Steam-Atomized Attemperation, and Duke HRH Attemperator Installations

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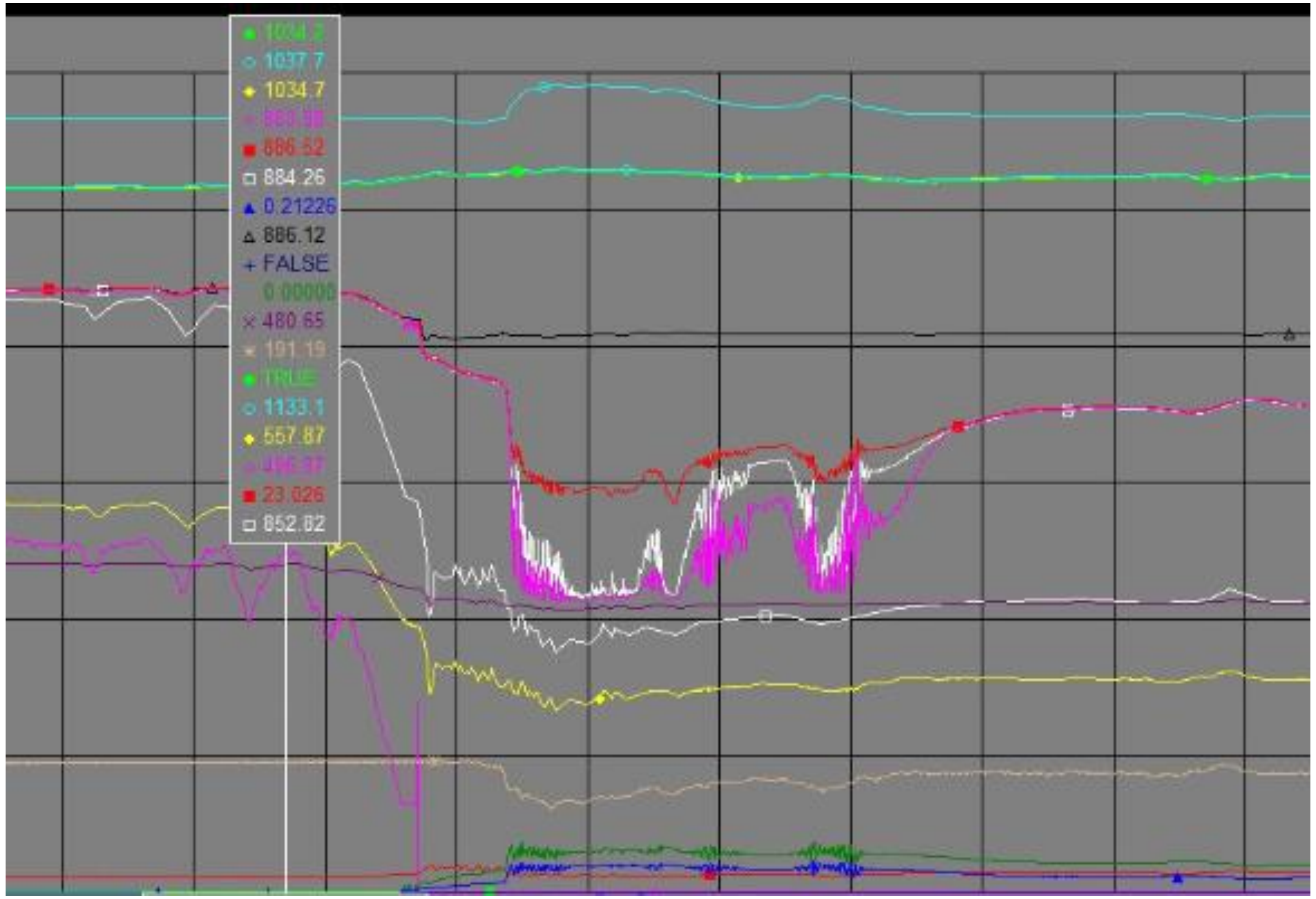
Agenda

- History / Background
- Operation of Traditional Attemperator Nozzles
- Basics of Steam Atomized Water Injection
- New Nozzle Development and Benefits
- Duke Energy Installations at Buck and Dan River Stations

History and Background

- Low GT load operation at Duke Buck Station and other combined cycle plants across the country have led to increases in overspray conditions in RH attemperators throughout the industry.

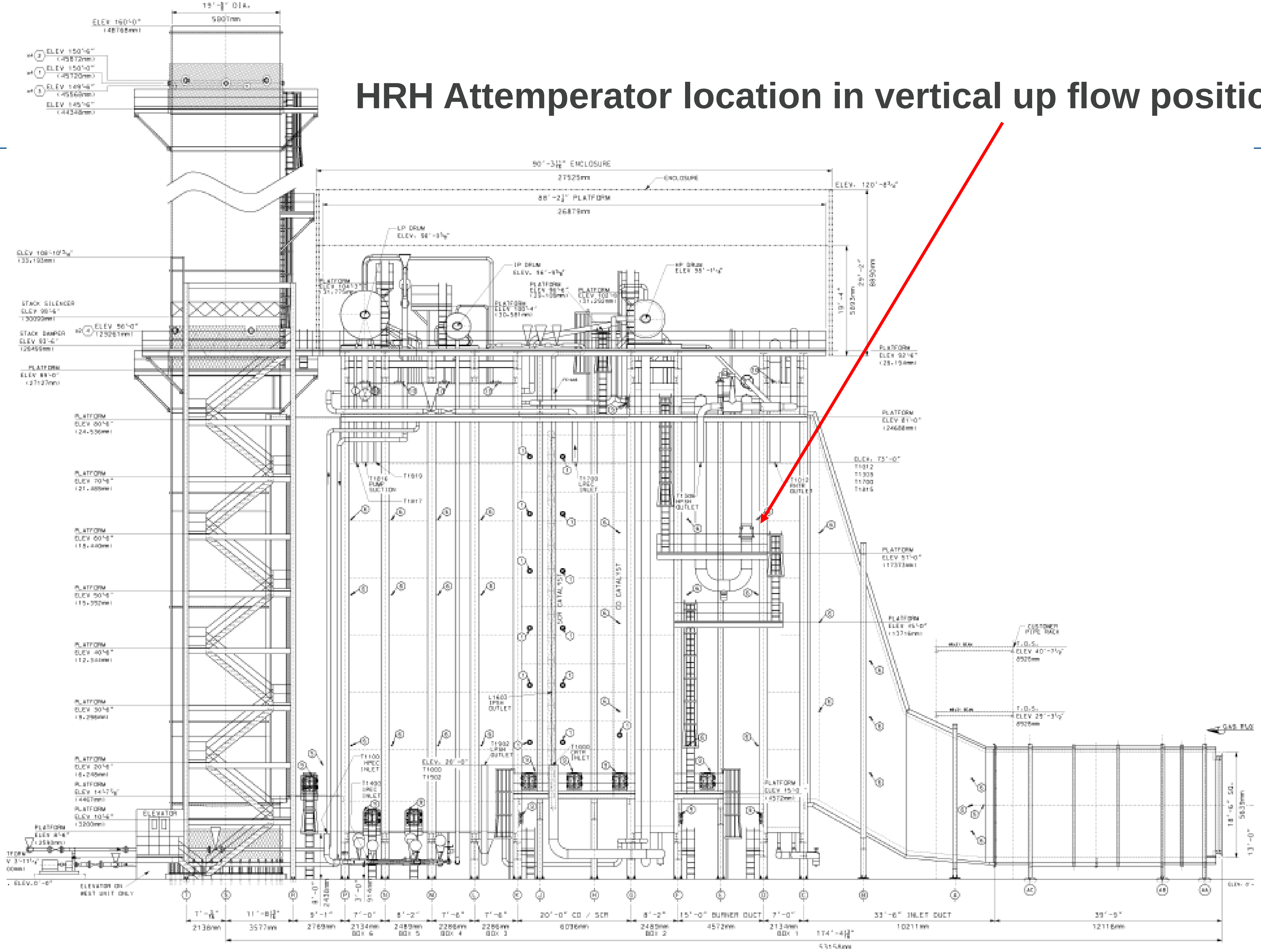
- Primary cause of the overspray under these conditions appear to be:
  - Lower GT load generates less steam flow, and steam is at lower pressures
  - Attemperator must inject larger amounts of water into lower steam flows, increasing risk of overspray
  - Traditional spring-loaded nozzles may be reaching the limits of their operational rangeability



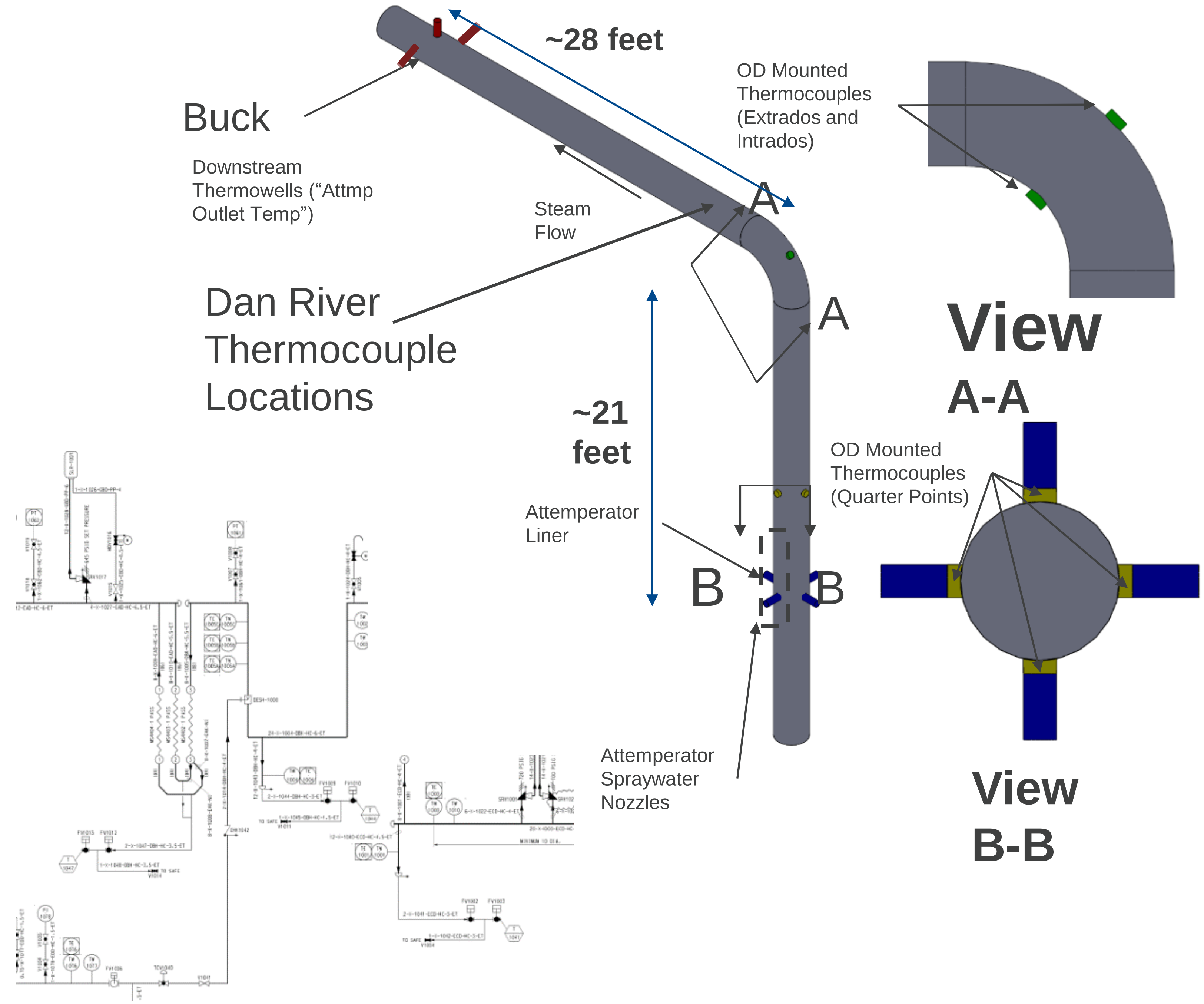
History and Background

- CT is GE 7FA.04
- High exhaust gas temperatures at low load isotherm
  - Between approx. 40 and 160 MW
  - Buck exhaust gas temperatures were operating at 1185 deg. F. This has been reduced to 1170 deg. F by a simple adjustment and Autotune. Dan River did not make this adjustment.
  - High temperature rise split across the reheater tubes (3 reheater sections downstream – 1 and 2 with split flow)
- Vogt HRSG COD of 2011 and 2012.
- Concerns of damage to downstream pressure parts including the elbow, welded steam lateral connections, tube to header welds.
- Downstream elbow was inspected using linear phased array in Spring of 2019. No cracking or advanced service damage found, however, analysis using operational data and elbow thermocouples shows a through wall crack in approximately 4.7 years of continued service.

