CORROSION AND CRACKING IN RECOVERY BOILERS

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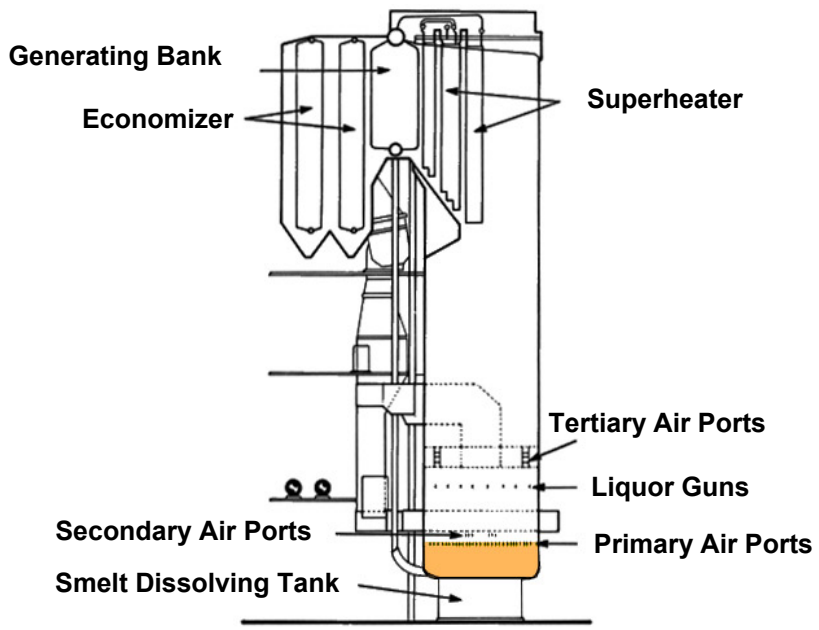
INTRODUCTION

- Different sets of chemical, mechanical and thermal parameters in different parts of an RB cause many different forms of corrosion and cracking
- Understanding their causes can help us
  - implement proven strategies to control corrosion
  - reduce risks of cracking failures

OUTLINE

- Introduction
- Lower furnace:
  - floor tubes and lower furnace tubes
  - air ports
  - molten smelt environments
- Upper furnace and furnace screen
- Superheater
- Generating bank
- Economizer, precipitator and stack
- Waterside



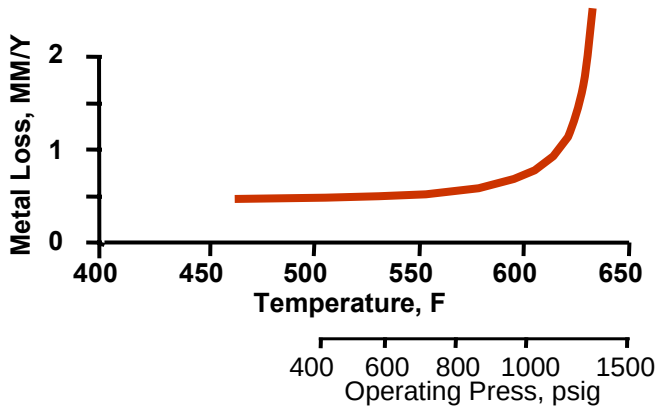
OUTLINE

- Lower furnace:
  - floor tubes and lower furnace tubes
    - cracking in composite floor tubes
  - air ports
    - cracking in wall tubes at smelt spouts and airports
  - molten smelt environments
- Upper furnace and furnace screen
- Superheater
  - cracking in generating bank tubes and in pendant tubes at restraints
- Generating bank
  - caustic cracking in boiler drums
- Economizer, precipitator and stack
- Waterside
  - stress-assisted waterside corrosion

FLOOR TUBES AND LOWER WATERWALL TUBES (1)

