REINHOLD ENVIRONMENTAL Ltd.

2019 REINHOLD Round Table Presentation

June 24 & 25, 2019, in Birmingham, Alabama / Hosted by Southern Company

Lessons Learned from a fleet of operating Bottom Ash Continuous Dewatering & Recirculation (CDR) Systems

Prepared for: 2019 REINHOLD Round Table

Presented By: Kevin L. McDonough

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Safety Moment

Overview

WTD Industry Update & CDR System Overview

Lessons Learned: Water Chemistry

Lessons Learned: R-SFC Design Enhancements

Conclusions & Recommendations

Overview

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Lessons Learned: Water Chemistry

Lessons Learned: R-SFC Design Enhancements

Conclusions & Recommendations

UCC Wet-to-Dry Ash Conversion Update

WTD Projects Awarded to UCC (2009-2019)

Project Type	# of Projects Awarded	# of Units Converted
Bottom Ash Wet-to-Dry Conversions	**56**	**117**
Fly Ash Wet-to-Dry Conversions	**26**	**56**

UCC Wet-to-Dry Ash Conversion Update

Coal Units: Dry Ash Handling Systems

Project Type	Unit Conversion %
% of U.S. Fleet installed with or converted to Dry Fly Ash (Includes Projects In Progress)	**>98%**
% of U.S. Fleet installed with or converted to Dry Bottom Ash (Includes Projects In Progress)	**>50%**

Bottom Ash Wet-To-Dry Conversions

Technology Alternatives

Submerged Flight Conveyor

- Long-Term Economical Choice (Low O&M Costs)
- Simple Solution if Space Under Boiler is Available

Re-Circulating Hydraulic System (3 Options)

- No Changes Under Boiler, Uses Existing Hopper
- Minimizes Outage Requirements

Clarifying Hydraulic System

- No Changes Under Boiler, Uses Existing Hopper
- Minimizes Outage Requirements
- Allows for Water Reuse (FGD Makeup per ELG)

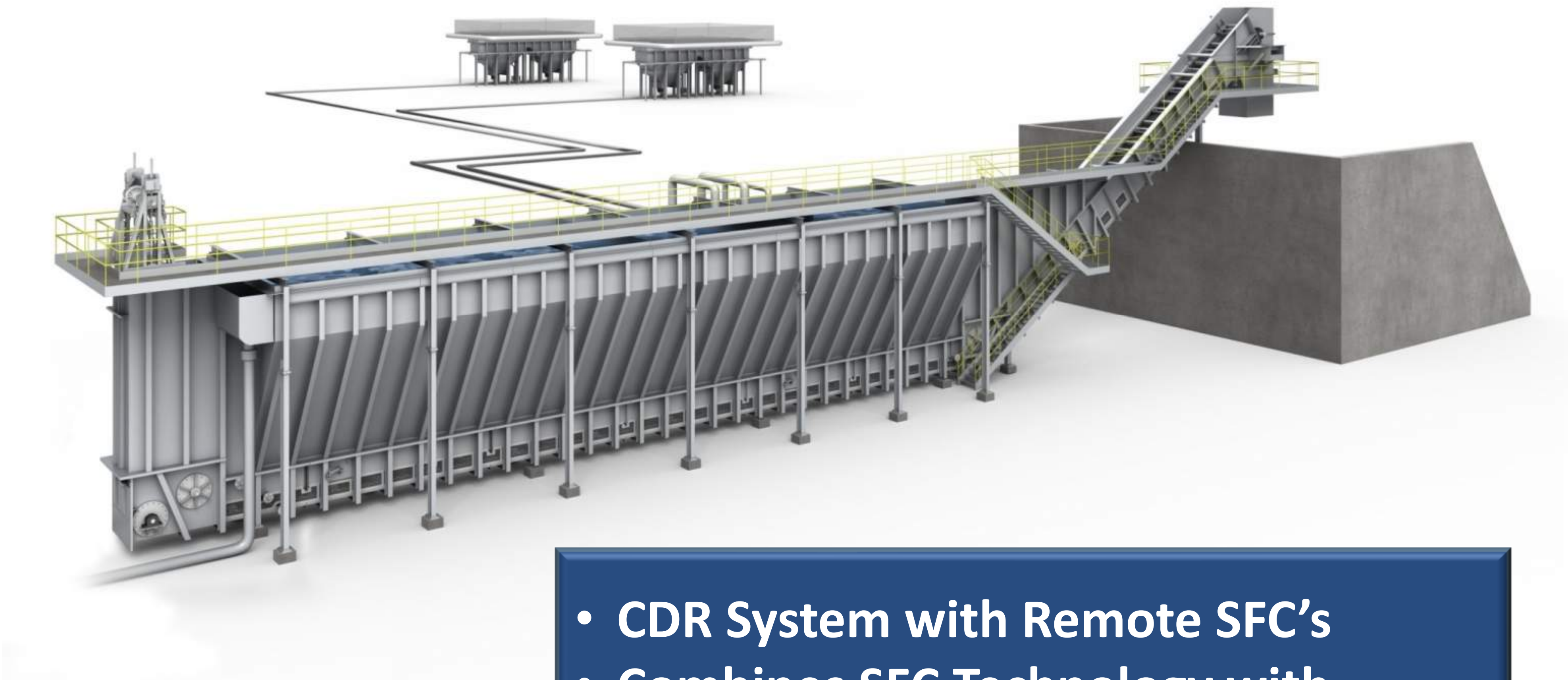
100% Dry Pneumatic / Mechanical Conveying

- No Water, Maintains O&M Flexibility, Reduces LOI
- Elimination of Long-term Environmental Wastewater Risk

Continuous Dewatering & Recirculation (CDR) System

Bottom Ash WTD Conversion Alternatives

Continuous Dewatering & Recirculation System (CDR) with Remote SFC's



- CDR System with Remote SFC's
- Combines SFC Technology with Conventional Recirculation System

Water Balance/Wastewater Considerations

Bottom Ash Sluice Water Demands for CDR Systems

Typical Water Requirements:

- High Pressure Sluice Conveying Water = 2,500-3,500 gpm
- Low Pressure Cooling Water/Seal Trough Flushing/Make-Up Water Supply = 150-300 gpm/unit

Water Balance/Wastewater Considerations

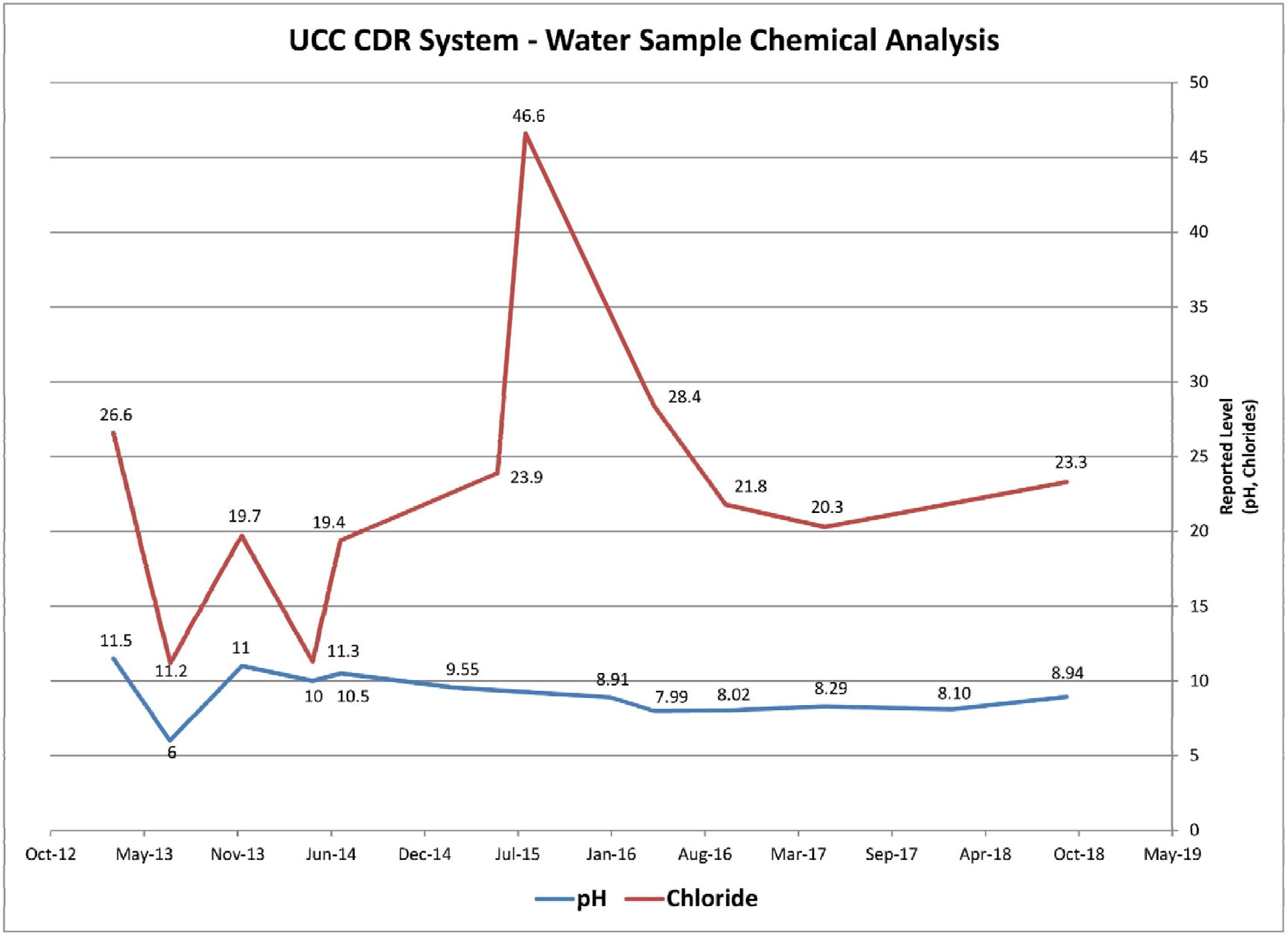
Bottom Ash Sluice Water Demands for CDR Systems

Water Balance Key Considerations

- **Losses**
  - Evaporation
  - Water Retention in Ash
  - Hopper Leakage
  - Seal Trough Flushing
- **Gains**
  - Chain Sprays – SFC (for CDR System)
  - Seal Water from Pumps (if not mechanical)
  - Rain
- **Will Have Net Loss of Water from System**
- **Water Balance can be complex**

Water Balance/Wastewater Considerations

Bottom Ash Sluice Water Quality and Chemistry (Fuel = Eastern Appalachian)



Overview

WTD Industry Update & CDR System Overview

Lessons Learned: Water Chemistry

Lessons Learned: R-SFC Design Enhancements

Conclusions & Recommendations

UCC Field Testing Summary

- Some plants have experienced low pH conditions in CDR Systems
- UCC conducted field investigations to identify root cause and develop remediation actions
- Case Study: Midwestern Plant
  - 4 Site Visits To Plant Over 7 Months
  - Samples Collected From All Units during High-load/Low-load Operations
- Total Of Samples Collected:
  - 95 Water Samples, 11 Bottom Ash Samples, 1 Coal Sample
- Samples Collected From:
  - Bottom Ash Hopper, Bottom Ash Hopper Overflow Tank (Inlet Pipe & Discharge Pipe To Pump), Pyrites System, Economizer System, R-SFC (Before Lamellas & Overflow After Lamellas)