HRH Attemperator location in vertical up flow position



Buck, Dan River HRH Attemperator – Piping and Thermowell Layout, Pipe External Thermocouple Installation



- To analyze the attemperator, thermocouples were mounted on the outer diameter of the piping
  - Two thermocouples on the downstream elbow, on the extrados and intrados
  - Four thermocouples downstream of the attemperator liner, at quarter points
- Thermocouple data was added to the plant DCS system for observation
  - More convenient and predicted to be more cost effective than an external data logger
- Data has been collected since late May 2018
- Grade 22 piping, 24” OD schedule 80

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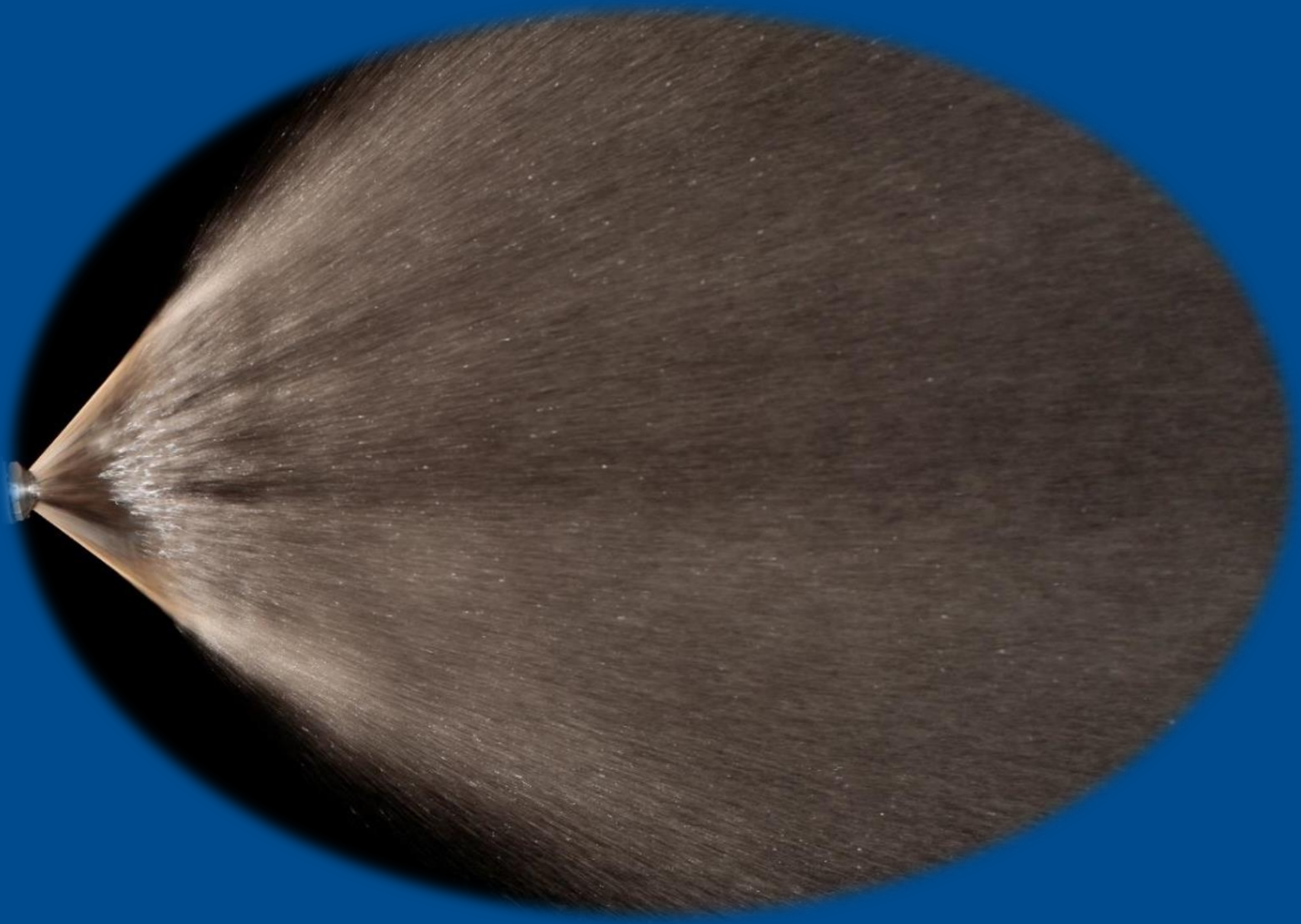
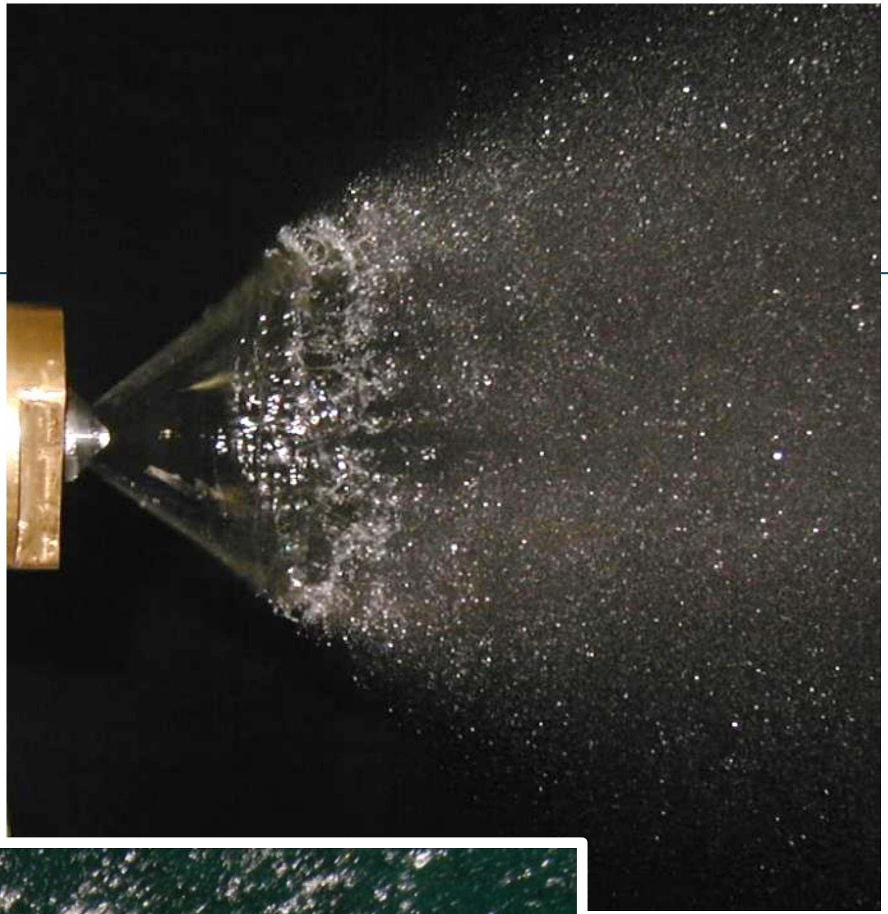
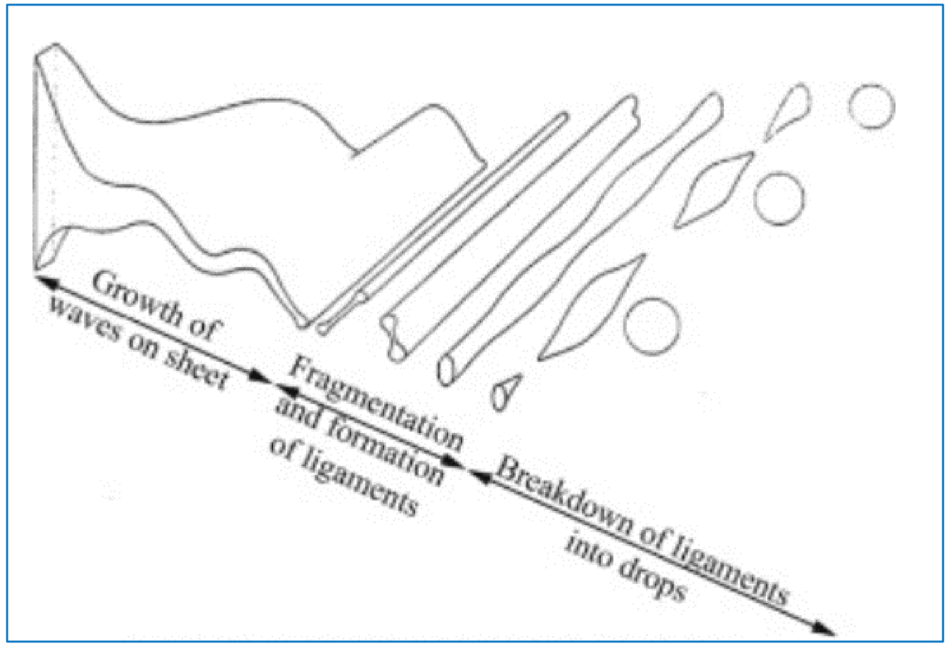


