REINHOLD ENVIRONMENTAL Ltd.

2017 APC & Wastewater Round Table & Expo Presentation

July 17 & 18, 2017 in Charlotte, NC / Hosted by Duke Energy

Review of Corrosion Findings from EPRI's 2016 Bromine Balance of Plant Survey

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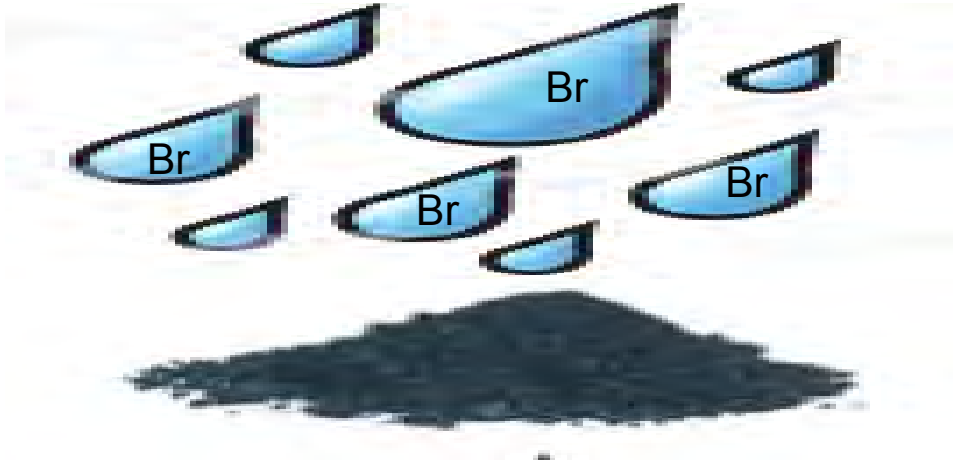
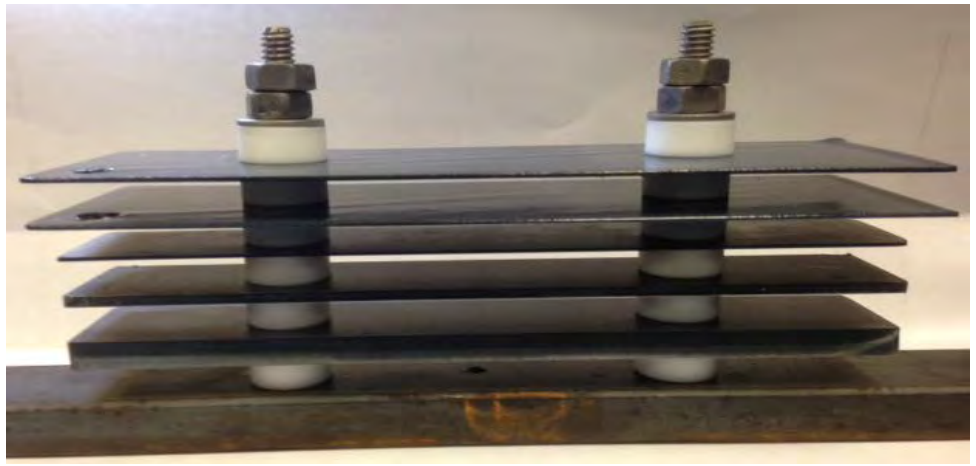
Reinhold APC & WW Roundtable
July 17, 2017



Implementation of Br-based Hg controls created need to understand balance-of-plant (BOP) impacts

EPRI Br BOP Survey

Air heater corrosion most reported BOP impact

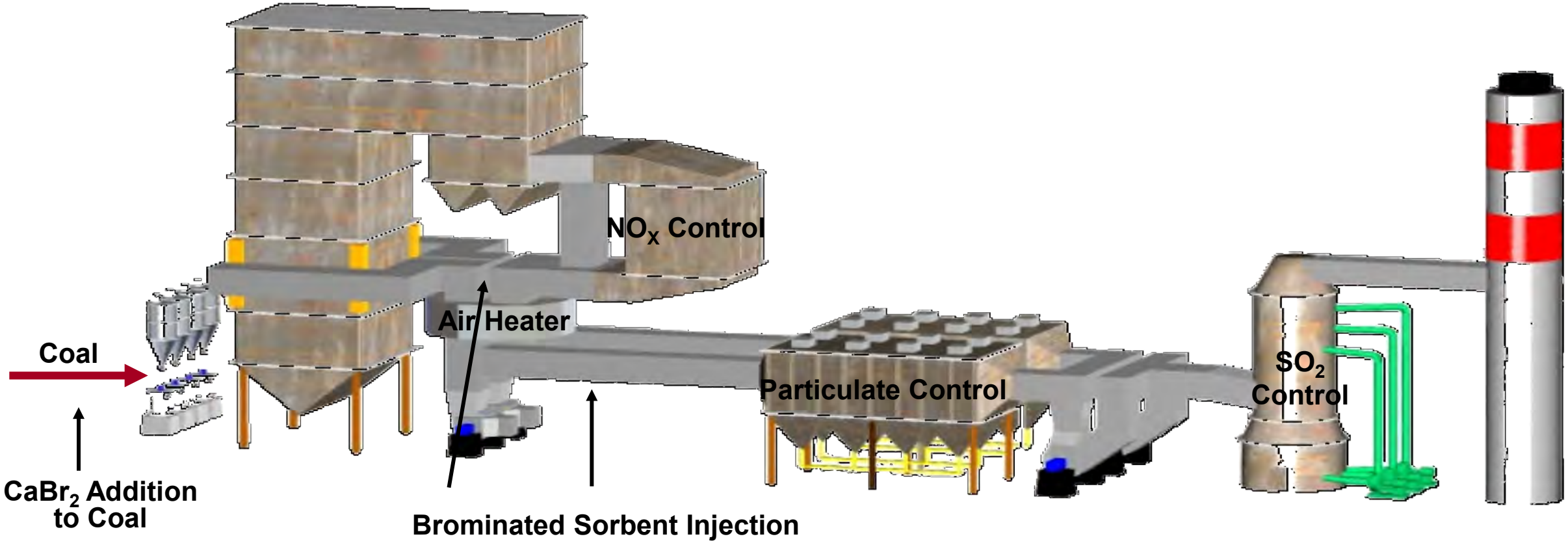


Field/lab studies evaluated Br role in corrosion

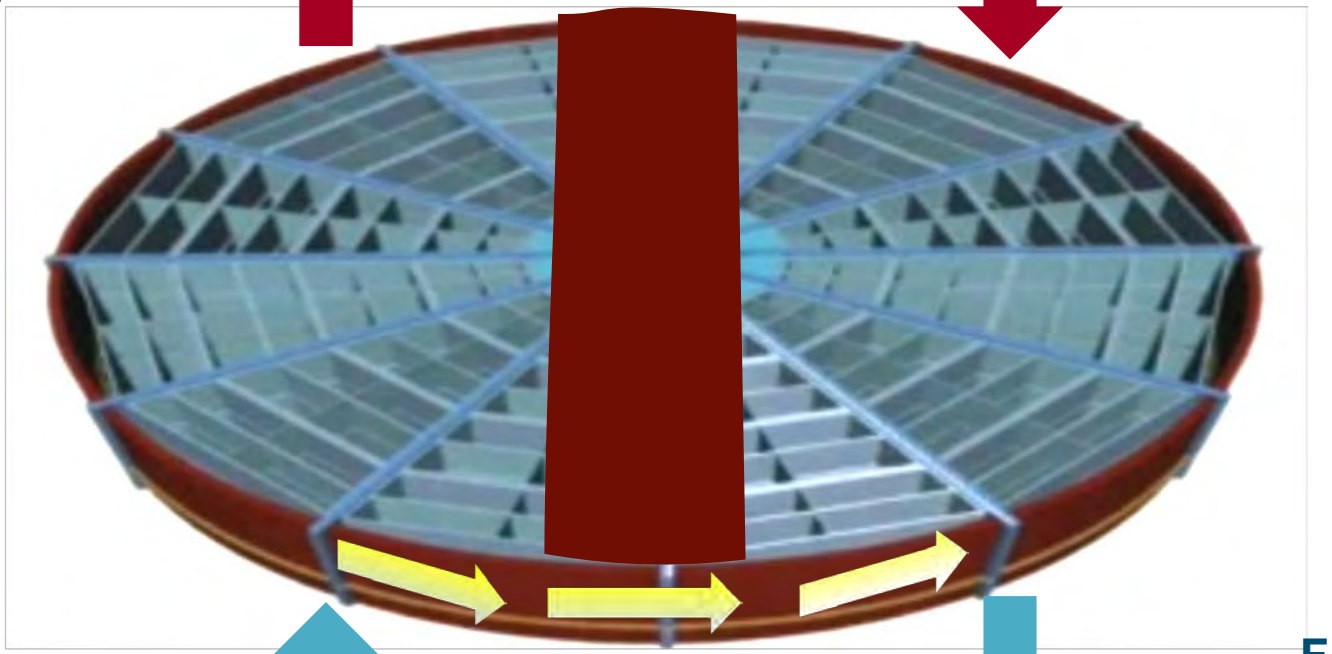
52 of 89 surveyed units had corrosion; AH corrosion most common