Abnormal Wear Issues / R-SFC Components & Overflow Tank Corrosion

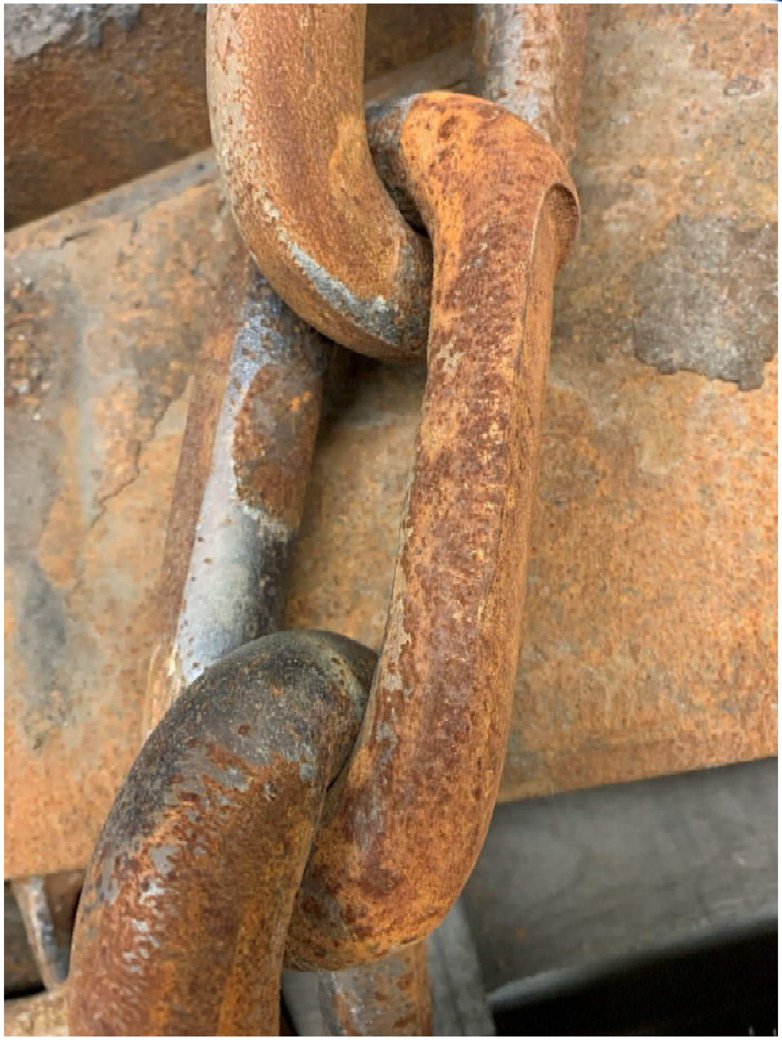
Issues – Corrosion
Overflow Tanks

Unit 3

Unit 1

- All Overflow tanks installed new as part of CDR project in 2017

Issues – Corrosion
SFC Materials – Chain



- Various chain samples collected from site for analysis

Issues – Corrosion

R-SFC Materials – AR400 Wear Plate

- Corroded and worn AR400 wear plate samples from R-SFCs collected for testing

Issues – Corrosion

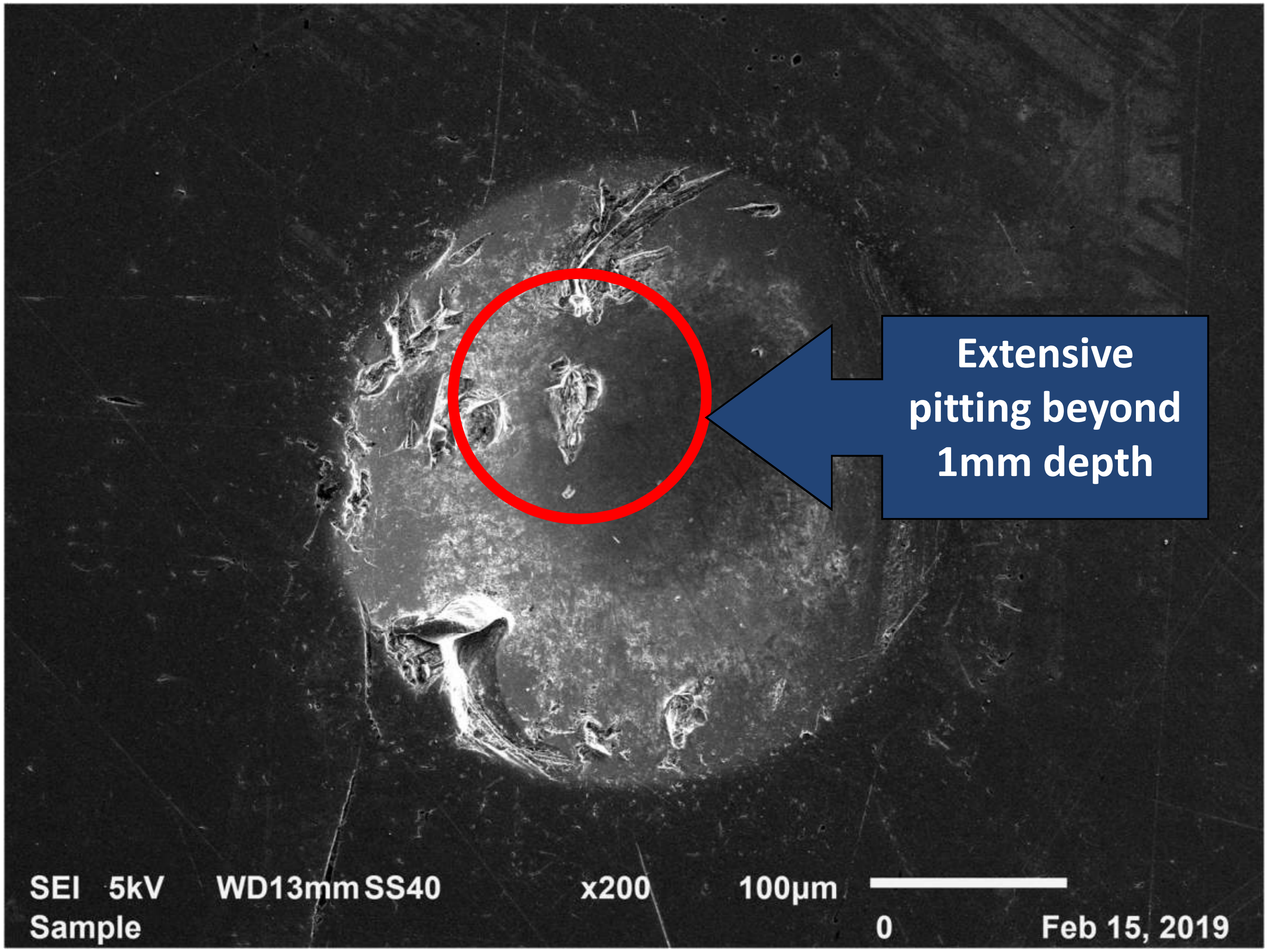
R-SFC Materials – Transition Wear Plate

- AR400 Sample ground down 1mm
  - Average hardness @ 1mm: 347 BHN
  - Average hardness @ 10mm: 394 BHN
- Sulfur Attack results in harness reduction by 12%

Issues – Corrosion

R-SFC Materials – Transition Wear Plate

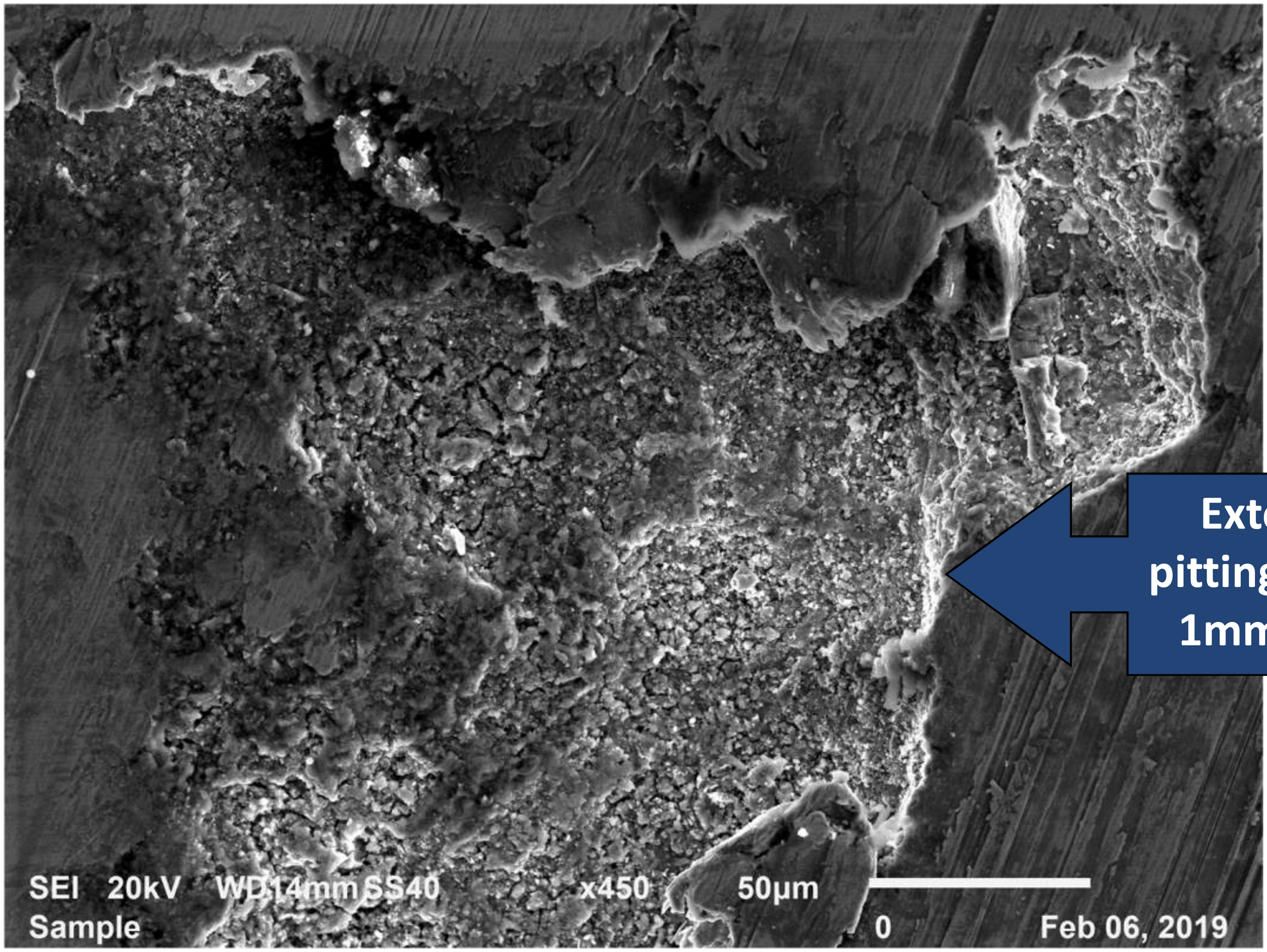
AR 400 Wear Plate – SEM (X200) Scan of 1mm Ground Down Tested Area



Issues – Corrosion

R-SFC Materials – Transition Wear Plate

AR 400 Wear Plate SEM (X450) Scan of Single Pit – 1mm Deep

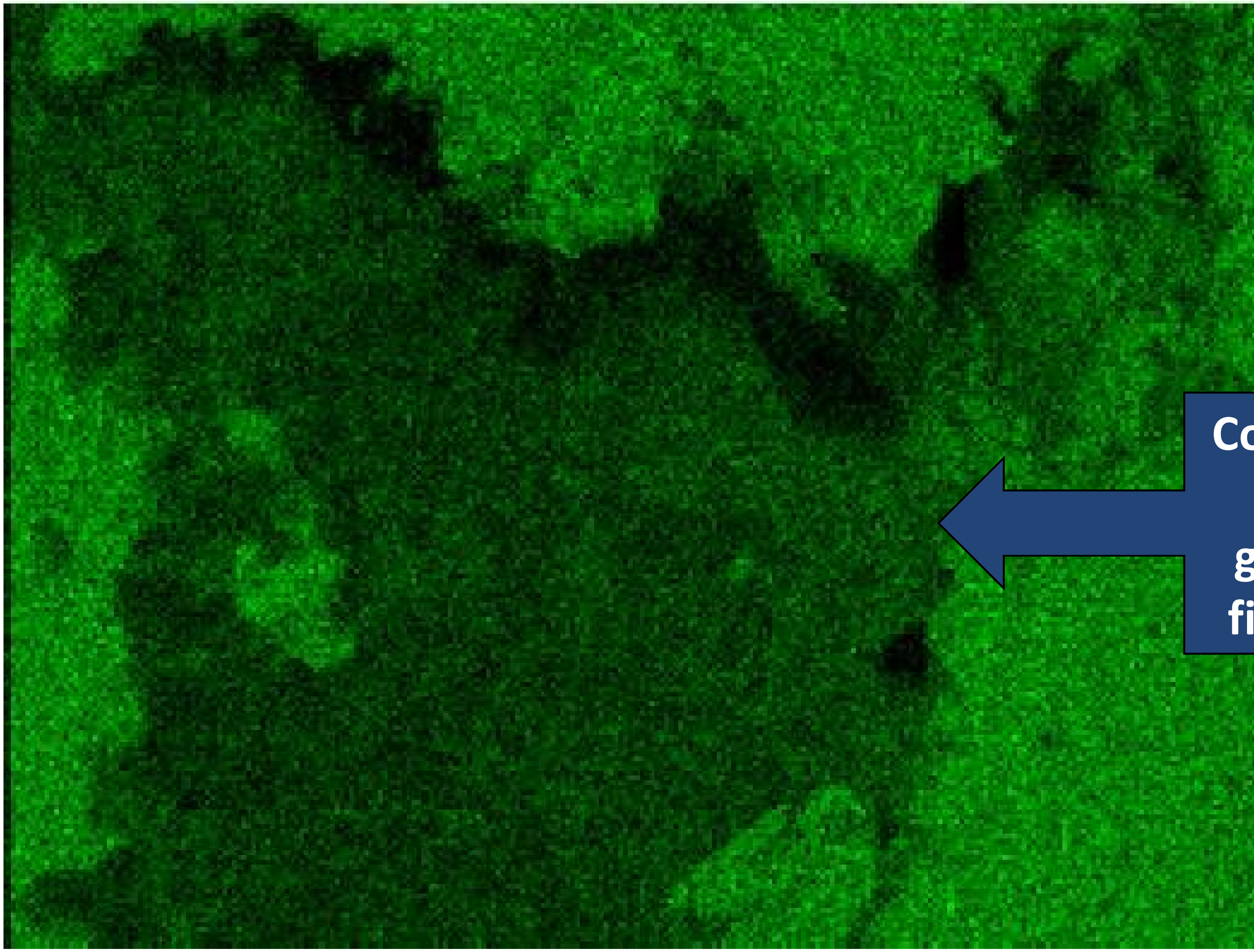


Extensive pitting beyond 1mm depth

Issues – Corrosion

R-SFC Materials –Transition Wear Plate

AR 400 Wear Plate SEM (X450) Scan of Single Pit – Iron

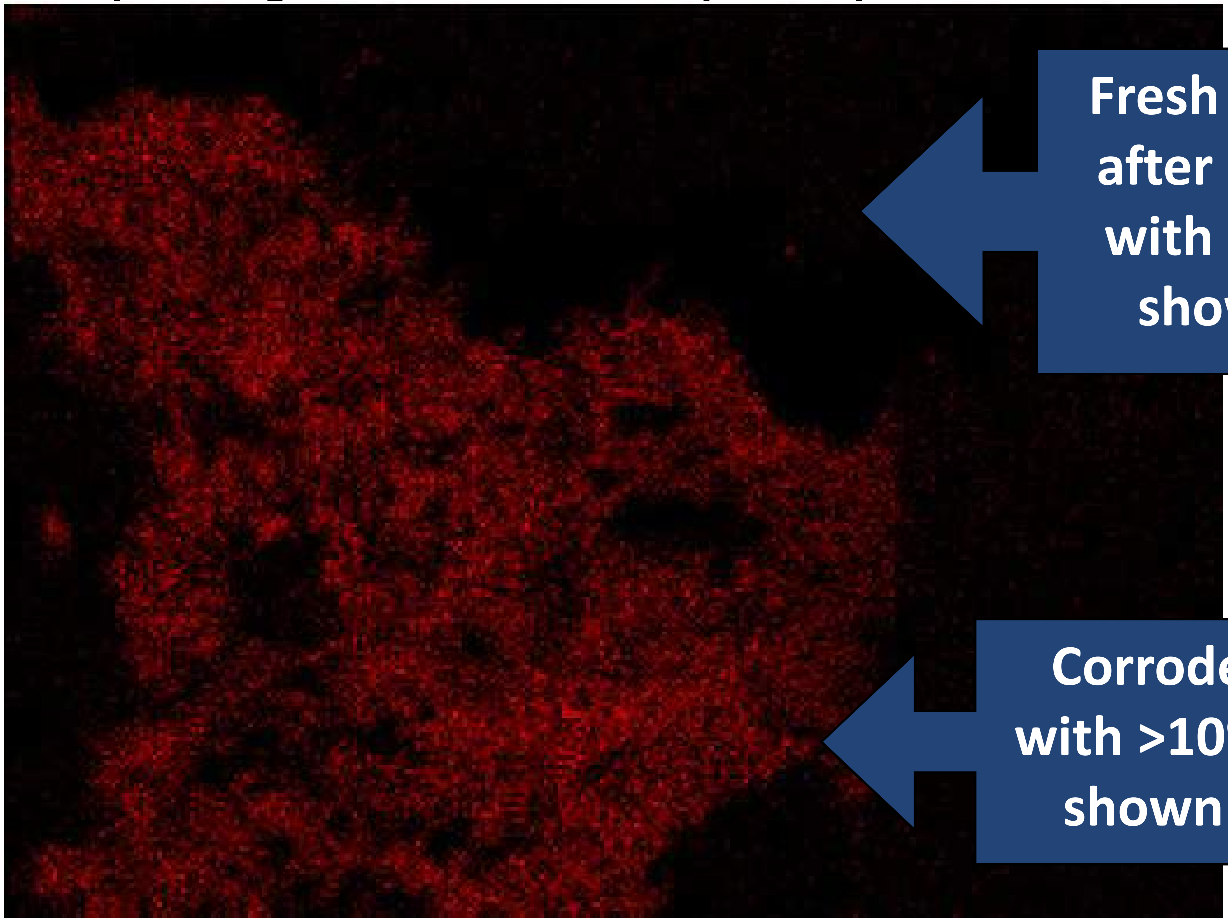


Corroded iron area shown in dark green under iron filter of SEM scan

Issues – Corrosion

R-SFC Materials –Transition Wear Plate

SEM (X450) of Single Pit – 10% Sulfur (in RED), Rest of Plate < 0.2% Sulfur



- High sulfur content in pit, compared to rest of ground sample (having less than 0.2%,) suggests extensive sulfur attack in pitting
- Sulfur attack likely cause of corrosion, much like the grinding of the sample, the corroded material is scraped away under normal mechanical wear, exposing fresh material to be corroded by the sulfur attack