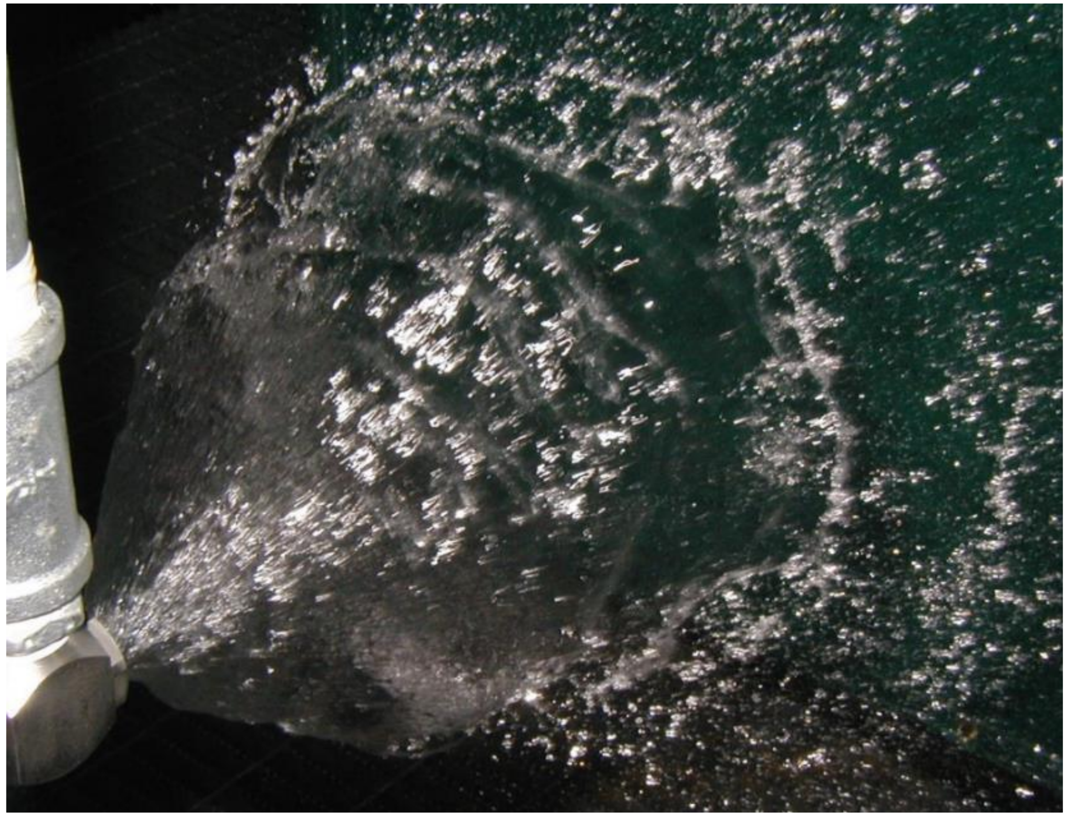
Operation of Mechanically-Atomized Attemperator Nozzles

Spray Nozzle Droplet Formation

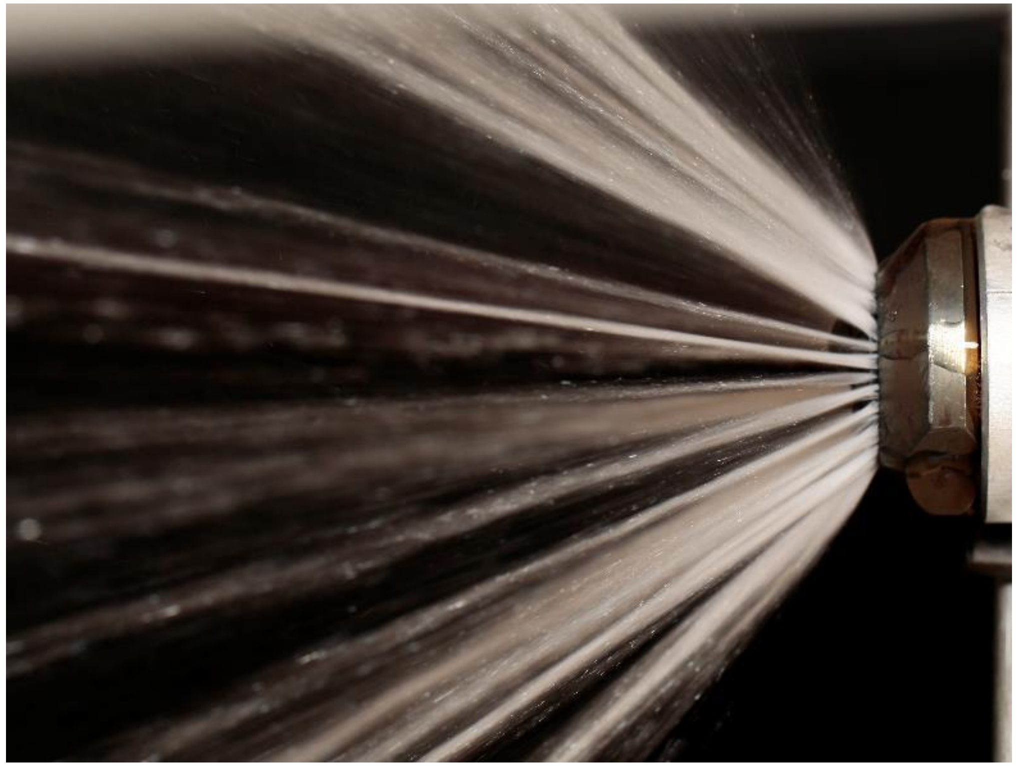


- **Primary atomization: at the nozzle**
  1. In the typical mechanical nozzle, the fluid exits as a “sheet” (in our nozzle types, this is normally a cone shape)
  2. Sheet begins to break into ligaments (rings for hollow cone nozzles)
  3. Ligaments break into droplets



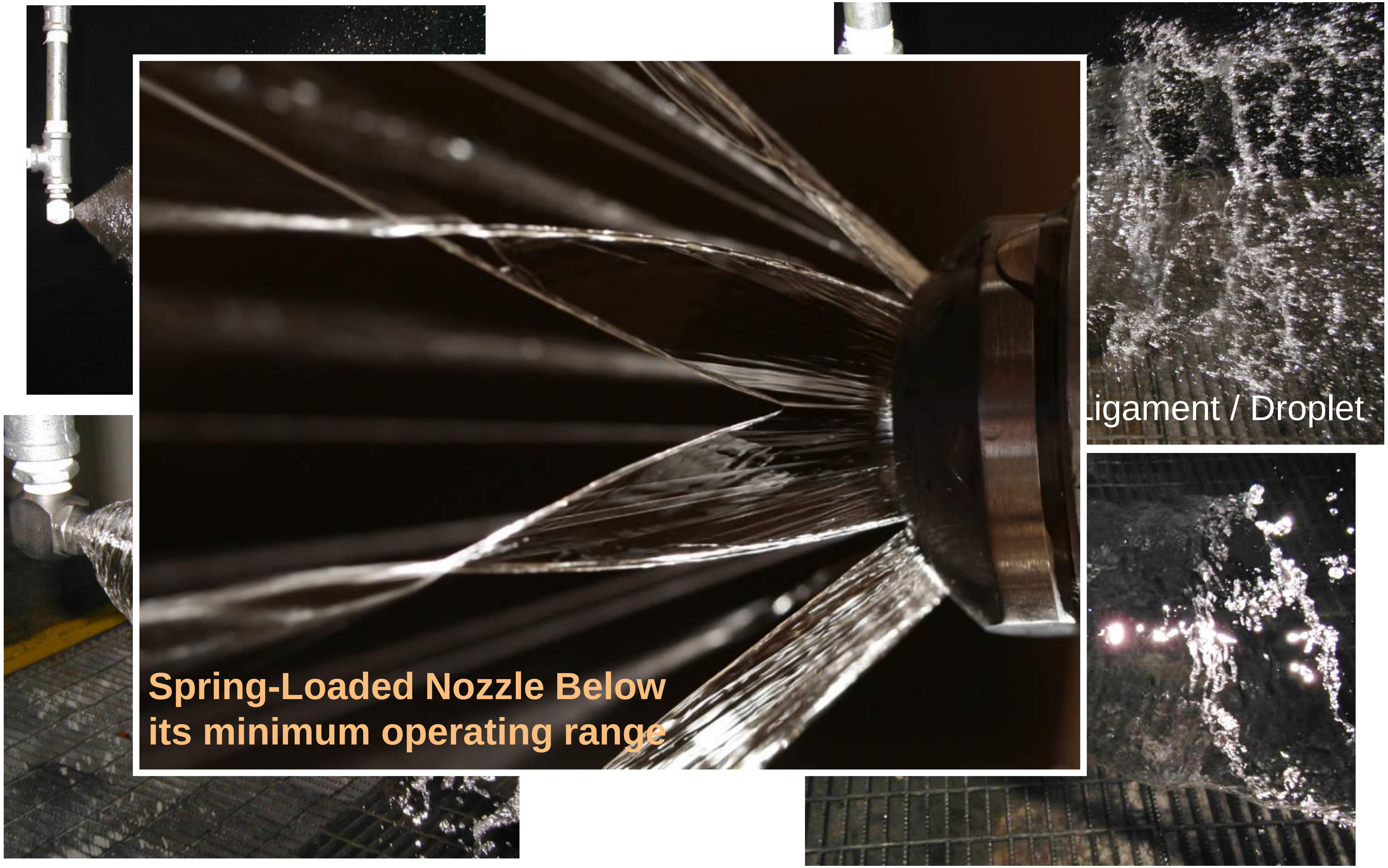


Limitations of Mechanically Atomized Nozzles



- Requires Adequate Water Pressure Drop to Atomize
  - See example on following slide
- Can Stick Open/Closed due to Clogging or Oxidation
  - When clogged and stuck open, a spring-loaded nozzle has greatly decreased rangeability, and can generate jets of water instead of spray.
- Damage to Sharp Edges Increases Droplet Sizes and Decreases Uniformity
  - Smooth passages and sharp edges ensure uniform flow and uniform droplet breakup
  - Wear and damage will reduce this uniform atomization performance
- Some operating scenarios may require smaller droplets than even a perfectly sized, clean mechanically atomized nozzle can generate
  - Example: Low steam velocities with high water requirements

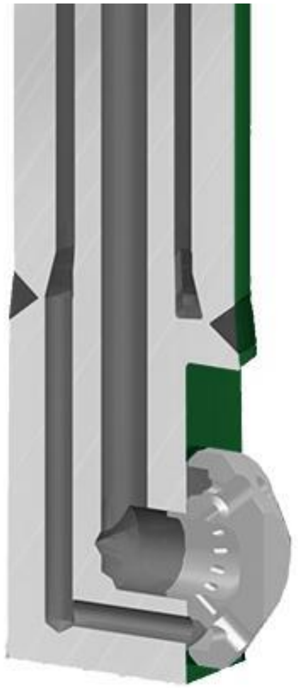
Example of Nozzle Pressure Drop Effects: Fixed Orifice Spray Nozzle



Steam-Atomized Water Injection

Principle of Steam Atomization

- Steam Atomization uses a high-pressure steam source as the mechanism to generate the spray
- Water is injected into a high-velocity steam flow, which shatters the water into very fine droplets
  - Results in a fog-like mist that is readily absorbed in the flowing steam.
- An important characteristic of steam atomization is the generation of fine droplets regardless of water flow, water pressure drop, or flowing velocity in the steam line



Fisher® DSA Desuperheater

Steam-Atomized Spray Produces the Finest Droplets, Which Allows for the Shortest Evaporation Distance, and Widest Rangeability

Next Generation RH Attemperation with Steam Atomization

To counter the issues experienced at Buck Station, Emerson Engineering began a project to develop a ring-style steam-atomized attemperator design, capable of high thermal cycling.