Location of Corrosion	# of Units Reported Corrosion
Ductwork upstream of coal crusher	1
Coal pulverizer	8
Boiler tube	1
Air heater	44
Air heater outlet duct	1
ESP	4
ESP outlet duct	4
Fabric filter	1
ID fan	4
SDA	1
FGD	6
Venturi scrubber	4

Coal additives increase flue gas HBr concentration; Lowest metal temperatures encountered in the air heater



Corrosion most likely in coldest parts of air heater



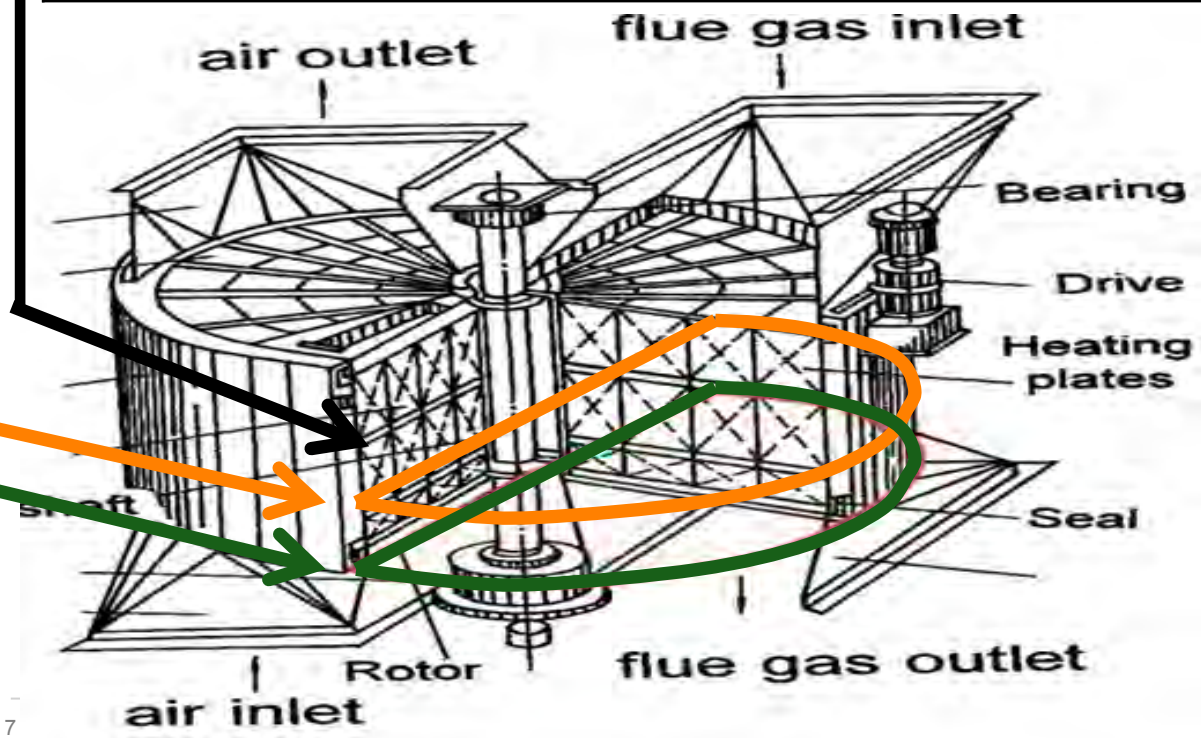
Severe air heater corrosion can occur within 12 months of Br addition

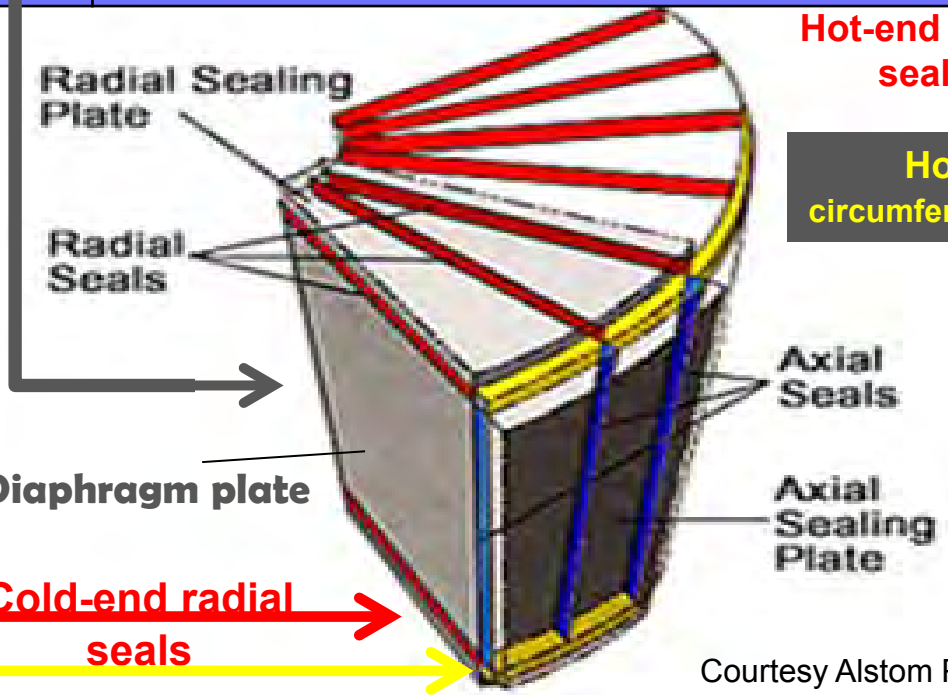
Cold-end baskets with 15 years operation

Cold-end baskets with 15 years operation
+ 1 year of Br addition

Air heater corrosion location

Air Heater Part	# Units Reporting Corrosion
Cold-end baskets (plane outlined)	43
Intermediate basket (plane outlined)	6
Cold-end basket bars	7
Diaphragm plate	4
Cold-end radial seal	13
Circumferential seal	3





