March 2017 WTUI Conference

March 21 Aero HRSG Users O&M

HRSG Evaporators

Presented by: Ned Congdon, P.E.

PLEASE

NO Video or Photography Allowed.

Presentations available at www.WTUI.com/forums

Introduction & HRST Background

- **HRST CEO: Victor Ferris, P.E.**
- **Founded in 1998 by Robert Krowech, P.E. (CEO Emeritus)**
  - Robert Krowech: 25-year Technical Engineering Manager with Deltak
- **HRST Staff: 37 experienced boiler engineers and designers, and field technical advisors**
- **Offices in Minnesota, Florida, Maine, Texas and California**
  - Headquarters in Eden Prairie, MN (near Minneapolis)
- **Rep office in Vietnam**
- **HRST Mission Statement:**
  - ***"HRST, Inc. strives to be the world's most trusted supplier of HRSG and boiler related technical services and products."***

Introduction & HRST Background

HRST Focus:

- **Inspections, Analysis**
- **Problem investigations and root cause failure analysis**
- **Equipment Design, Component upgrades and retrofits**
- **Technical advisor service**
  - **HRSG repairs**
  - **Coil replacement (coils by others or by HRST)**
  - **Tube bank cleaning**
  - **Steam Turbine repairs**
- **Training**

Training – HRST Academy

Classroom instruction remains grounded in reality when abstract concepts are discussed

Training – HRST Academy

Master BBQ Iron Chef
Bob Krowech

Riverboat Gambling

Upcoming Academy

- June 13-15, 2017 – Glen Allen, Virginia (register at www.hrstinc.com)

HRSG Outage Inspection and Technical A

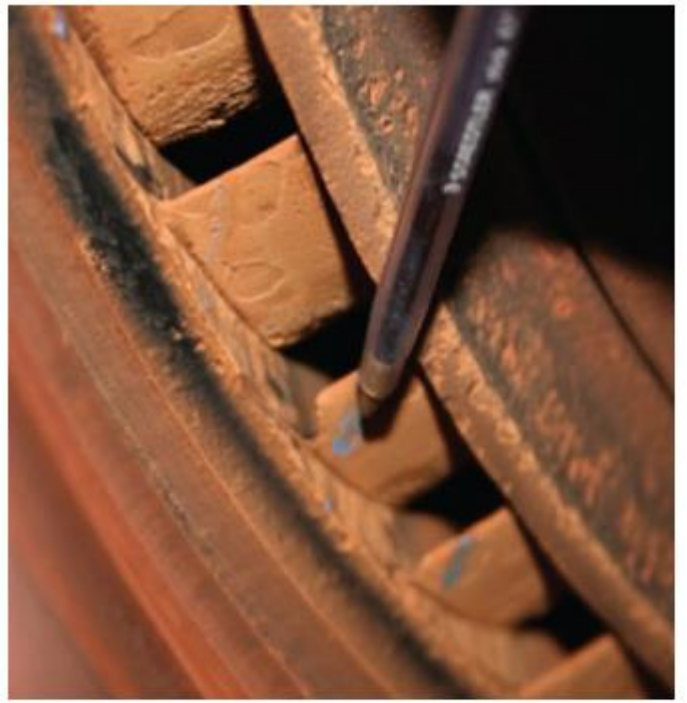
Jack Odlum – California office

Steam Tur
The Construction
Turbine Life Cycle

Protect Your Investment
Applied Expertise to Ensure Success

Robust Structure
Planning, Inspection & Qualification

A Solid Foundation
Inspection Finding RCA Support



Diaphragm nozzle trailing edge failure
Primary driver:
Vibration induced cracking enhanced by erosio
Recommendations:
Nozzle weld repair or replacement of diaphrag

Steam Turbine Inspection and Repair TA

- Root Cause Analysis -

temperatures inside the HRSG dropped below freezing, see Figure #1. Water trapped in tube panels by the frozen drains then froze. The trapped water would first freeze in the finned tube area, and work its way downward, increasing pressure in the water trapped in the lower header and tubes, ultimately yielding tubes (swelling) until a tube burst, relieving pressure.

RECOMMENDATIONS

1. Drain the HRSG while still warm, and under some pressure, prior to dry lay-up during winter weather. Obey the Deltak Operating Instructions, and do not exceed the 50 psi/min drum pressure rate of change, especially at lower pressures.
2. Periodically (~monthly) "blow-down" all drain lines to remove sediment. Perform the "blow-down" off-line, while the under some pressure.

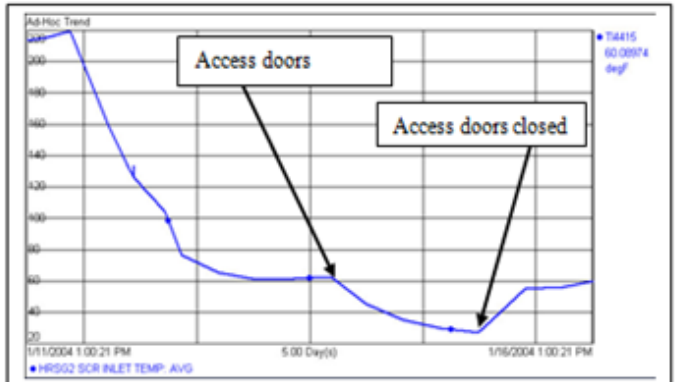
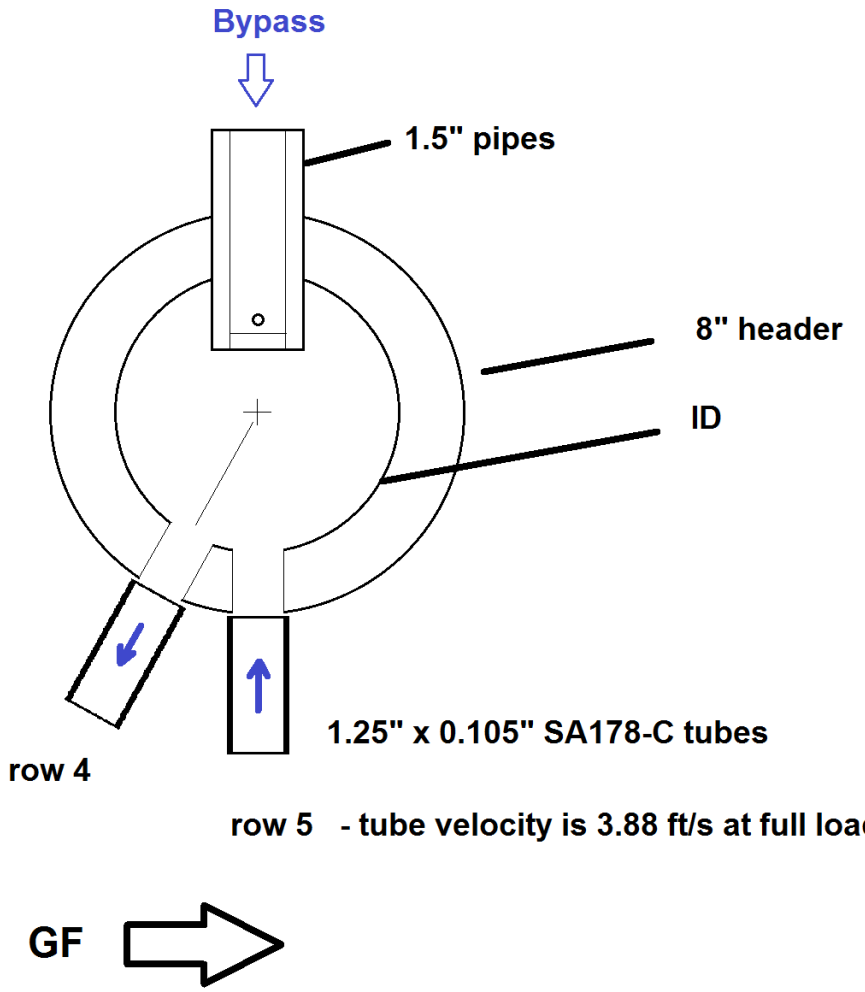
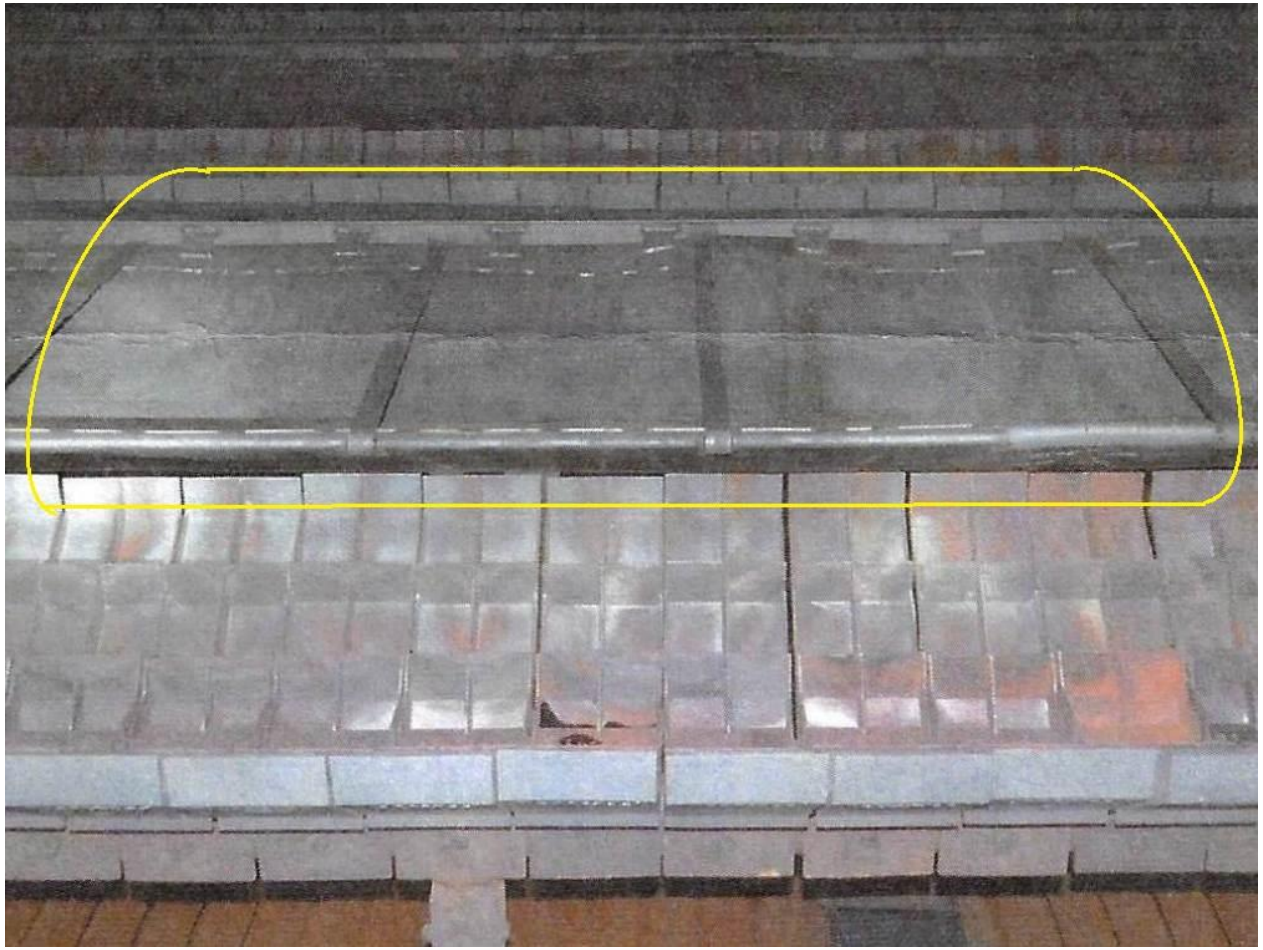


Figure #1 – Temp inside HRSG at SCR Inlet. Temp drops below freezing after access doors were opened for inspection.

3. Consider the installation of permanent freeze protection "heaters" that can be activated in the HRSG lower header crawl space area when the unit is off line in the winter and wet storage is necessary. Based on the good performance of the radiant propane heaters during the repairs this week, a few strategically placed heaters will provide significant protection. HRST has design concepts on how best to accomplish this, which we'd like to offer.