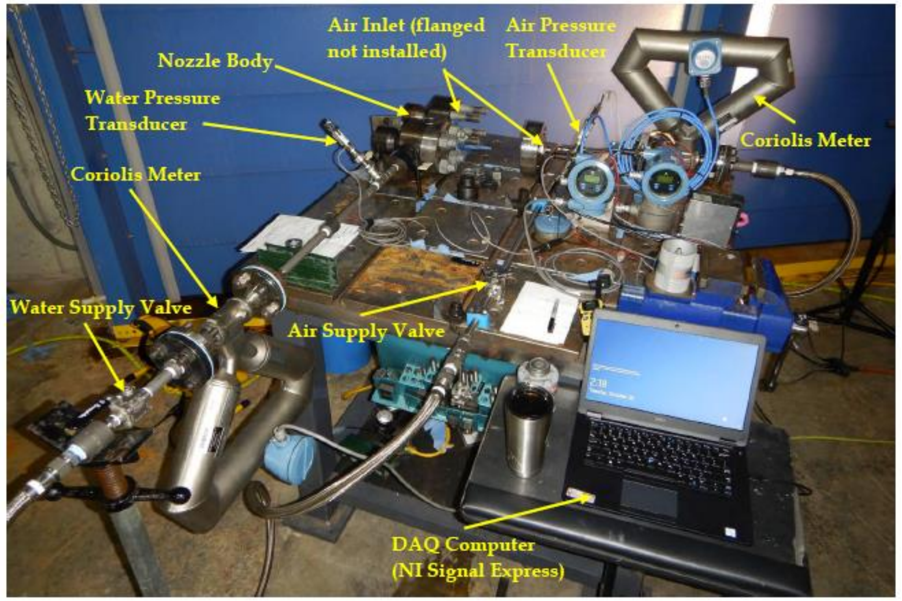
- **Project Goal:** Design new steam-atomized nozzle to replace existing Fisher spring-loaded spray nozzles in the Duke Buck RH Attemperators

- **Primary Design Objectives**
  1. New design must retrofit into the existing Fisher TBX-T ring-style attemperator to minimize field piping work (new steam-atomized nozzles to fit in existing nozzle bodies)
  2. There shall be no fabrication joints, shrink-fits, threads, etc. within the nozzle to ensure long life in heavy cycling, attemperator environment.
  3. Atomizing steam source connection should be as simple as possible, using flange connection
- **Secondary Objective:**
  - Decrease required downstream piping lengths and increase rangeability for new attemperator installations

Original nozzle and sleeve to be replaced

Design Process Steps

- Develop concepts
  - Brainstorming sessions generated many different nozzle geometries to investigate
  - Initial evaluation criteria centered around:
    1. Geometry for most effective steam atomization
    2. Internal geometry to best handle thermal stresses from repeated thermal shock and transient operation
- Test parts in lab environment
  - Several nozzle geometries were produced and spray tested to select best exit geometry
  - Flow rate/Pressure measurement gathered to confirm actual Cv versus predicted
- Perform FEA and CFD Simulations
  - Confirm internal passages could handle thermal expansion and associated operational stresses, adjusting concepts as needed for maximum fatigue life
  - Confirm new nozzle body flange with steam inlet passage could handle the design pressure/temperature (burst tested)
  - Confirm hand calculations for steam and water capacities
- Finalize design



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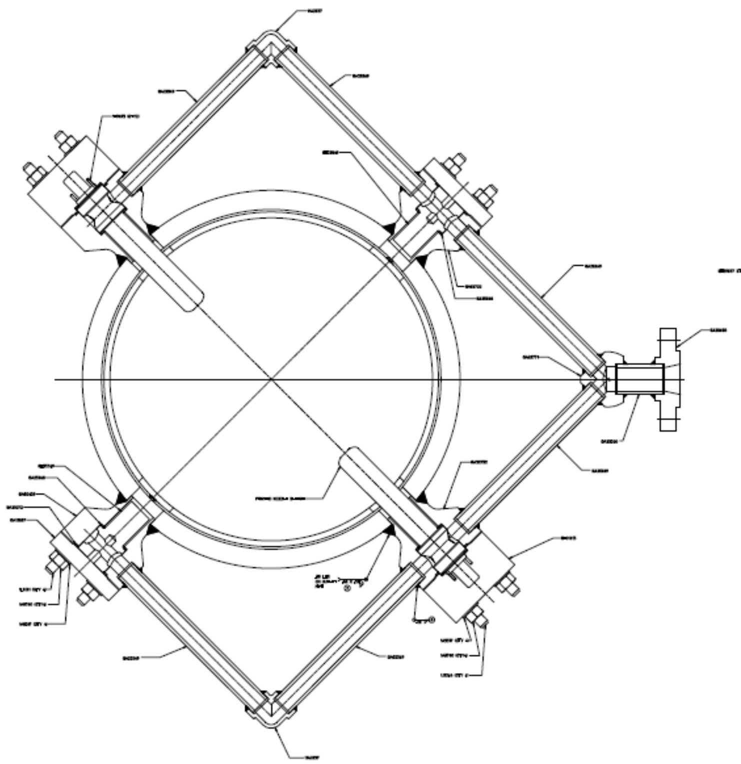
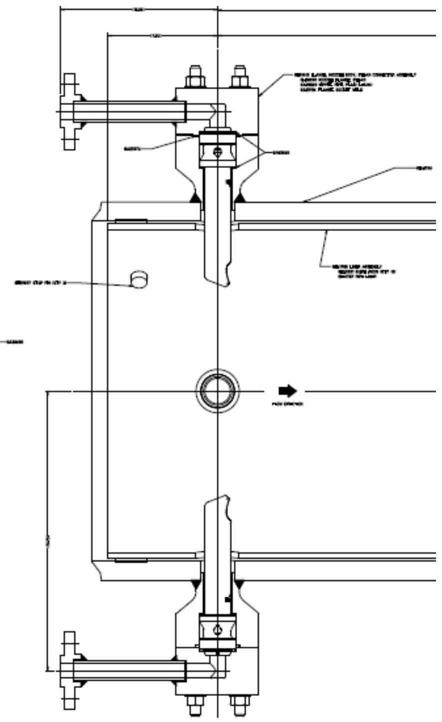
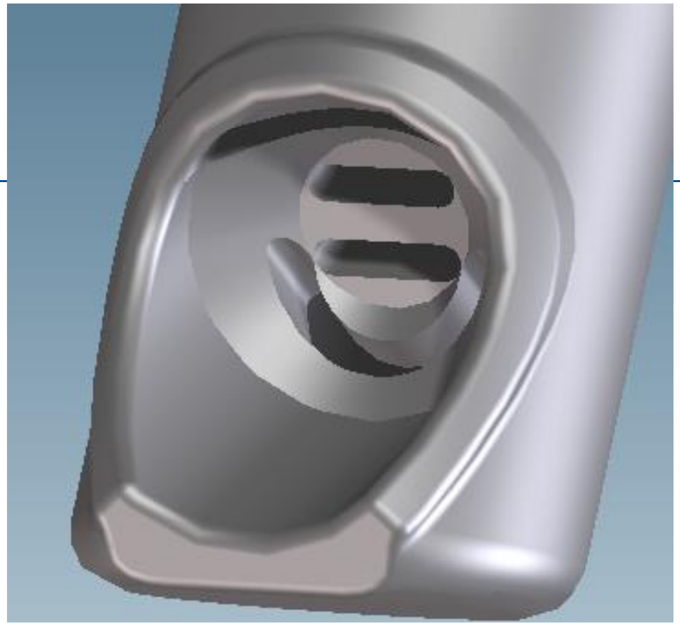
Final Steam-Atomized Nozzle Design

- Best Solution Came Through Additive Manufacturing
  - Utilize Laser Powder Bed Fusion process to produce the water / steam passages within the nozzle
  - Additive manufacturing eliminated 100% of weld joints where most severe thermal stresses occur: Inside the nozzle
- Final Design
  - 1 Patent granted, 2 additional patents pending





Lab Spray Demonstration

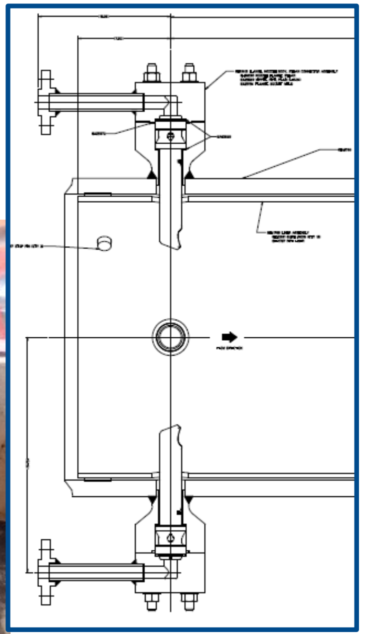


- Videos were here

Other Benefits of the Steam-Atomized Attemperator

- **Eliminate thermal shock failures of probe-style attemperators**
  - No trim or weld joints in thermal-stress-prone locations
- **Highly Resistant to Plugging**
  - Nozzle does not require small passages and sharp edges to create fine spray
  - Much larger flow passages than spring-loaded nozzles means it can pass much larger particulate without plugging.
- **Completely eliminates the two most common failure modes of spring-loaded attemperator nozzles:**
  - No moving parts / sliding fits to stick open or closed
  - No spring to weaken / relax
- **Highly Corrosion Resistant Nozzles**
  - Nozzle Material: R31233 Cobalt-Chrome Alloy.
  - Has excellent resistance to corrosion in fluids from water and steam to oxidizing environments to a wide range of strong acids

- **Simple Maintenance: Quick Nozzle Replacement**
  1. Unbolt Nozzle flange and atomizing steam flange
  2. Pull out nozzle; Insert new nozzle
  3. Bolt up with new gaskets