Hot-end radial seals

Hot-end circumferential seals

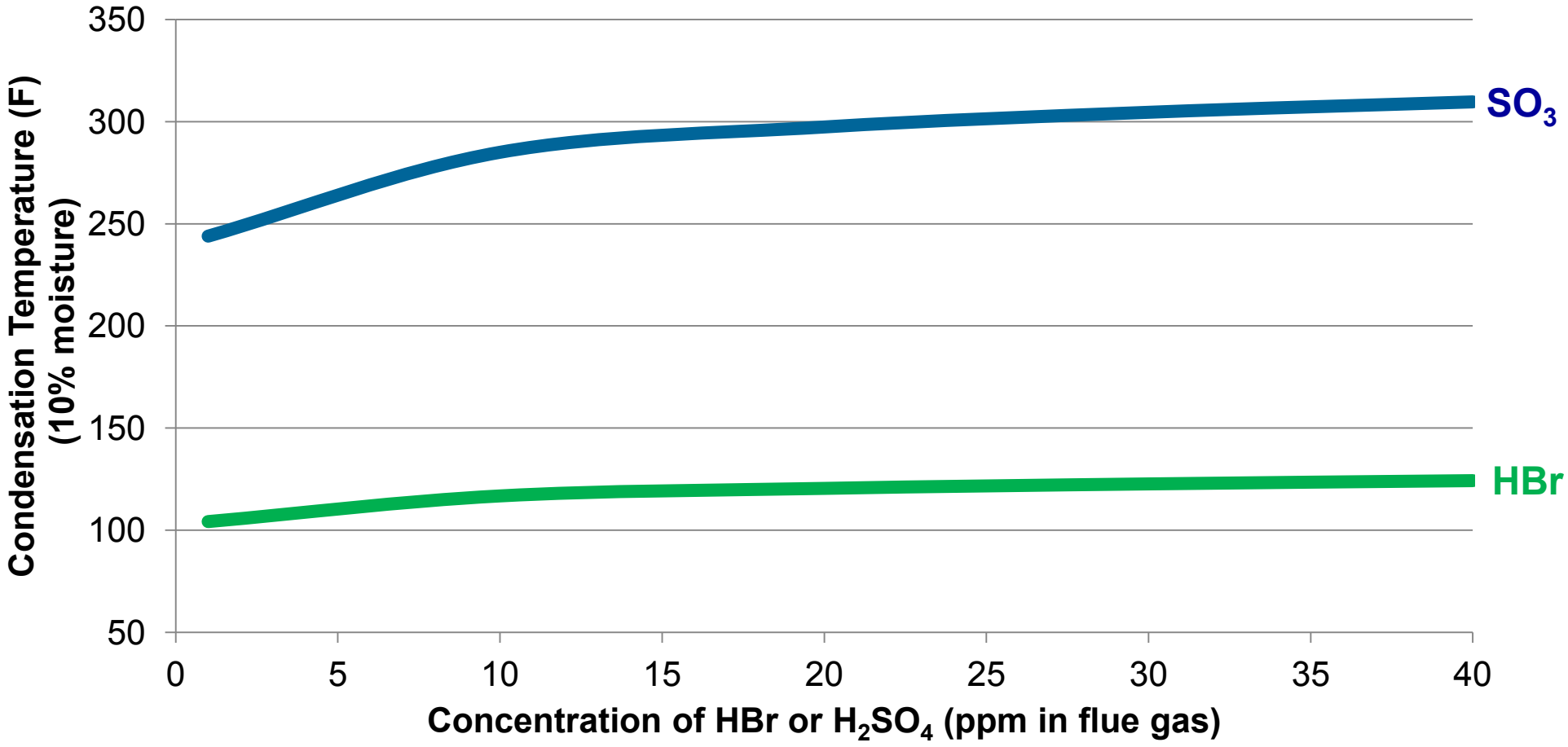
Cold-end radial seals

Cold-end circumferential seals

Courtesy Alstom Power

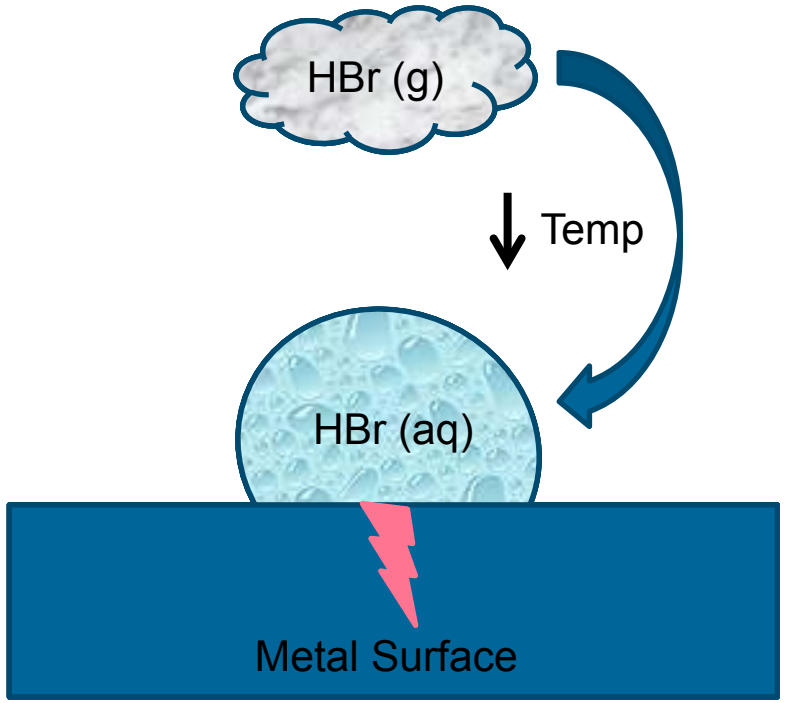
EPRI ELECTRIC POWER RESEARCH INSTITUTE

HBr condenses at a much lower temperature than SO_3

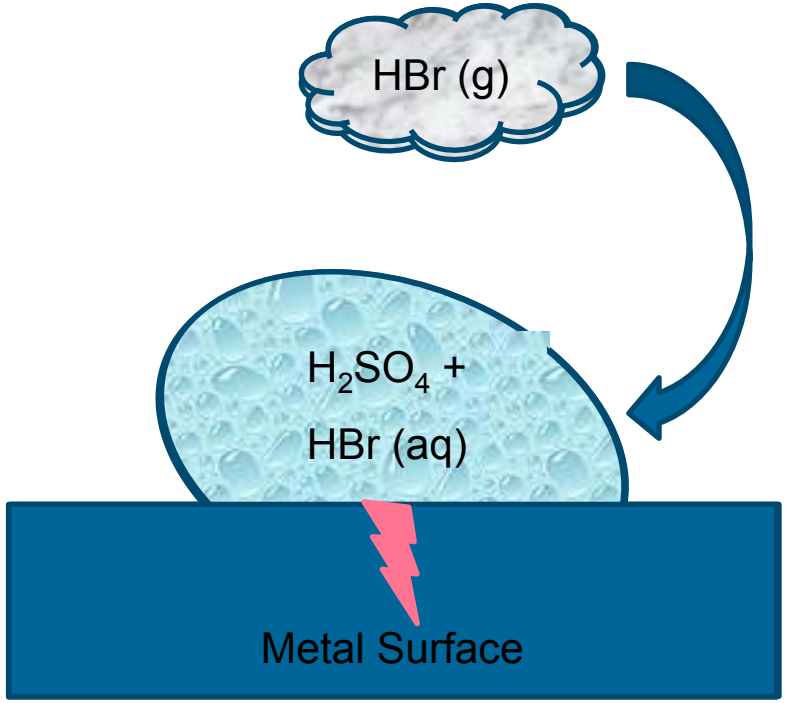


Possible AH corrosion mechanisms

- **Direct condensation of HBr on the metal**
  - **Below HBr condensation temp**