Issues – Corrosion

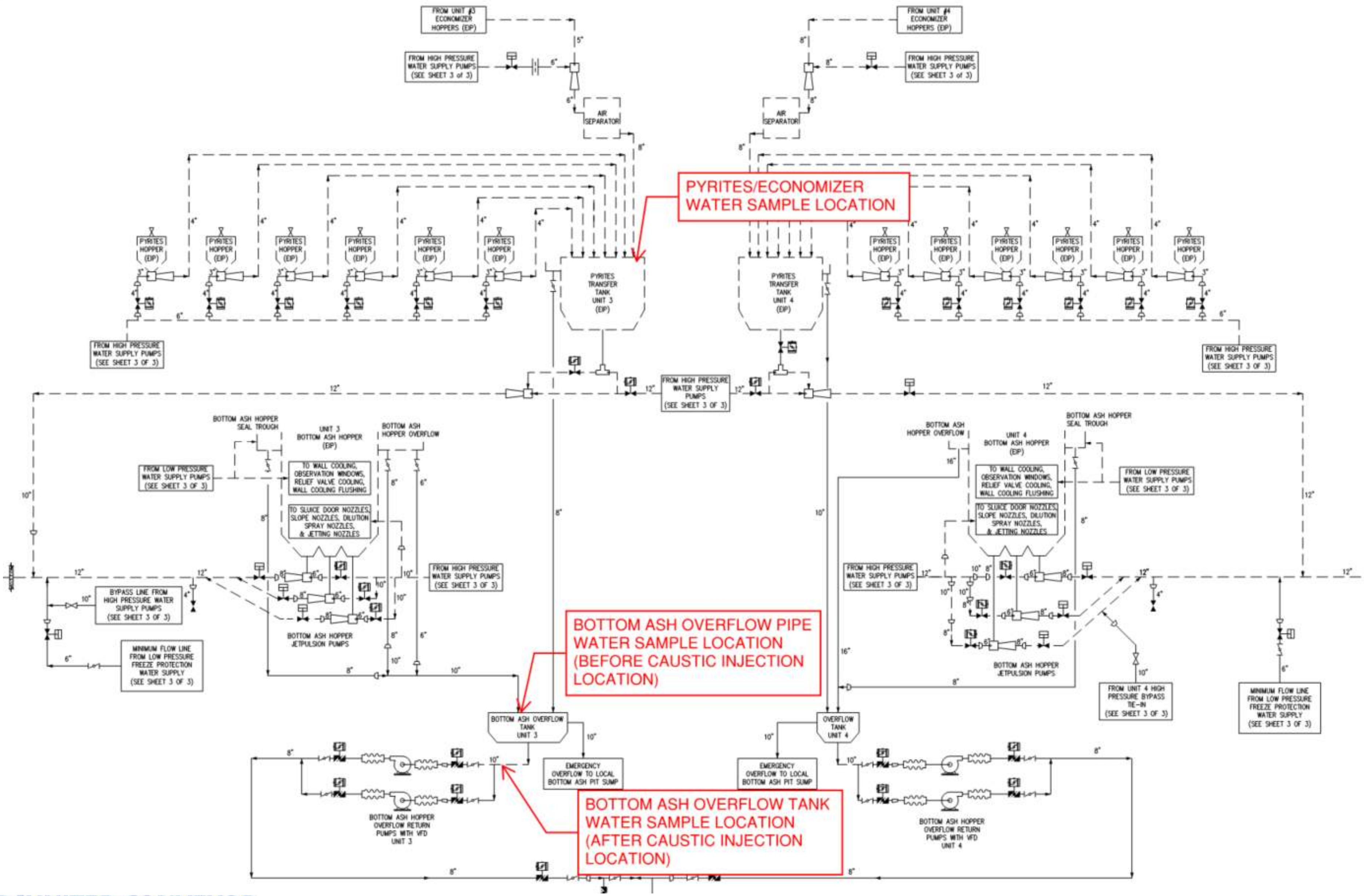
- “Corrosion can modify significantly the extent of wear between contacting sliding surfaces”
- “Corrosive wear can be considered as a combination of two independent processes”
  - (a) The chemical or, in the case of an electrolyte, the electrochemical interaction of the metal in direct contact with a corrosive medium.
  - (b) The mechanical action, which subsequently may remove either the protective film or products of corrosion from the contacting surfaces, leaving them freshly exposed to further attack.”
- “Weakening of the surfaces by removal of (such) hard carbides decreases the inherent resistance of the cast iron to abrasive wear”

“The Influence Of Corrosion On The Wear Of Cast Iron In Sulphuric Acid Solutions”

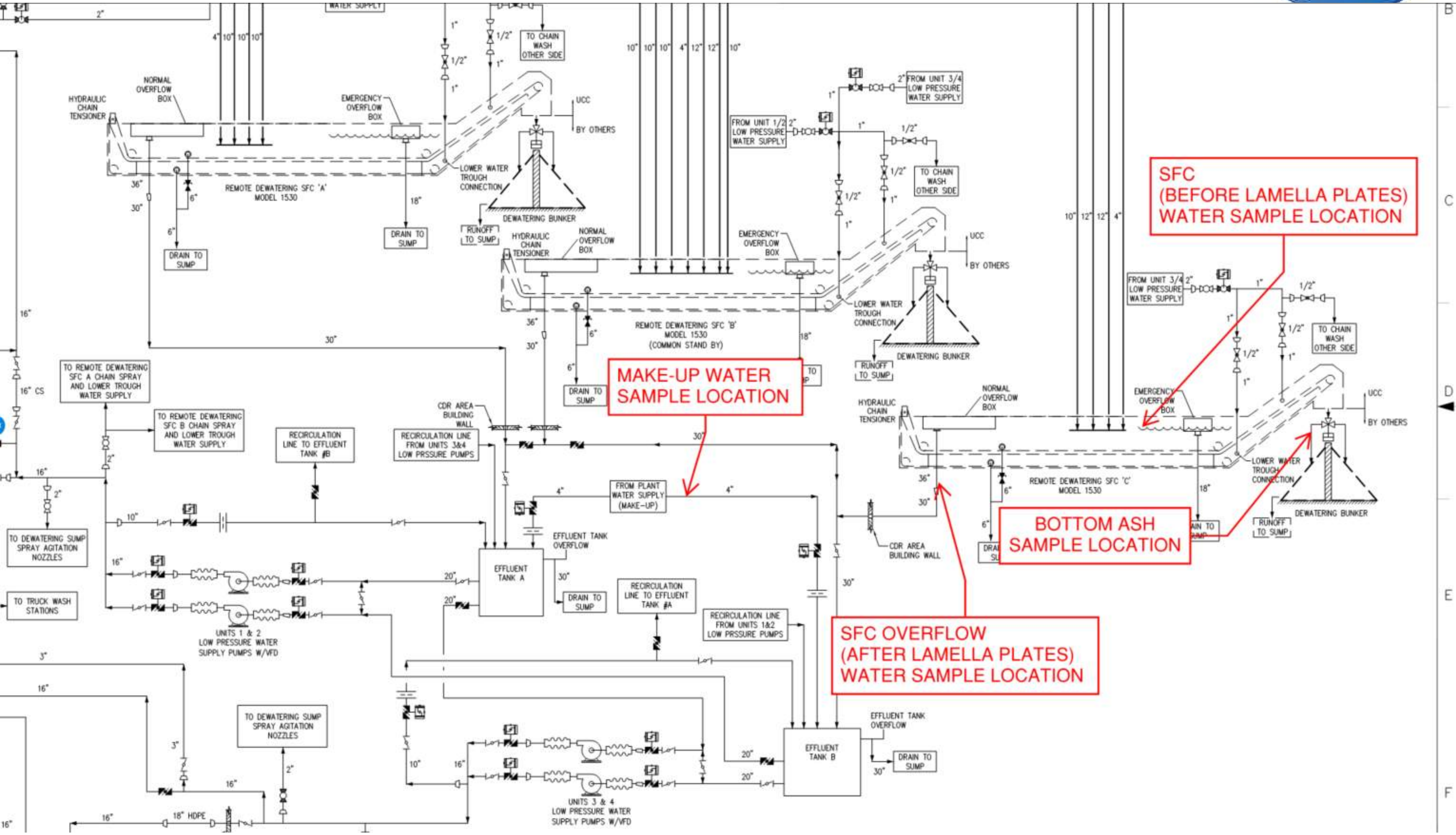
Stott F.H., Breakell J.E. 1993 Wear, ISSN: 0043-1648, Vol: 135, Issue: 1, Page: 119-134

Bottom Ash Transport Water Sample Locations & pH Measurements

Sampling Locations

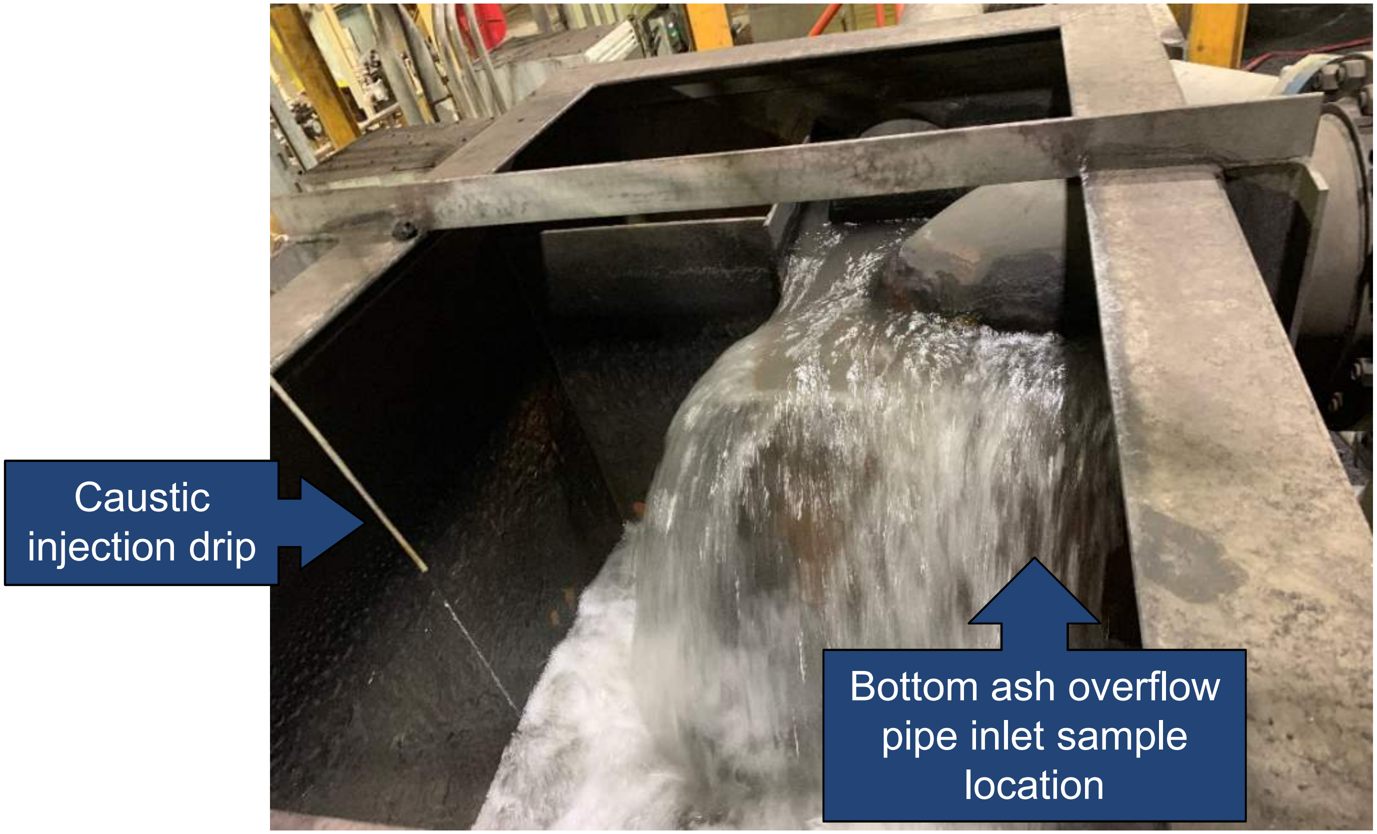


Sampling Locations



Sampling Locations

Overflow Pipe



- On other units where existing weir box was intact, overflow pipe inlet samples could be collected from overflow of weir (before mixing with caustic injection drip)

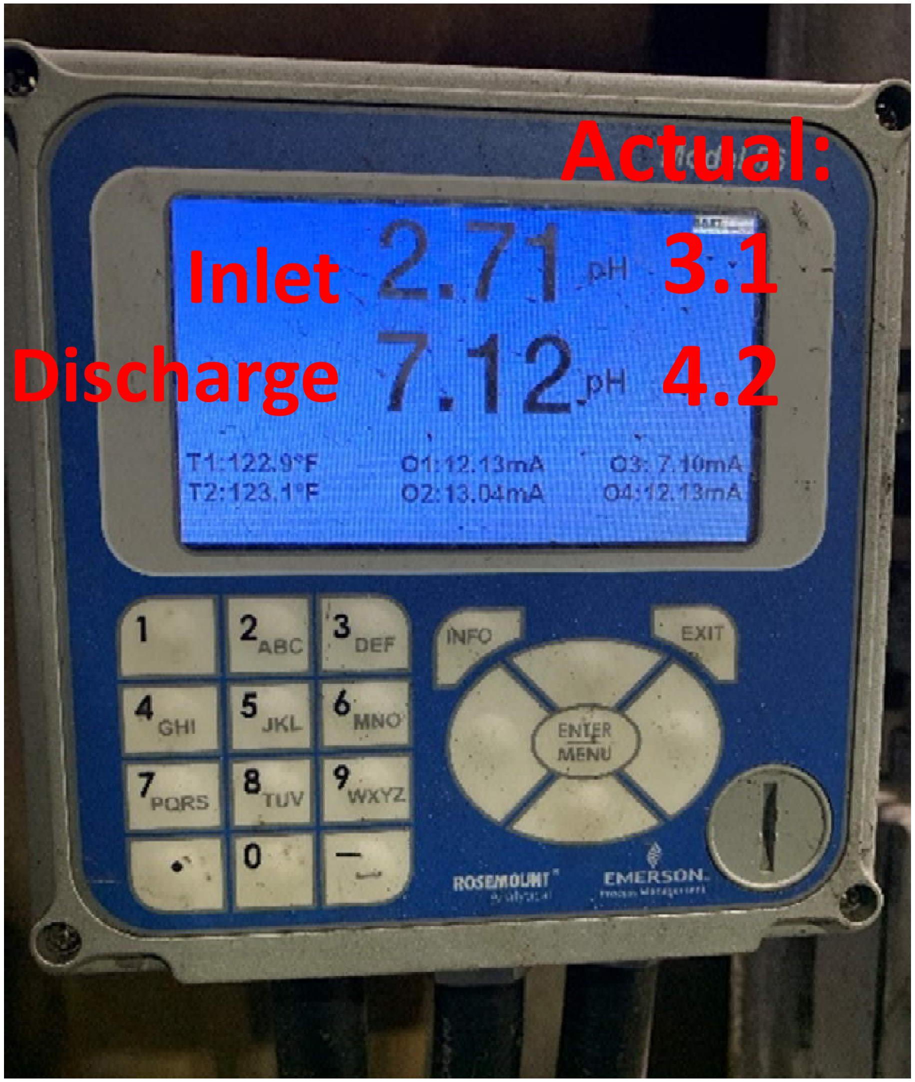
Sampling Locations

Overflow Tank Discharge - After Caustic

- Overflow tank discharge (after caustic injection location) water sample location, before overflow pumps