- Upgrade Components -

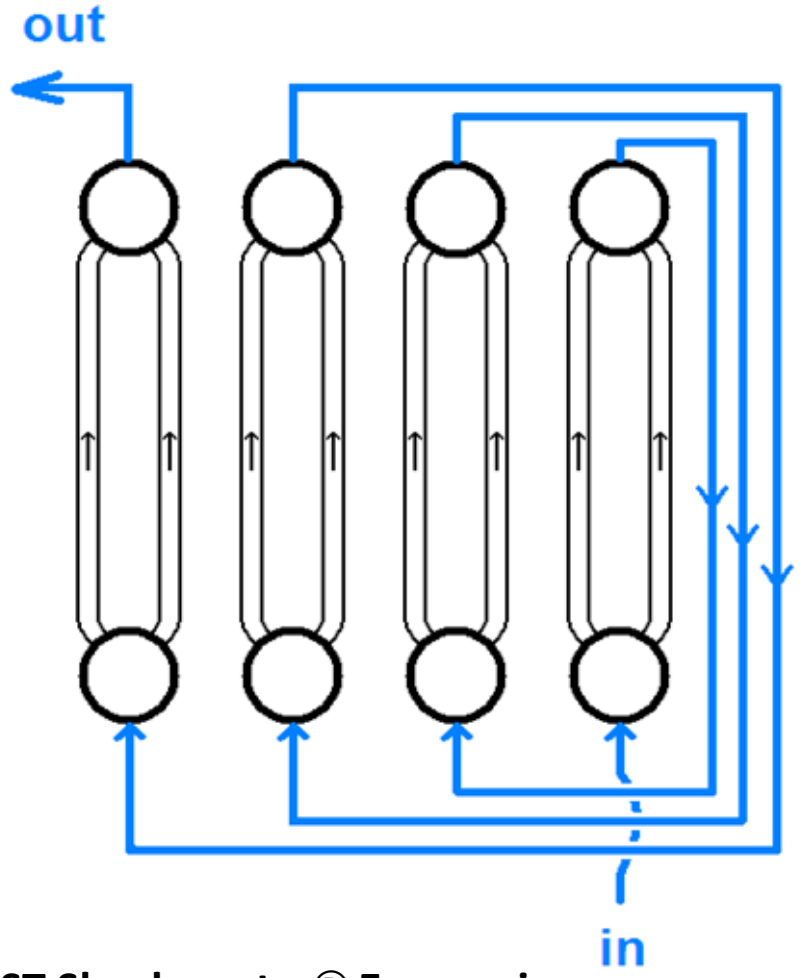


Burner Baffle Reinforcement

6 ft Tall Access Door

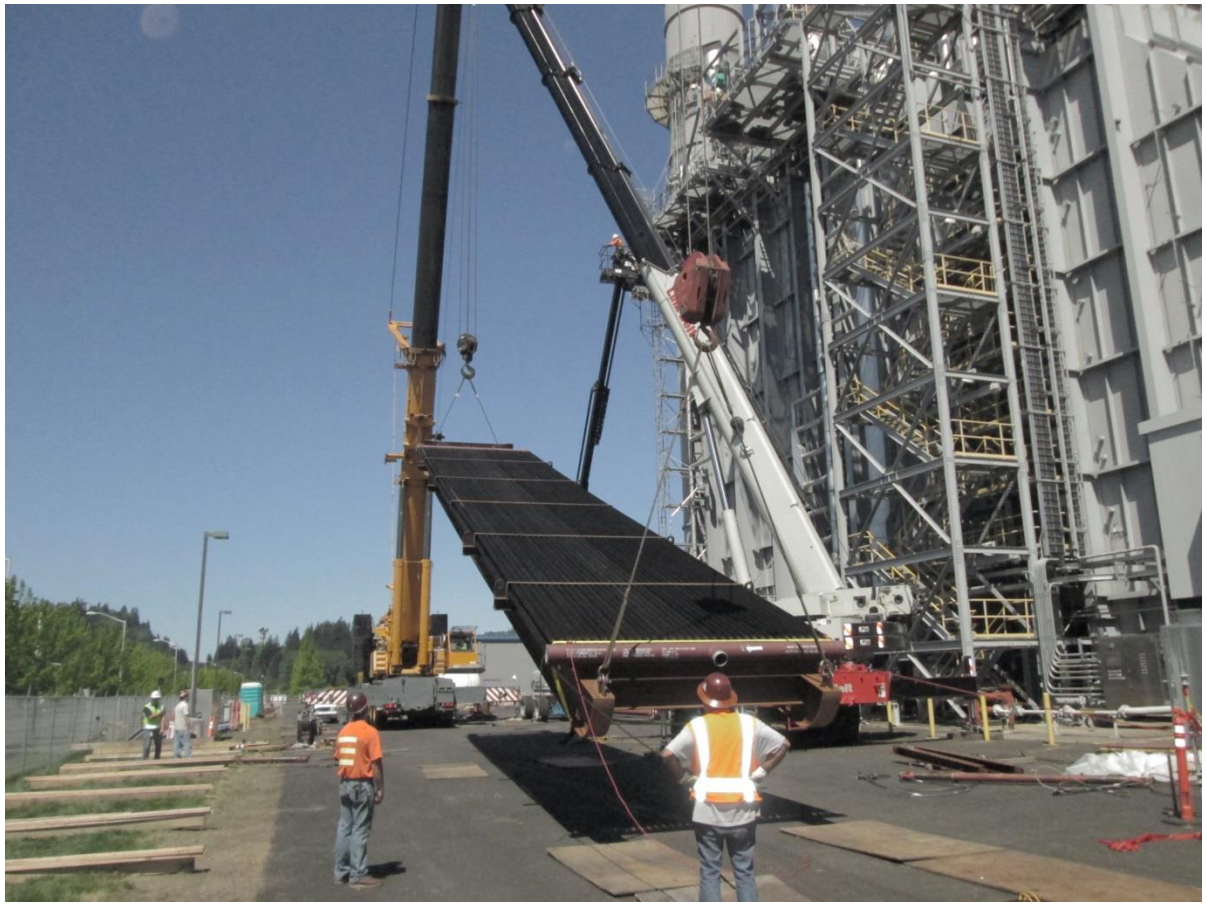
HRST Upgrade Components

Duct Burner Camera for Control Room Viewing



HRST Shockmaster® Economizer – License

HRST Upgrade Components



Replacement HRST Shockmaster® economizer bundle

HRST Shockmaster® Conversion

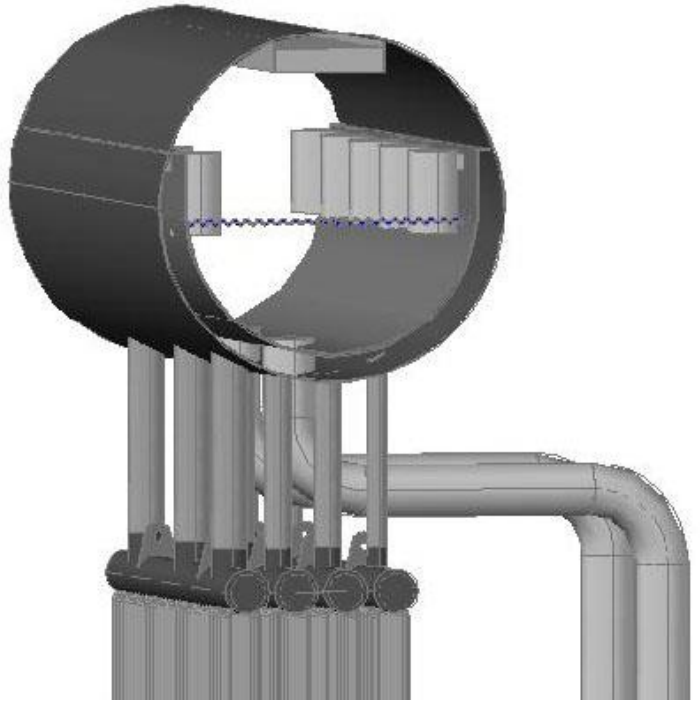
Agenda

- **What is the evaporator**
- **Natural Circulation Evaporators**
  - **How do they work?**
  - **What is the purpose of the drum?**
  - **Common problems**

- **Once-Through Steam Generators (OTSG)**
  - **Advantages and Disadvantages**
  - **Couple of problem illustrations**

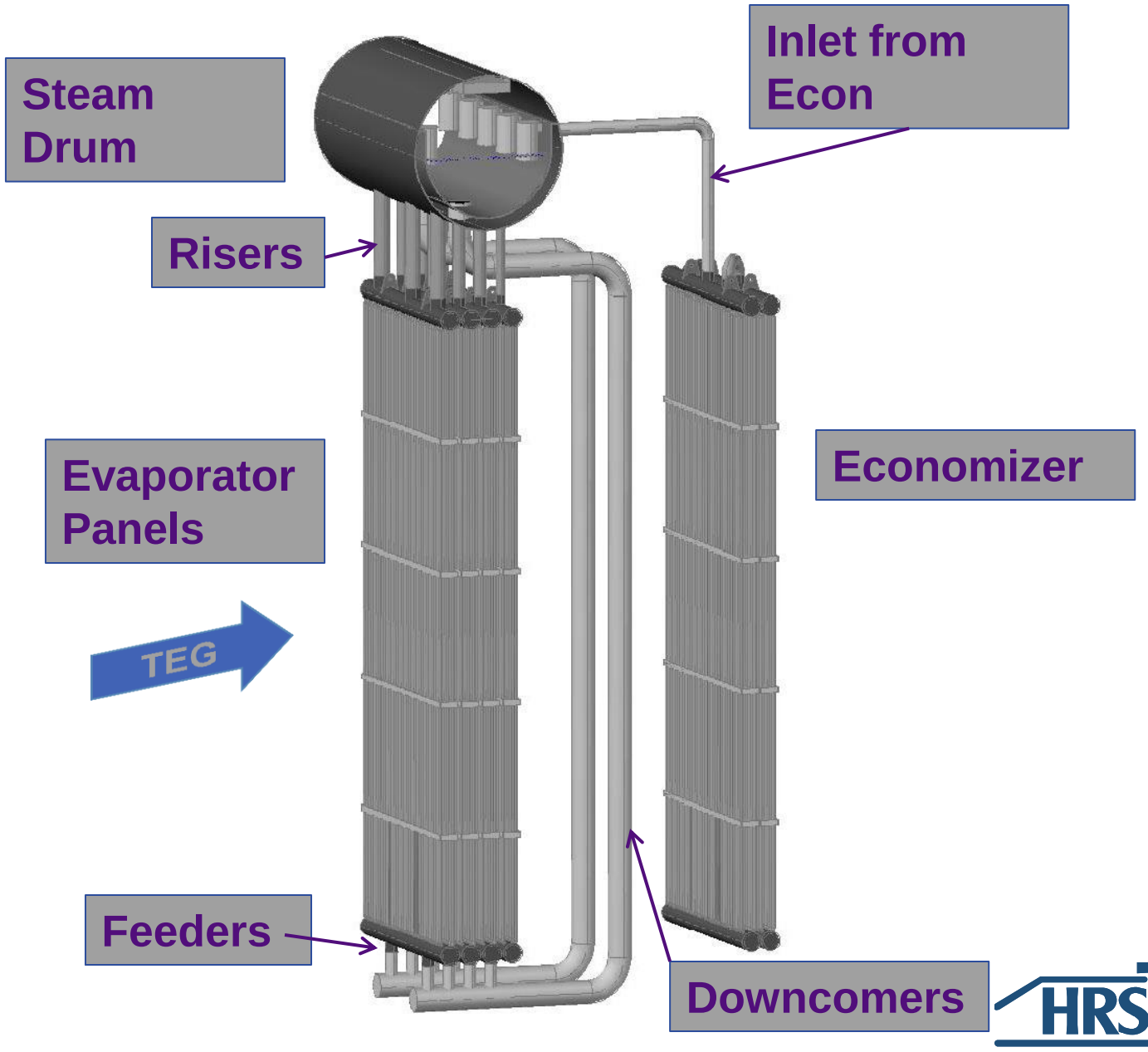
What is the evaporator?

- **Receives sub-cooled water from the economizer**
- **Generates saturated steam**
- **Sends saturated steam to the superheater**



Components

- **Downcomers – Take liquid water from drum to feeders**
- **Feeders distribute water into panels**
- **Evaporator panels convert some of the water to steam**
- **Risers take the steam/water mixture to the drum**
- **Drum separates the steam from the water and sends steam to the superheater and water back to the downcomer**



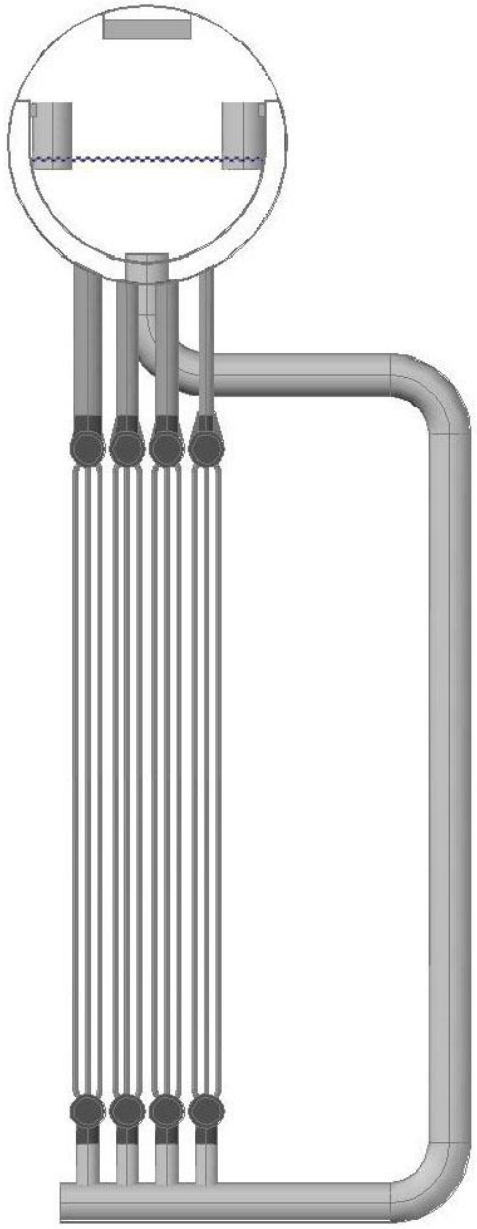
Agenda

- What is the evaporator
- **How does natural circulation work**
- What is the purpose of the drum
  - How does steam separation work
- Common problems