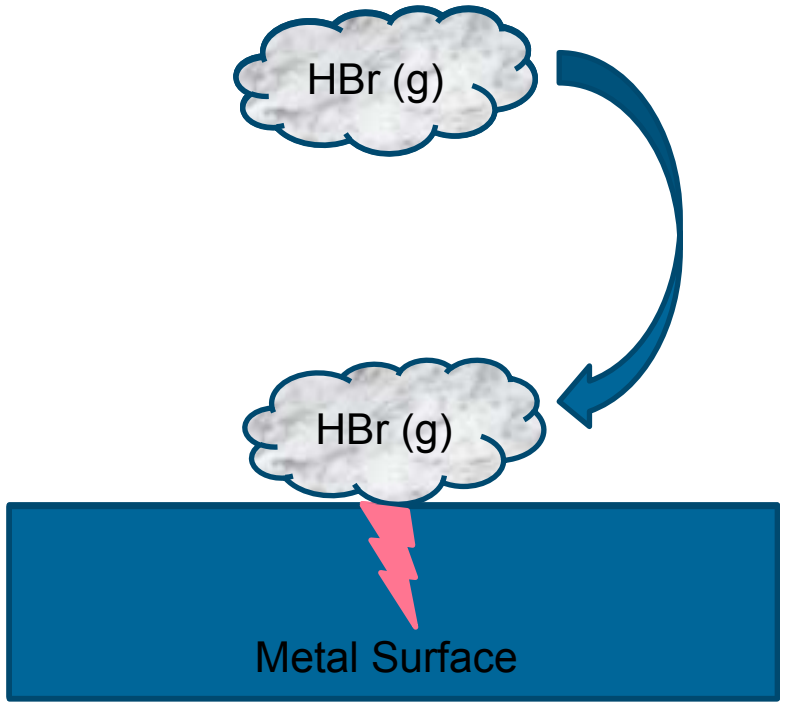


- **Absorption of HBr into condensed acid**
  - **Above HBr condensation temp**

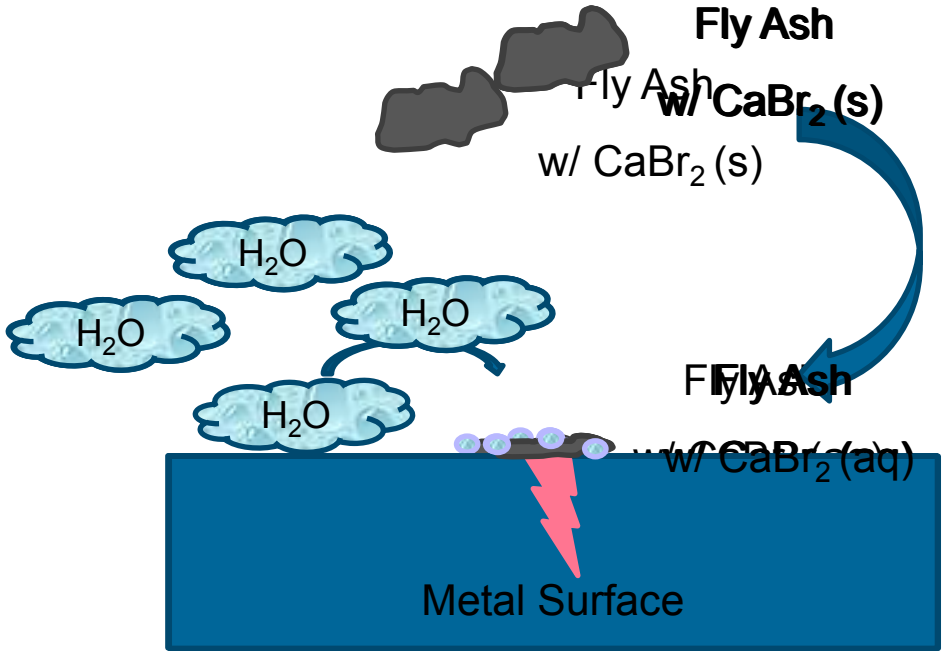


Possible AH corrosion mechanisms

- **Gas phase oxidation by HBr/Br_2**
  - **Above HBr condensation temp**

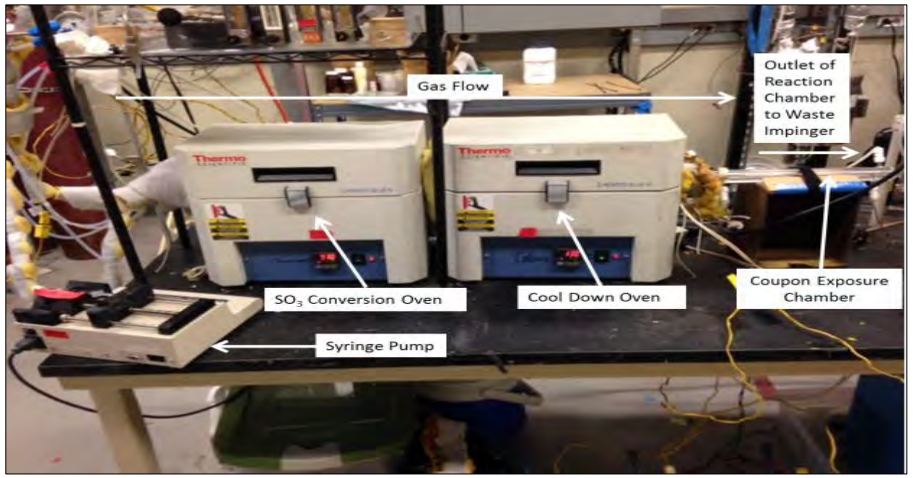


- **Corrosive deliquescent $CaBr_2$ salt**

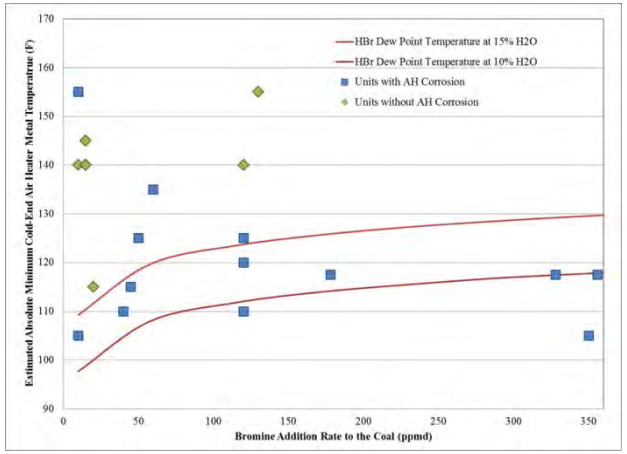


Three-pronged investigation of corrosion mechanisms

Field coupon racks installed on rotating air heater baskets at 20 units

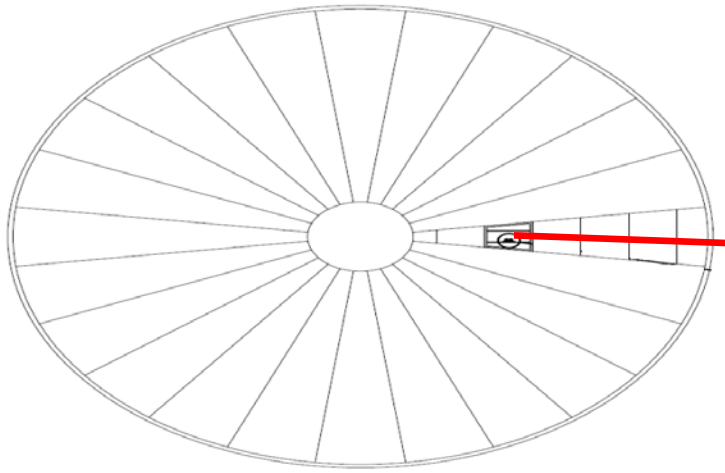


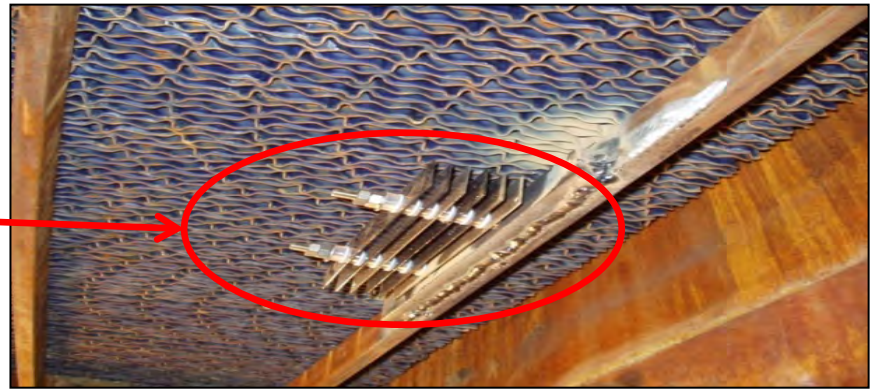
Lab tests under controlled conditions



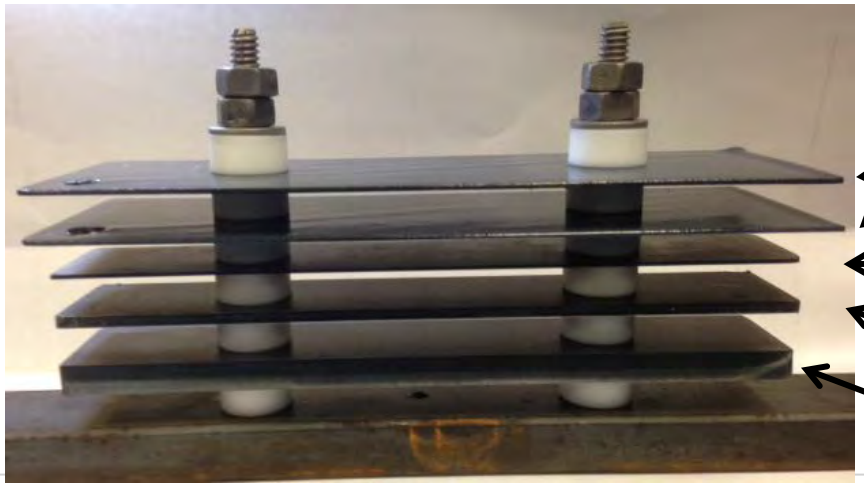
Survey data compared to theories

Field: AH corrosion on all coupons except enameled coupons; thin elements experienced severe corrosion