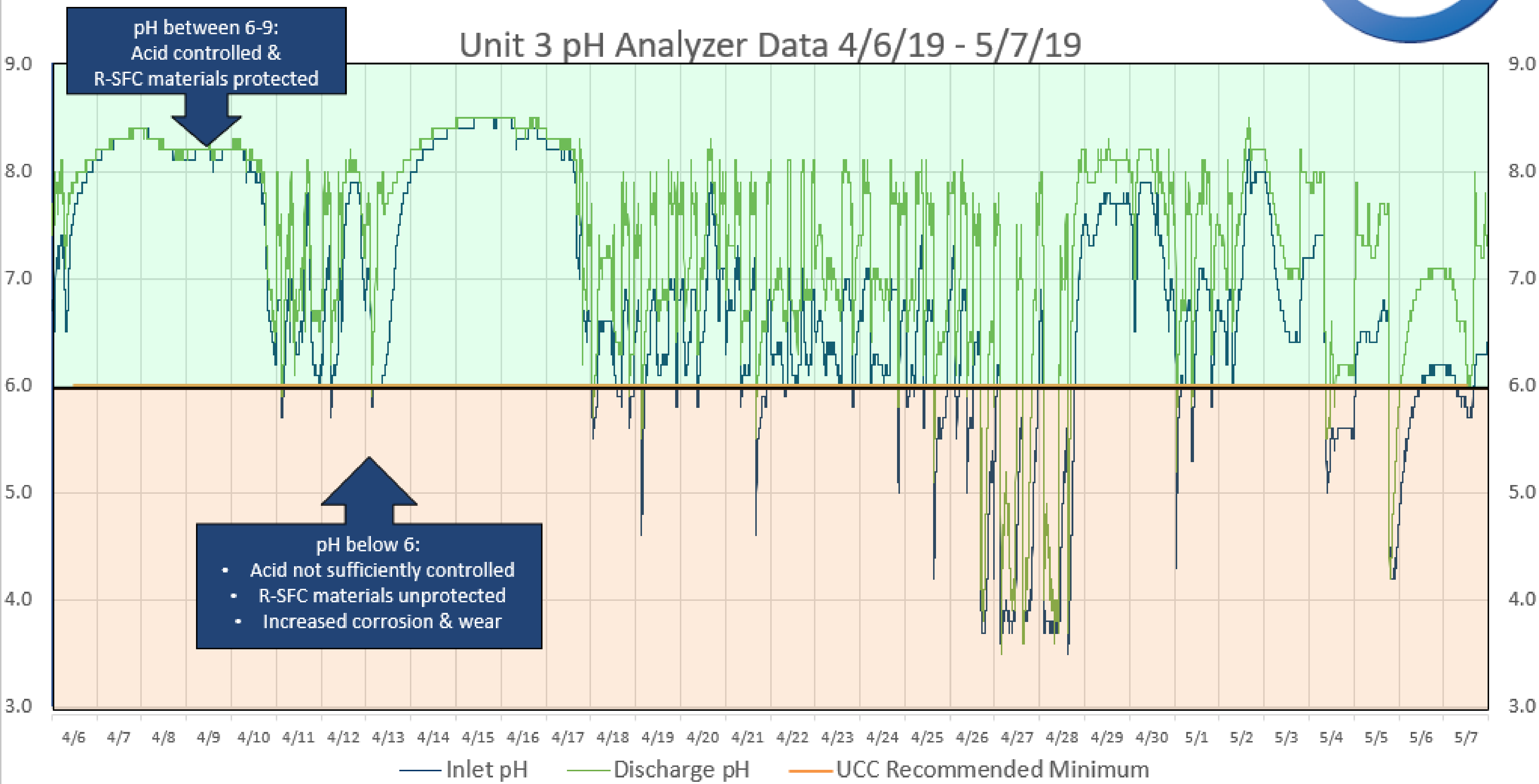
pH Probe Calibration

Issues – pH Probe Calibration



- Top value = Overflow Inlet
- Bottom value = Overflow outlet
- pH probes falling out of calibration
- pH probe connected to injection skid that controls caustic injection rate
- Result = Under-injecting caustic
- R-SFC not protected
- All downstream piping and equipment not protected
- Ultimately, all Closed-loop equipment not protected

Issues – pH Still Falling Below UCC Recommended Threshold

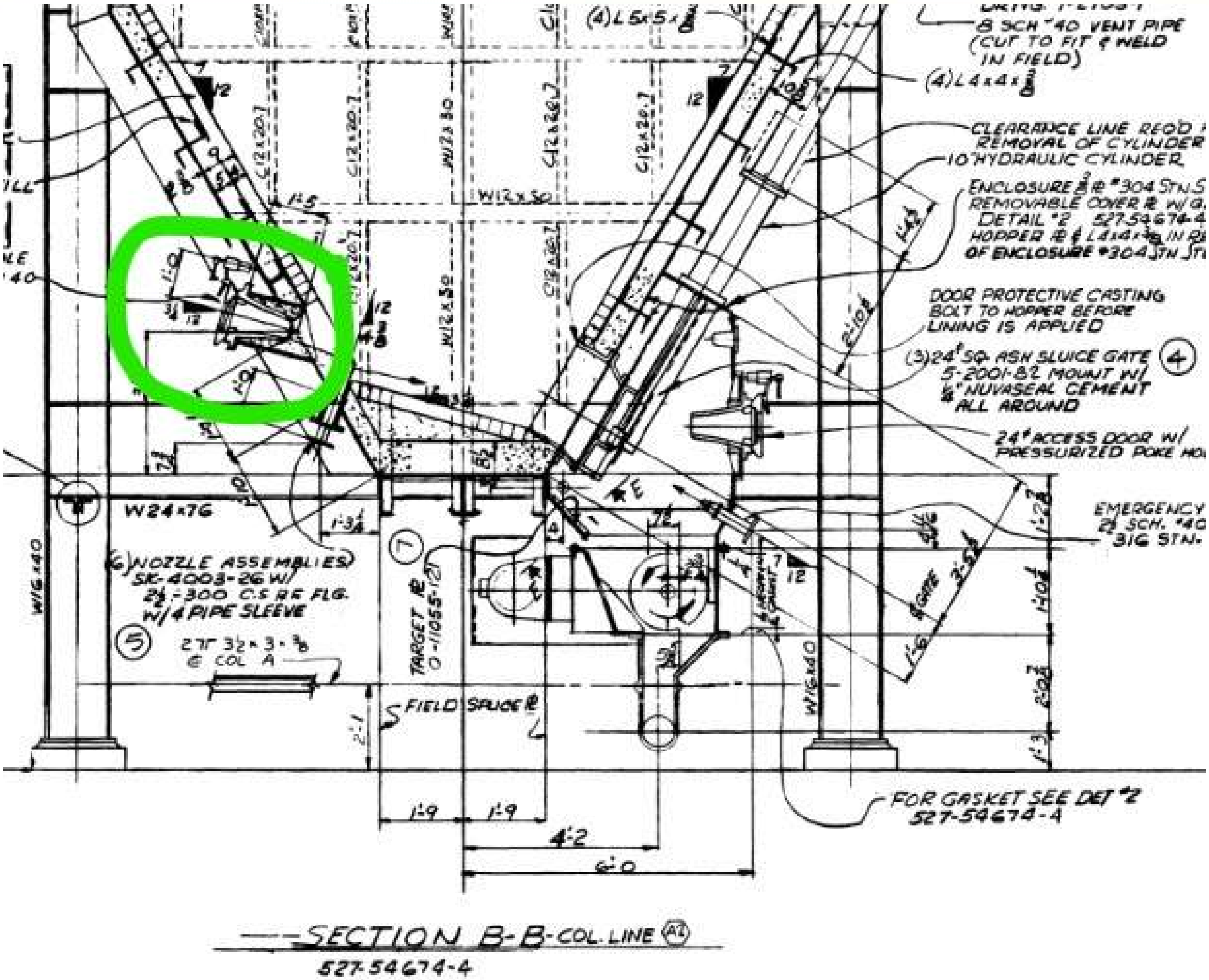


- pH probes calibration – ensure all pH probes are calibrated weekly
- Adjust caustic injection rates to ensure discharge pH is between 6-9

