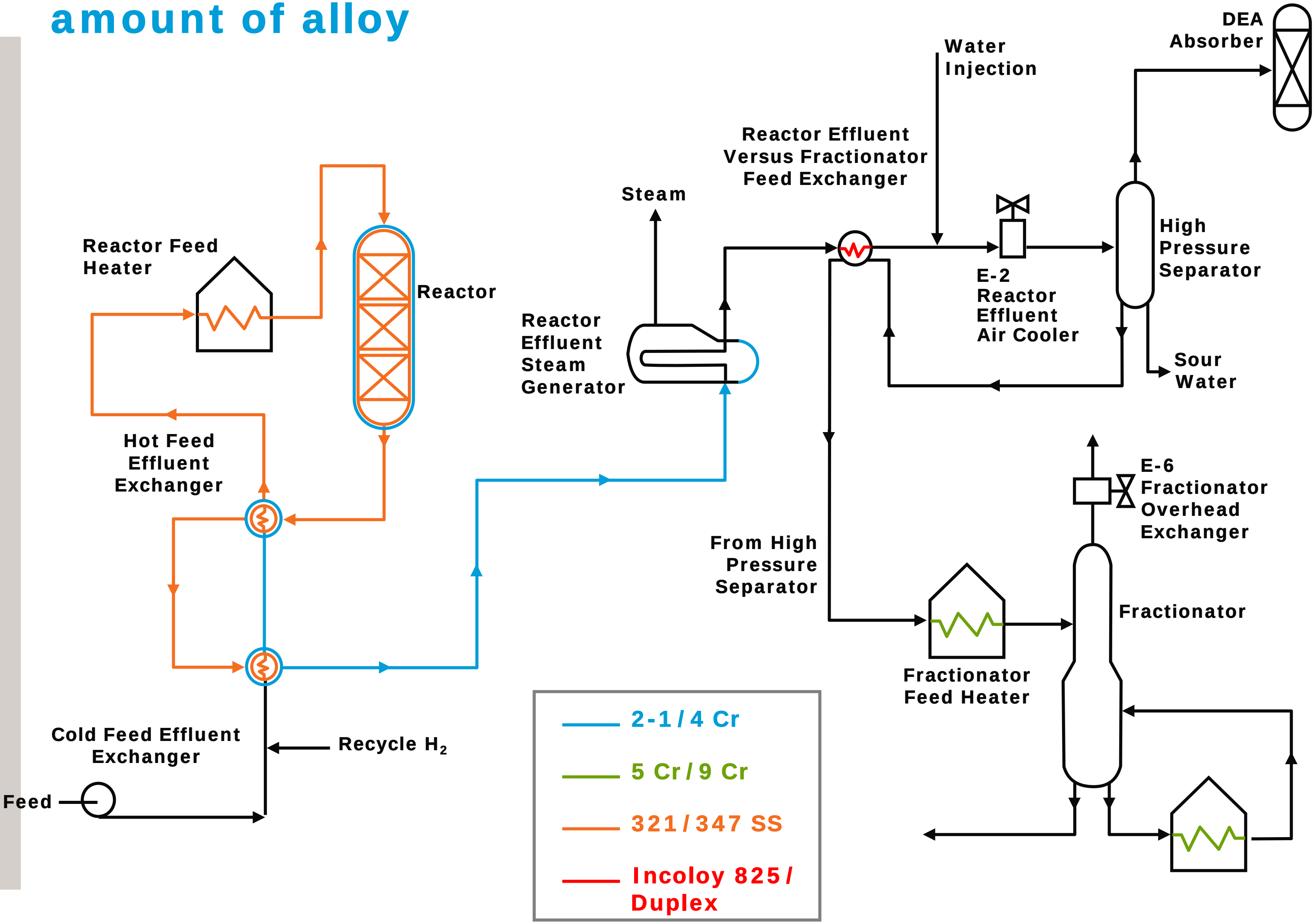
- Overall perspectives from long term use of hydrogen piping in refining.
- Piping specifications and practices.
- The (few) problem areas.
- Related industry work: American Petroleum Institute corrosion and materials work on high temperature hydrogen attack.