Evaporators

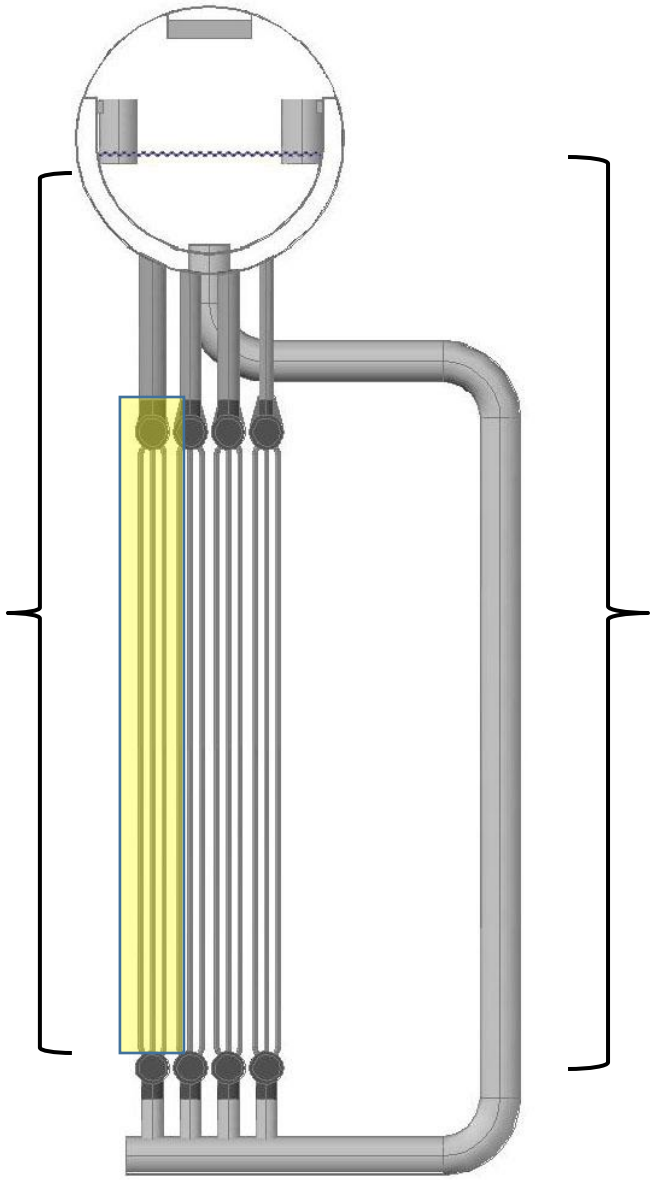
Circulation

- **Circulation is driven by the difference in density between the water in the downcomer and the mixture of saturated steam and water in the tubes and risers.**



Evaporators

Circulation



Average density of mixture = 25 lb/ft³ (400 kg/m³)

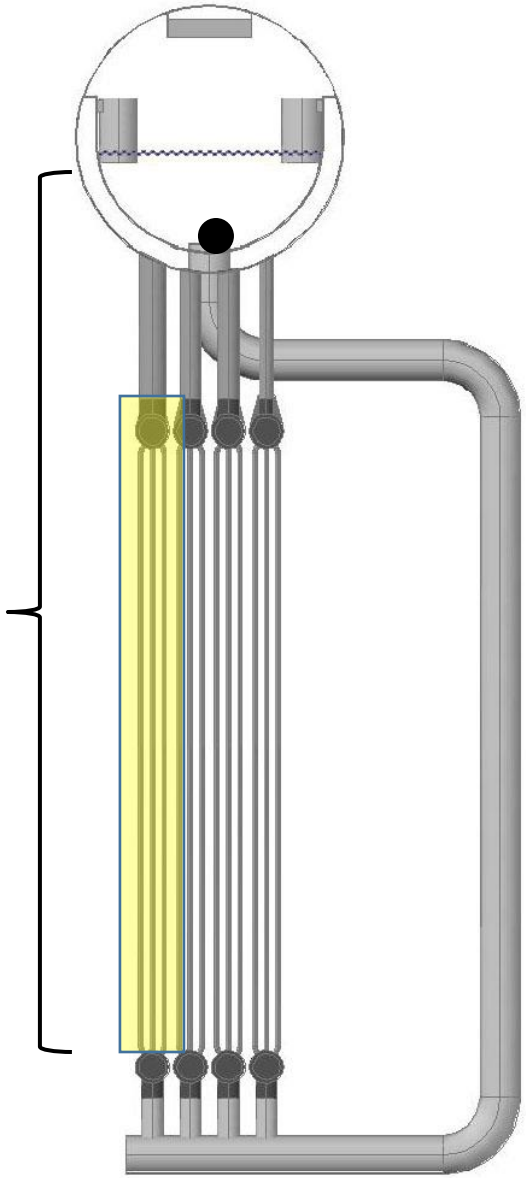
Average density of water = 58 lb/ft³ (929 kg/m³)

- **With a height of 70 feet (21 m), the difference in density creates a pressure head of ~16 psi (1.1 bar)**

Evaporators

Circulation

- **With a height of 70 feet (21 m), the difference in density creates a pressure head of ~16 psi (1.1 bar)**



- **Minimum Ratios vary by pressure level**
  - HP systems typically 4-8
  - IP or LP systems are typically 15-30
- **Low pressure steam bubbles are bigger and need more water to maintain good flow regimes**

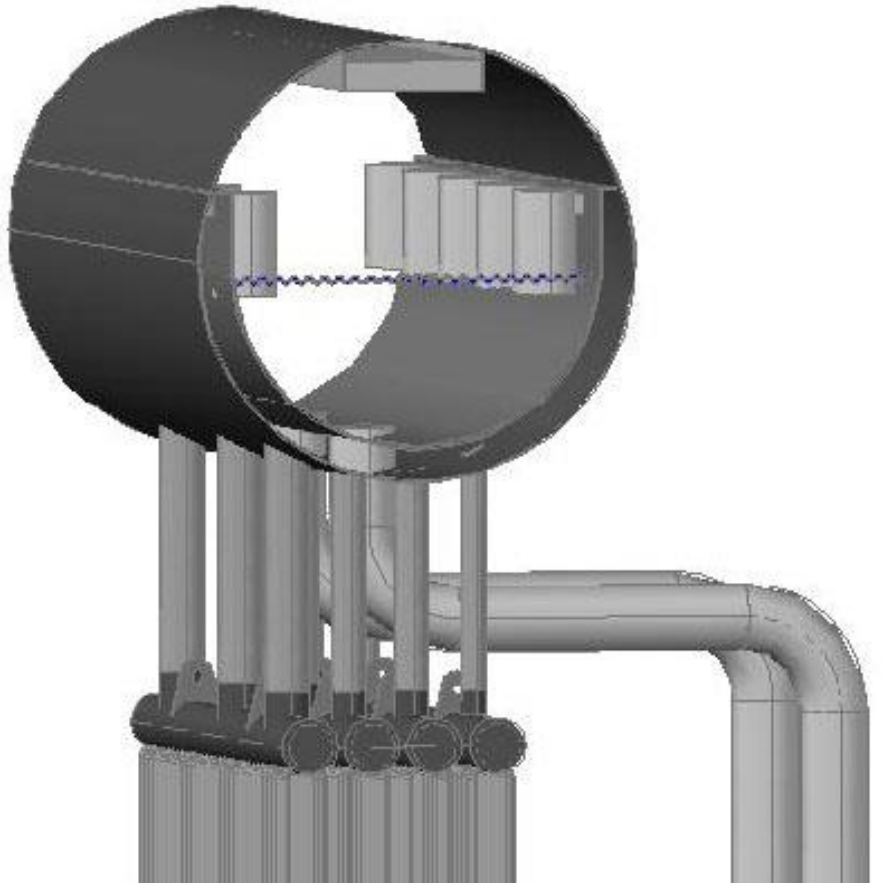
Agenda

- What is the evaporator
- How does natural circulation work
- **What is the purpose of the drum**
- Common problems

What is the purpose of the drum?

1. Retention time
2. Surge capacity
3. Steam separation
4. Chemical injection point
5. Blowdown of dissolved solids

Drum size & internals help accomplish these tasks



Retention Time

- **Time to low water cut out, if feedwater flow stops**
- **Typically 3-5 minutes**
- **Driven by steam production**
  - LP drum often acts as a storage tank for other pressure levels

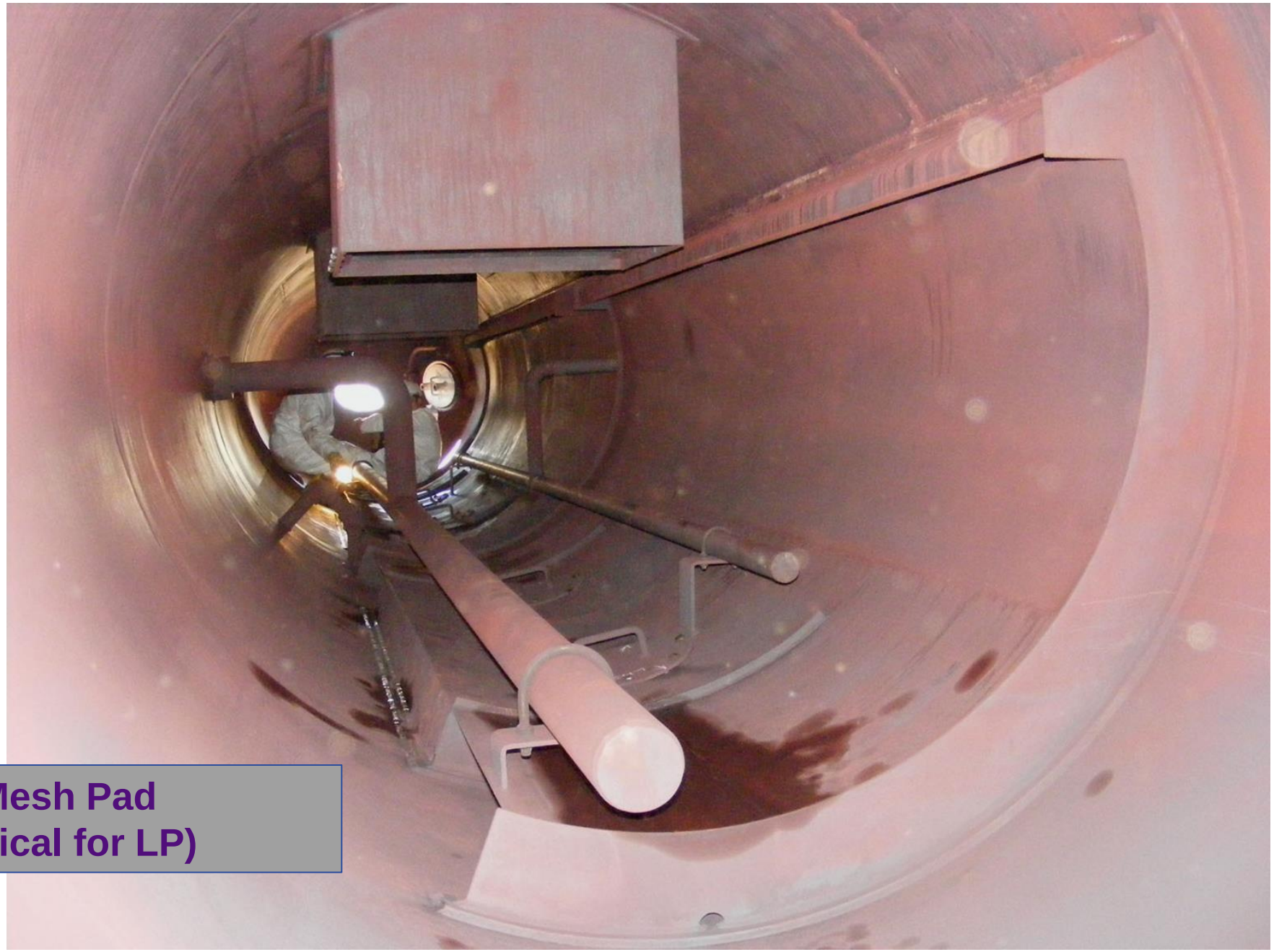
Surge Capacity

- **Steam bubbles form on the tube walls**
- **Natural circulation hasn't yet started**
- **Level in the drum rises from the increase volume of the steam bubbles**
  - drum "swell"

Steam Separation

- **Impurities in the drum can't be carried out in the steam**
- **Can be carried out in water droplets entrained in the steam**
  - Think about a boiling pot of water
  - Will plate out on superheater surfaces or steam turbine