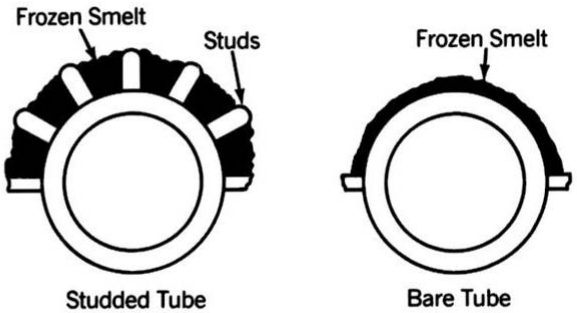
- Most smelt-water explosions occur here
- Reducing gas environment contains
  - insufficient O_2 to form Fe_2O_3 on CS tubes
  - sufficient TRS to stabilize FeS

FLOOR TUBES AND LOWER WATERWALL TUBES (2)



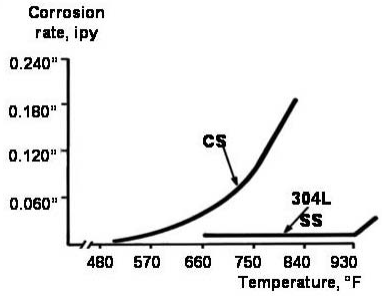
Boilers operating at > about 900 psi produce unacceptably high corrosion rates on CS

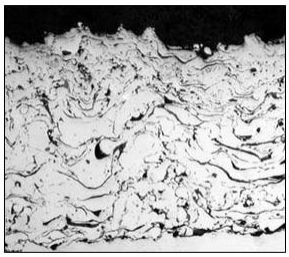
TO REDUCE CORROSION RATES OF CARBON STEEL TUBES (1)



Reduce tube surface temperatures by anchoring an insulating frozen smelt layer with studs

TO REDUCE CORROSION RATES OF CARBON STEEL TUBES (2)



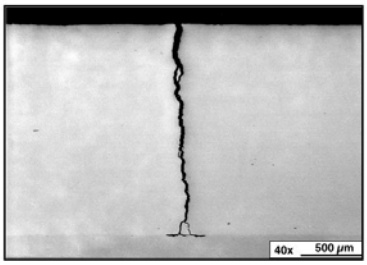


Form more protective surface oxides by alloying with Cr

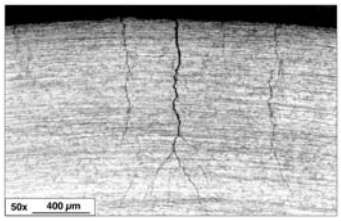
- Composite tubes
- Thermal spray coatings
- Chromizing

FIRESIDE CRACKING IN COMPOSITE TUBES (1)

- **Cracking of composite tubes not normally found without cracking in**
  - **composite spout opening tubes**
  - **composite floor membranes**
- **Sloped floor units tend to crack on**
  - **bent floor tubes**
  - **near spout openings**
- **Fortunately floor tube cracks stop at SS/CS interface**

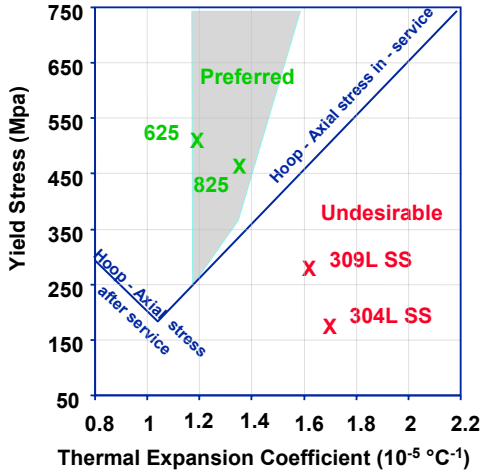


FIRESIDE CRACKING IN COMPOSITE TUBES (2)



- Cracking probably occurs during shutdowns
- SCC occurs in 304SS under tensile stress in conc. $Na_2S.9H_2O$ + NaOH at 320-392ºF (160-200ºC)
- FEA shows local temperature excursions produce tensile stresses that remain after cooling
- FEA shows Alloy 825- and Alloy 625- clad tubes develop much lower tensile stresses than 304L SS

FIRESIDE CRACKING IN COMPOSITE TUBES (3)



Alloy 825-clad and Alloy 625- clad tubes develop much lower tensile stresses than 304L SS

FIRESIDE CRACKING IN COMPOSITE TUBES (4)