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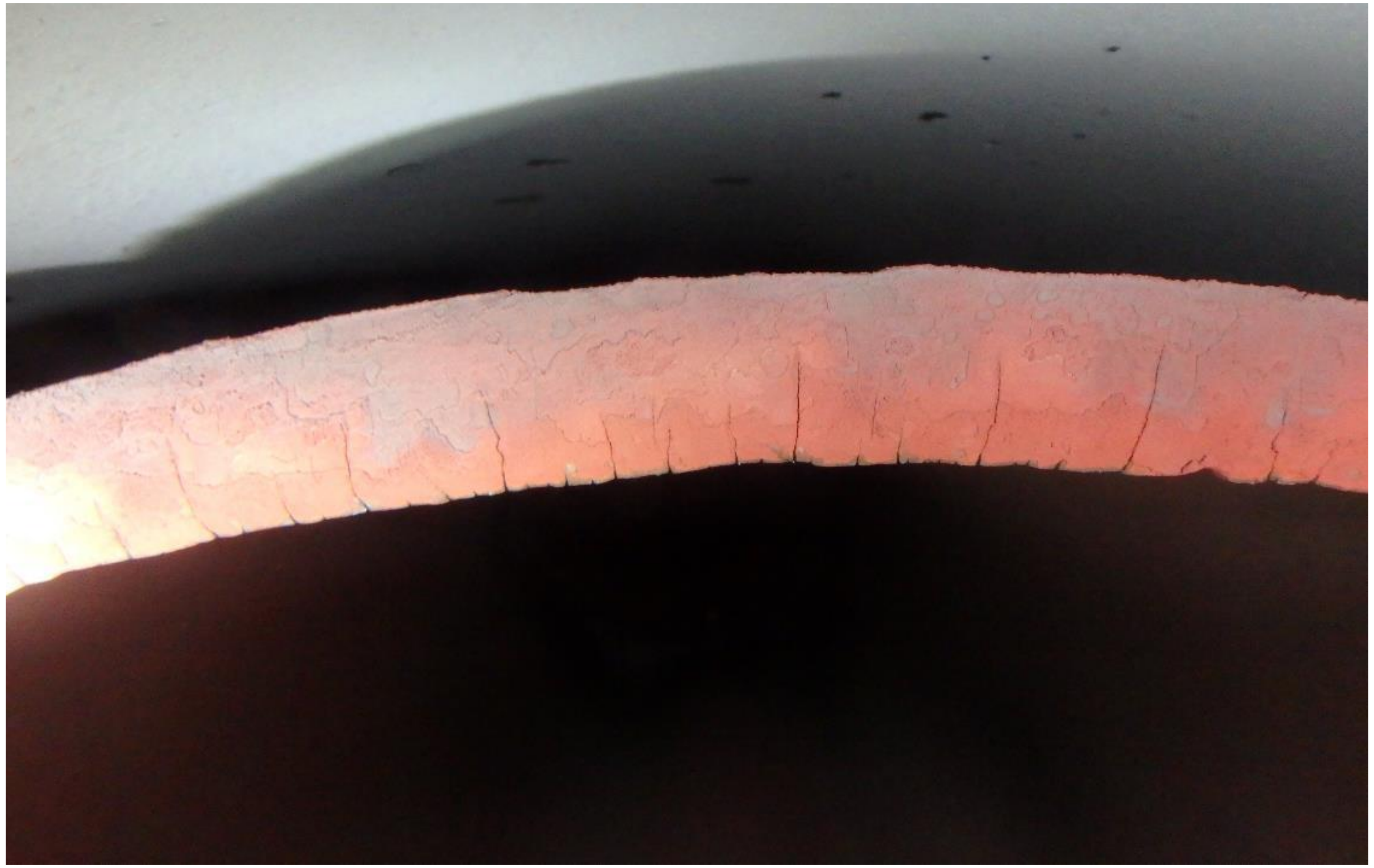
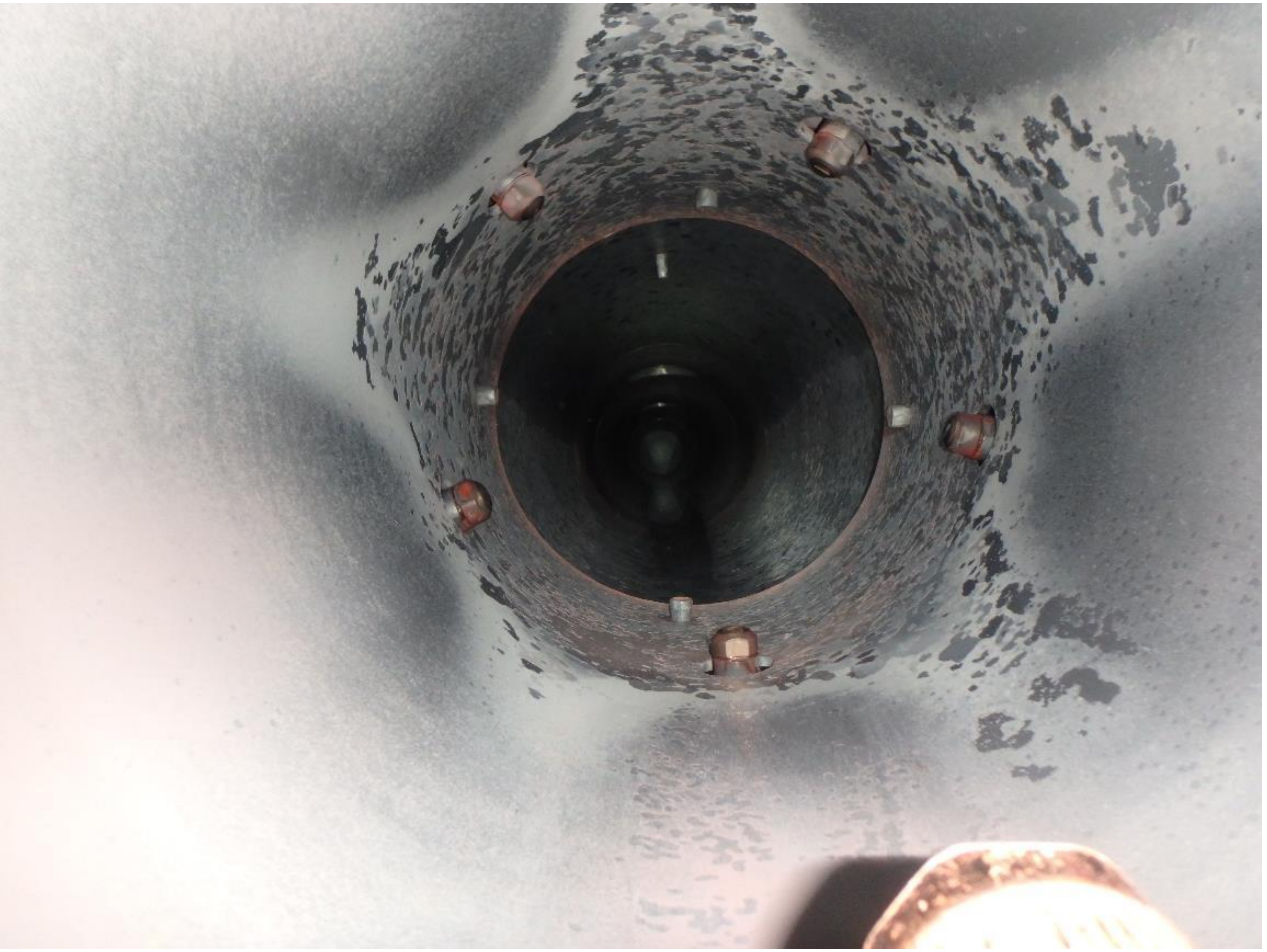
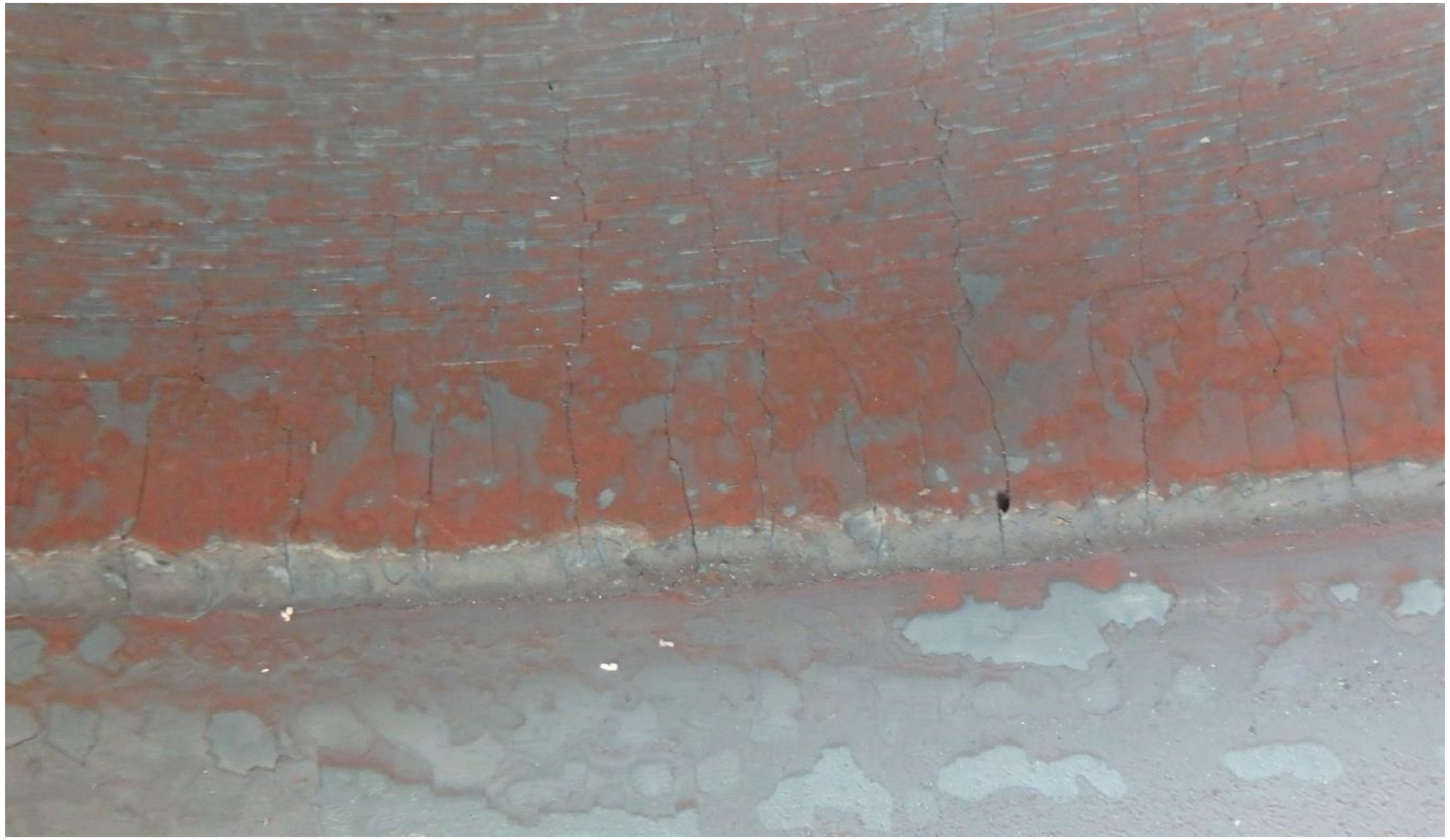
Duke Energy Installations