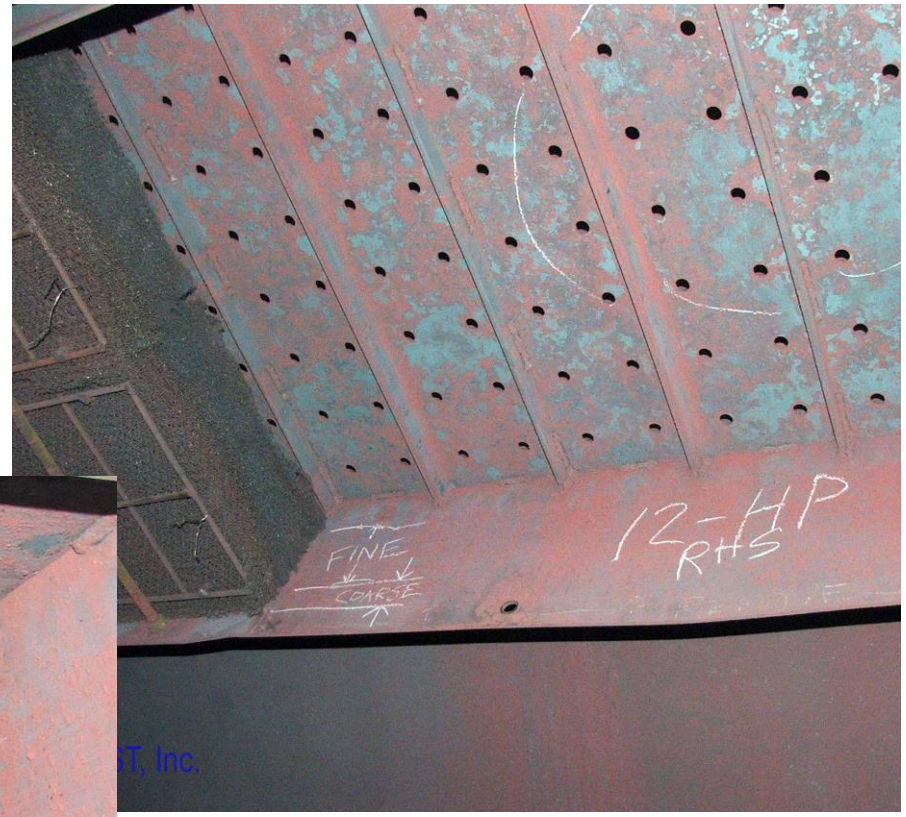
Cyclone and Mesh Pad Arrangement



Baffle Plate and Mesh Pad Arrangement (typical for LP)

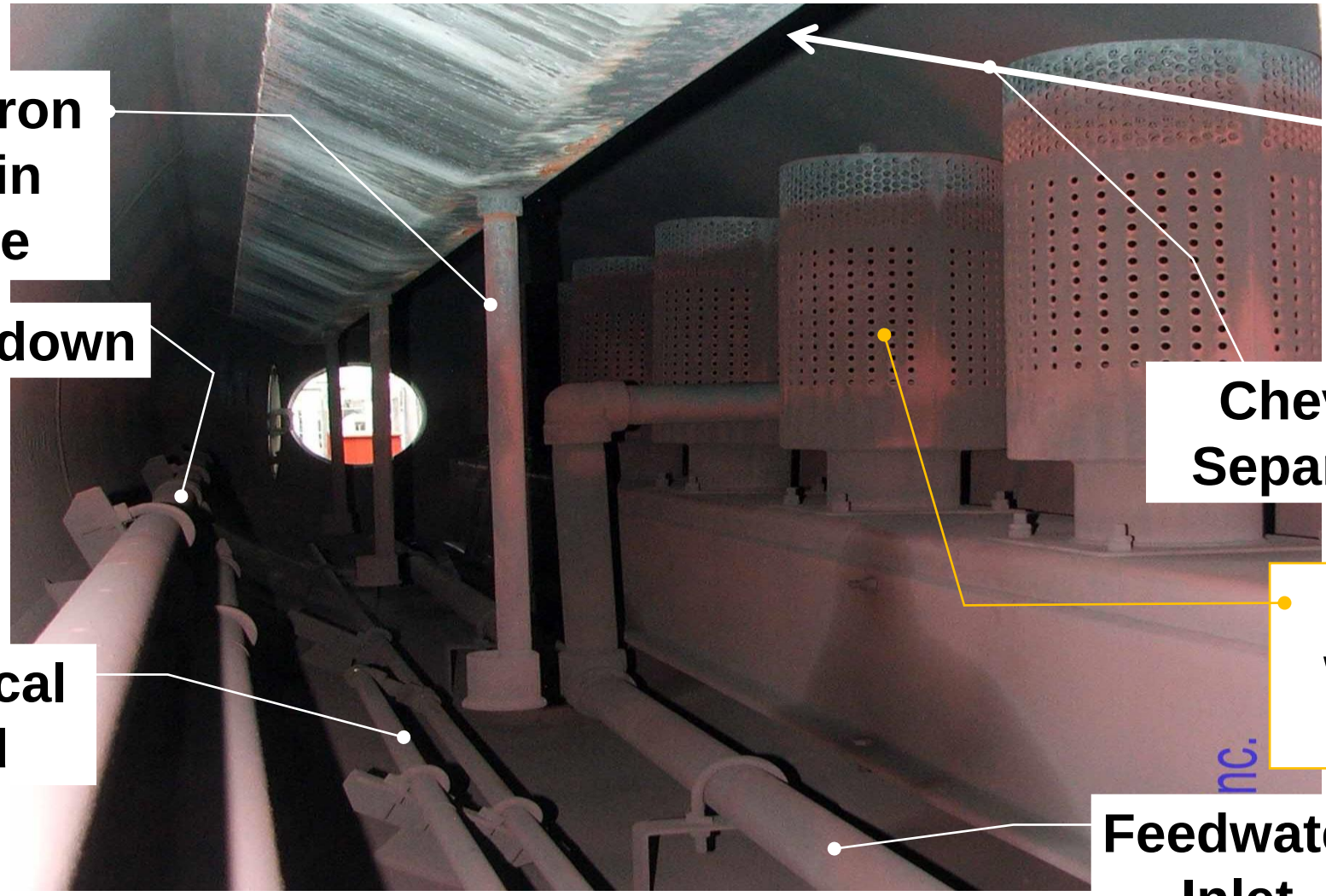
Tortuous path formed by mesh wires

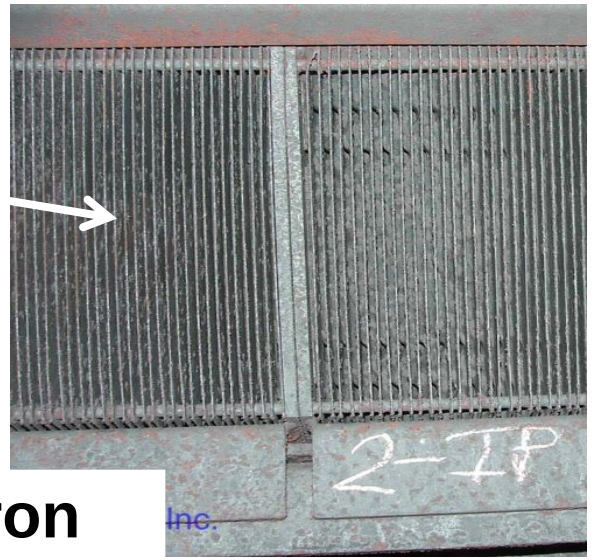
Steam Separator Mesh Pads



Course mesh below fine mesh, perforated plate above mesh

Chevron Final Separator





Chevron Drain Pipe

Blowdown

Chemical Feed

Chevron Separator*

Primary Separator with Agglomerator On Top

Feedwater Inlet

Continuous Blowdown

- **Used to remove dissolved solids from the evaporator**
- **Dissolved solids accumulate in the circulating boiler water due their introduction with feedwater and chemical additives**
- **CBD is a slip stream of water normally drawn from the top of the liquid level in the drum**

Agenda

- What is the evaporator
- How does natural circulation work
- What is the purpose of the drum
- **Common problems**

Common Problems

- Flow Accelerated Corrosion
- Under Deposit Corrosion
- Drum Nozzle Cracks
- Baffle Cracking
- Steam Separation Failures

2011 view of FAC damage before header replacement

FAC in general

- **Major Design (mechanical) Contributors:**
  - Temperature. Damage can occur over a temperature range of approximately 200-500°F (93-260°C), but is most aggressive at 300°F (149°C).
  - Materials. Carbon steel corrosion from FAC is much faster than low-chrome alloys (T11, T22).
  - Fluid impingement or Geometry. Applies to water and water/steam mixtures. Higher velocity or turbulence = faster oxide removal & faster base metal corrosion.

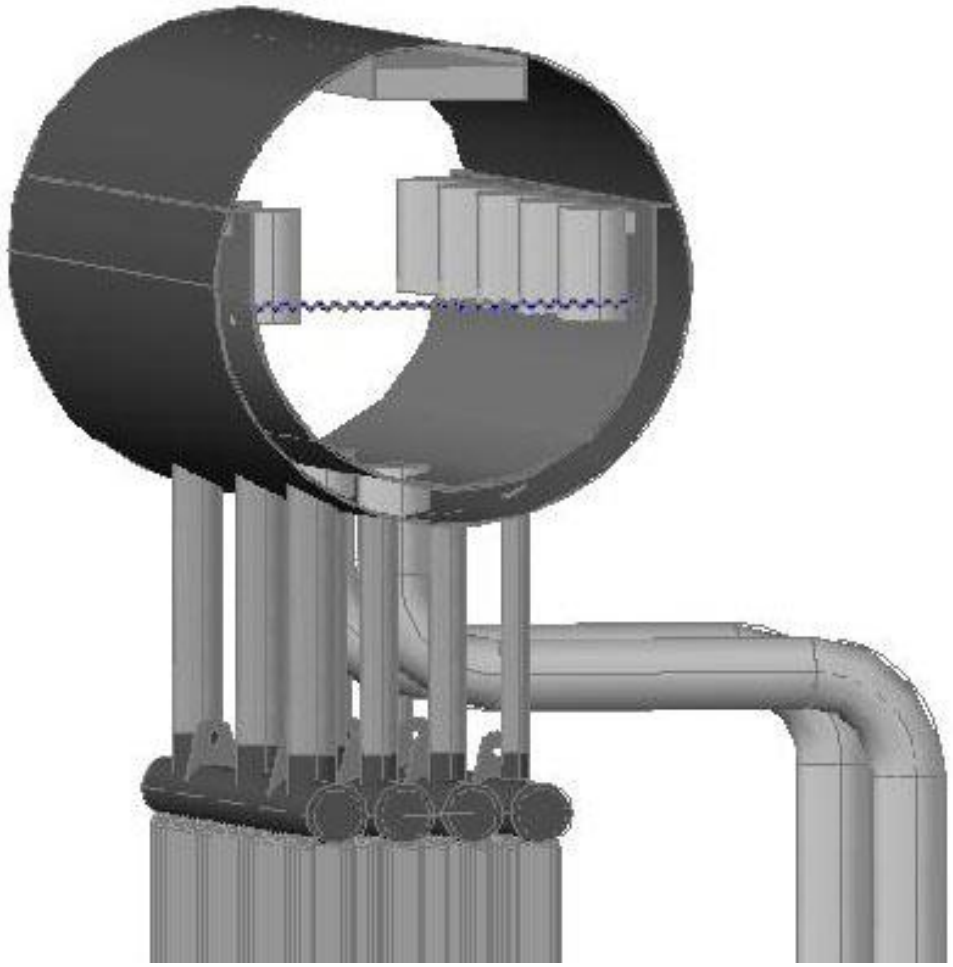
FAC in general

- **Major Water Chemistry Contributors:**
  - pH levels below 9.4
  - Water oxygen levels < 5ppb and/or presence of residual reducing agent**
  - Iron dispersing polymers have been found to increase wear rates in some systems

caution: water systems that contain copper may require zero oxygen and use of scavengers despite elevating risk of FAC

FAC Specific to Evaporators

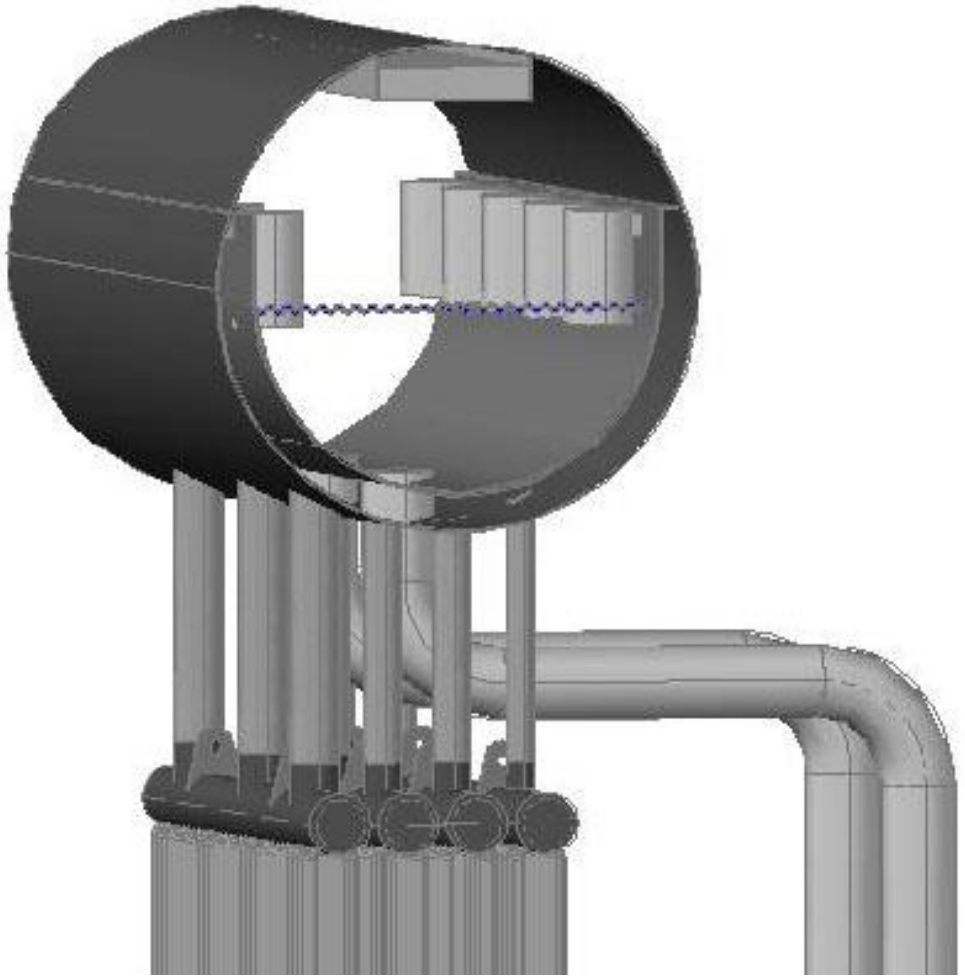
- **Higher velocities in tops of evaporator panels and risers**
- **Damage can be localized**




from wall

All Volatile Chemistry

- **With AVT chemistry, 2 phase flow is more susceptible**
- **Ammonia prefers to be in a gaseous state**
  - The water has a depressed pH
- **Necessary in LP if desuperheater spraywater comes from LP drum**