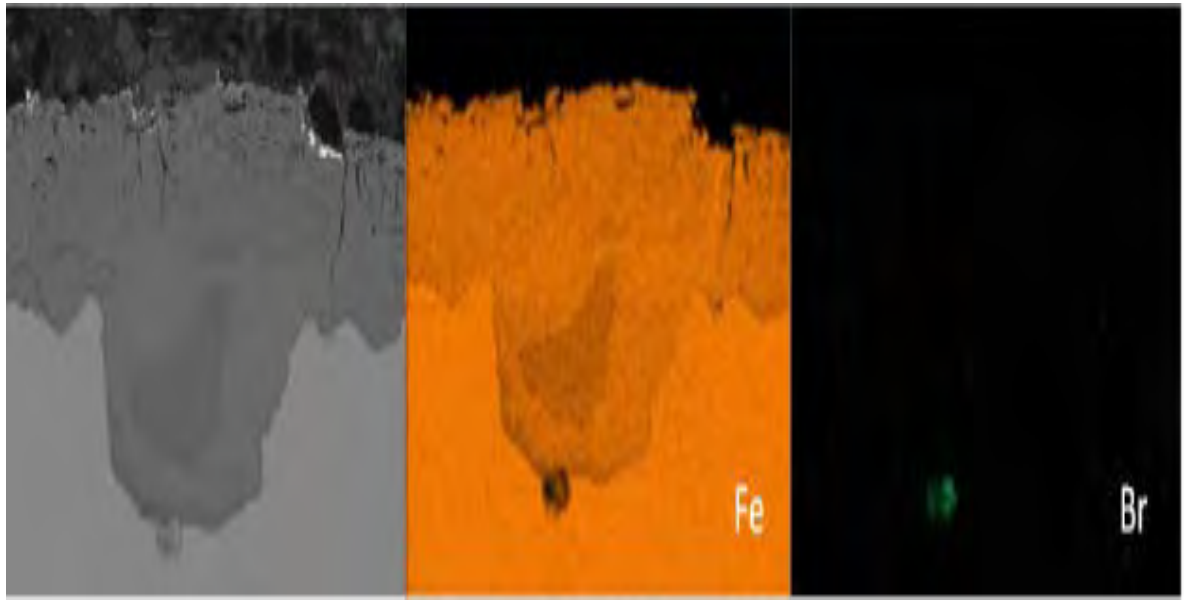


AH coupon before installation

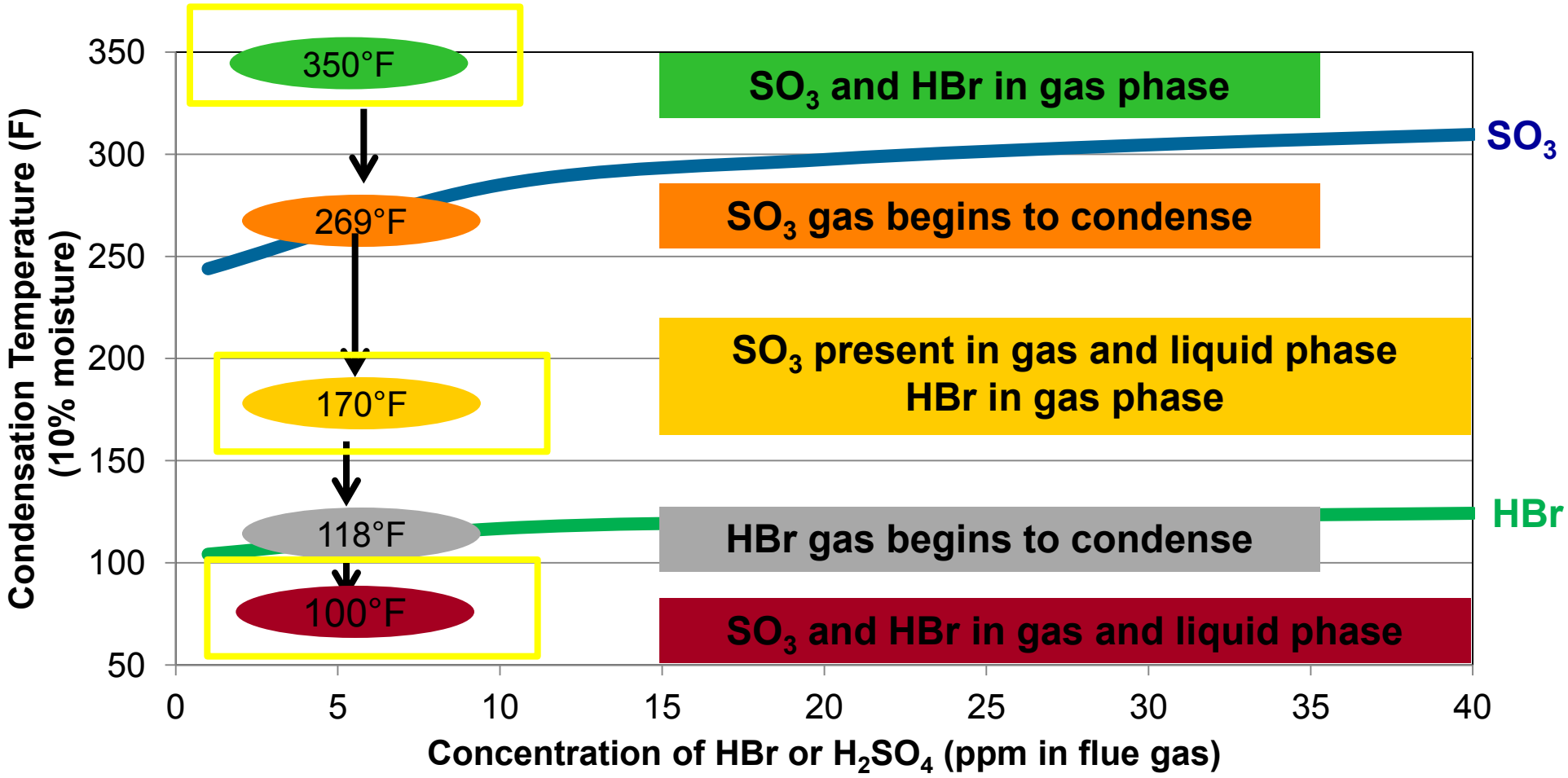


AH coupon after removal

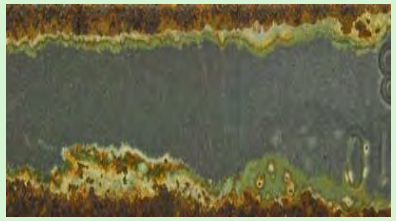
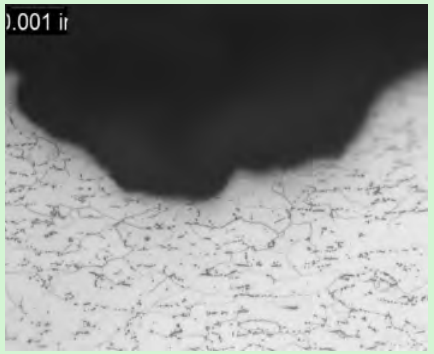
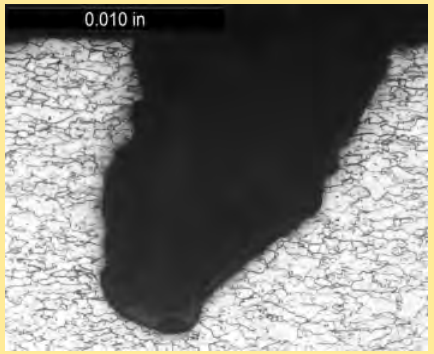
Field: Br only evident at deposit/metal interface



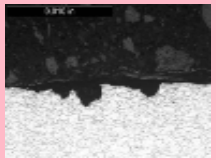
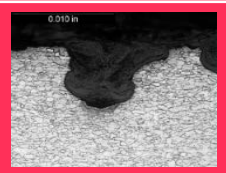
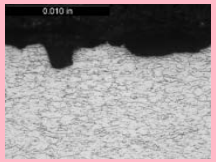
Lab: Test temperatures probed gas-phase, absorption, and condensation corrosion mechanisms



Lab: Higher moisture coals more vulnerable to AH corrosion, even at lower Br rates

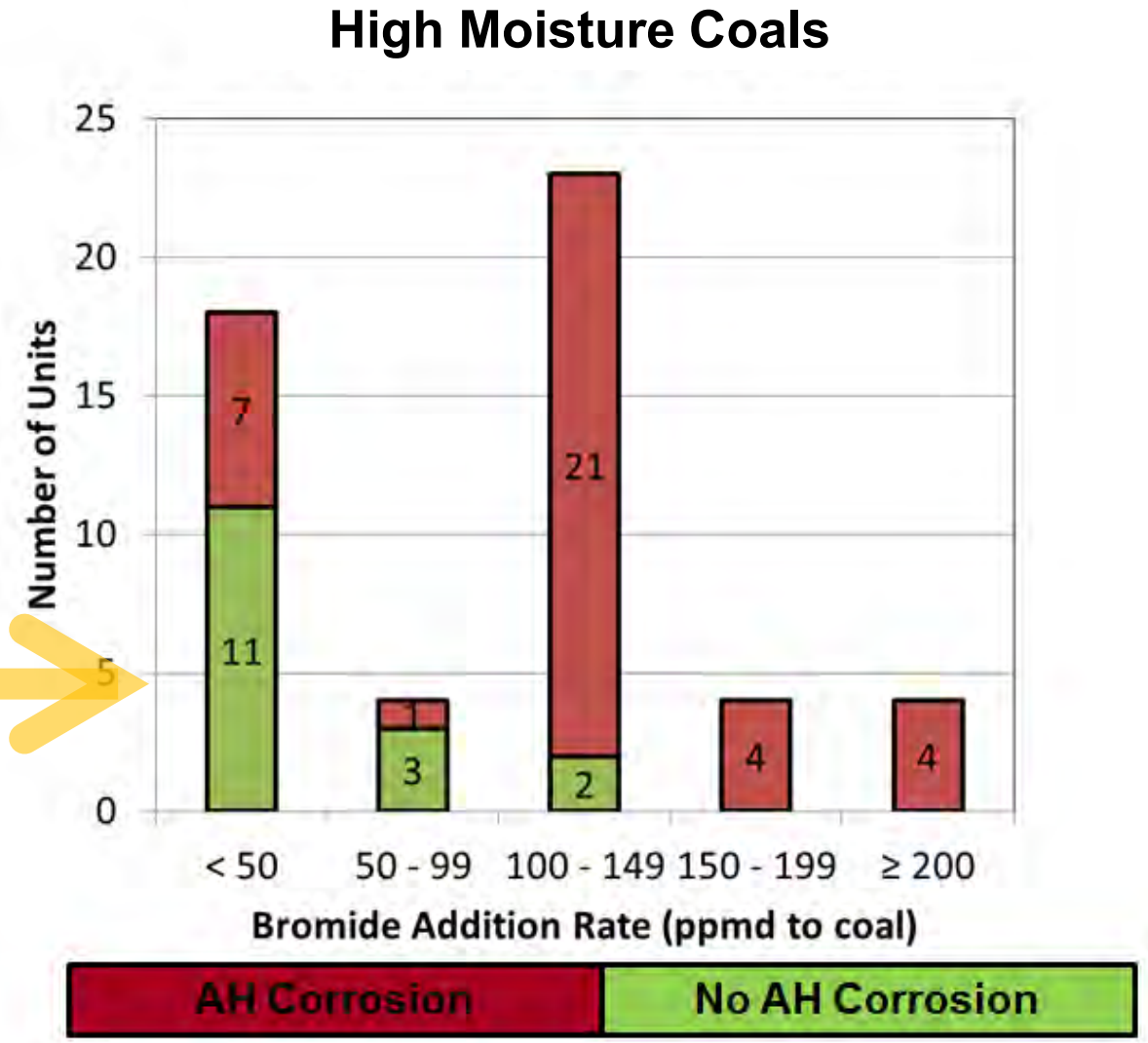
Test temperature (°F)	170°F *Above HBr Dew Point, Below SO_3 Dew Point*	
Coal flue gas simulated	Low Moisture	High Moisture
Gas moisture (%)	5	12
HBr (ppm)	8	2
SO_3 (ppm)	8	2
SO_2 (ppm)	1500	200
Maximum Pit Depth (in)	**0.002**	**0.013**
Visual		
Metallography		

Lab: HBr more aggressive than H_2SO_4; 170°F more aggressive than other temperatures