Low pH Source Identification & Root Cause Analysis

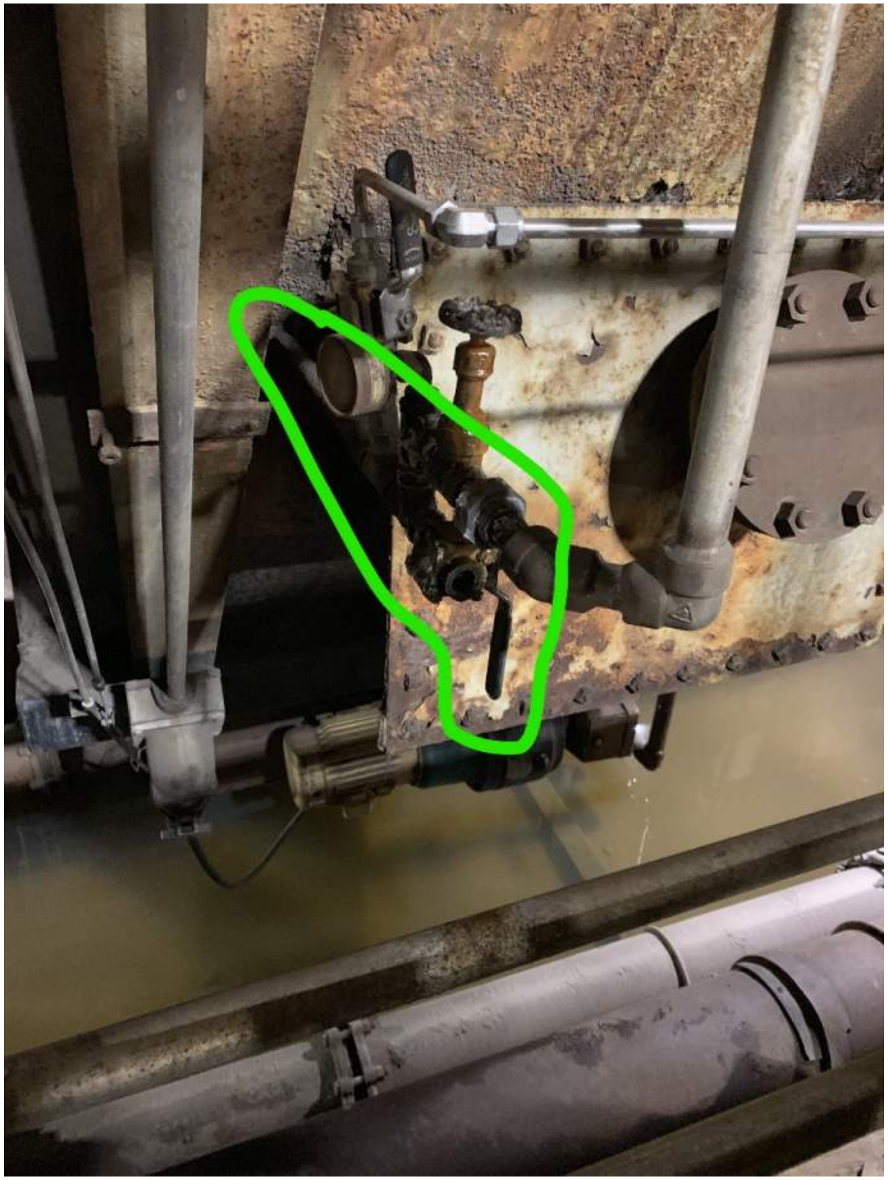
Sampling Locations

Bottom Ash Hopper – Low Measuring Point

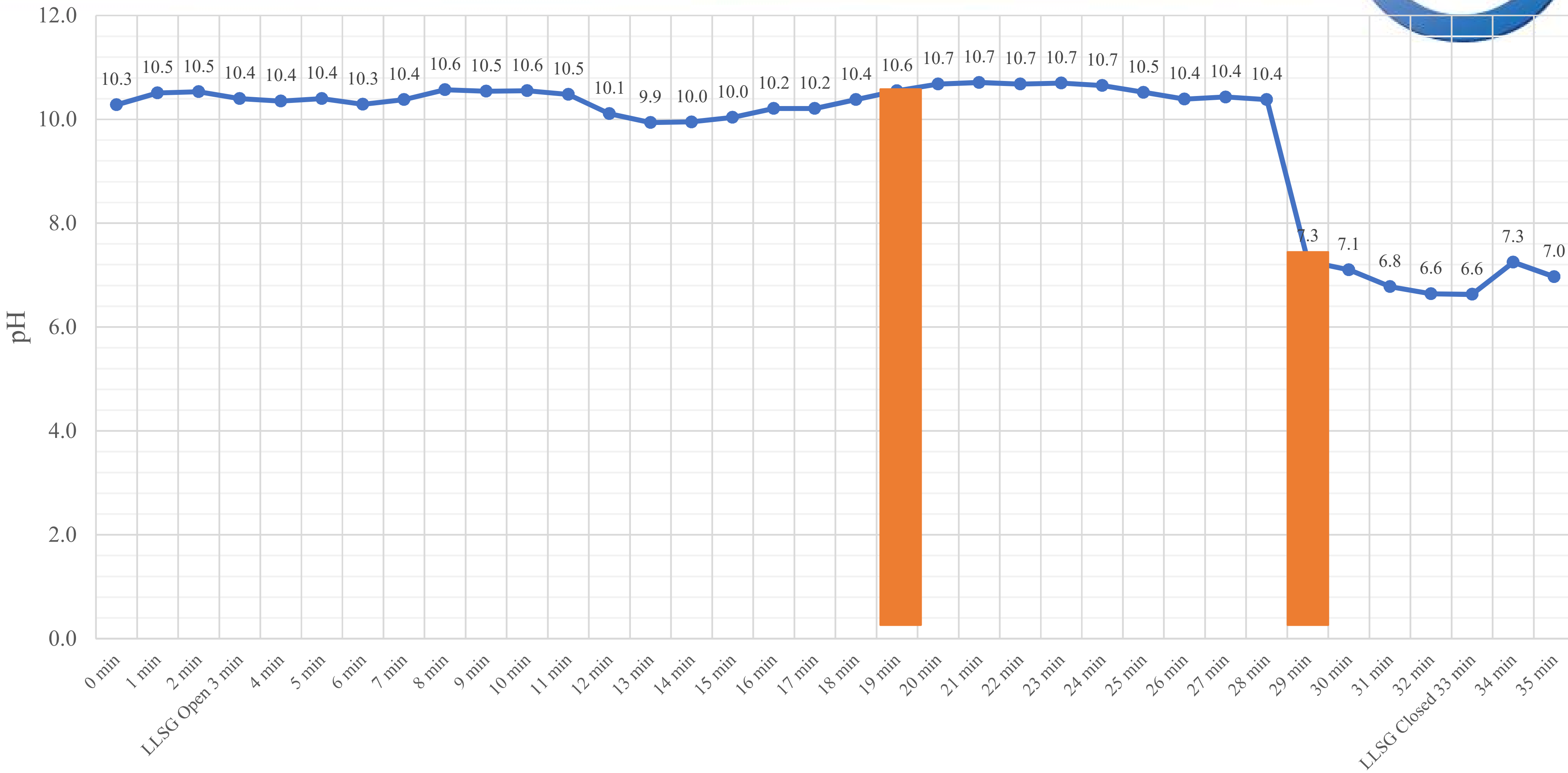


Sampling Locations

Unit 1 Bottom Ash Hopper – Low Measuring Point



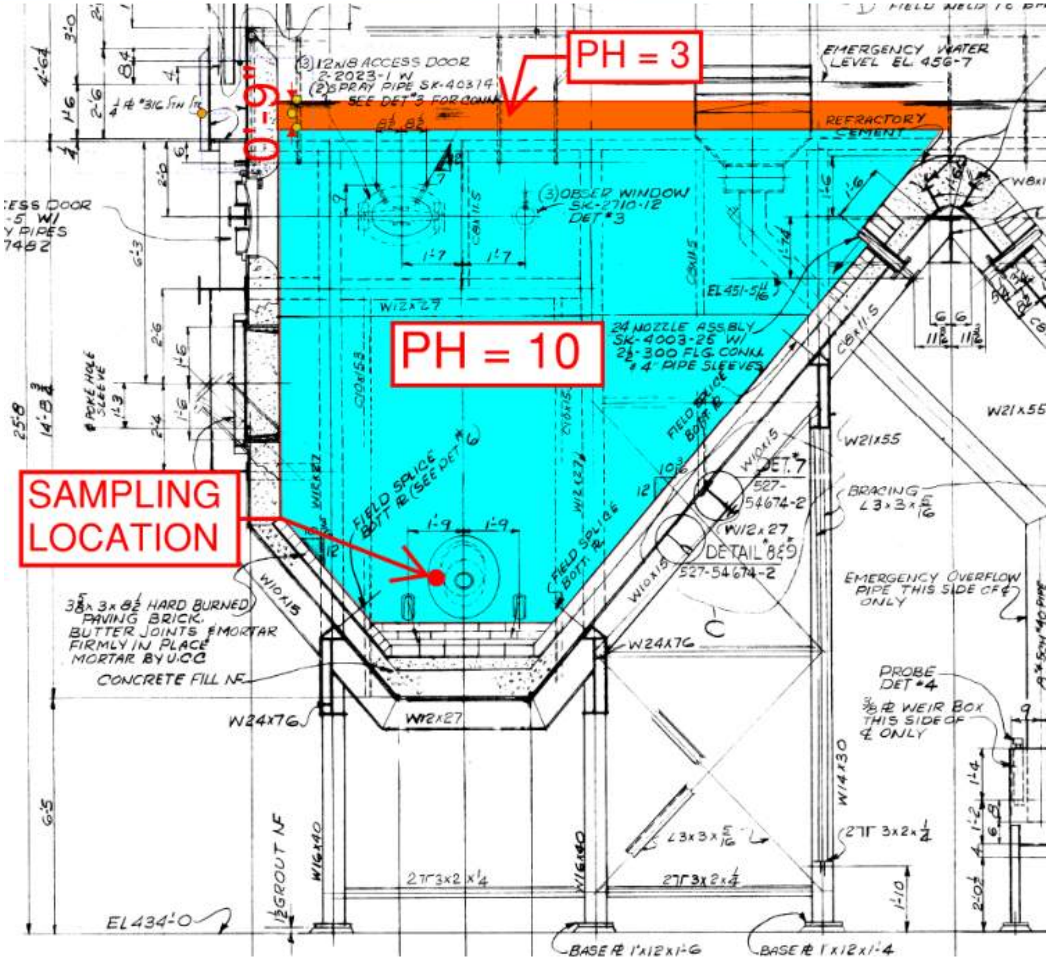
Unit 4 BA Hopper Low Measuring Point pH During Conveying Sequence



- Water sample was collected every minute from bottom ash hopper lower poke hole (shown in previous slides), while the hopper V-section was emptied.
- pH of samples were steady between 10-11 pH from start of cycle until surface water band (mixed with incoming make-up water) dropped pH to 6.6 pH, then raised to >7.0 pH (fresh make-up water) after sluice gate closed

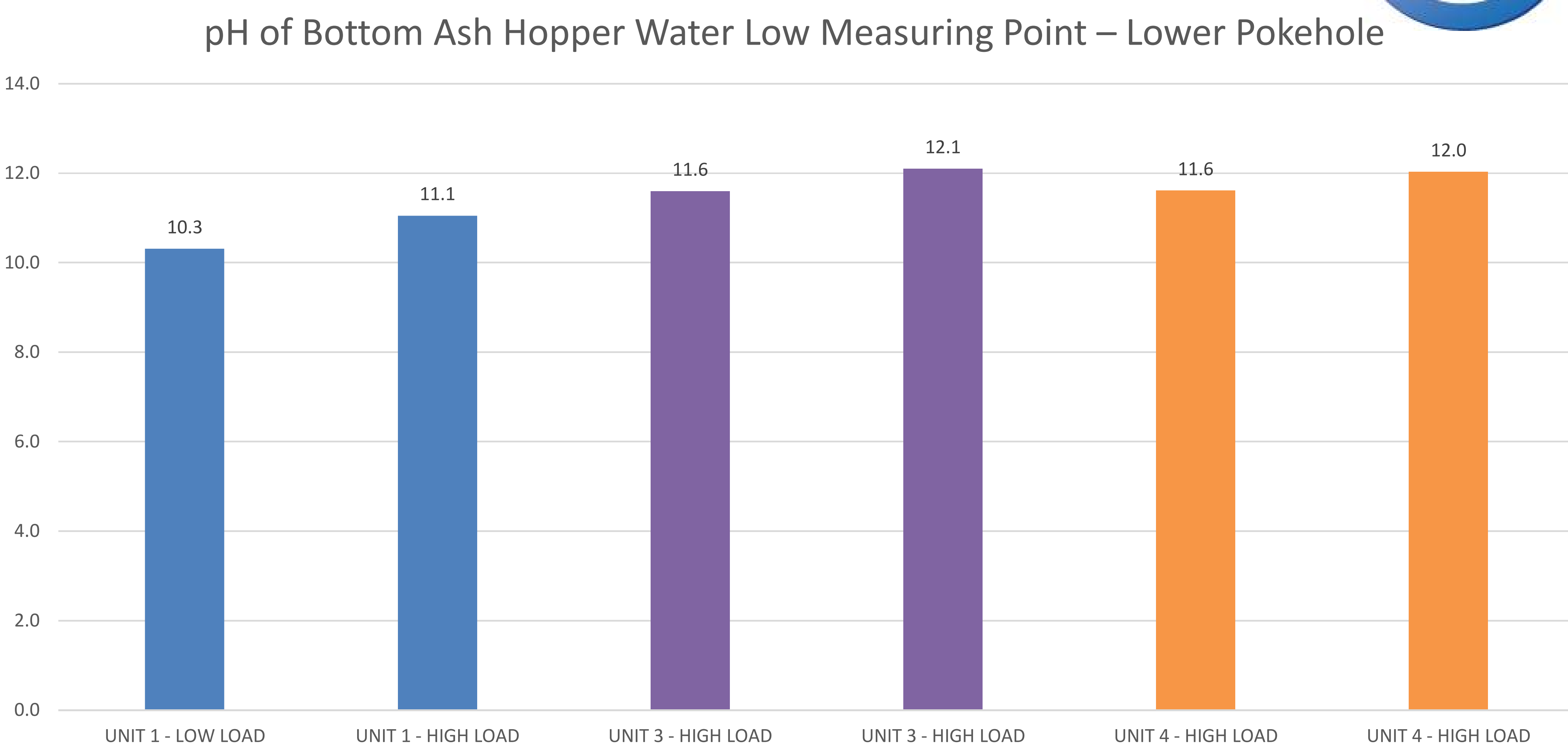
Unit 4 Bottom Ash Hopper

pH Stratification



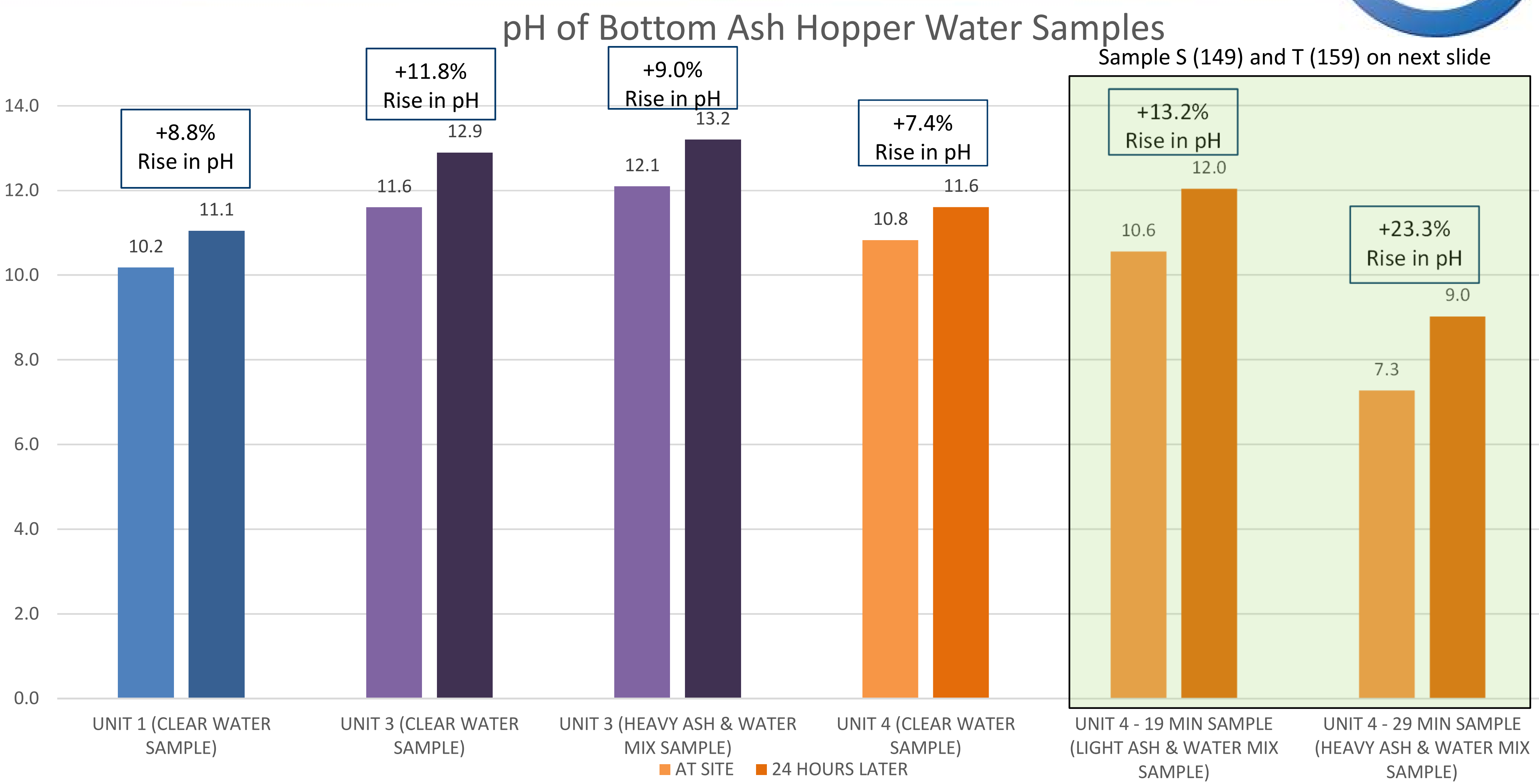
- There is a significant stratification of the pH inside the bottom ash hopper
- Water in contact with bottom ash (most of the volume of the hopper V-section) is between 10 to 13 pH
- A band of water in contact with boiler gases, estimated to be between 6” to 15”, has much lower pH (as low as 3.1)
  - This is the water feeding the overflow boxes