Overall Perspectives

- Few problems with hydrogen piping operating at ambient to at least 800F and pressures up to at least 3000psia as long as we stay within well-defined limits
  - H2S contamination presents many more problems, beyond the scope of this talk
  - We will note a couple of specific vulnerabilities
- Refining tracks materials performance in hydrogen, will briefly discuss API work
- High community sensitivity to hydrogen related incidents

Major events can stem from small initial failures (in this case, 2” hydrogen piping failure)

Hydrogen piping experience largely from hydroprocessing plants, but due to higher temperatures and pressures we use a fair amount of alloy



Typical carbon steel piping specifications and practices for hydrogen service

- Chevron commonly defines “high pressure” H_2 service as above 100 psia hydrogen partial pressure
- Follow ASME code for pressure piping, B31.3 (Process Piping)
- 300# minimum flange ratings (ASME 16.5)

Typical carbon steel piping specifications and practices for hydrogen service (Cont'd)

- Seamless pipe (SA 106GrB or less commonly SA 333 Gr6); may call for A672 (specific grades) electric-fusion-welded pipe for sizes >16"
- 100% radiographic examination required for all welds
- Postweld Heat Treatment requirements as a function of thickness (>3/4") per code

Typical carbon steel piping specifications and practices for hydrogen service (Cont'd)

- No threaded connections, bridge weld couples, leave no exposed threads (leave no stress concentrators, keep everything "beefy")
- Minimize flanges or other potential leak sources
- Where flanges are required, gasket reliability is a major focus and continues to evolve:
  - Typically moving to spiral wound gaskets for lower pressure classes
  - 1500# classes are reviewed case-by-case, temperature one factor, may need "RTJ" (confined metal) gaskets
  - 2500# classes are typically "RTJ" style or proprietary engineered confined metal gaskets
- Need excellent valve quality and tight shutoff: quality of supply chain is essential, some plants call for specific brands
- We have learned to assume that all check valves leak

A couple of potential problem areas:

1. Hydrogen induced cracking of hard materials

   - The refining industry has had very few cases of hydrogen related cracking in pure hydrogen service.

     - Sour (H_2S) service that charges hydrogen into the material from corrosion is much more a threat; we have industry and company guidelines to avoid these failures

     - There have been a few cases of very hard materials cracking in essentially pure hydrogen service (few if any cases in our refineries, we do not need such hard materials)

A couple of potential problem areas:

2. Hydrogen assisted fatigue crack growth rate

   - For many years it has been well established that hydrogen service significantly accelerates fatigue cracking