Under Deposit Corrosion

- **Concentration of chemicals under a deposit**
- **Water seeps through a porous deposit then boils off when it contacts the tube wall**
- **Initiated by dirty boiler tubes and chemical upset or certain chemical conditions**

Under Deposit Corrosion

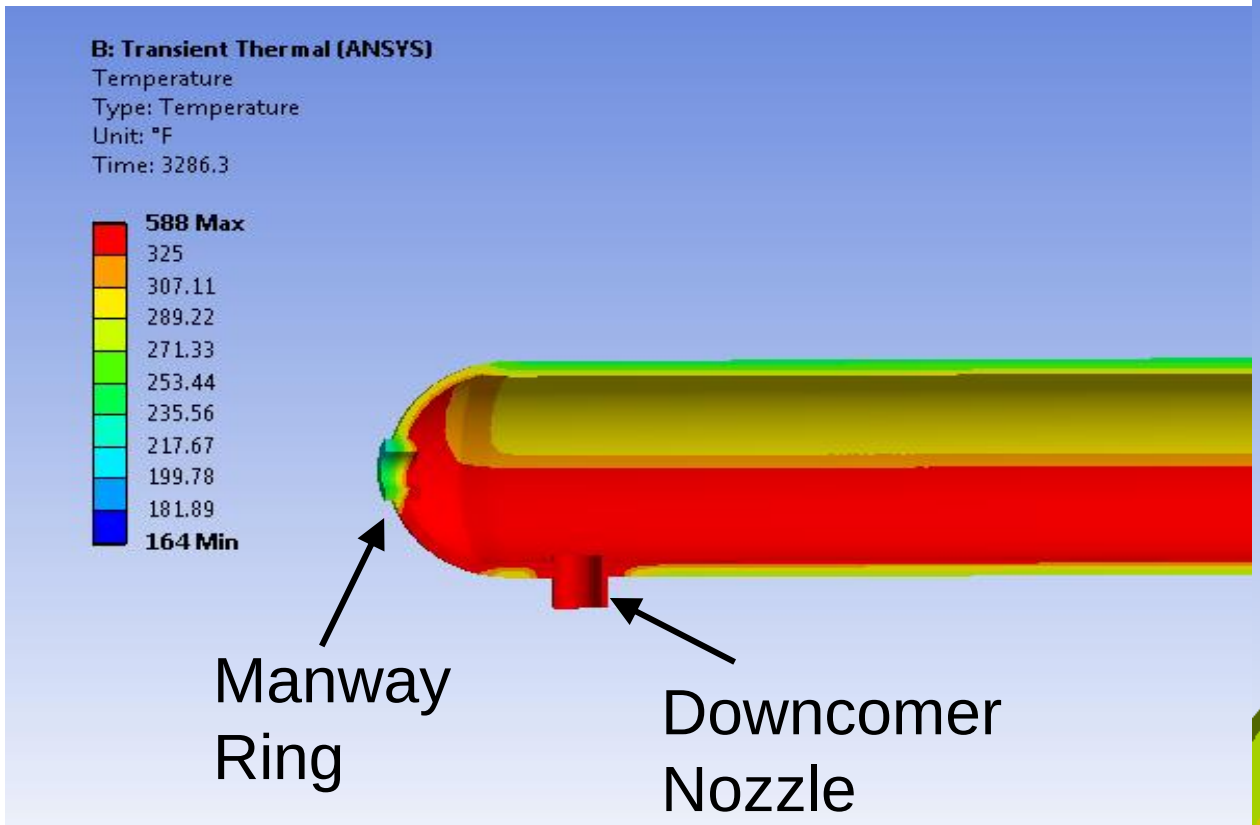
- **Self sustaining**
  - Corrosion results in more deposit material
  - Enlarging deposit escalates concentration of chemicals

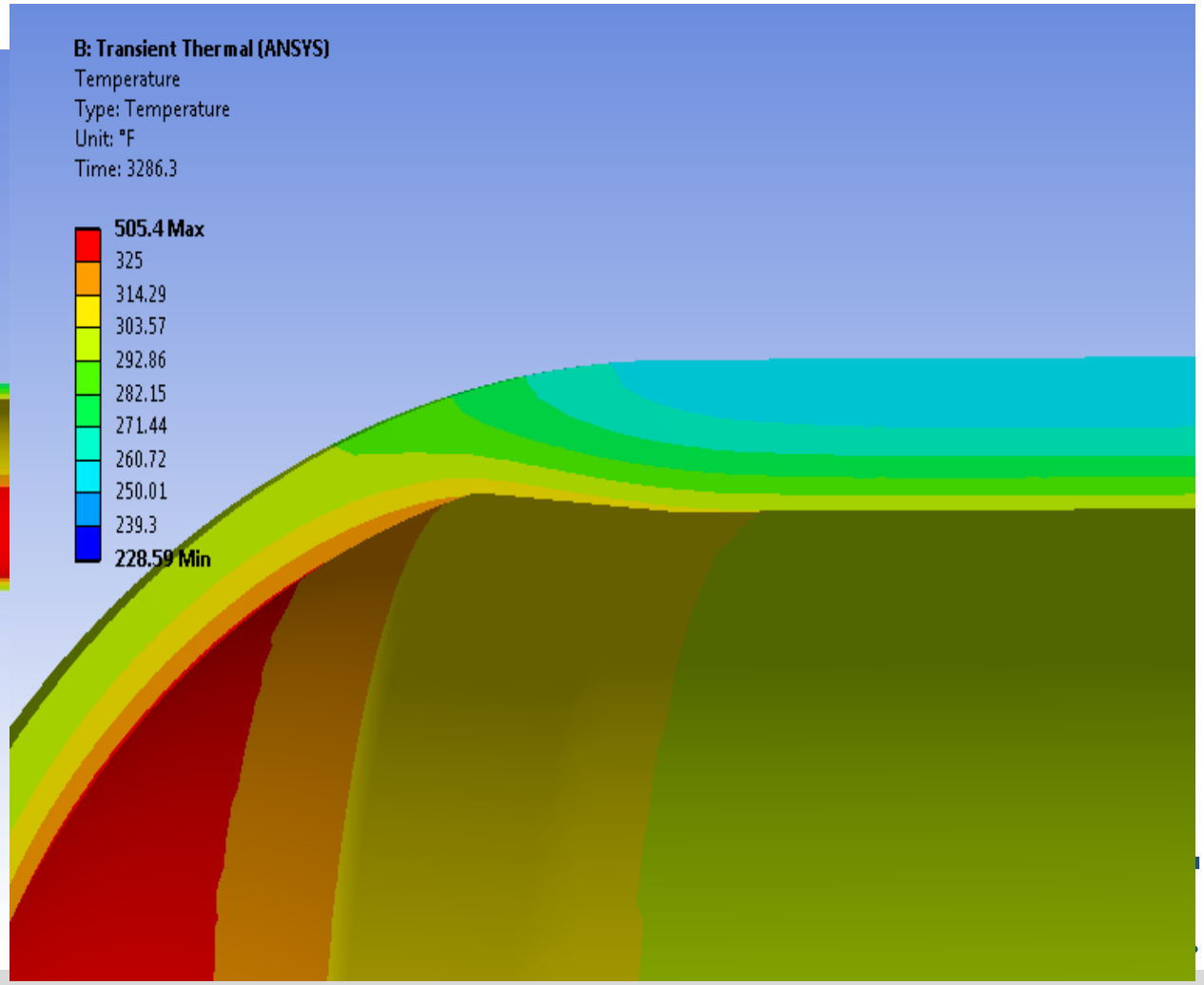
Cycling Evaporators

- **HP Drum Shell Limitations:**
  - Temperature difference limits dependent on drum thickness, material, nozzle & weld details, etc
  - Not “one-size-fits-all”
  - Allowable gradients typically large (>100°F or 56°C), so rapid changes of pressure in small increments may be acceptable for fatigue
  - Limits apply to increasing and decreasing temps

Drum Cycling & Nozzle Stress

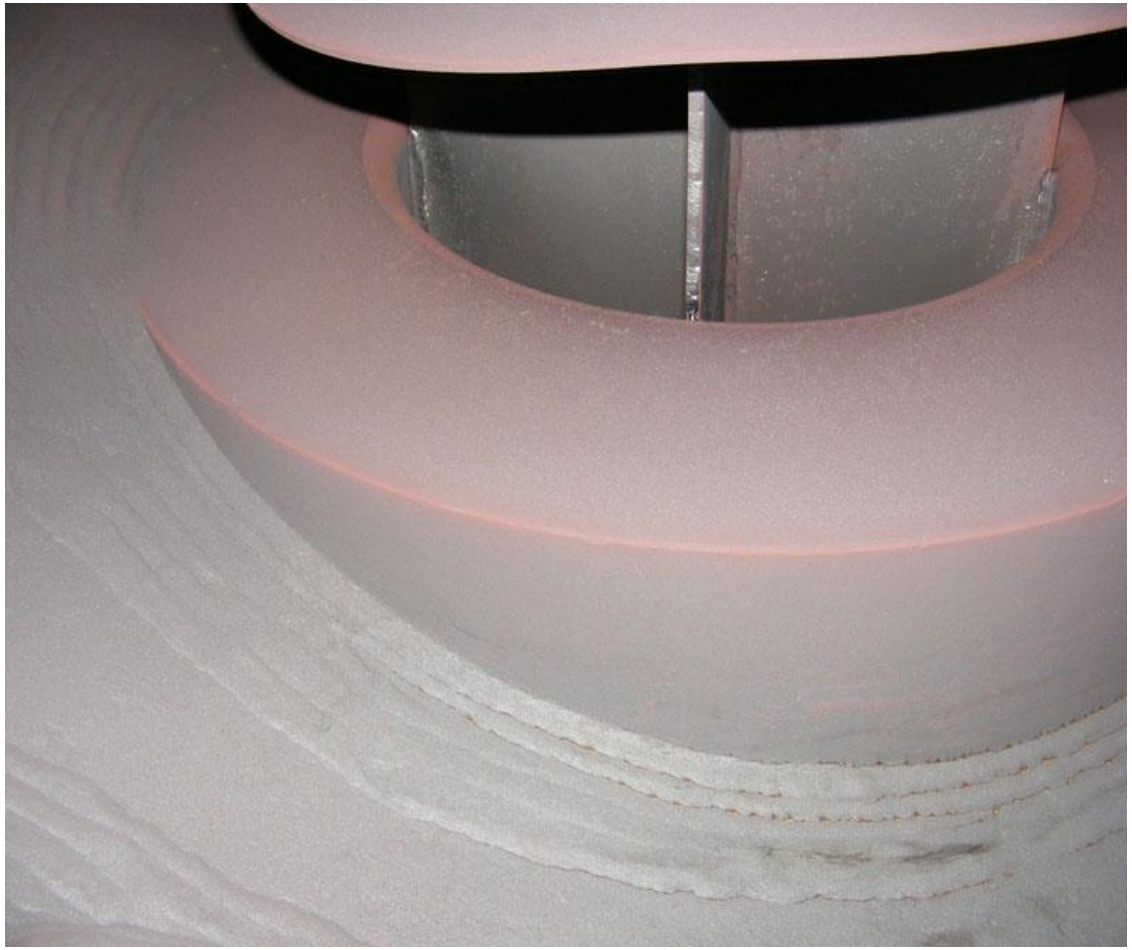
- **Inside surface tracks water and/or boiling temp, outer surface lags behind**





Cracking in HP drum downcomer nozzles

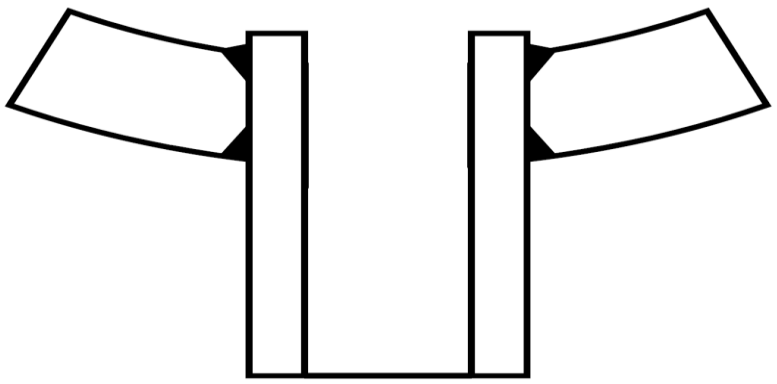
- Caused by thick nozzles heating & cooling at a different rate than the drum shell
- Most common in the HP drum
- Some nozzles styles are more tolerant than others.
- “Pass through” style shown.