Bottom Ash Hopper Water pH Measurements



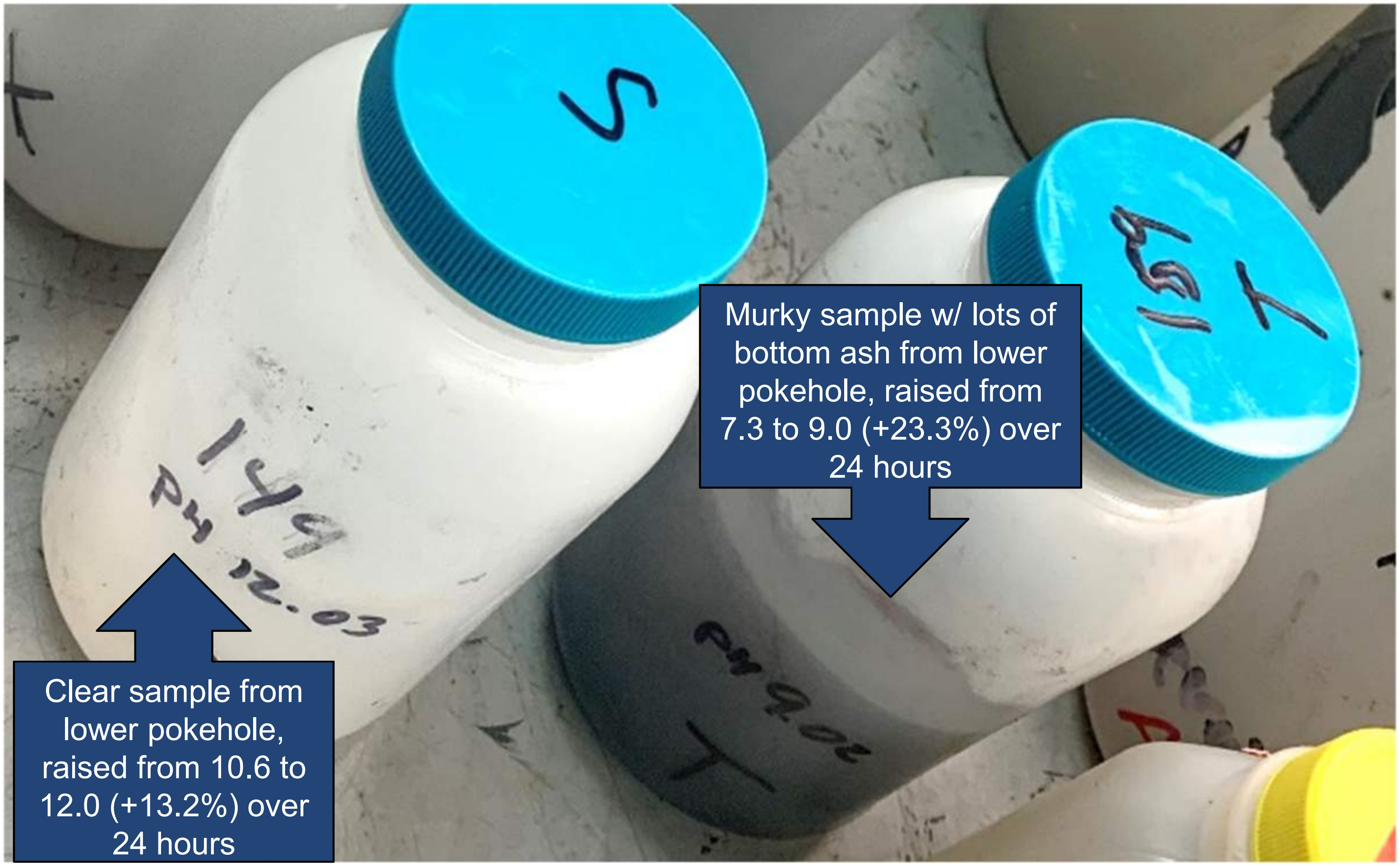
- Samples collected from lower pokehole of bottom ash hopper repeatedly basic in pH (>9.0)

Bottom Ash Hopper Water pH Measurements



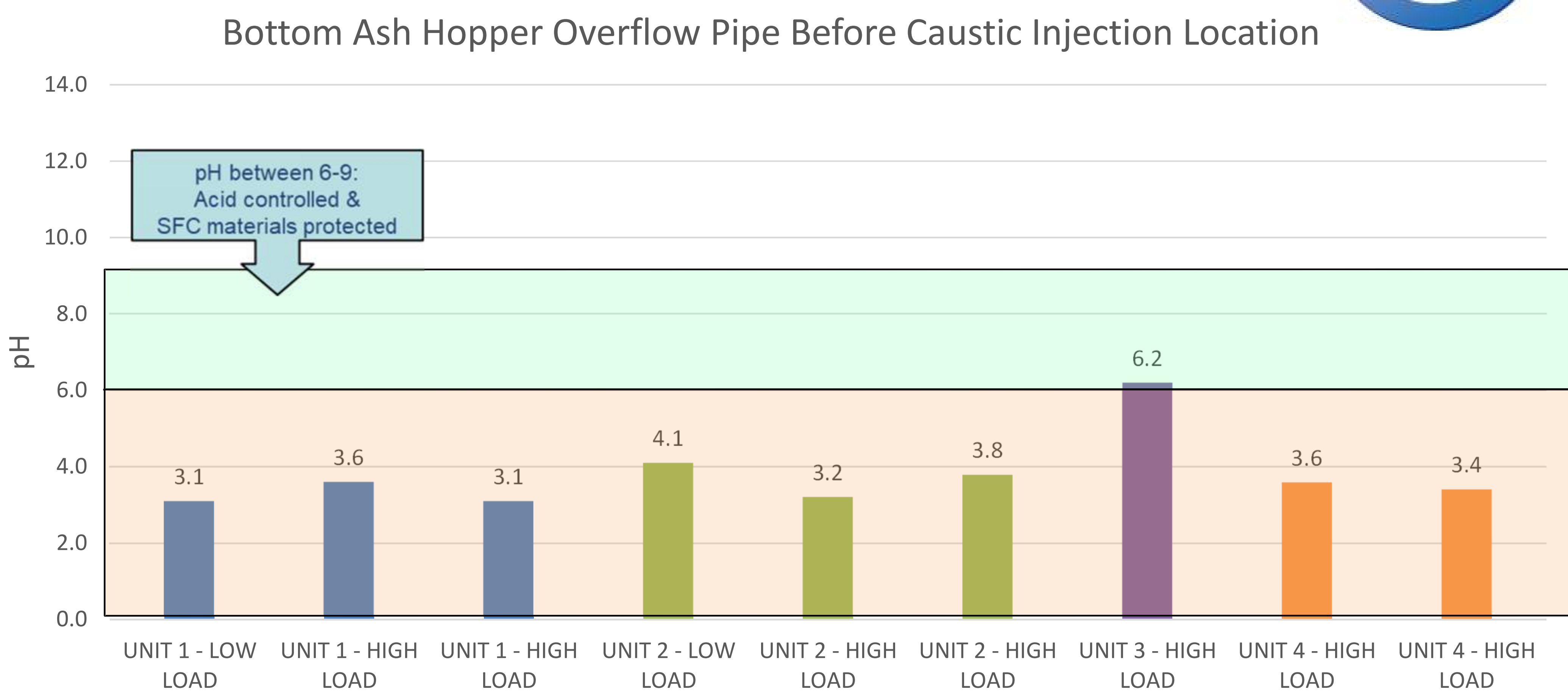
- pH of samples taken from lower pokehole of bottom ash hoppers increased an average of 12.25% over 24 hours

Bottom Ash Hopper pH Measurements



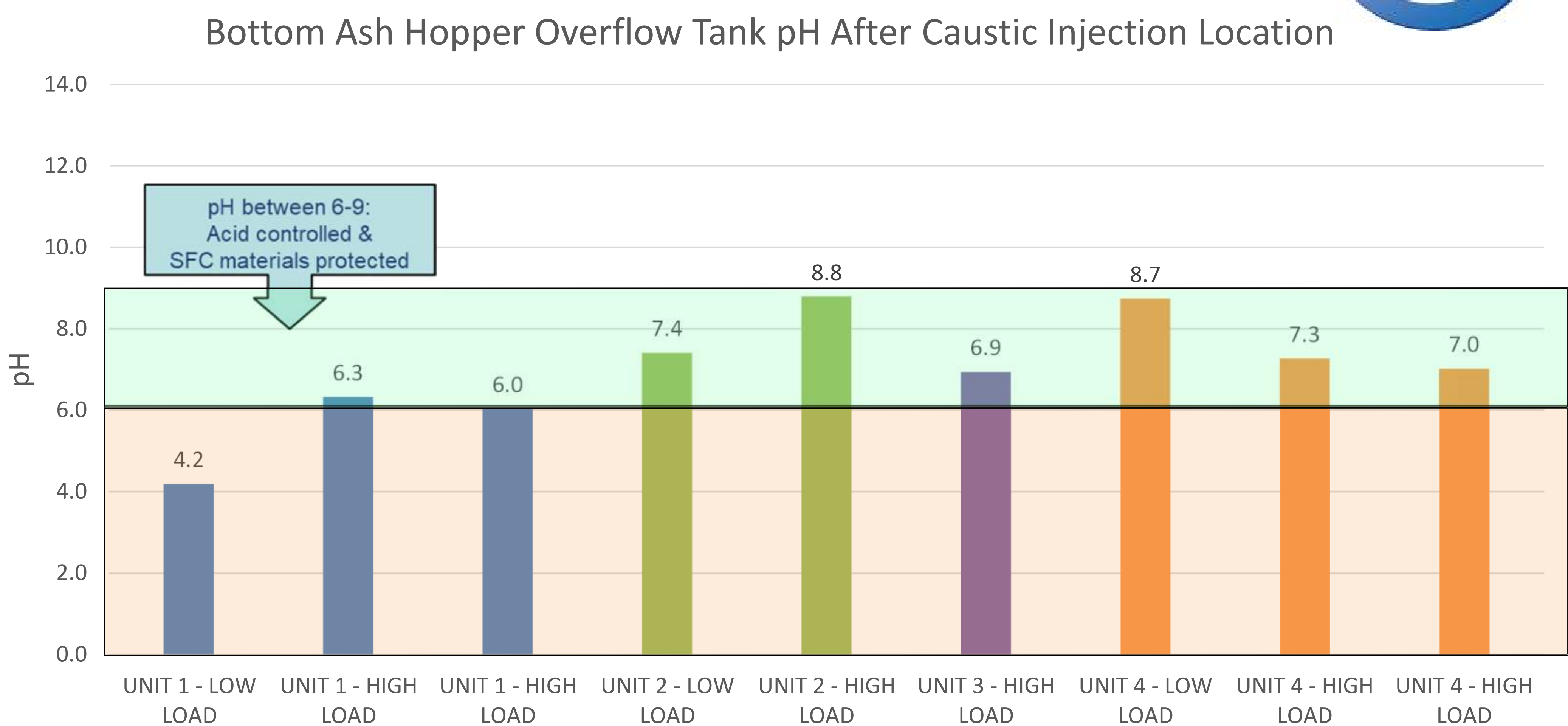
Bottom Ash Hopper Overflow Pipe – pH

Before Caustic Injection Location



- pH of bottom ash hopper overflow pipe (before caustic) very low
  - Determined to be source of acid into system
- * Unit 3 sample taken with 20 hours of bottom ash stored in hopper, causing very high levels of ash in hopper, allowing mixing of acidic surface water with basic bottom ash water

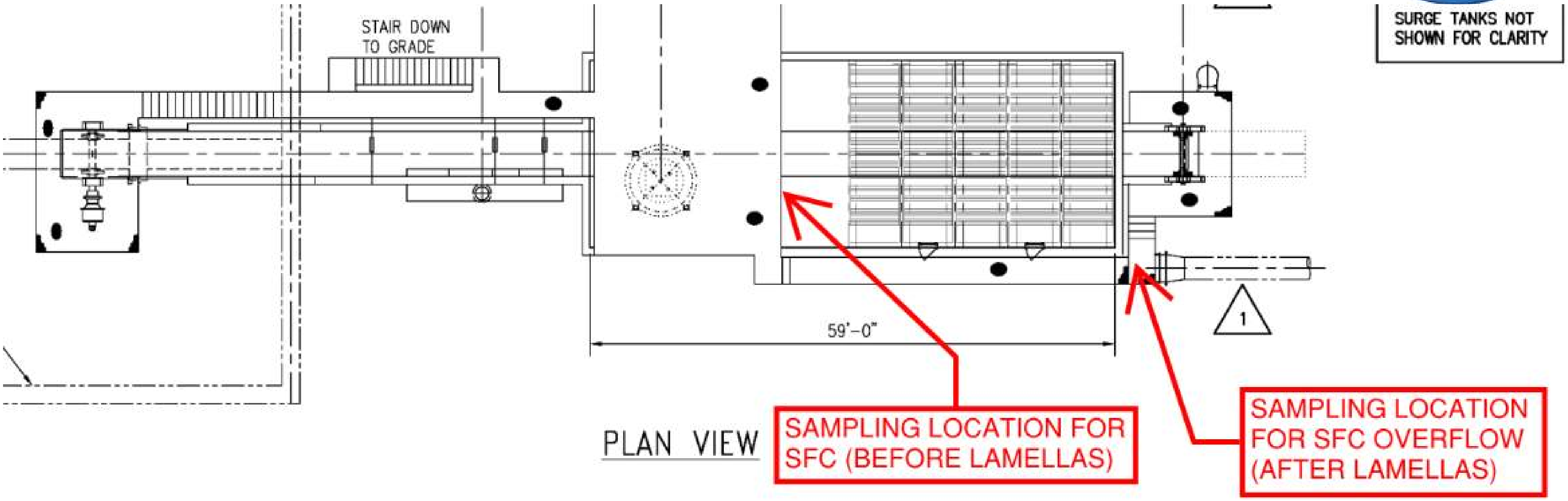
Bottom Ash Hopper Overflow Tank Discharge After Caustic Injection Location



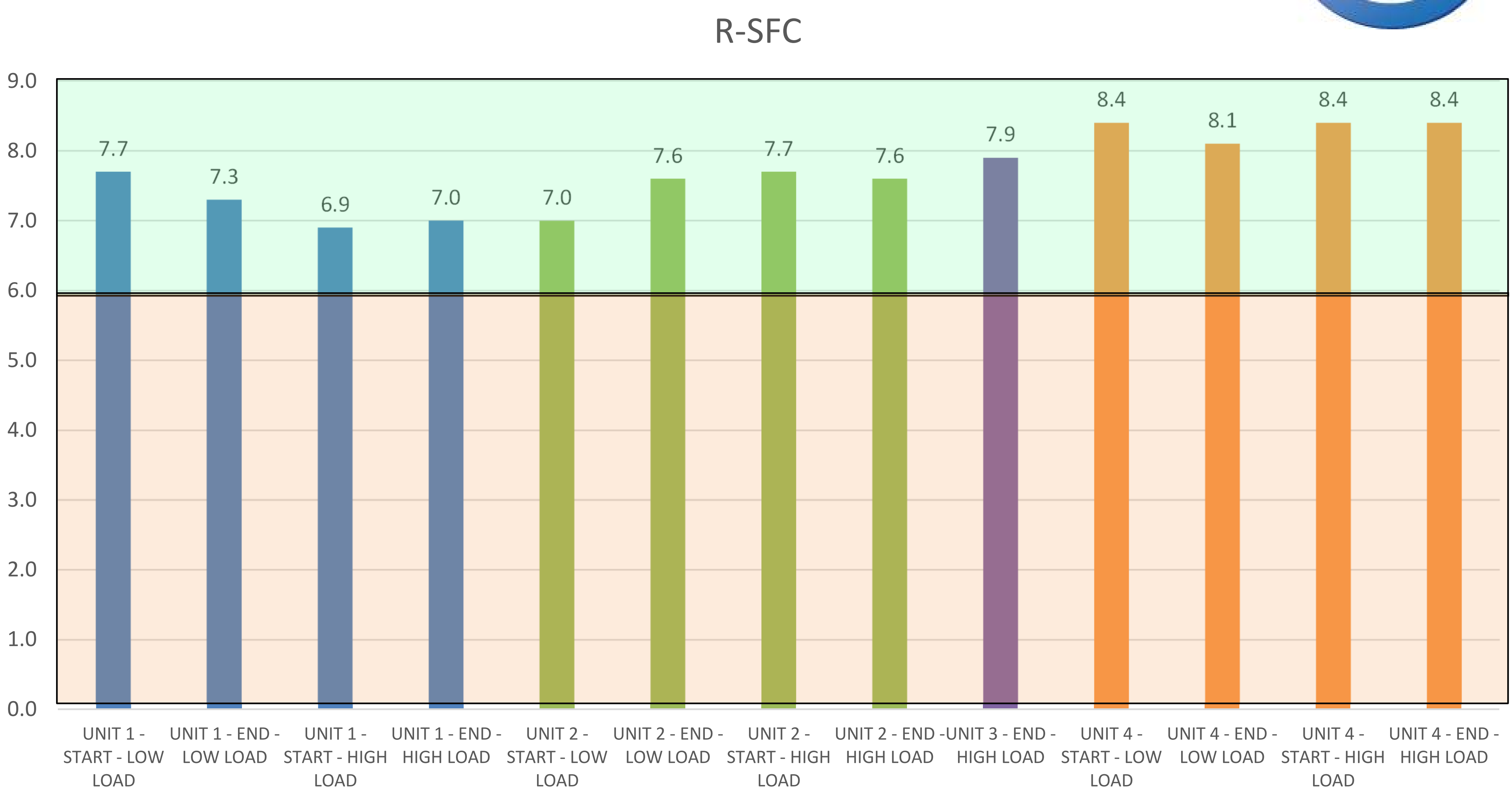
- When properly calibrated, caustic injection increases the pH of overflow tank discharge to within UCC recommended range of 6-9
- * Unit 1 sample of 4.2 pH due to probes not calibrated
  - Per previous slide, pH probe on injection skid measured 7.12