Smith PB4 Unit 8 HRH Attemperator Nozzles and Liner

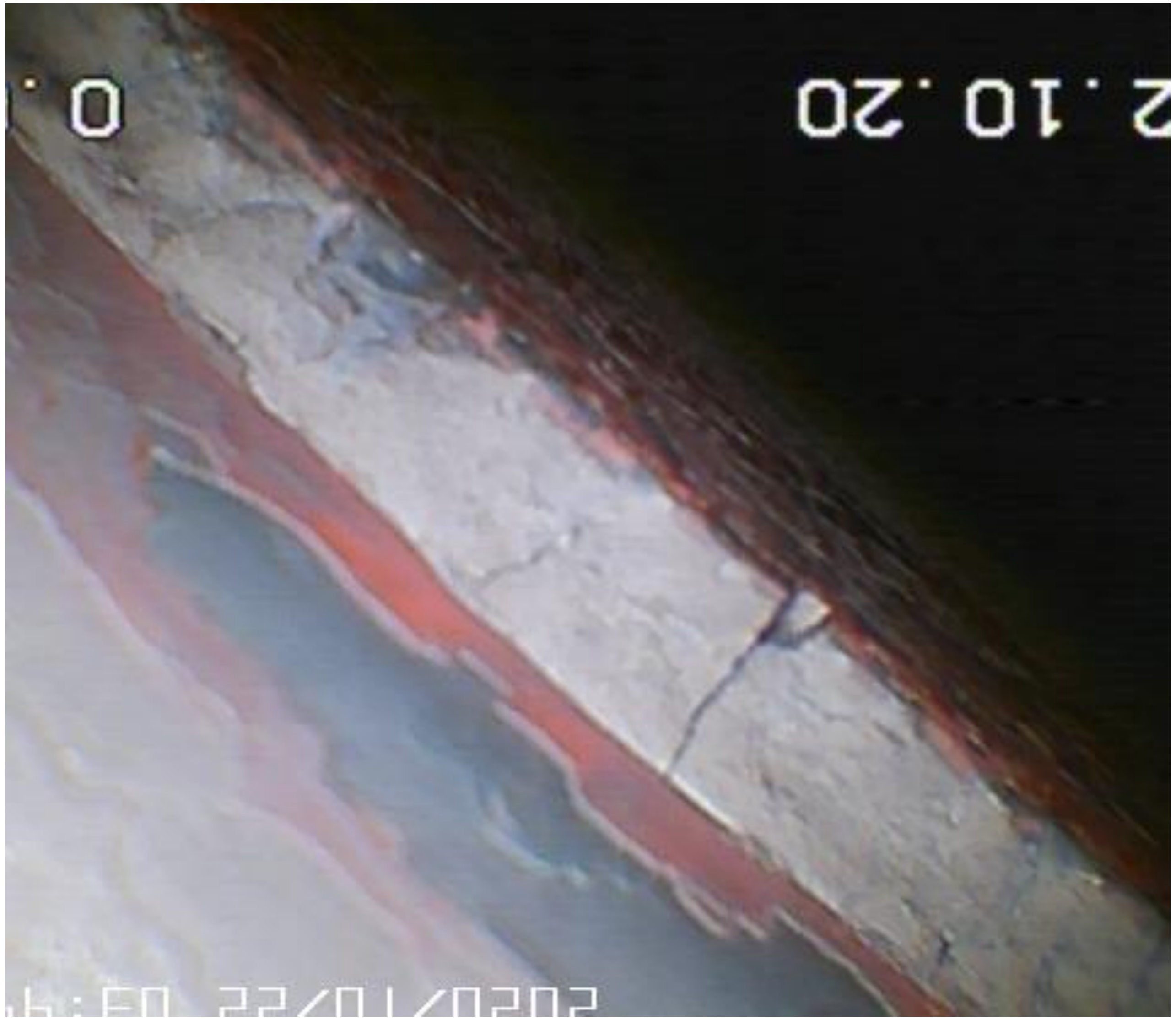




Smith PB4 Unit 8 HRH Steam Piping Downstream of the Attemperator

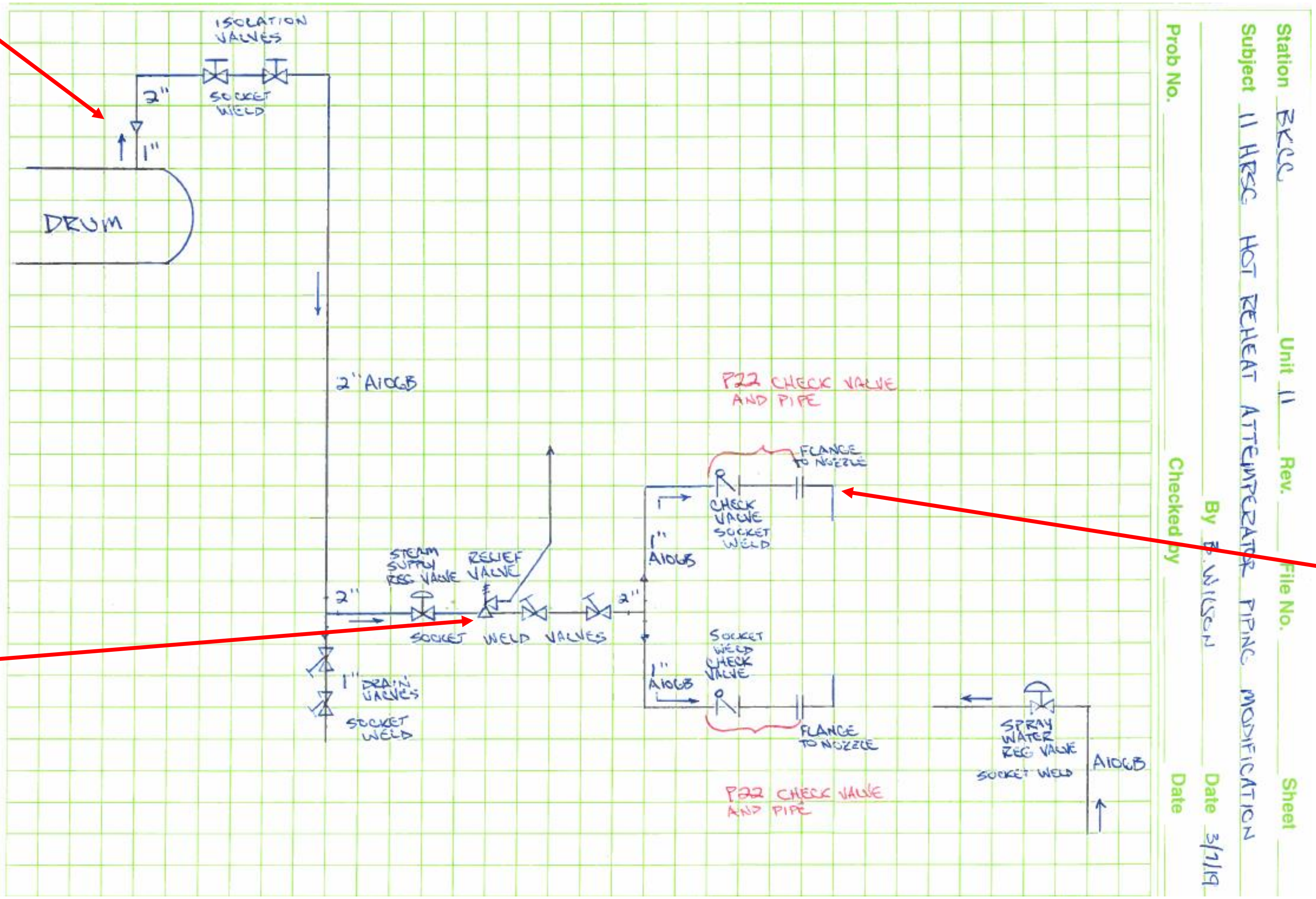


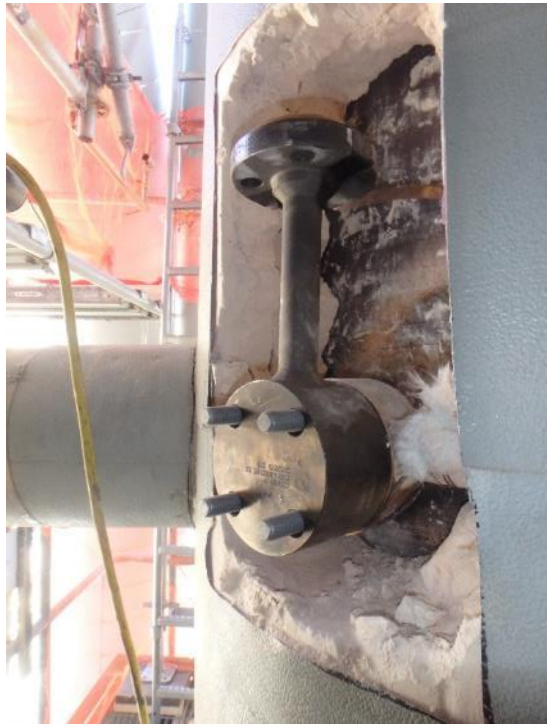
Root of downstream steam pipe weld from the inside bottom