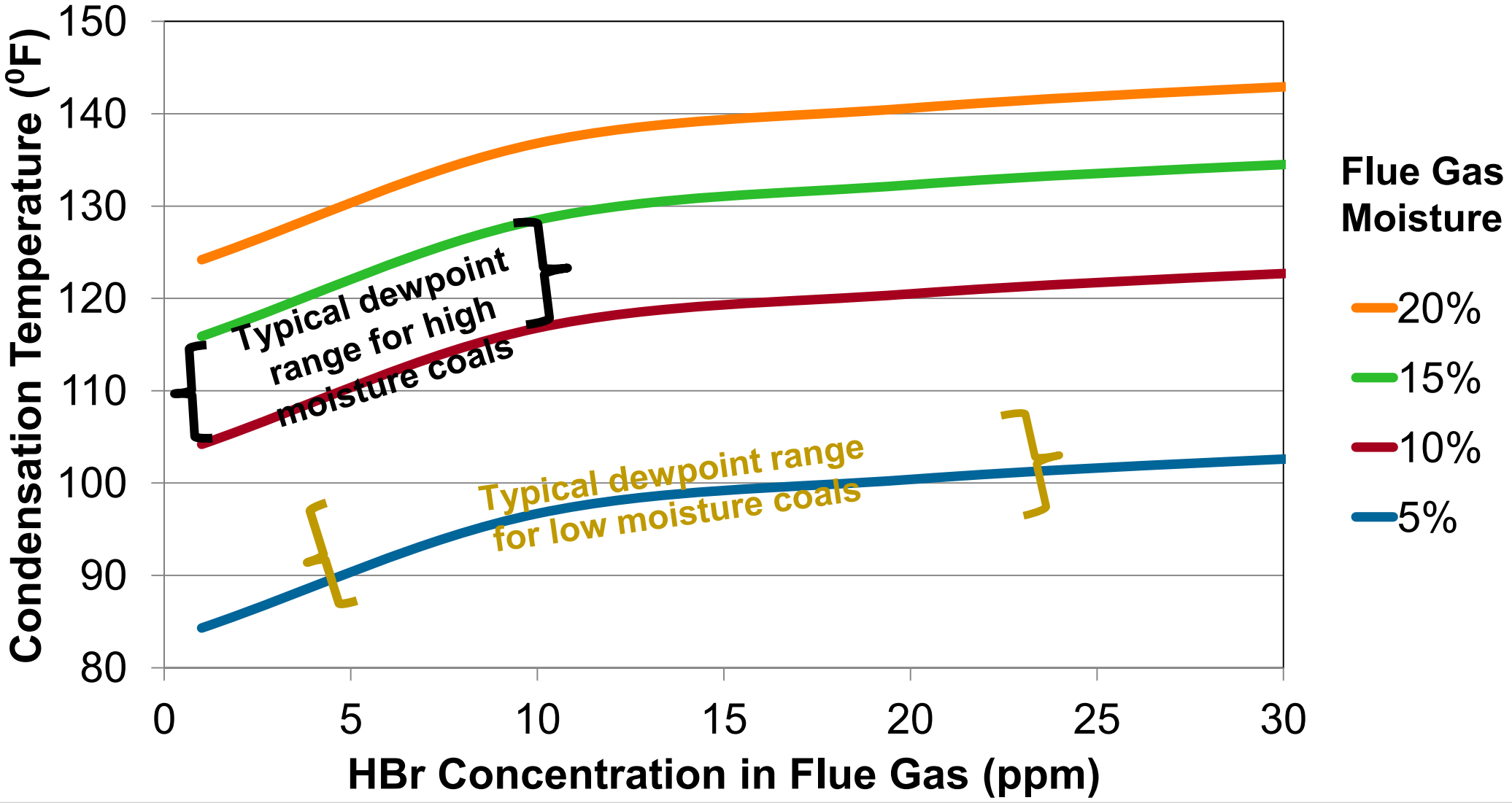
No Pits or Shallower Pits			Deeper Pits		
H_2SO_4 alone					HBr alone or H_2SO_4 + HBr
Temperature 100 and 350°F					Temperature 170°F
Fly ash					No fly ash

Survey: AH corrosion observed on units firing high-moisture coals

Coal Type	# of Units in Survey	# Units with AH Corrosion	Typical Br addition rate (ppm to coal)
Low-moisture coals (typically high sulfur)	21	1	50 - 400
High-moisture coals (typically low sulfur)	68	43	2 - 250



High moisture coals may be more vulnerable to corrosion due to higher HBr condensation temperatures

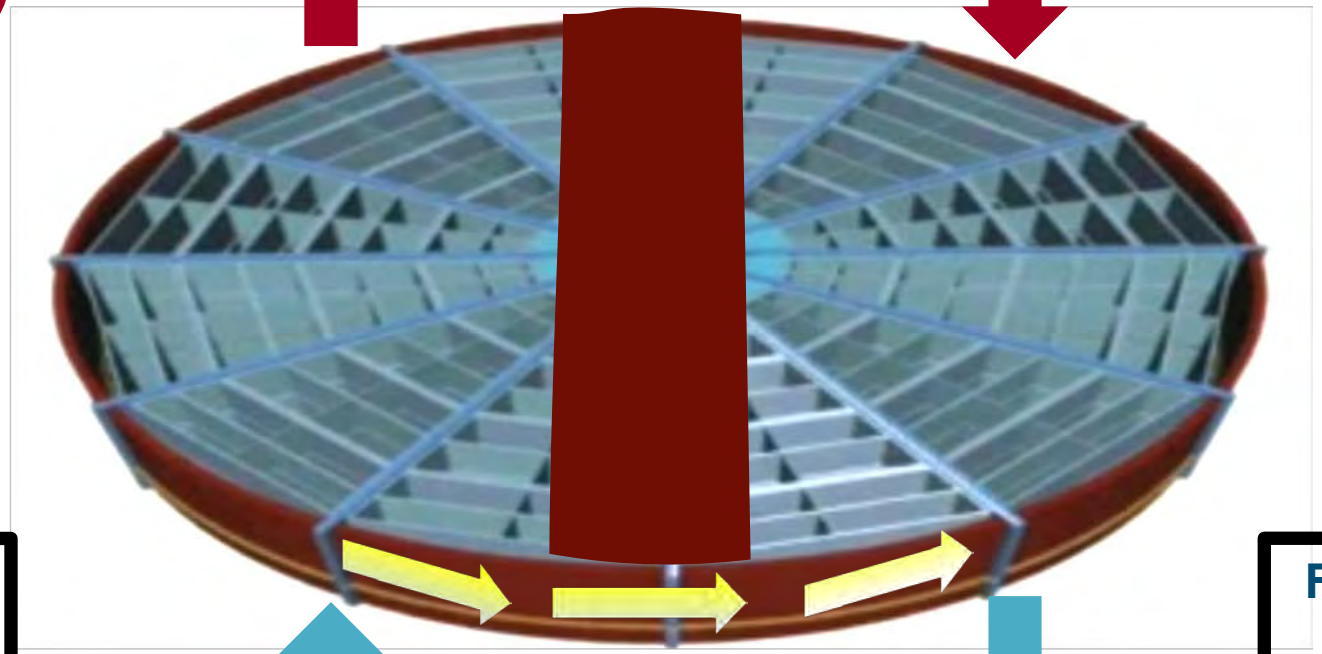


Plants control average cold-end metal temperature of air heater

Air for combustion (to boiler ~500°F)

Hot-end

Flue gas from boiler (~700°F)



Ambient air sometimes preheated (~70-120°F)

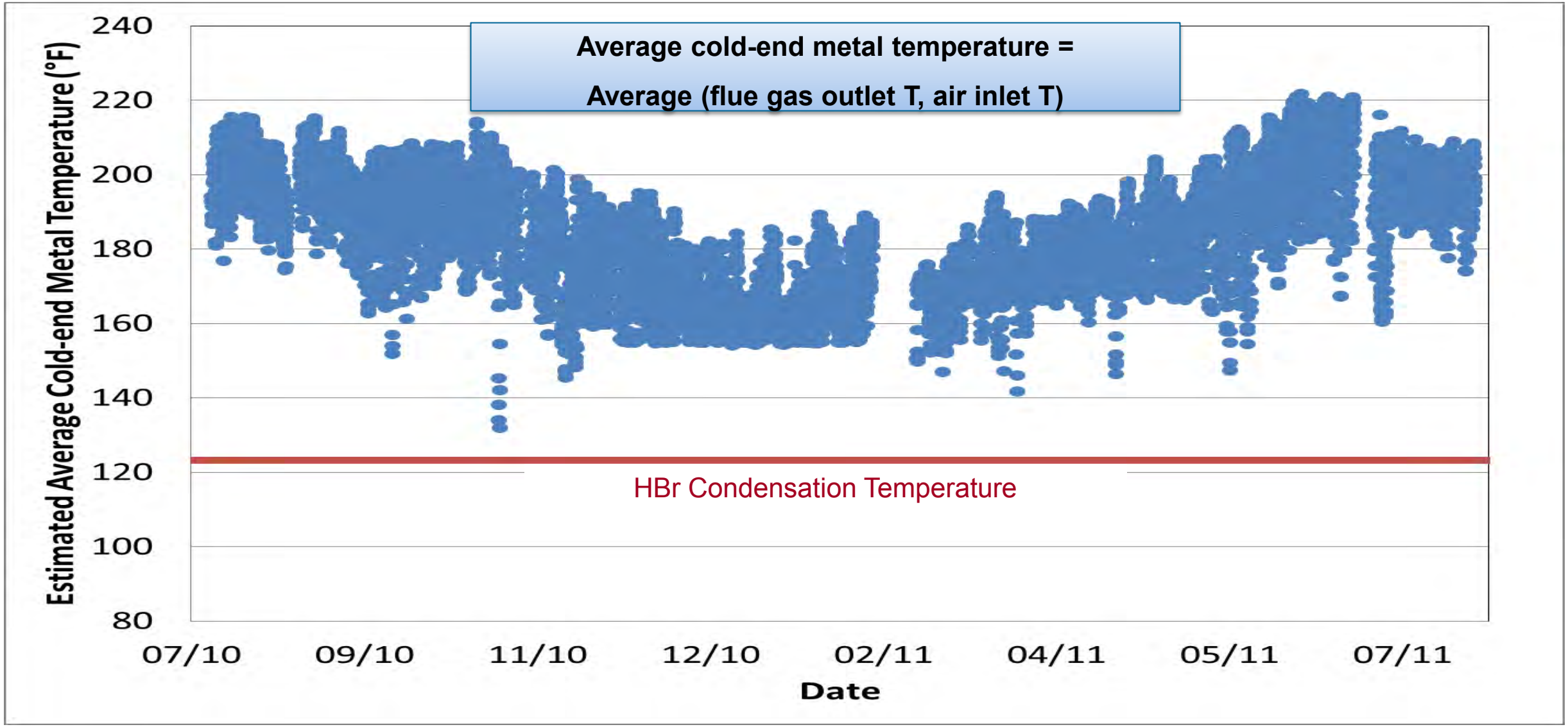
Ambient air (~20-100°F)