- Do not begin to water wash till floor tube temperatures fall below 160ºC (320°F)
- Clean all smelt from floor tubes before firing boiler
- Replace cracked floor tubes with 825- or 625- clad tubes
- Consider eliminating floor temperature spikes by installing packed refractory or interlocking tiles

PORT TUBES (1)

- Carbon steel tubes:
  - Furnace side thinning caused by exotherm
  - Windbox side thinning in air port "corners"
  - Molten NaOH condenses on cool tubes in absence of CO_2
  - NaOH fluxes Fe_3O_4, produces $NaFeO_2$
- Eliminate stagnant areas by
  - Maintaining refractory packing
  - Avoid high-Cr refractories because
  - NaOH dissolves Cr_2O_3 as $NaCrO_4$

PORT TUBES (2)

- Composite tubes:
- Furnace side wastage caused by exotherm
- NaOH fluxes otherwise protective Cr_2O_3
- Corrosion faster on SS (0.01 - 0.05" per year) than on exposed CS (0.03 - 0.08" per year)
- Produces expanding but not deepening "bald spots"

PORT TUBES (3)

Inhibit "balding" of composite air port tubes by maintaining refractory packing to eliminate stagnant air pockets

Repair bald patches by pad welding with Alloy 625

CRACKING IN COMPOSITE AIR PORT TUBES (1)

CRACKING IN COMPOSITE AIR PORT TUBES (2)

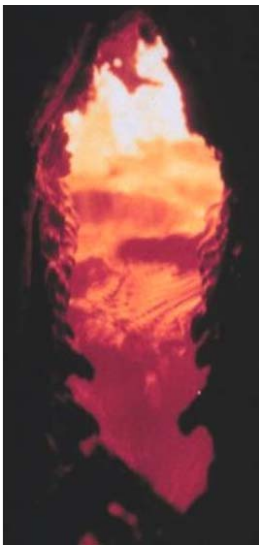
- Thermal fatigue cracking in CS and SS
  - tubes that form primary air ports
  - several tubes on either side of spout openings
  - cracks can penetrate carbon steel inner layer
- Temperature cycles
  - when insulating frozen smelt removed by rodding
  - when molten smelt washes against tubes
- Cracking aggravated by residual tensile stresses
  - from forming of tube bends
  - from attachment welds

CRACKING IN COMPOSITE AIR PORT TUBES (3)

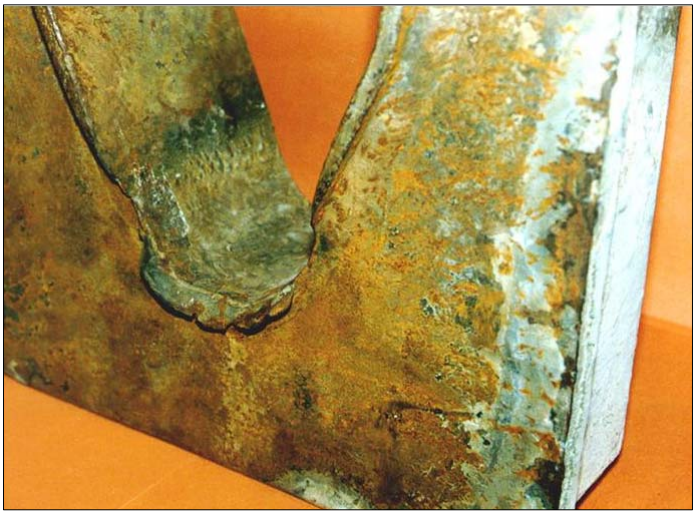
- Maintenance:
  - Improve firing practices to minimize thermal spikes
  - Replace cracked 304L-clad tubes with Alloy 825-clad or Alloy 625-clad composite tubes

MOLTEN SMELT (1)

- Molten smelt delivers high heat flux, especially when flowing
  - thin insulating frozen smelt layer on tubes
  - dissolves or erodes protective corrosion products
- Rates up to 50” per year on CS if metal is as hot as smelt



MOLTEN SMELT (2)



Smelt line corrosion

MOLTEN SMELT (3)