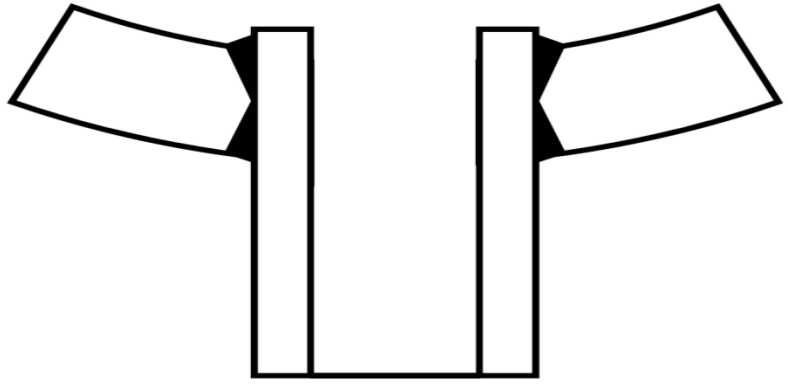
HP Downcomer Cracks

Cycling Evaporators

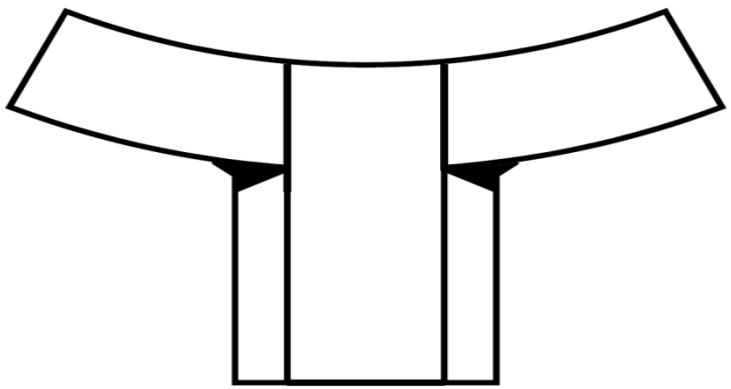
- **HP drum nozzle cracks are surprisingly common in cycling HRSGs.**
- **Nozzle weld design is a big factor.**



Pass-Through,
Partial Penetration Weld

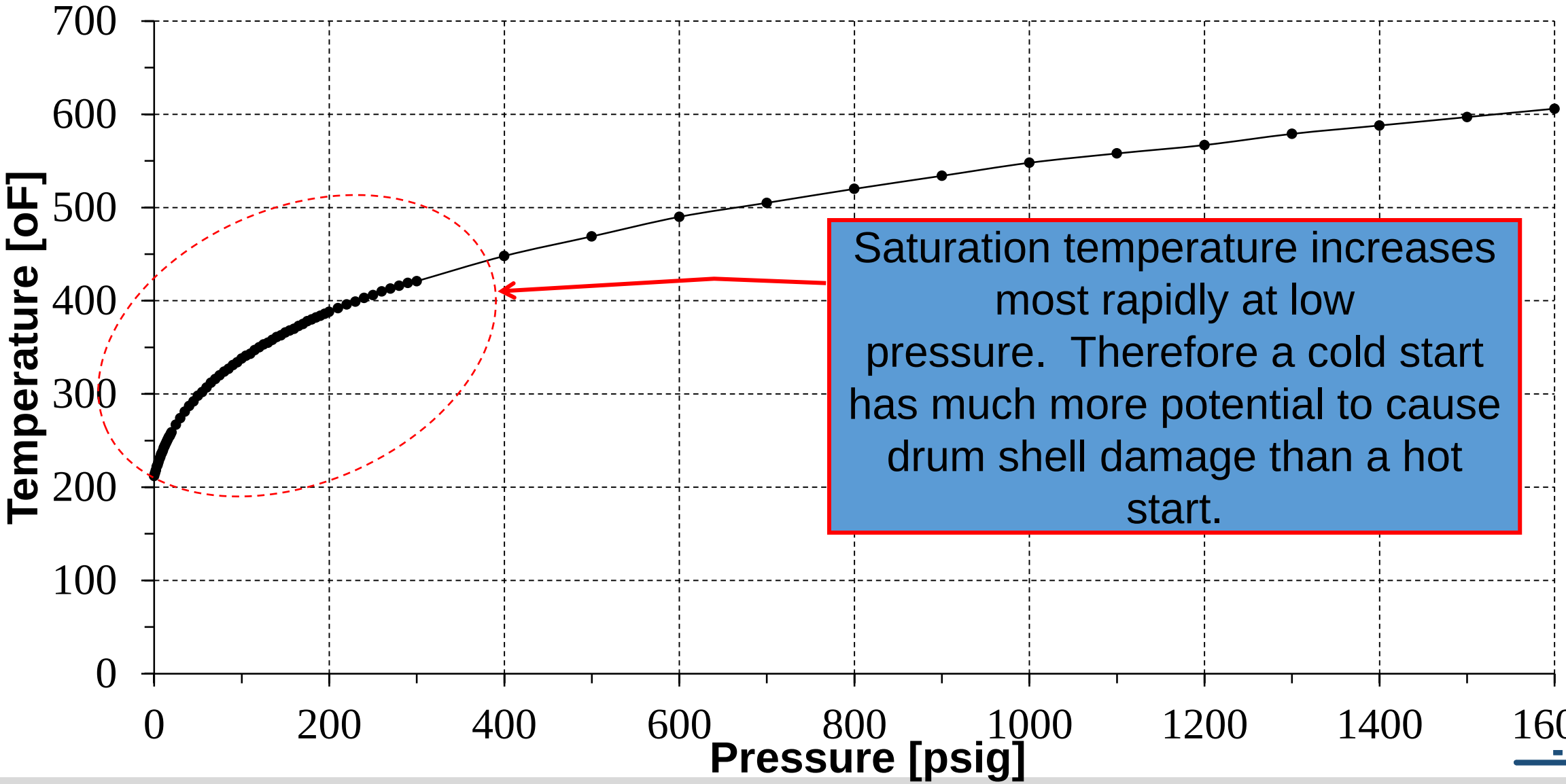


Pass-through,
Full Penetration Weld



Set-on,
Full Penetration Weld

Properties of Saturated Steam



Saturation temperature increases most rapidly at low pressure. Therefore a cold start has much more potential to cause drum shell damage than a hot start.

Steam Drum Nozzle Cracking

Takeaways

- **Minimize risk of drum nozzle cracks by controlling start-up and shut-down temperature ramp rates.**
- **Try to catch cracks early, before they propagate deep into weld or into drum shell.**
- **Crack propagation is not linear.**
  - Maximum crack depth of ½” (1.3 cm) in a 5 year old HRSG doesn’t mean it will be 1” (2.5 cm) deep at 10 years.
  - It might be 1” (2.5 cm) deep after 5 ½ years!
- **Weld repair, if required, is complex and requires careful planning.**

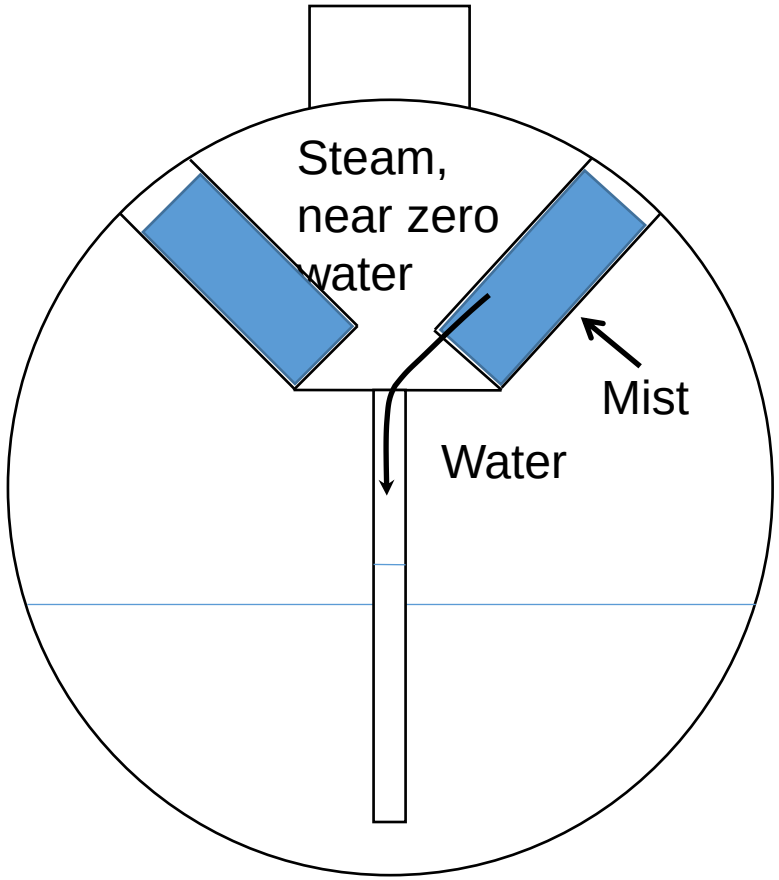
Cycling Evaporators

- **How to avoid problems:**
  - Short term: do not exceed guidelines from OEM, refer to their manuals. Many OEMs tend to be conservative (slower than required).
  - Program DCS to alarm if ramp rates are exceeded. Monitor both start-up and shut down.
  - Optimized: Analyze the limits of your specific arrangement and measure differentials directly to control ramp rates to acceptable levels.
    - Worth doing only if drum ramp rate is hindering overall startup.
    - Often overall start time has many trade offs between HRSG and ST.

Steam Separation Failures

- **Carryover can cause solids to plate out on the superheater panels**
- **Some common failures (or oversights) are shown next**

Chevron Final Separator



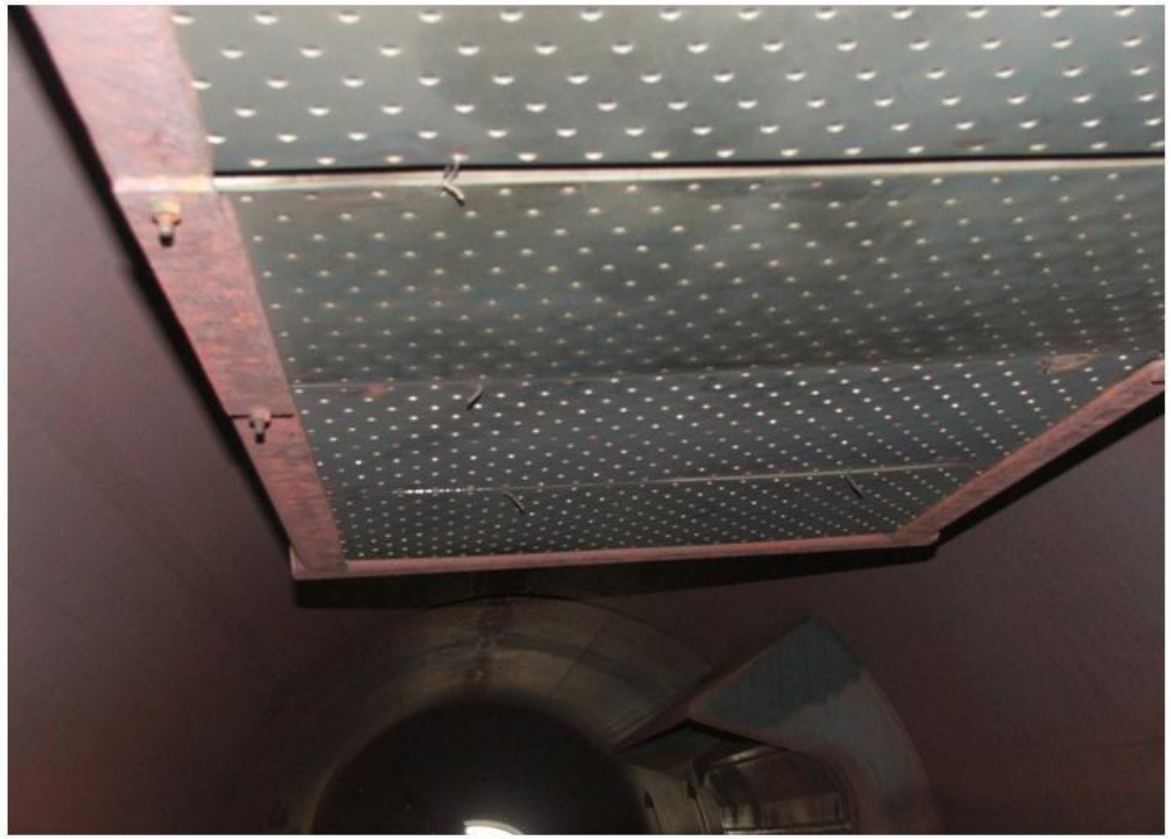
- Water drains in cross-flow relative to the chevron.
- Water drains down a “trap”

Spot the difference?