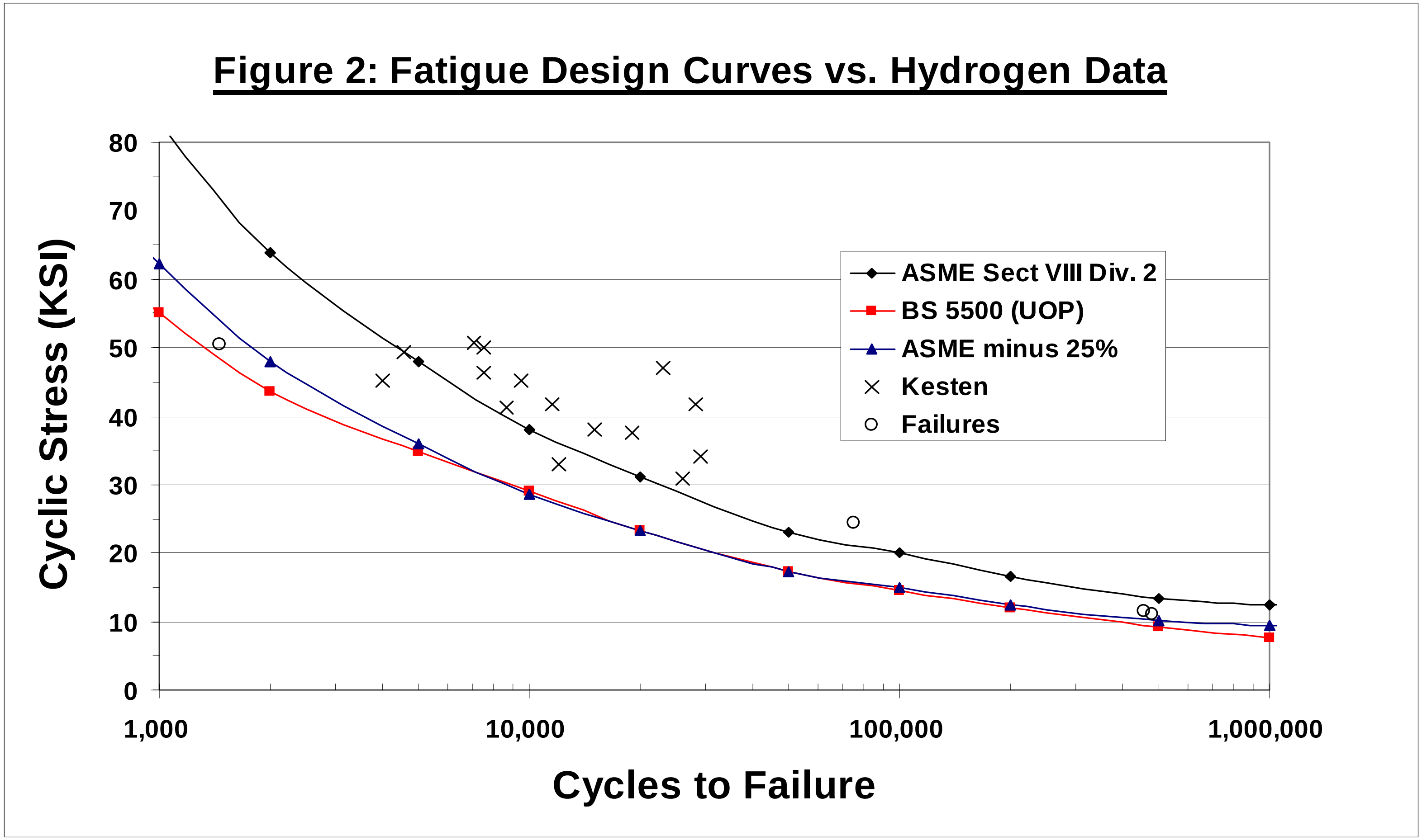
     - Not always recognized by less experienced engineers

     - Many of our practices such as bridge welding are effectively aimed at preventing fatigue initiation

3. (fracture toughness reduction due to hydrogen has not been a practical problem in refining piping applications; materials engineers do focus on this for thick walled pressure vessels)

Quantitative data on hydrogen vs. fatigue is scattered, but is significant:

(Example figure from a current fatigue analysis)