- Water-cool spouts to stabilize frozen smelt layer
  - Lowering cooling water temperature 40°F can increase spout life x 4
- Use stainless spout materials for greater corrosion resistance

CRACKING CAUSED BY MOLTEN SMELT

- Rodding causes sudden heating that can produce thermal fatigue cracks
- Smelt washing causes similar thermal cycles
- Inspect at smelt line
- Attachment welds (heat sinks) on fireside of composite tubes initiate cracks because of differential thermal expansion

UPPER WATERWALLS, ROOF AND FURNACE SCREEN (1)

- Radiant heat flux lower, pO_2 higher than in lower furnace
- Protective oxides stabilized
- CS tubes OK because corrosion rates 2-3 x lower than in lower furnace

UPPER WATERWALLS, ROOF AND FURNACE SCREEN (2)

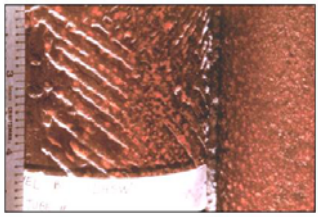
Potential problems:

- **Cold-side pitting on tangent tubes**
  - **Minimize time of wetness of cold side tube deposits (0.001" per day)**

UPPER WATERWALLS, ROOF AND FURNACE SCREEN (3)

Potential problems:

- **Low m.p. $NaHSO_4$ deposits (cool beds, high SO_X) flux off otherwise protective oxides, cause pitting**
  - **Improve operational control**
- **Locally reducing environments under partly-burned liquor particles cause corrosion similar to lower furnace corrosion**
  - **Reduce excessive load**

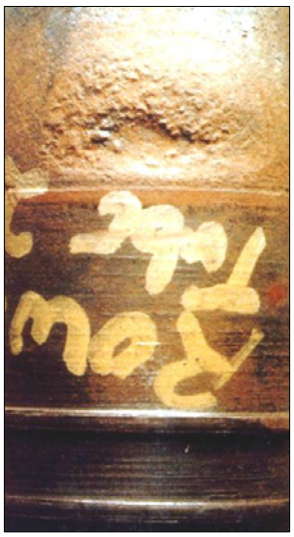


GENERATING BANK (1)

- Environment relatively cool and oxidizing
  - Corrosion rates generally low (~ 0.001" per year)
  - CS tubes designed with low or non-existent corrosion allowance
- Potential problems: Sootblower erosion, when steam contains water droplets, especially near boiler walls
  - Use IRIS or eddy current to detect thinning
  - Add condensate traps

GENERATING BANK (2)

- Potential problem "Near-drum thinning" <0.5" from drum surface. Elliptical depressions where sootblowers blow dust from drum surface against tubes, scouring off oxide
  - Use IRIS or eddy current to detect thinning
  - Use shields to limit thinning



GENERATING BANK (3)

Potential problems:

- **Low m.p. $NaHSO_4$ deposits (cool beds, high SOx) flux off otherwise protective oxides, cause pitting**
  - **Improve operational control**

CAUSTIC STRESS-CORROSION CRACKING IN BOILER DRUMS

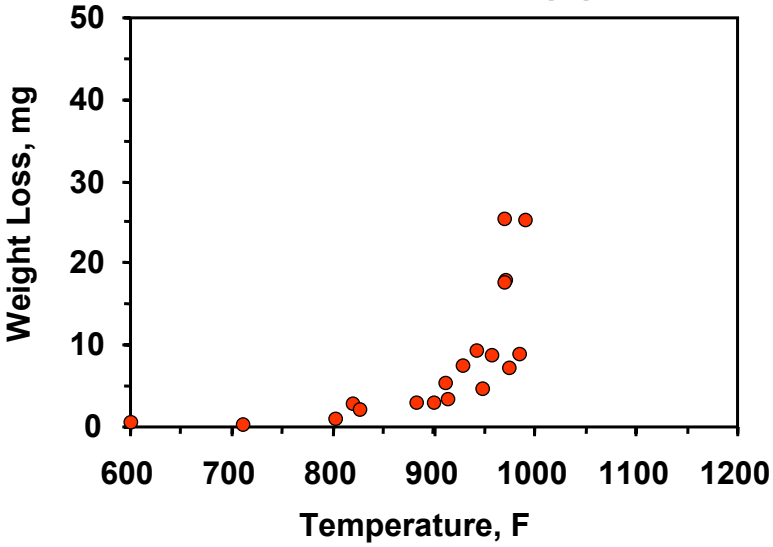
- **Caustic SCC ("caustic embrittlement") occurs in CS if tensile stress, > 5% NaOH, > 300ºF**
- **Water leaks from tube seals flash, concentrate water treatment chemicals at drum surface**
- **Drum hole surfaces in tensile stress from rolling stresses and operating stresses**
- **Can produce hole-to-hole stress-corrosion cracks in drum, especially if high-strength steel**
- **Re-rolling and seal welding often causes more problems**