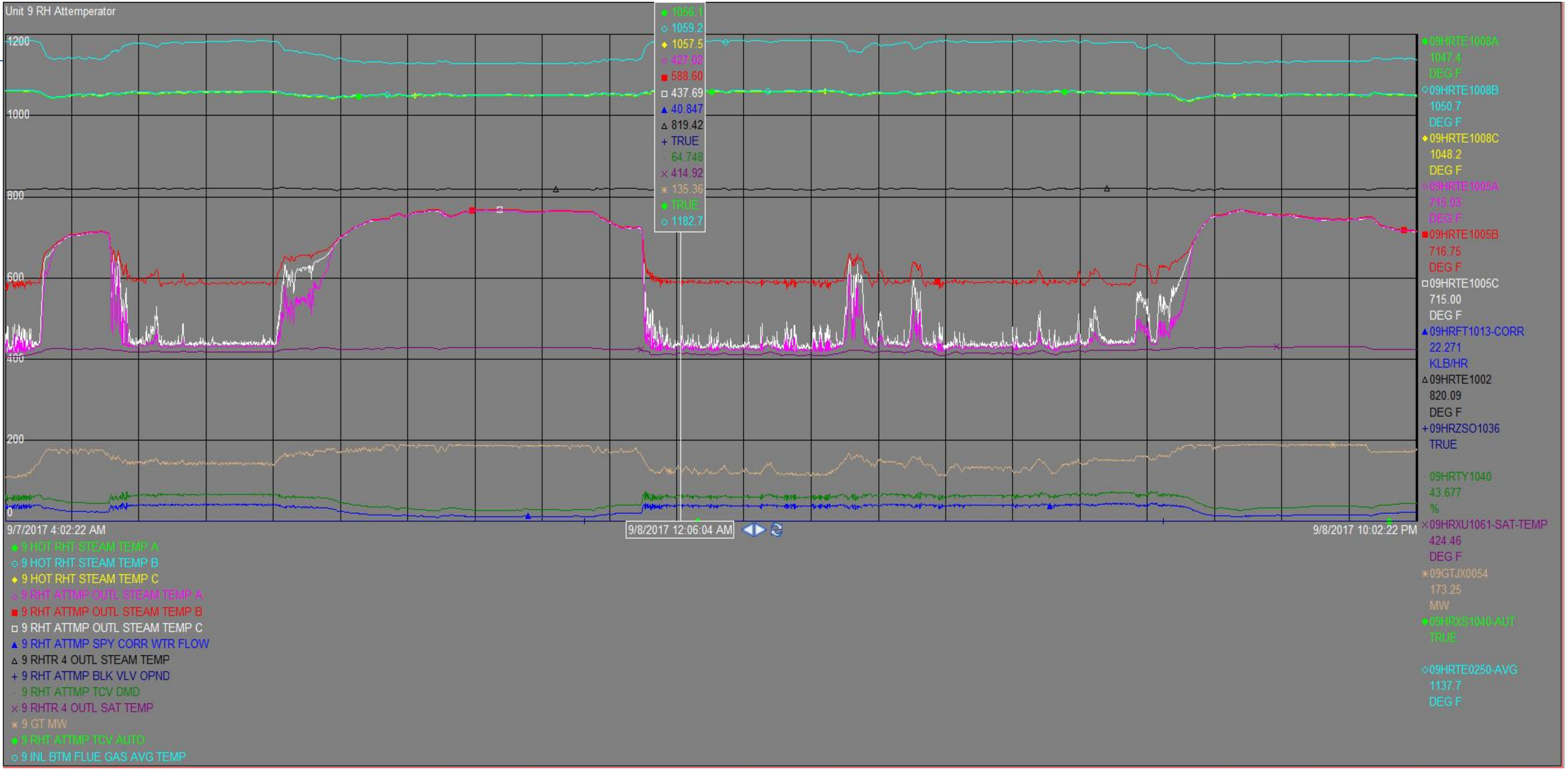
Field Trial Installation

- HP drum steam connection at hydrotest piping

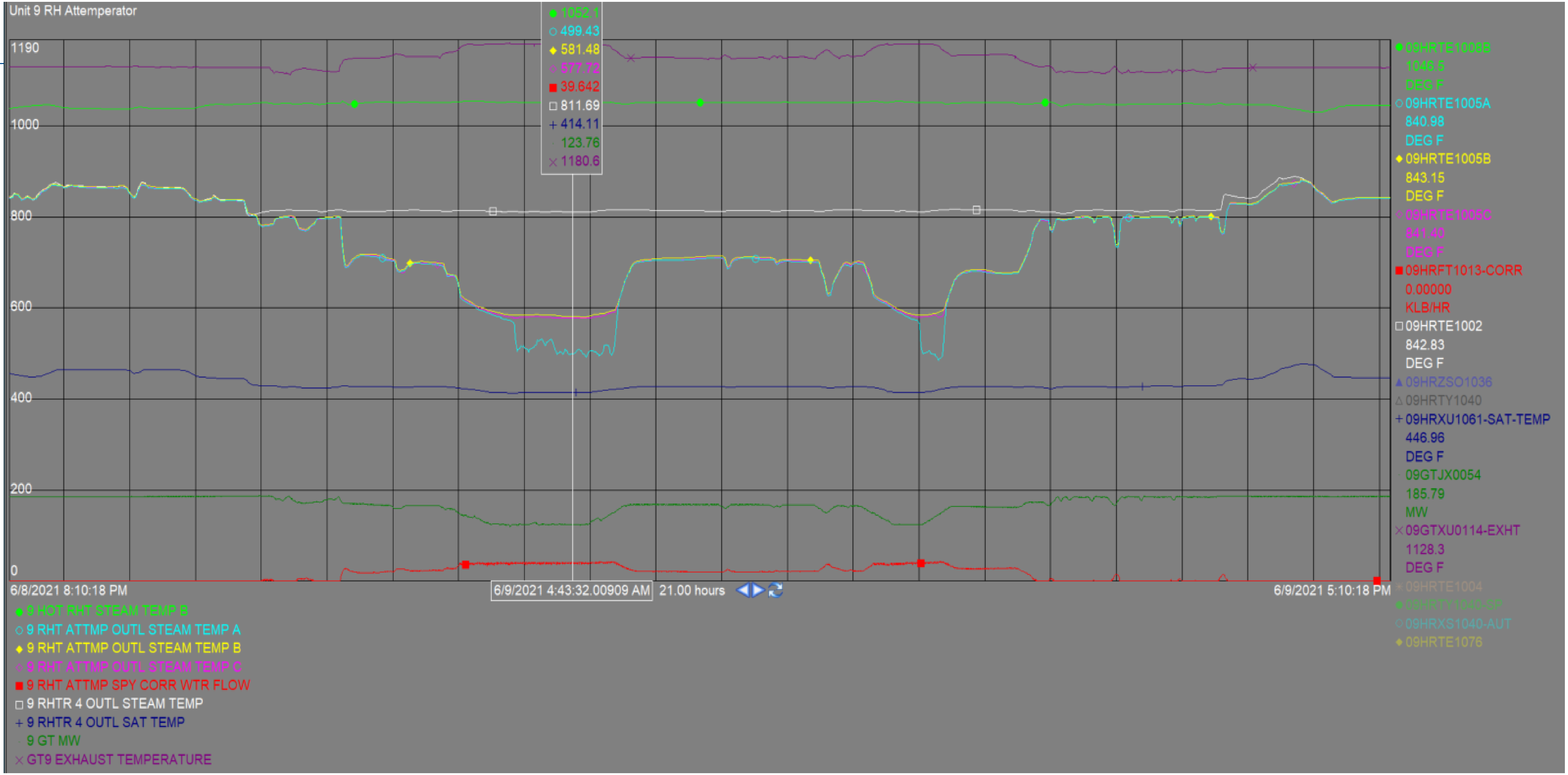


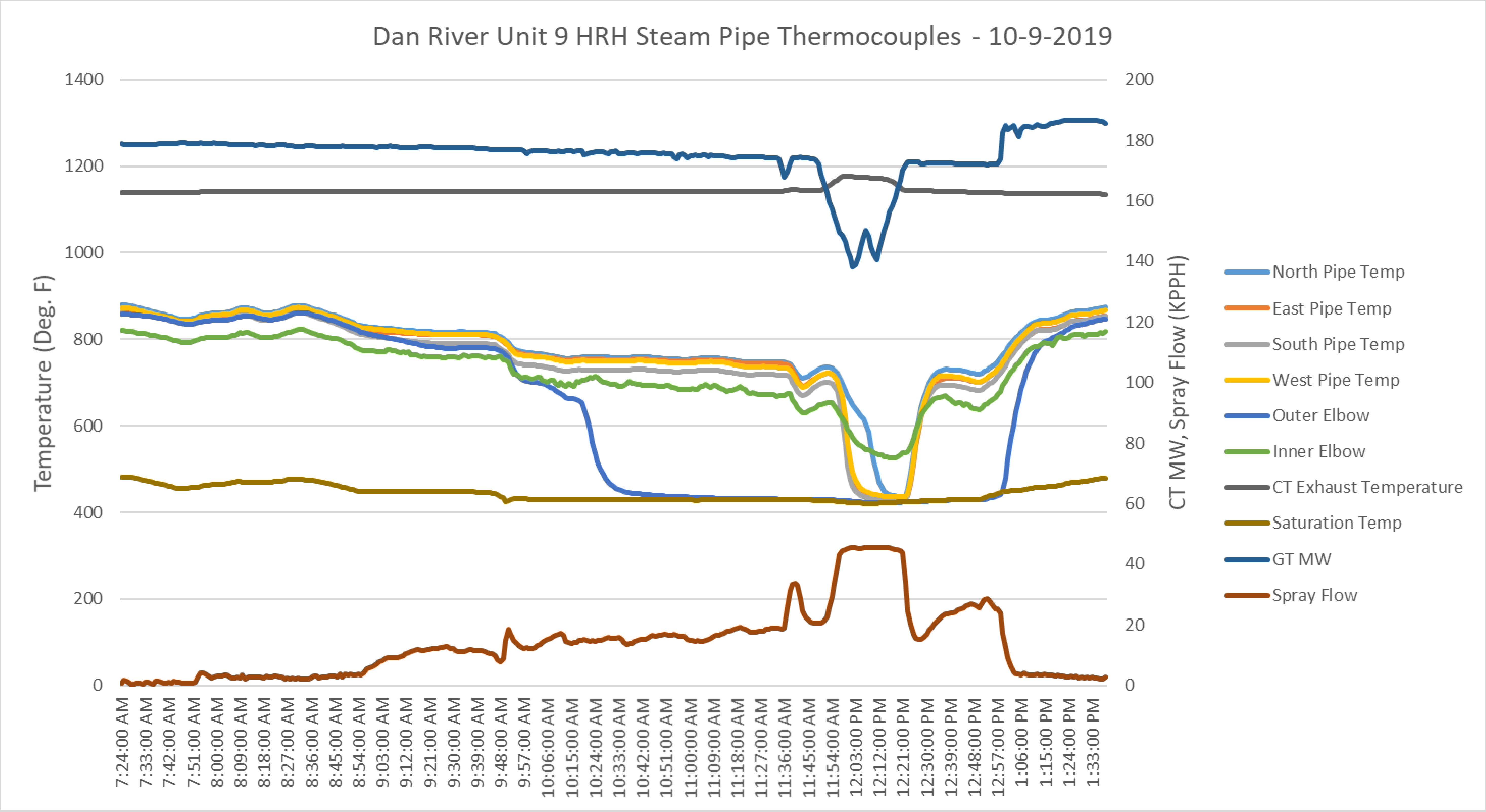


Dan River Before

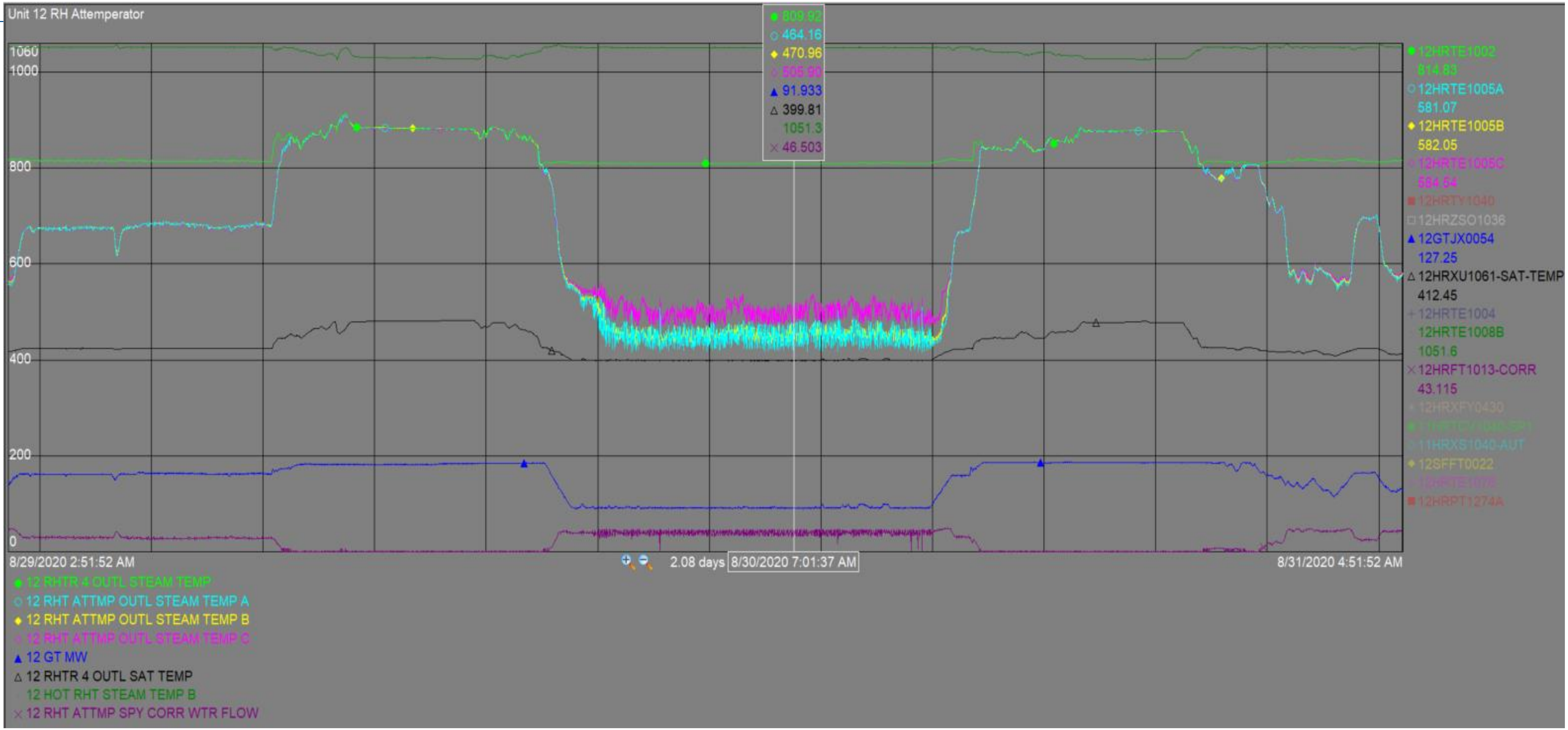


Dan River After

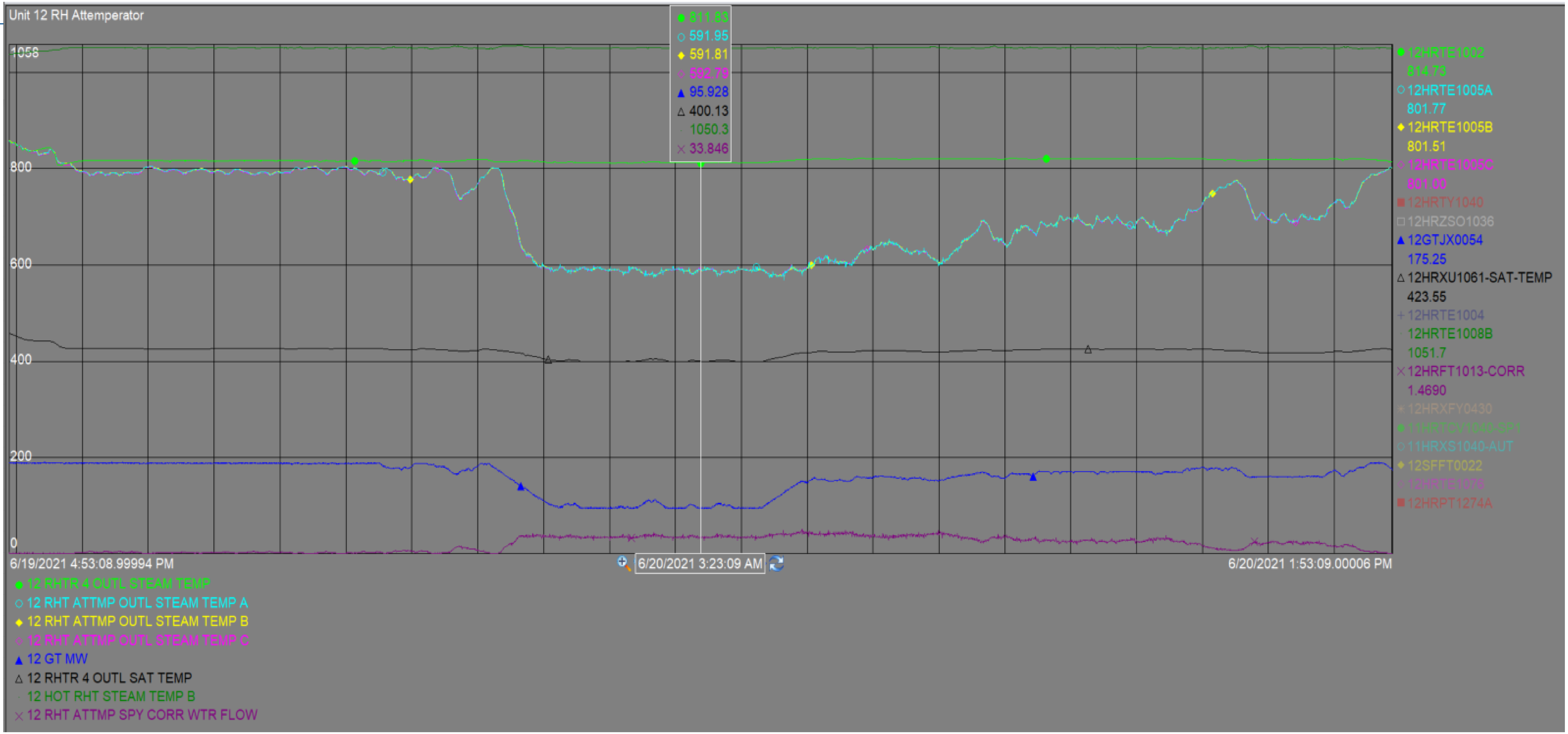



Dan River Unit 9 HRH Steam Pipe Thermocouples - 10-9-2019
Temperature (Deg. F)
CT MW, Spray Flow (KPPH)
1400
1200
1000
800
600
400
200
0
200
180
160
140
120
100
80
60
40
20
0
7:24:00 AM
7:33:00 AM
7:42:00 AM
7:51:00 AM
8:00:00 AM
8:09:00 AM
8:18:00 AM
8:27:00 AM
8:36:00 AM
8:45:00 AM
8:54:00 AM
9:03:00 AM
9:12:00 AM
9:21:00 AM
9:30:00 AM
9:39:00 AM
9:48:00 AM
9:57:00 AM
10:06:00 AM
10:15:00 AM
10:24:00 AM
10:33:00 AM
10:42:00 AM
10:51:00 AM
11:00:00 AM
11:09:00 AM
11:18:00 AM
11:27:00 AM
11:36:00 AM
11:45:00 AM
11:54:00 AM
12:03:00 PM
12:12:00 PM
12:21:00 PM
12:30:00 PM
12:39:00 PM
12:48:00 PM
12:57:00 PM
1:06:00 PM
1:15:00 PM
1:24:00 PM
1:33:00 PM
North Pipe Temp
East Pipe Temp
South Pipe Temp
West Pipe Temp
Outer Elbow