Flue gas to stack (~220-400°F)

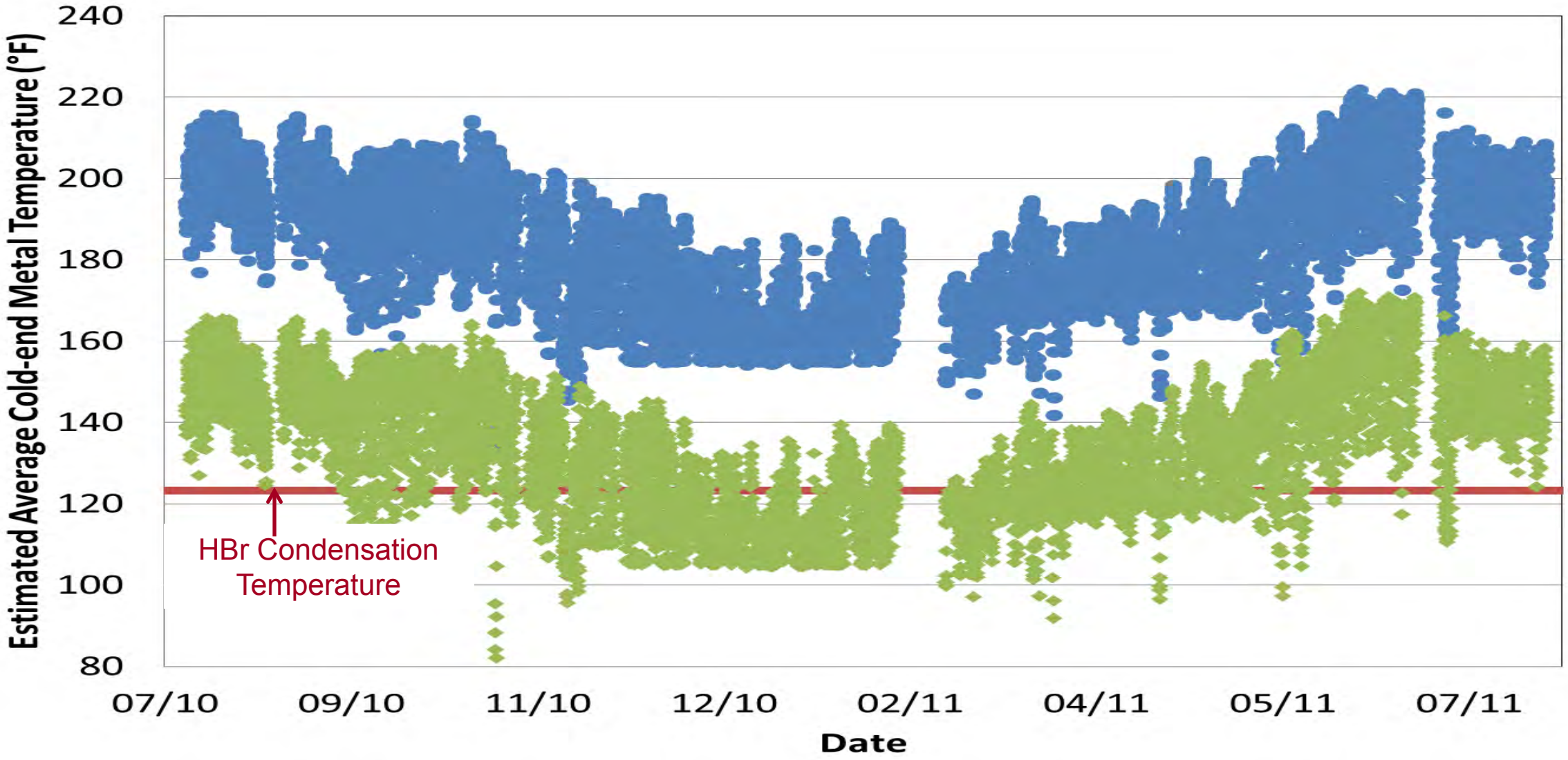
Cold-end

Average cold-end metal temperature =
Average of air inlet and flue gas outlet temperature

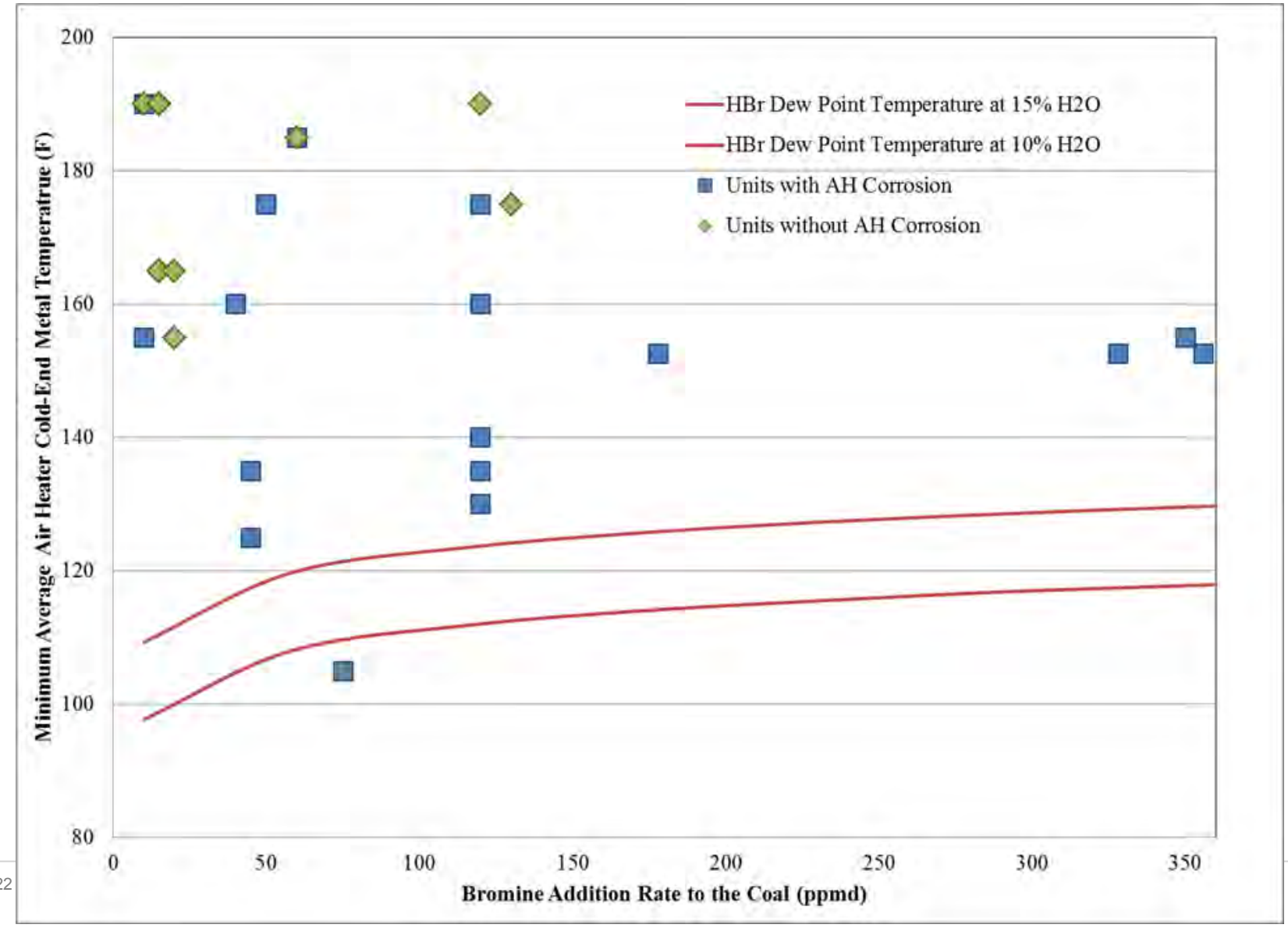
Average AH cold-end metal temperature
Br addition rate of 250 ppmd to coal, coal moisture 30%