Sampling Locations

R-SFC

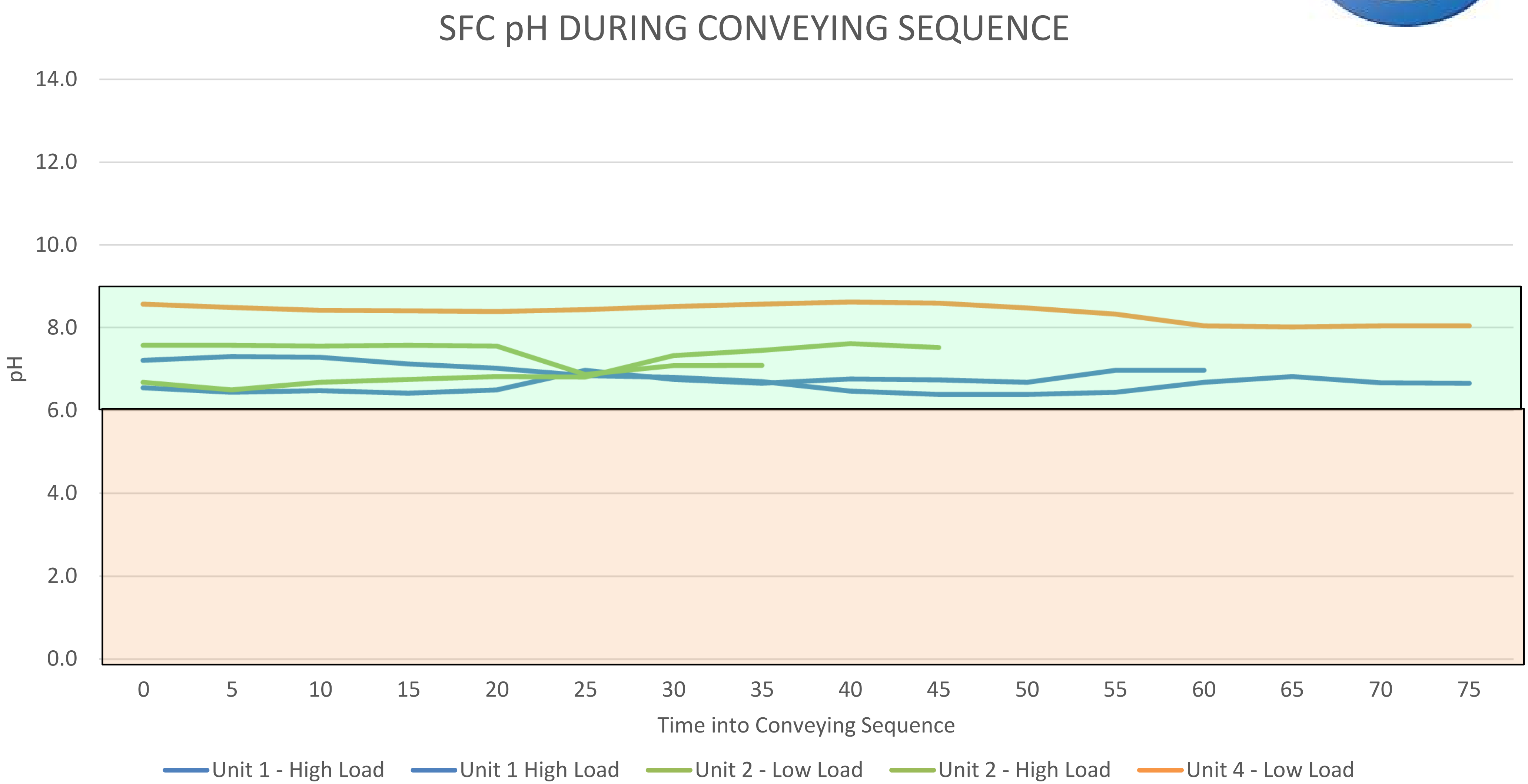


R-SFC – pH Measurements



- pH of R-SFC was maintained within UCC recommended range of 6-9 during all site visits

R-SFC – pH Measurements



- pH of SFC was maintained within UCC's recommended range of 6-9 during entire conveying sequence
- Source of acid determined not to be during conveying sequence

Bottom Ash & Water Observations

- Bottom Ash is Not Source of Acid in System
- Surface water of Bottom Ash Hopper, in contact with boiler gases, determined to be source of acid into system
- Bottom Ash Retention Time in Water raises pH
- Bottom Ash Hopper Overflow Tank is the ideal location for Caustic Injection to control pH
  - As close to source of acid generation as possible
- When Caustic System is operated as intended, acid is properly controlled and recirculation water remains in 6-9 pH range
  - Caustic system raised pH from an average of 3.8 to an average of 7.8

Issues – Corrosion

R-SFC Materials – Chain

After 12 Months of Service
Before pH Control

After 9 Months of Service
After pH Control

- Wear of SFC chain after pH control installed is much less than before pH control was installed, and more inline with typical chain wear

Issues – Corrosion

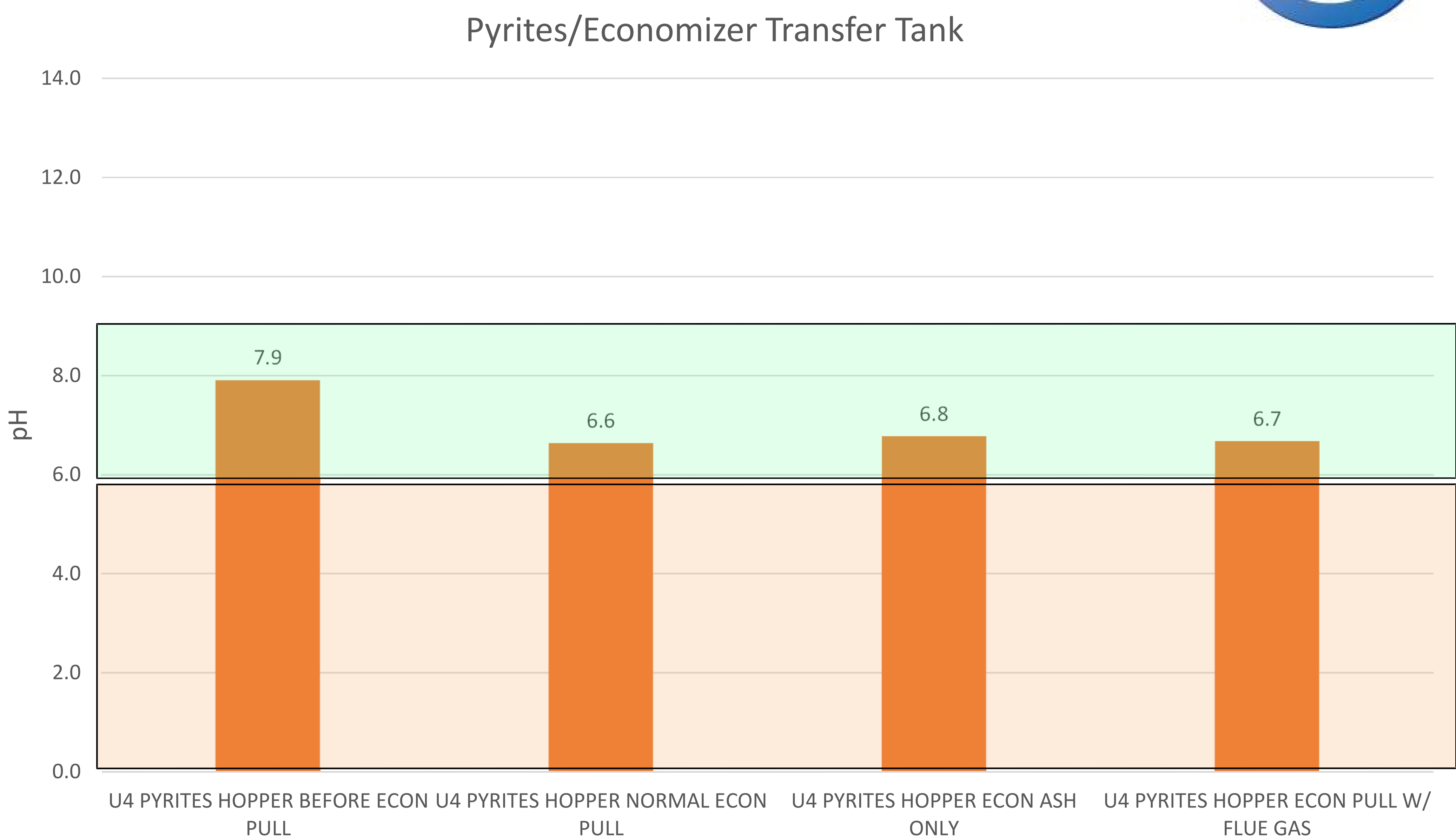
R-SFC Materials – Chain

- New R-SFC chain showing very little wear since pH control was installed, compared to original chain

Other Water Feed Sources (Pyrites & Economizer Ash)

Sampling Locations
Pyrites Tank

Pyrites/Economizer Tank pH Measurements



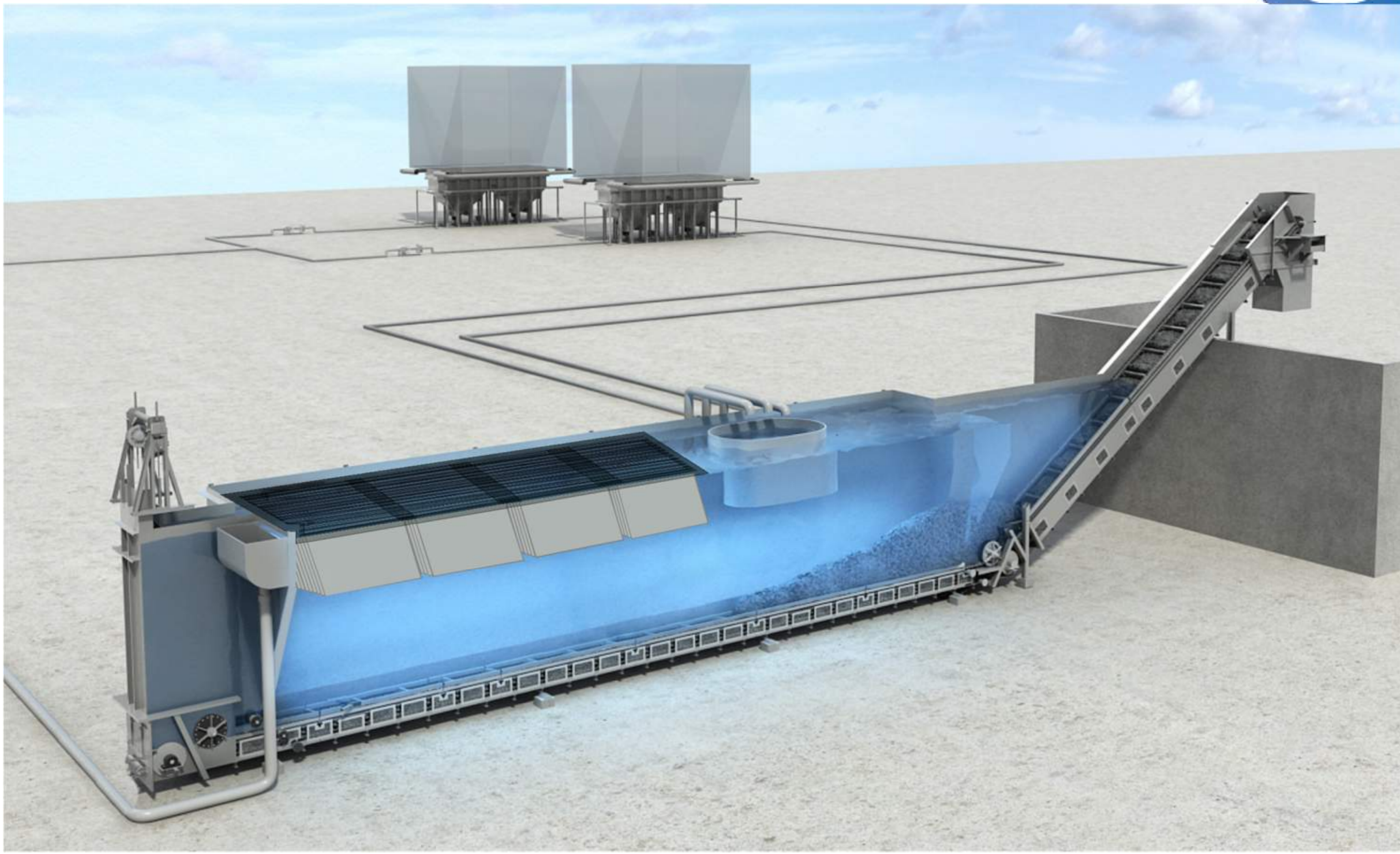
Pyrites/Economizer Systems

- Pyrites Conveyed to Holding Tank Periodically During Shift
  - pH of 7.9
  - Pyrites do not appear to be a significant source of acid
- Economizer Ash Conveyed to Pyrites Holding Tank Only When Conveying to R-SFC Using Hydroveyor
  - Pyrites tank with mix of Pyrites and Economizer Ash/Water: 6.6 pH
  - Pyrites tank after completely emptying tank of Pyrites/Econ. Ash/Water and refilled only from Econ. system under normal operating condition of pulling until empty: 6.8 pH
  - Pyrites tank after continuing to pull same Econ. hopper for an additional 5 minutes after empty to pull as much flue gas as the system would ever see: 6.7 pH
  - Economizer Ash conveyed does not appear to be a significant acid source