Inner Elbow
CT Exhaust Temperature
Saturation Temp
GT MW
Spray Flow

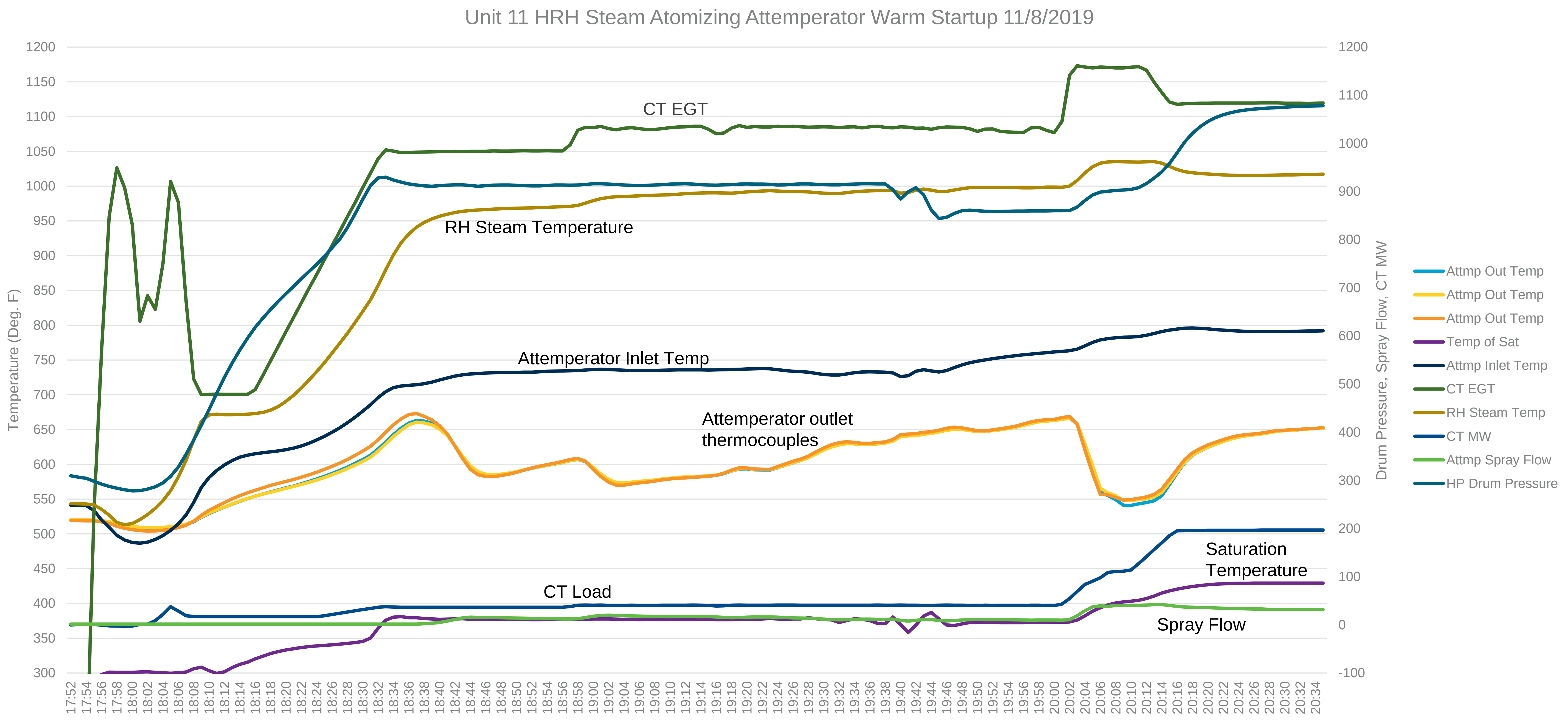
Buck Unit 12 Before Installation



Buck Unit 12 After Installation



Buck 11/8/2019 Warm Startup



Project Milestones

Q2
2019
Initial Buck field trial installed on Unit 11

Q4
2019
Unit 11 modifications completed – upgraded to a pressure control valve

Q4
2020
Installation completed Buck Unit 12

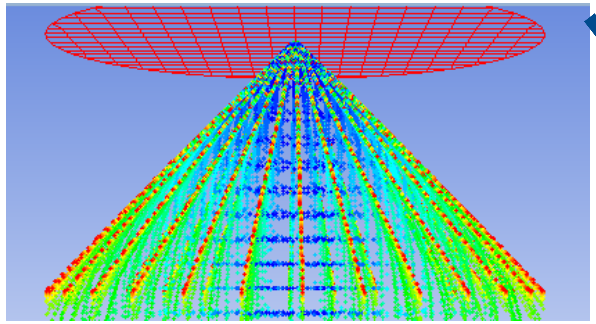
Unit 11 final modifications and nozzle testing

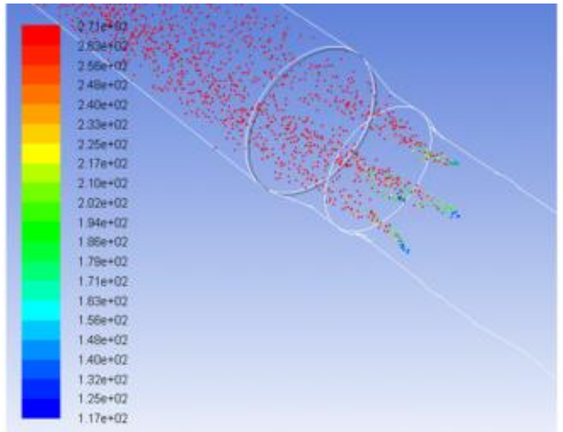
Q2 2021

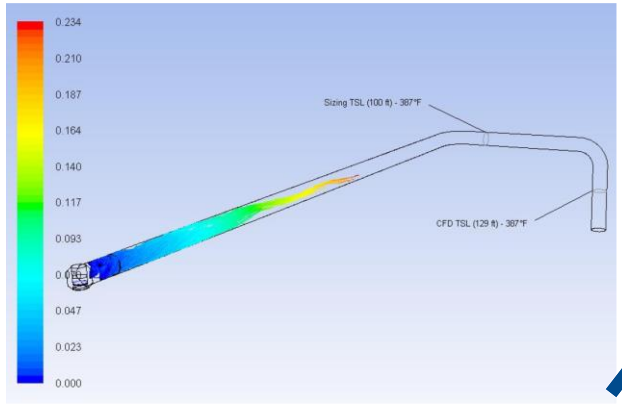
Dan River completed installation on both units

Q4
2021
Projects planned for Smith PB4

Designing for Innovation at Emerson







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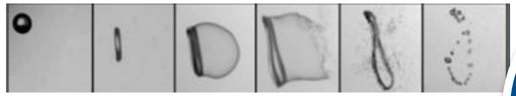
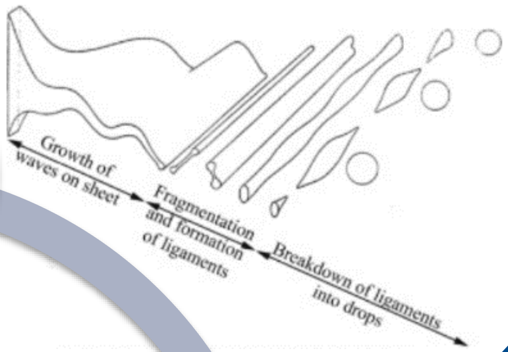




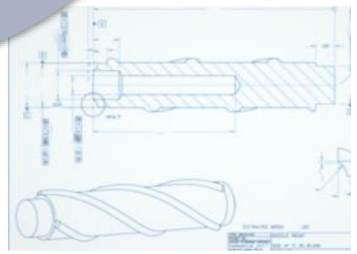
Research

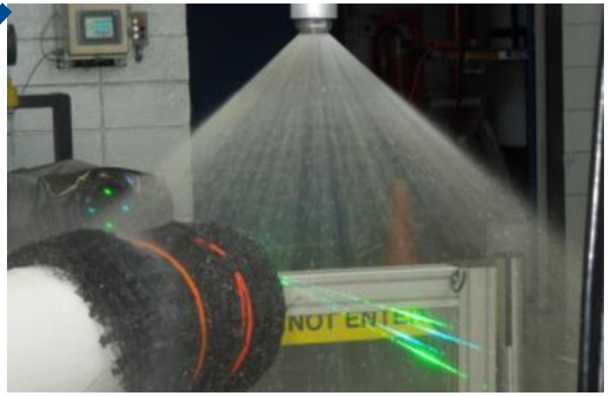
Simulate

INNOVATE

Test

Design





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