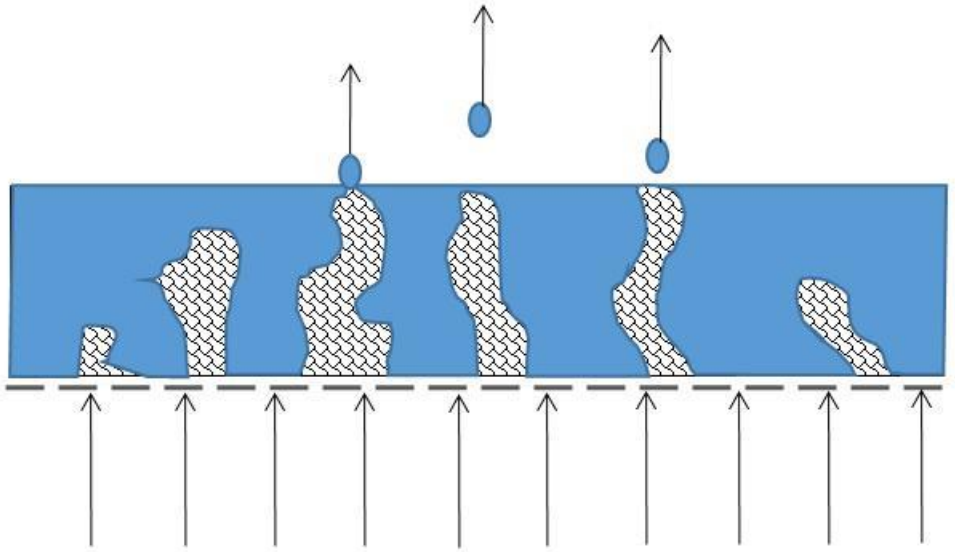
Drain Traps in place

Drain Traps missing

MESHPAD - Perforated plate mis-installed



Mesh pad separator
with perforated plate below the mesh



Water can't escape mesh

HP Drum Gasket Leaks & Blow-Outs

- **HP Drum gasket leaks can be very dangerous.**
- **Platforms are narrow. Safe work distance can be a challenge.**
- **Industry practice has encouraged “hot retorquing.” Dangerous.**

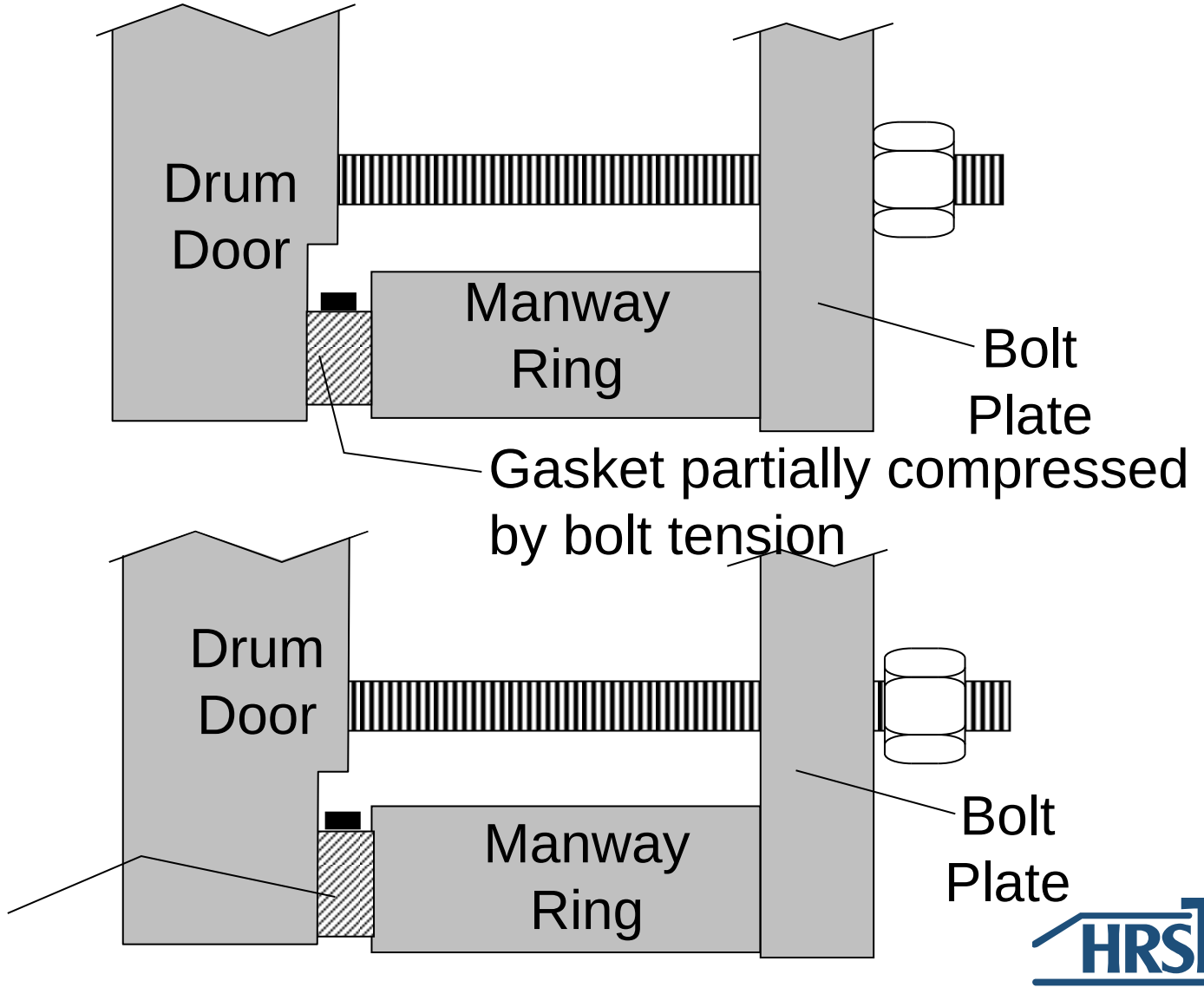
HP Drum Gasket Alignment & Compression

- **Typical HP drum door/hinge/manway alignment is not perfect.**
- **Heavy door must be pried into final position.**
- **Gasket can move during this process.**
- **Good alignment critical. Poor alignment can cause leaks or dangerous blow-outs.**

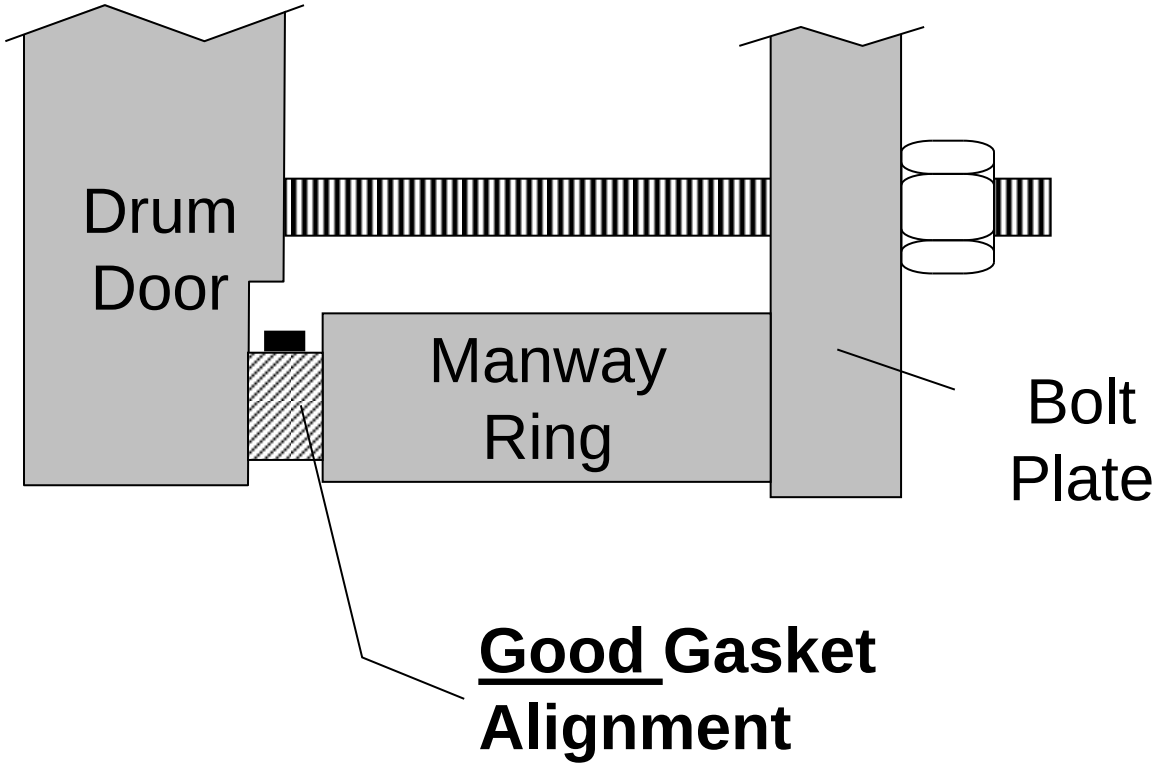
Compression & Minimum Seating Pressure

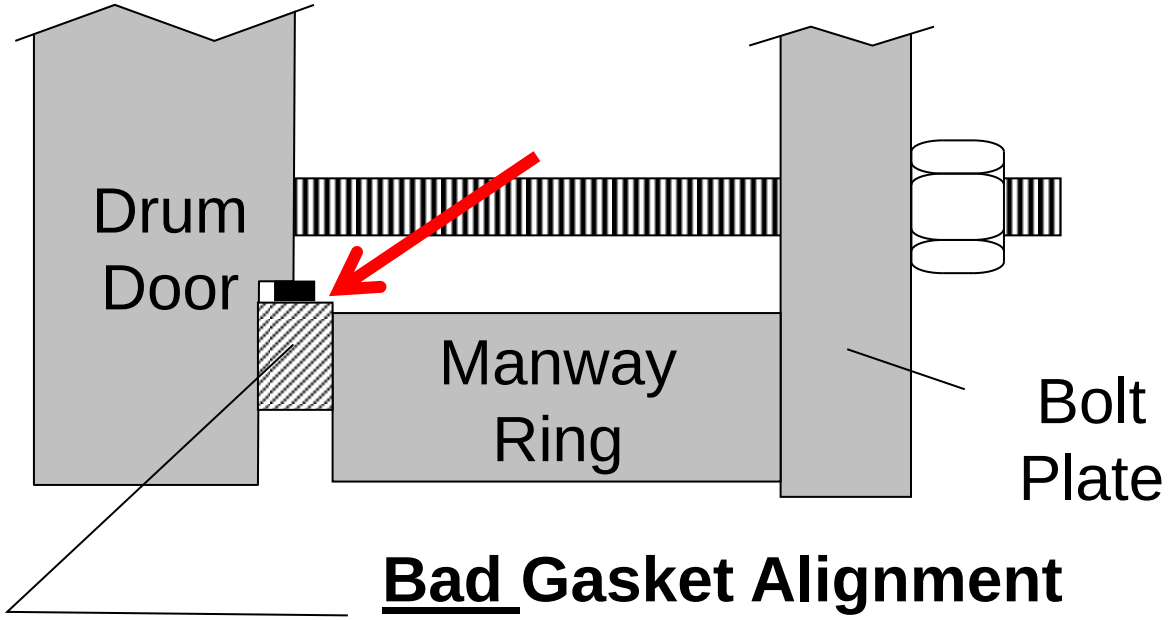
- **Gasket literature includes "minimum seating stress" for various gasket types**

- Difficult to achieve with studs and torque wrench.
- Drum pressure during start-up completes the process.
- Many HRSG OEMs include "hot retorquing" procedures.