SUPERHEATER (1)

Highest surface temps: strongly oxidizing conditions

- Case 1: Surface Deposits Frozen
  - CS tubes corr. rate OK to 750ºF (400°C): $Fe3O_4$
  - Add Cr for higher temperatures: $(Cr,Fe)_3O_4$
  - Stabilized γ SS for highest temps: Cr_2O_3
- Some use composite (310/SS) tubes because of concerns about
  - Waterside SCC
  - Windward surfaces sulfidized by unburned liquor particles

SUPERHEATER (2)



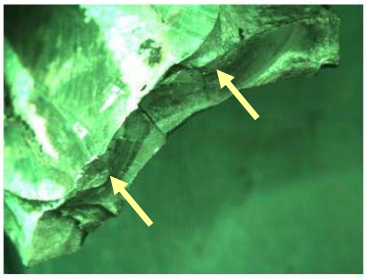
SUPERHEATER (3)

- Case 2: Surface Deposits Molten
- Existing alloys have unacceptably short life
- Beware of partial pluggage (unbalanced gas flow) that could heat deposits above their m.p.
- Corrosion rate x 4 in 5°F temperature increase at deposit m.p.
- High Cl, high K, high Na/S ratio, low bed temp all depress m.p. of deposits
  - Avoid these conditions
  - Remove deposits regularly with sootblowers

GEN. BANK, PENDANT TUBE CRACKING AT RESTRAINTS (1)

- Fireside fatigue cracks initiate at nodes, e.g.
  - where vibration bar clamps restrain pendant tubes at toe of welds attaching adjacent pendant tubes
  - where a generating bank tube passes into a drum
  - where an economizer tube is welded into a header
- Cracks often appear as pairs on either side of a tube in the plane of vibration
  - propagate toward tube center, largely unaffected by corrosion processes
- Minor leaks can thin large areas on adjacent tubes and produce fish-mouth ruptures

GEN. BANK, PENDANT TUBE CRACKING AT RESTRAINTS (2)

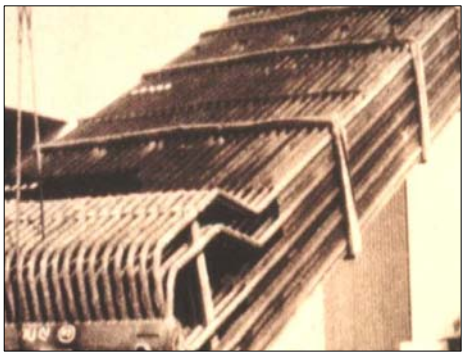


GEN. BANK, PENDANT TUBE CRACKING AT RESTRAINTS (3)

- Vibration bars problematic in generating bank unless drum-to-drum distance exceeds 31’
- Where vibration bars are required, make them from Type 304L stainless steel
- Sootblowing (particularly with high energy nozzles) makes pendant tubes swing and causes high amplitude vibration. Both promote fatigue corrosion
  - Evaluate sootblowing; avoid excess
  - Inspect attachment welds for sharp corners or profile and thinning caused by rubbing.