TSS Measurements

Bottom Ash Transport Water TSS Control

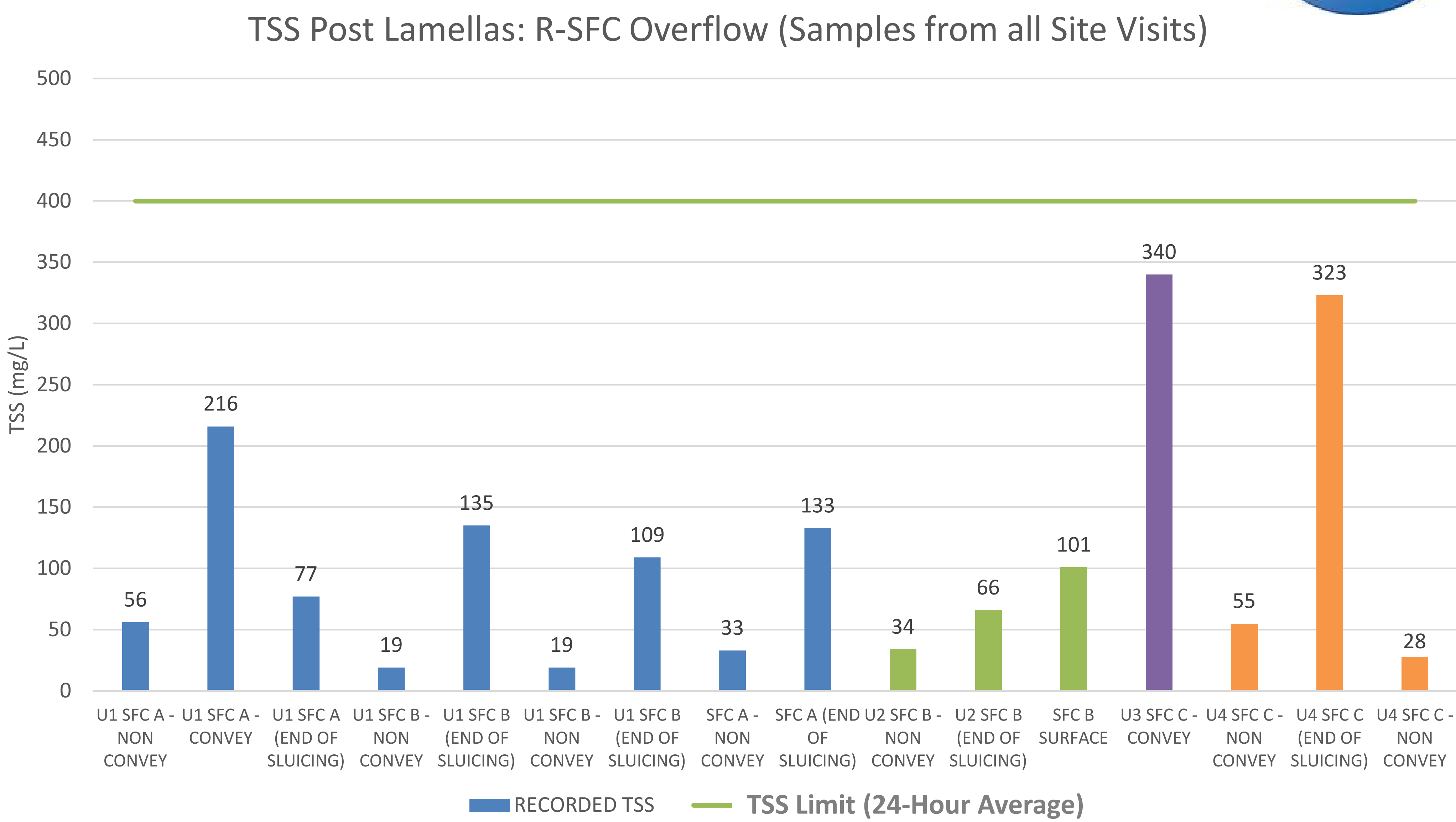
UCC Lamella Packs



Bottom Ash Transport Water TSS Control

UCC Lamella Packs

Total Suspended Solids (TSS) Measurements



Overview

WTD Industry Update & CDR System Overview

Lessons Learned: Water Chemistry

Lessons Learned: R-SFC Design Enhancements

Conclusions & Recommendations

Issue: Ash Over-boarding

- Larger than expected ash build-up on the ramp section of the SFC
- Occasional Bottom Ash over boarding the R-SFC ramp walls at inclined section
- More commonly occurred when conveying two Units simultaneously into (1) R-SFC

Issue: Ash Over-boarding

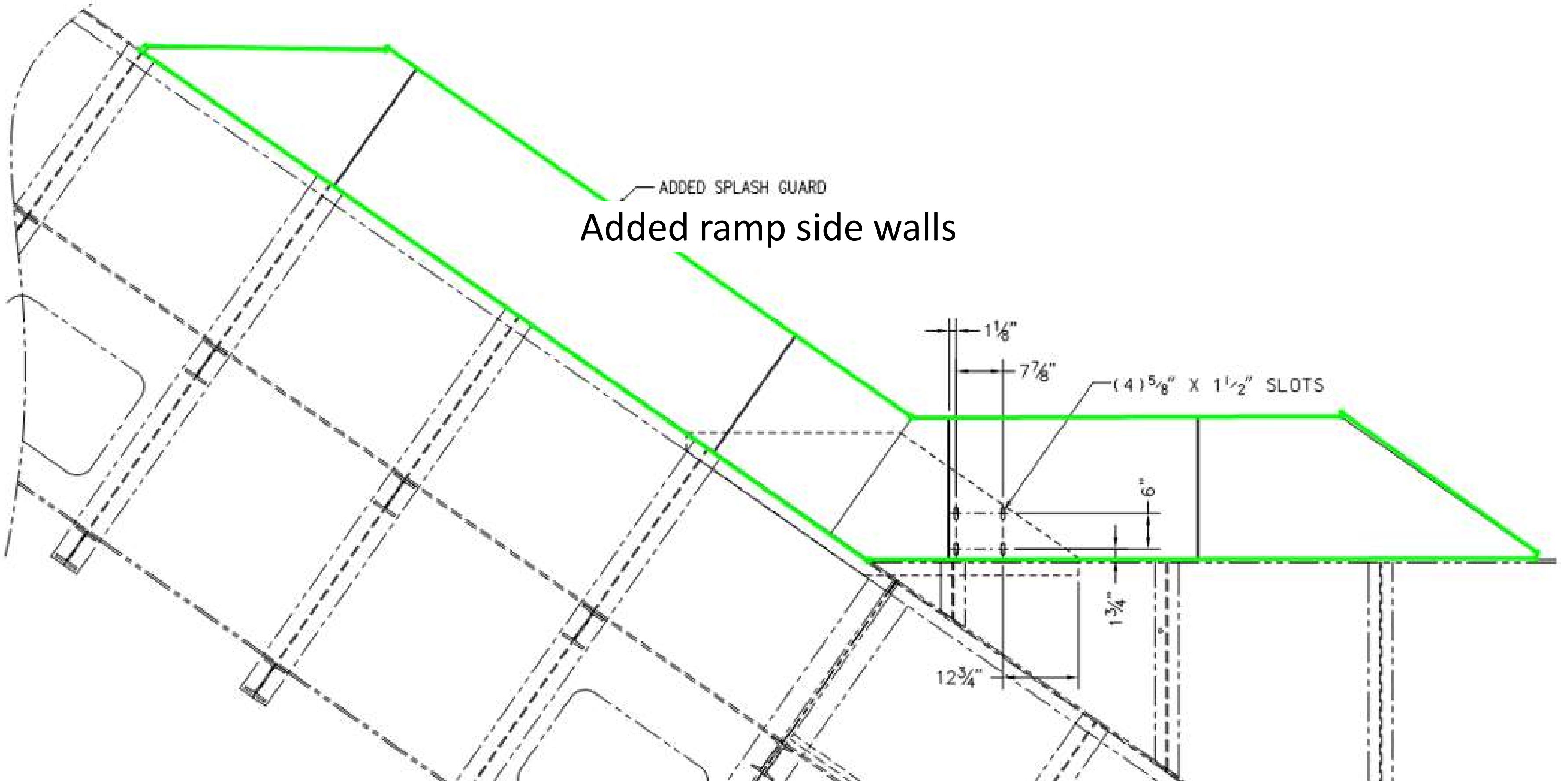
- Fine, high LOI, ash has a negative impact on R-SFC conveying capacity
- High accumulation of ash in the SFC caused ash “slide back” on ramp, forming a dam at the ramp waterline
- Needed greater R-SFC immediate take-away capacity to avoid excessive ash inventory

Ash Sliding Back on Ramp

Issue: Ash Over-boarding

R-SFC Enhancements

- **Increase size of ramp side walls**
  - Avoids situations where ash could spill over the sides of the ramp during periods of high-capacity conveying



Issue: Ash Over-boarding

R-SFC Enhancements

Issue: Ash Over-boarding

R-SFC Enhancements

Issue: Ash Over-boarding

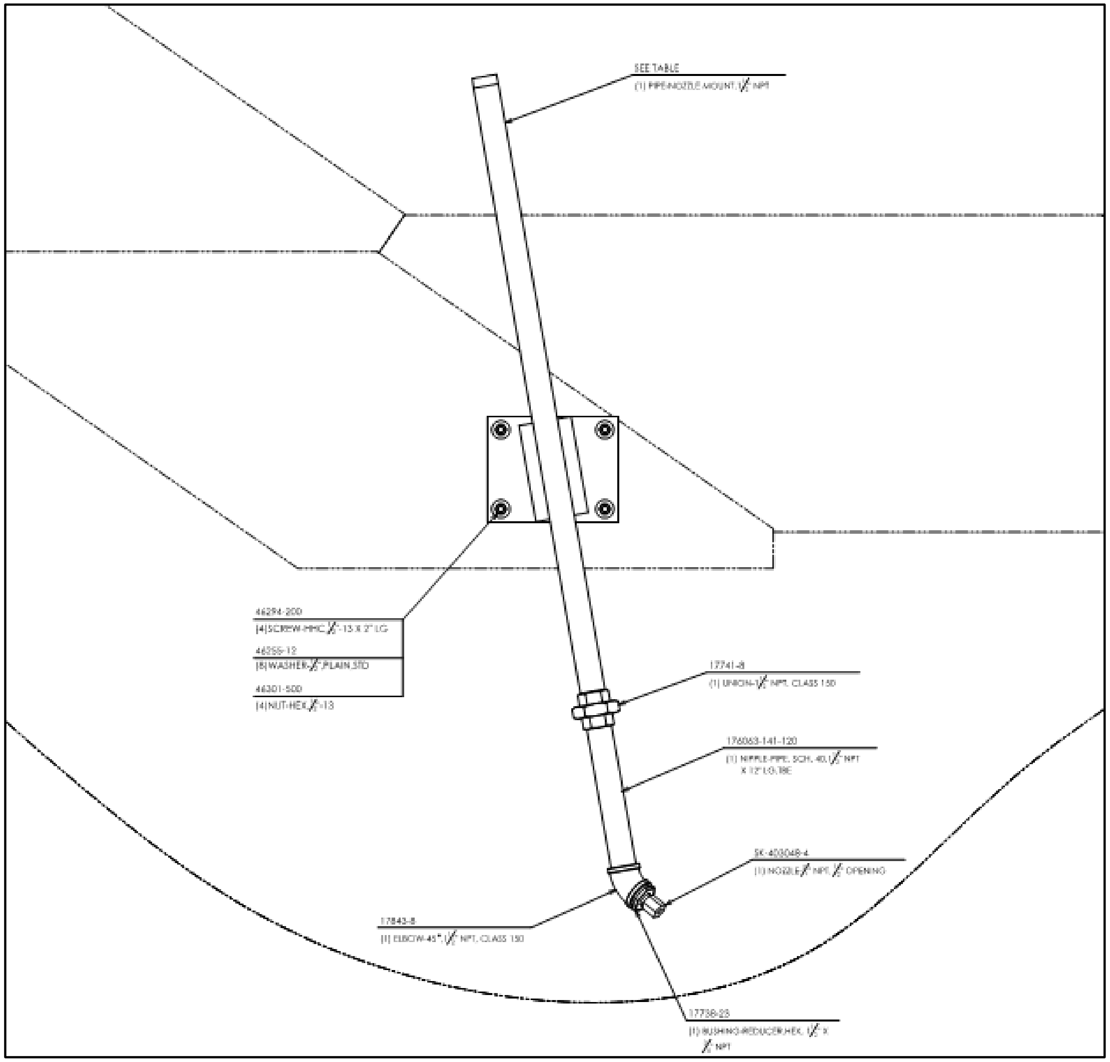
R-SFC Enhancements

- **Add Upper Ramp Nozzles**
  - Integrate use of ramp and bent sections nozzles into operating sequence (automatically controlled based on hydraulic pressure)
  - Provides a means to control the amount of ash build-up on the ramp during periods of high-capacity conveying

Issue: Ash Over-boarding

R-SFC Enhancements

- **Add Upper Ramp Nozzles**



Effect of Adding Nozzles At Ramp

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CDR System Lessons Learned: Water Chemistry

Conclusions & Recommendations

- Boiler Flue Gas / Bottom Ash Hopper Water interface appears to be source of acid generation (likely in T-fired units) in CDR recirculation systems
- Bottom Ash influences Transport Water by increasing alkalinity
- Collect Bottom Ash Hopper Overflow Water Samples prior to conversion over a range of operation conditions to confirm water chemistry (pH, Sulfates, CaCO3, etc.)
- Thoroughly inspect existing Bottom Ash Hopper Overflow Weir Boxes and Overflow Piping for signs of past/ongoing corrosion
- Collect Ash Samples prior to conversion to confirm particle characteristics (chemical and physical)
- Include pH control instrumentation and chemical injection in initial system design, or plan for potential future addition
- Confirm pH probes/transmitters are calibrated properly and sending signals to control system
- Inject caustic as close to source of acid generation as possible

CDR System Lessons Learned: R-SFC Enhancements

Conclusions & Recommendations

- Confirm Bottom Ash generation rates as accurately as possible
- Collect Ash Samples prior to conversion to confirm particle characteristics (chemical and physical, particularly particle size distribution)
- Confirm Bottom Ash Hopper pull sequencing needs (simultaneous vs. sequential)
- UCC standard R-SFC design has been upgraded to include ramp side walls
- UCC standard R-SFC design now incorporates provisions for ramp nozzles

Questions ?


THANK
YOU