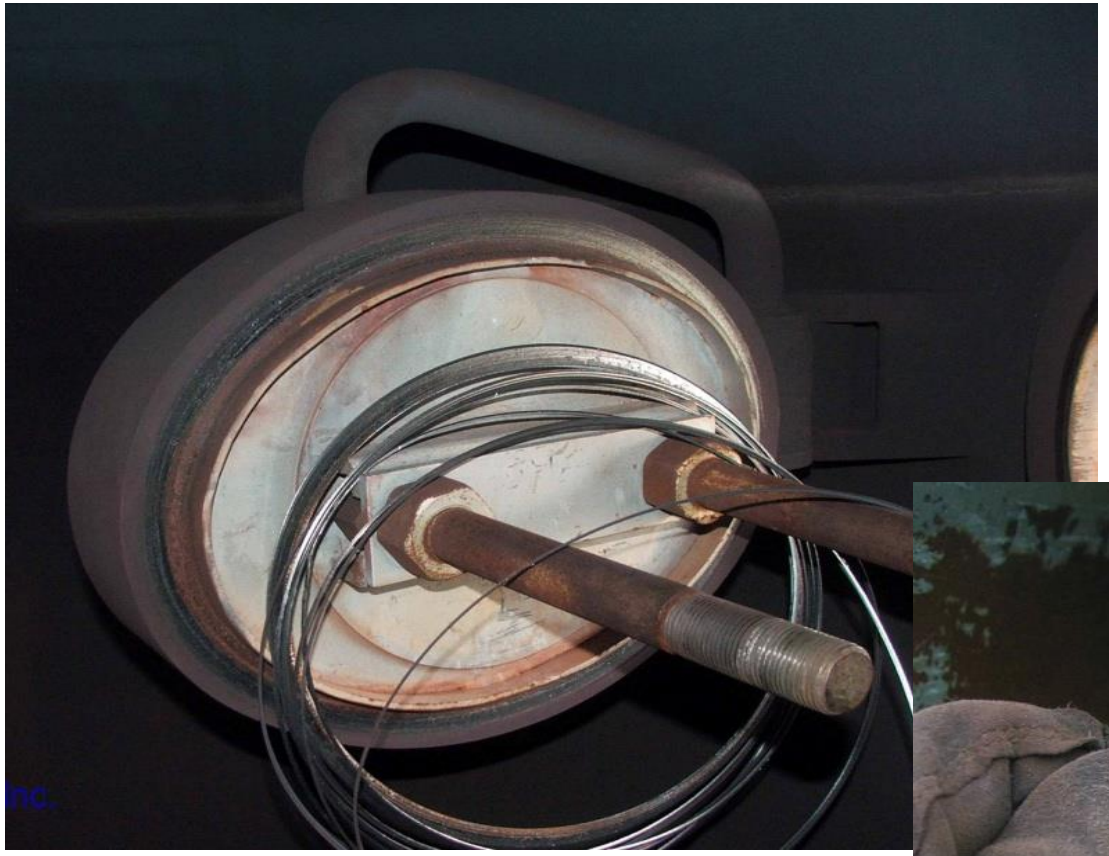
Gasket Alignment





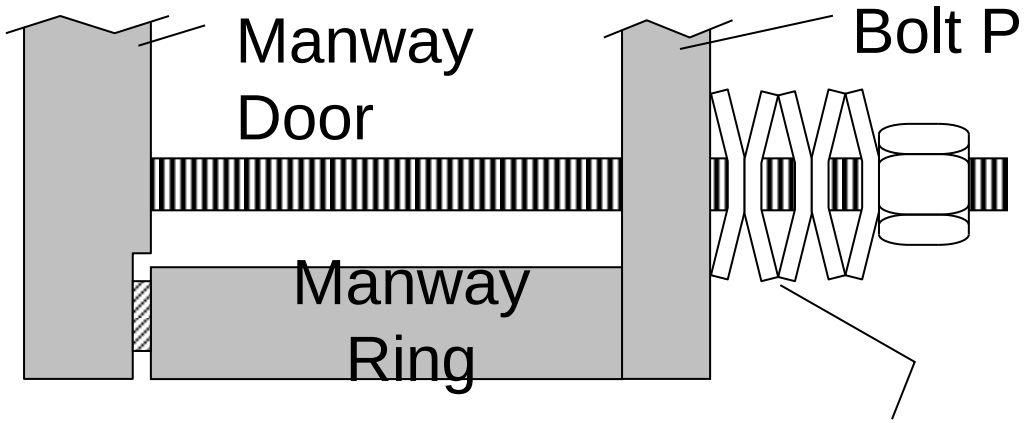
HP Drum Gasket Alignment & Compression

- **Spiral wound gasket metal strip must be completely sandwiched in sealing flanges.**
- **If not, gasket can leak or blow-out.**

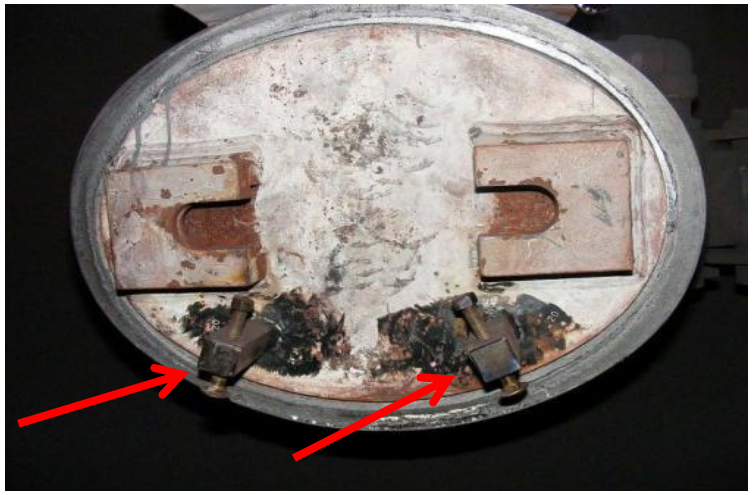


Recommendations & Caution

- Retorquing under pressure (hot retorquing) is dangerous and should be avoided.
- Develop careful gasket alignment and safe torquing procedures.
- Optimize drum door hardware to reduce steam leak safety risks.
- Consider Belleville washer arrangement on drum studs (illustration above)
- Add door alignment screws to close door with accurate alignment (**HRST design**→)



Belleville washers maintain bolt tension



Once-Through Steam Generators (OTSG)

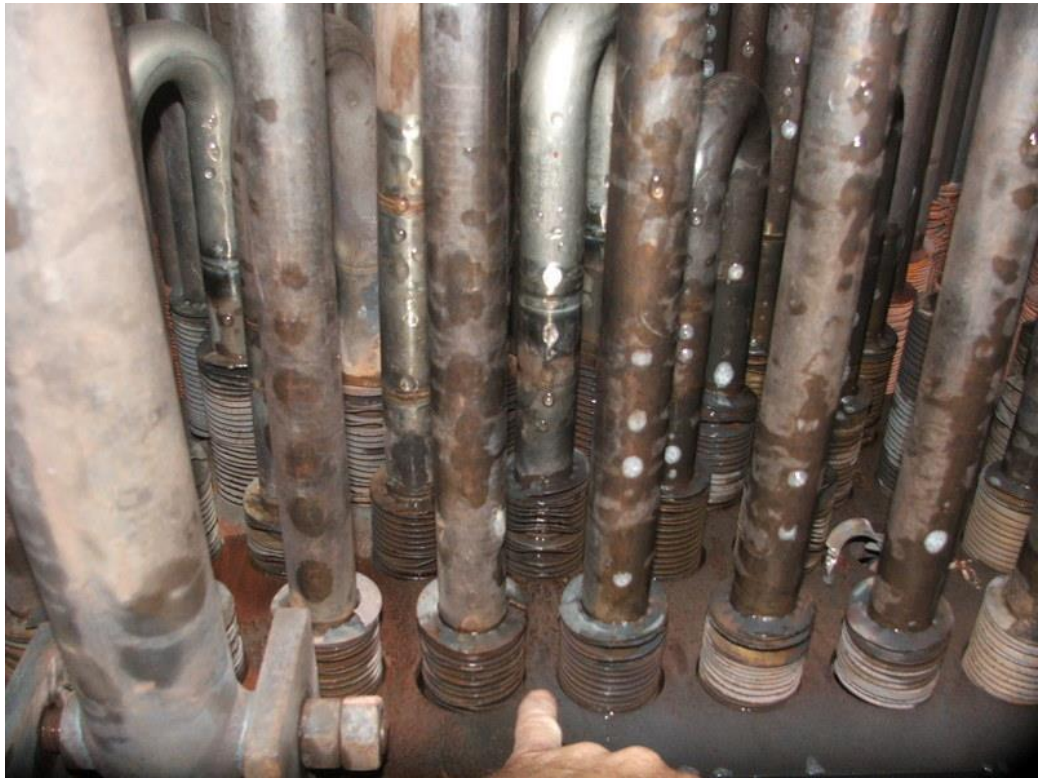
Once-Through Steam Generators

- **Advantages**
- **Disadvantages**
- **Couple of problem illustrations**

Once-Through Steam Generators

Failure in IST Superheat section due to water hammer – wet startup

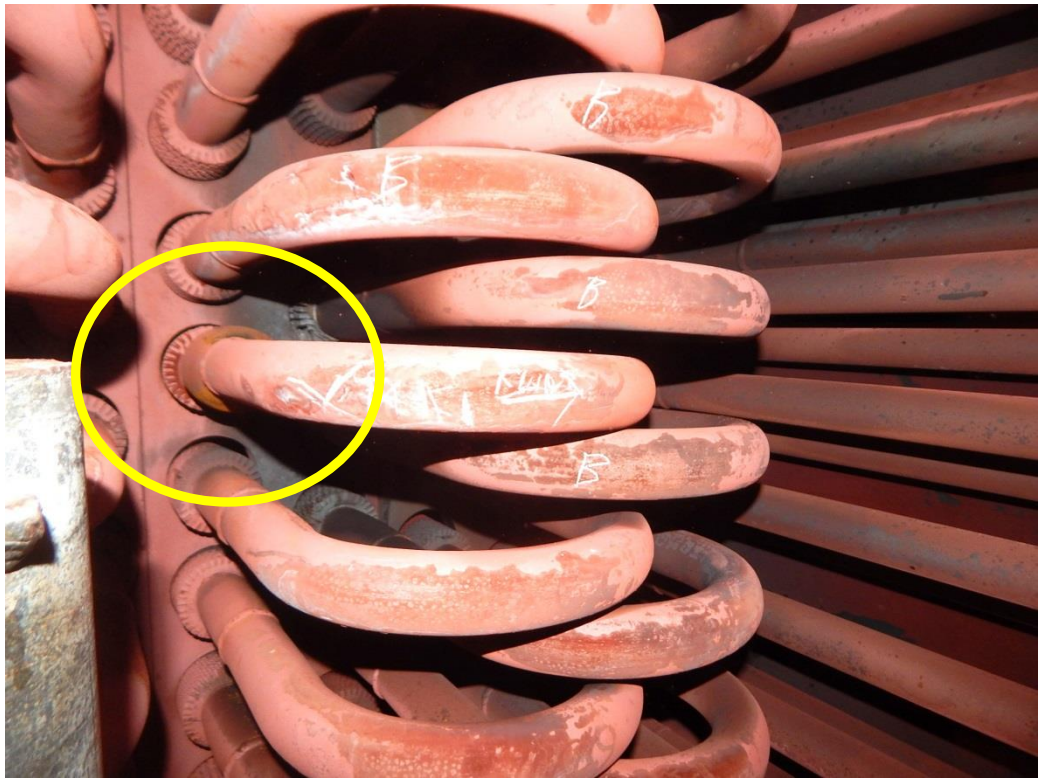
(Repair in progress)



Failure sample

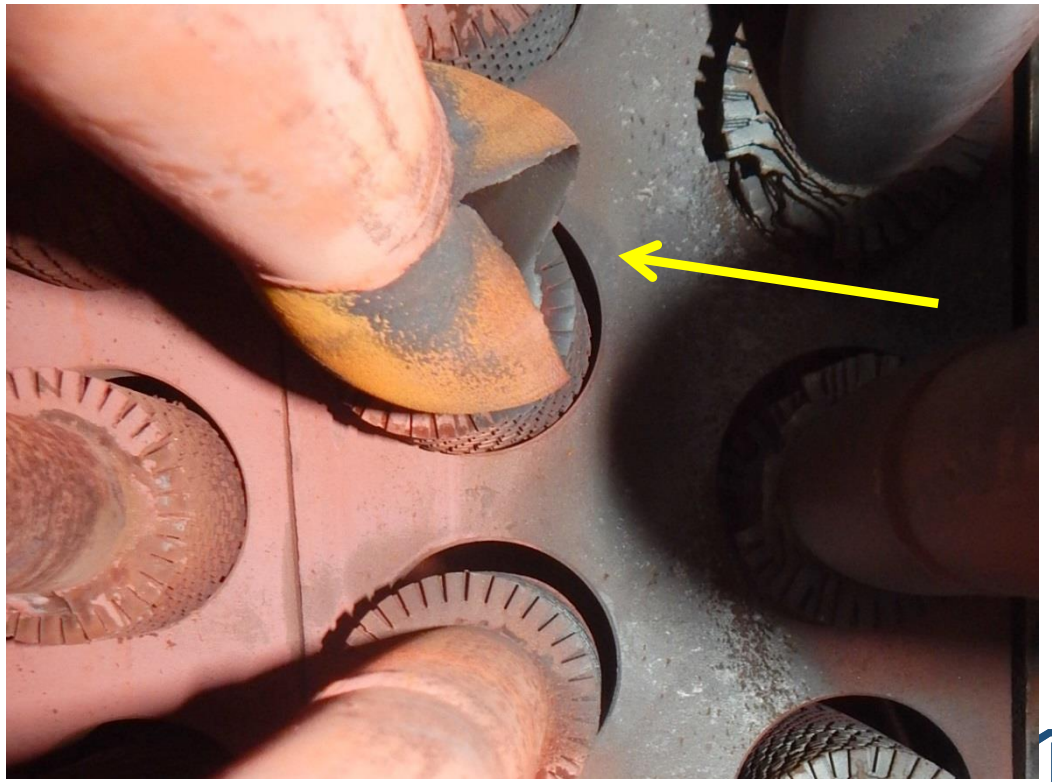
Once-Through Steam Generators

Failure in Evaporator section due to excessive circuit temperature (superheated) – alloy was needed here



Tube Failure at material change

(change boundary should have been located in a colder section)



Agenda

- **What is the evaporator**
- **Natural Circulation Evaporators**
  - **How do they work?**
  - **What is the purpose of the drum?**
  - **Common problems**

- **Once-Through Steam Generators (OTSG)**
  - **Advantages and Disadvantages**
  - **Couple of problem illustrations**

HRST

Questions?

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