ECONOMIZER, PRECIPITATOR AND STACK (1)

- Flue gases oxidizing and cool; corrosion damage rare
- Some units suffer sootblower erosion, external fatigue cracking, dew point corrosion



ECONOMIZER, PRECIPITATOR AND STACK (2)

- Below water dew point (155-170°F; 68-77°C)
  - moisture condenses
  - acid flue gases dissolve
  - pH falls (3.0 - 2.5)
  - CS corrodes at up to 0.030 ipy.
- Find cold spots with IR thermography

ECONOMIZER, PRECIPITATOR AND STACK (3)

- Insulate and/or heat shell
  - more cost-effective than higher exit gas temp.
- Where condensation is unavoidable (e.g. wet-bottom precipitator liquor line), use polymer coatings or SS

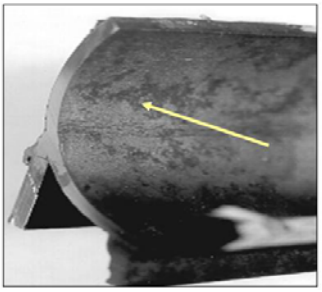
WATERSIDE CORROSION (1)

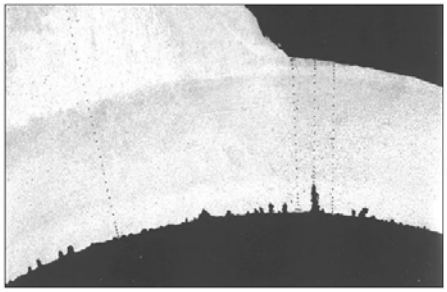
- Most waterside damage is caused by inadequate feed water quality or improper chemical cleaning
  - Both need careful monitoring
- Thick deposits inhibit heat transfer, raise tube temperatures, thin even composite tubes
- Measure deposit thickness on tubes that experience high heat transfer (near burners, at smelt line) to determine how and when to chemically clean

WATERSIDE CORROSION (2)

- Localized deposits cause “oxygen pitting” where under-deposit environment is starved of oxygen
- High NaOH resulting from local boiling or waterline evaporation produces localized “caustic gouging” with smooth contour
- Foreign body tube blockage causes rapid corrosion/rupture where cooling is lost

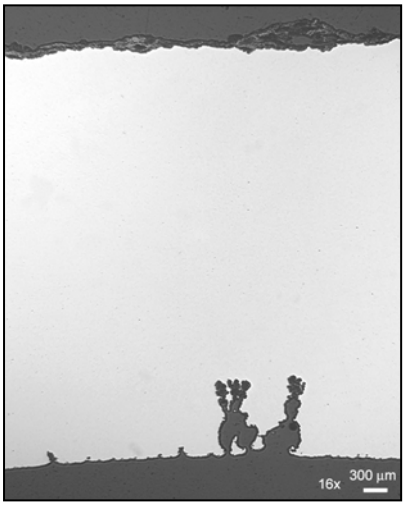
WATERSIDE STRESS-ASSISTED CORROSION (1)





- Slow-growing waterside fissures “under” external attachment welds
- Despite mfr. cautions, mills did not inspect until Missoula explosion (1991). First inspections found 80% of RBs >12 years old contained SAC. Many replaced CS lower furnace tubes

WATERSIDE STRESS-ASSISTED CORROSION (2)



- Common features of SAC fissures
  - all same depth
  - bulbous x-section

WATERSIDE STRESS-ASSISTED CORROSION (3)

- Recent research has shown
  - SAC occurs during low pH, high O_2 water quality upsets where waterside oxide is fractured by tensile thermal stresses
  - Heating to operating temperature produces waterside tensile residual stresses within ~1" of attachment welds
  - SAC has little effect on burst strength
- Most vulnerable are heavy attachment welds at floor-to-sidewall seals, windboxes, smelt spouts
  - Detect SAC and estimate its severity with specialized RT techniques

AVOIDING STRESS-ASSISTED WATERSIDE CORROSION

- Minimize SAC by avoiding feed water quality excursions
- Monitor chemical cleaning, consider chelant
- In new boilers, make attachments to membranes, avoid large, strong attachments
- In deaerators, avoid water hammer
  - Inspect welds at and below the water line
  - Check design calculations and weld quality in new vessels and stress relieve

CONCLUSION

- Use well-planned inspection programs to identify corrosion and cracking problems
- Implement strategies to reduce corrosion and inhibit cracking based on the underlying causes of each problem