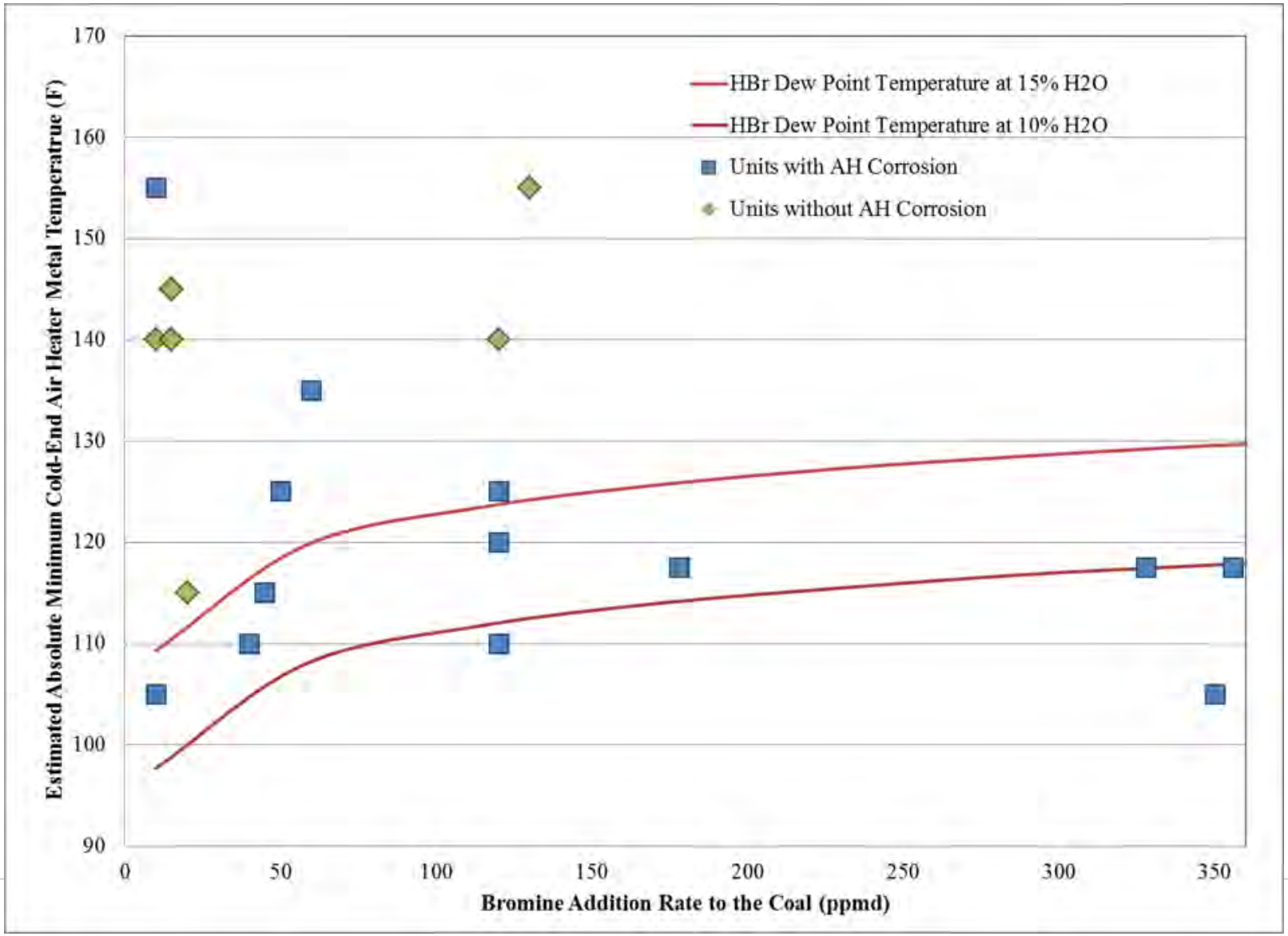
Minimum metal temperatures can be 50°F lower than average → closer to HBr condensation temperature



Average cold end metal temperature was not a good predictor of observed air heater corrosion



Absolute minimum metal temperature was a better predictor of air heater corrosion



Activated Carbon Injection Survey Results

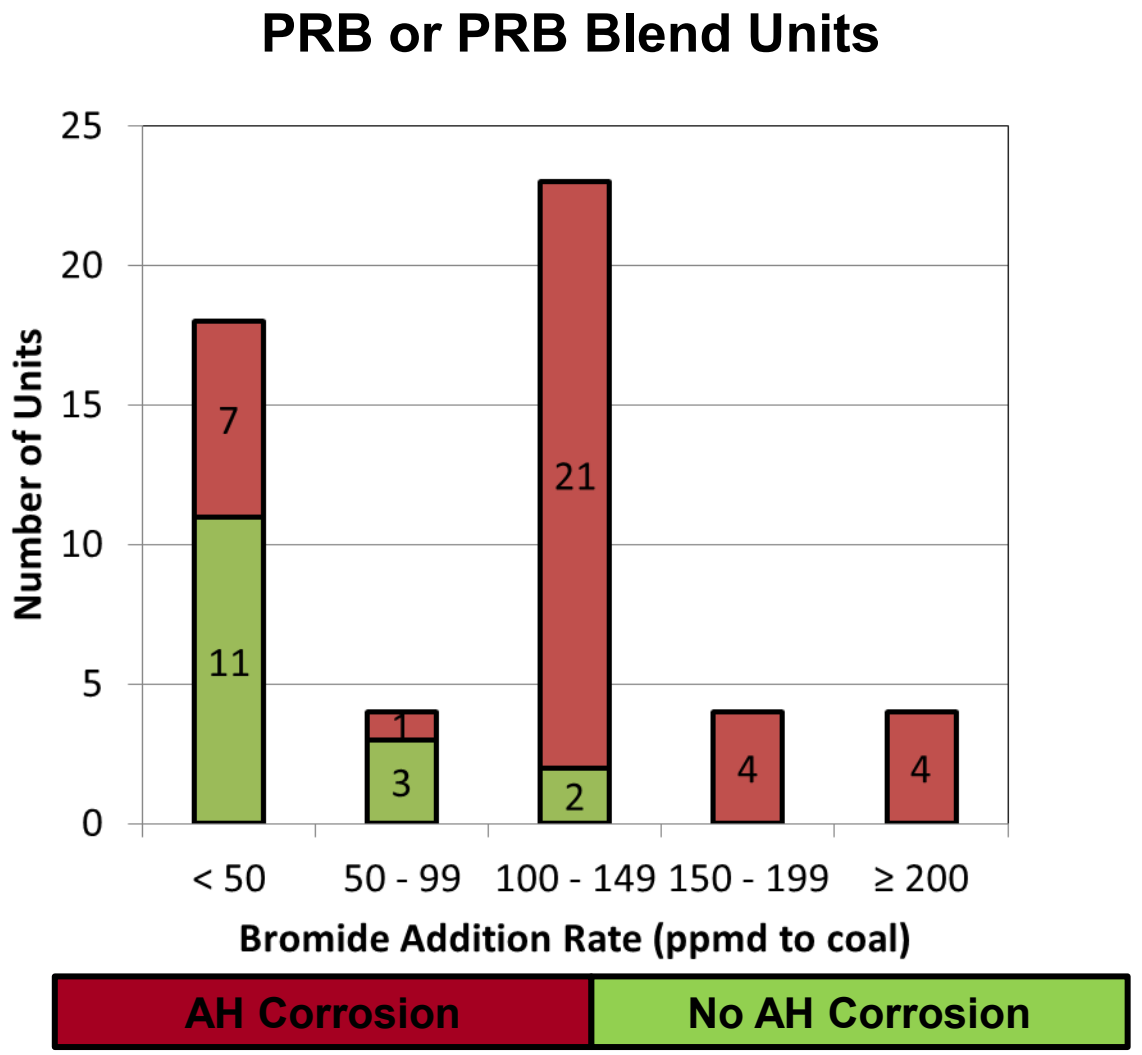
Br-ACI Survey Results

- AH corrosion
  - Units with Br-ACI injection upstream of the AH are vulnerable to corrosion (13 of 16 units)
- Silo corrosion
  - All five unlined silos that were inspected showed corrosion
  - Unlined silos have not been inspected
- Rotary feeder valve corrosion
  - Failure of instrument air system; valve now emptied after each use
- ESP deposits
  - Seven units inject PAC upstream of ESP and have large deposits on plates
  - Unit outage required to clean plates
  - Injection moved upstream of AH; now there is AH corrosion

Summary

Parameters that increase vulnerability of AH corrosion

- Burning high moisture coal
- High Br addition rates
  - Nearly All PRB units with Br rates ≥ 100 ppm reported air heater corrosion
- Low AH operating temp
- Injecting PAC upstream AH



Parameters that reduce the risk of AH corrosion

- Lower Br addition rates
- Proactive AH maintenance
- Maintain a conservative minimum AH operating temperature
- Preheat air to AH
- Optimize sootblowing

- Enamel cold-end baskets
  - 27 PRB units have enameled baskets and no reports of corrosion
  - No corrosion observed on field enameled coupons
  - Other parts of AH still vulnerable to corrosion
    - Radial seal corrosion reported by one unit with enameled baskets

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