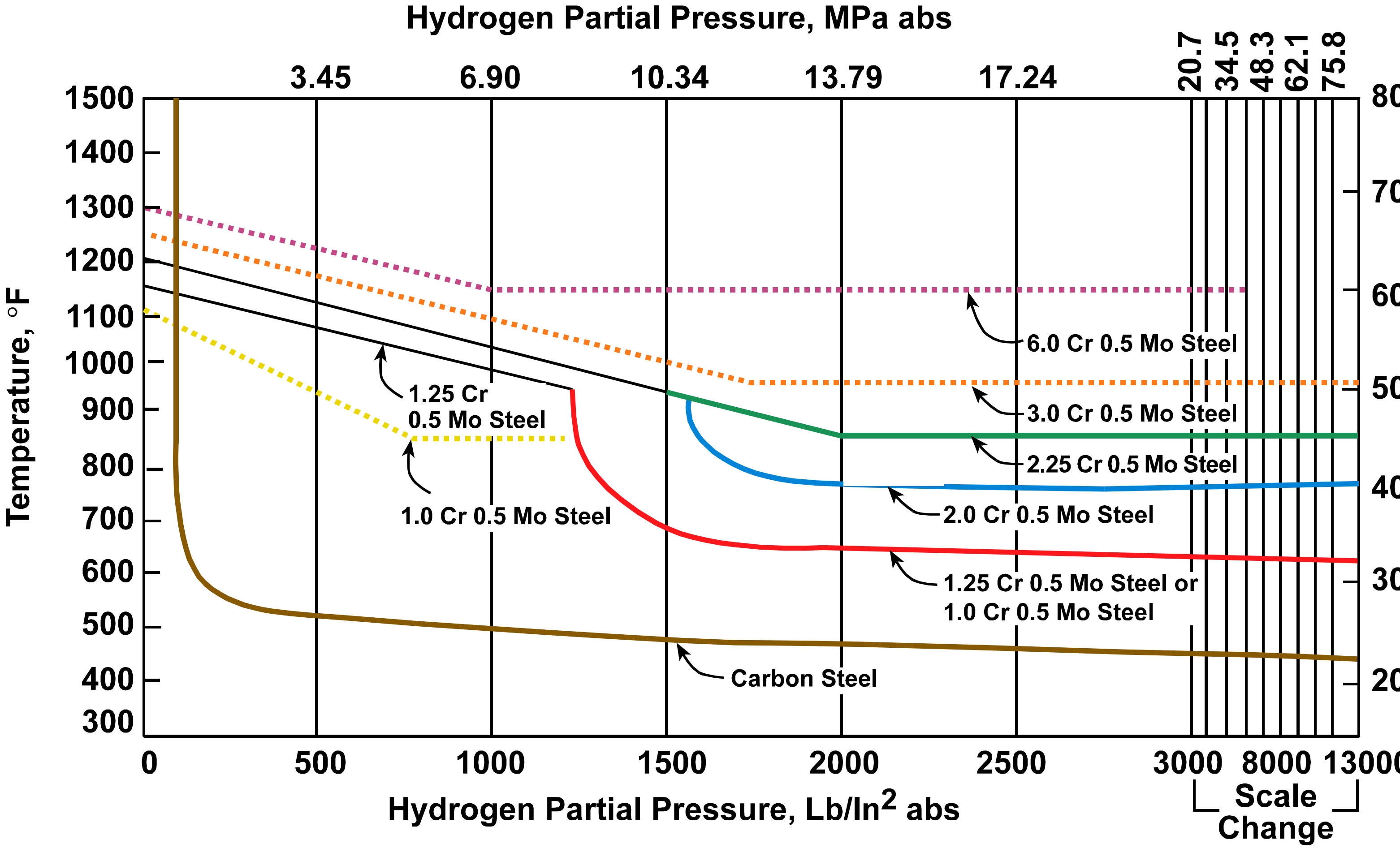
Some notes: API Refining Subcommitte on Corrosion and Materials

- This group is responsible for supporting safe and reliable refinery operations through consensus development of industry standards in the corrosion and materials area
- Often work with pipeline metallurgical colleagues to share expertise in overlapping issues
- Past focus in hydrogen service has been for high temperature, moderately high pressure applications
- As yet little group focus on supporting new hydrogen technologies, although individuals in our member companies are involved

API Refining Subcommitte on Corrosion and Materials (Cont'd)

- For many years the SCCM task group on high temperature hydrogen attack (HTHA) has maintained refining industry data on HTHA, and developed guidelines to deal with it
- Reference: API 941 "Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants"—see example below
- This year we will issue a detailed summary of the technical basis for the industry guidelines
  - The technical basis work improves our fundamental understanding of HTHA, provides better judgment as to the accuracy of the empirically derived curves, how to handle short-term process upsets, the benefits of alloy cladding, etc.

Operating Limits for Steels in H_2 Service
(Adapted from API Publication 941, *reproduced courtesy of the American Petroleum Institute)*



Surface Decarburization	----------
Internal Decarburization	———— (Hydrogen Attack)

See current edition of API Publication 941 for detailed comments, including special comments regarding 0.5 Mo Steel.

Adapted from API Publication 941 (1990)

Summary

- Overall refining experience with hydrogen piping has been very good. But--
  - Consequences of even relatively minor events can become major
  - High community sensitivity to hydrogen events
  - Metallurgists are cautious in extrapolating data and experience beyond proven limits
- Refining experience is in line with the known factors of hydrogen accelerating fatigue crack growth, and cracking of (very) hard materials. Reduction of fracture toughness due to hydrogen is known but not a practical limitation for the piping conditions and thicknesses typically encountered in refining
- We (oil company materials specialists) appreciate being aware of materials issues related to new hydrogen infrastructure