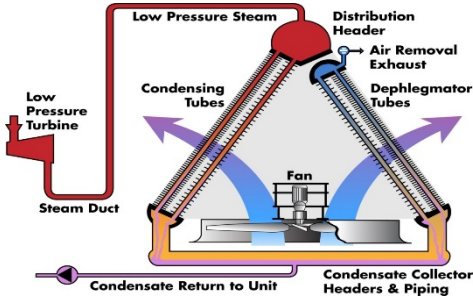
Air Cooled Condenser Users Group

Air-cooled Corrosion/FAC and Cycle Chemistry



ACCUG

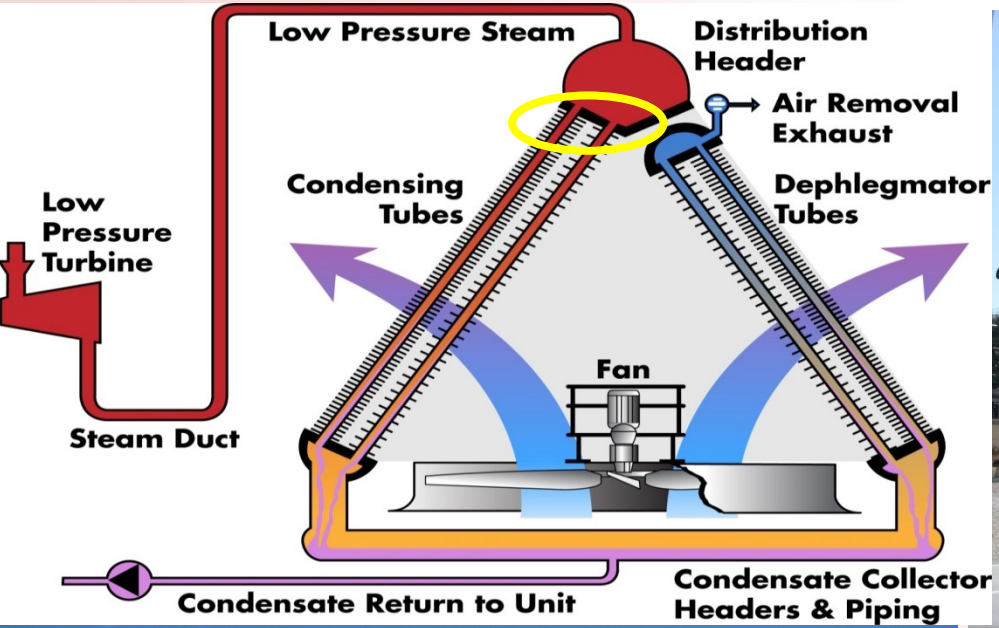
Las Vegas, Nevada, USA

3rd – 4th October 2017

Barry Dooley

Structural Integrity Associates, Inc.

ACC Come in Many Sizes



But the FAC / Corrosion damage is the same worldwide with all chemistries. The latest understanding and inspection was covered at ACCUG2016

Typical ACC Damage

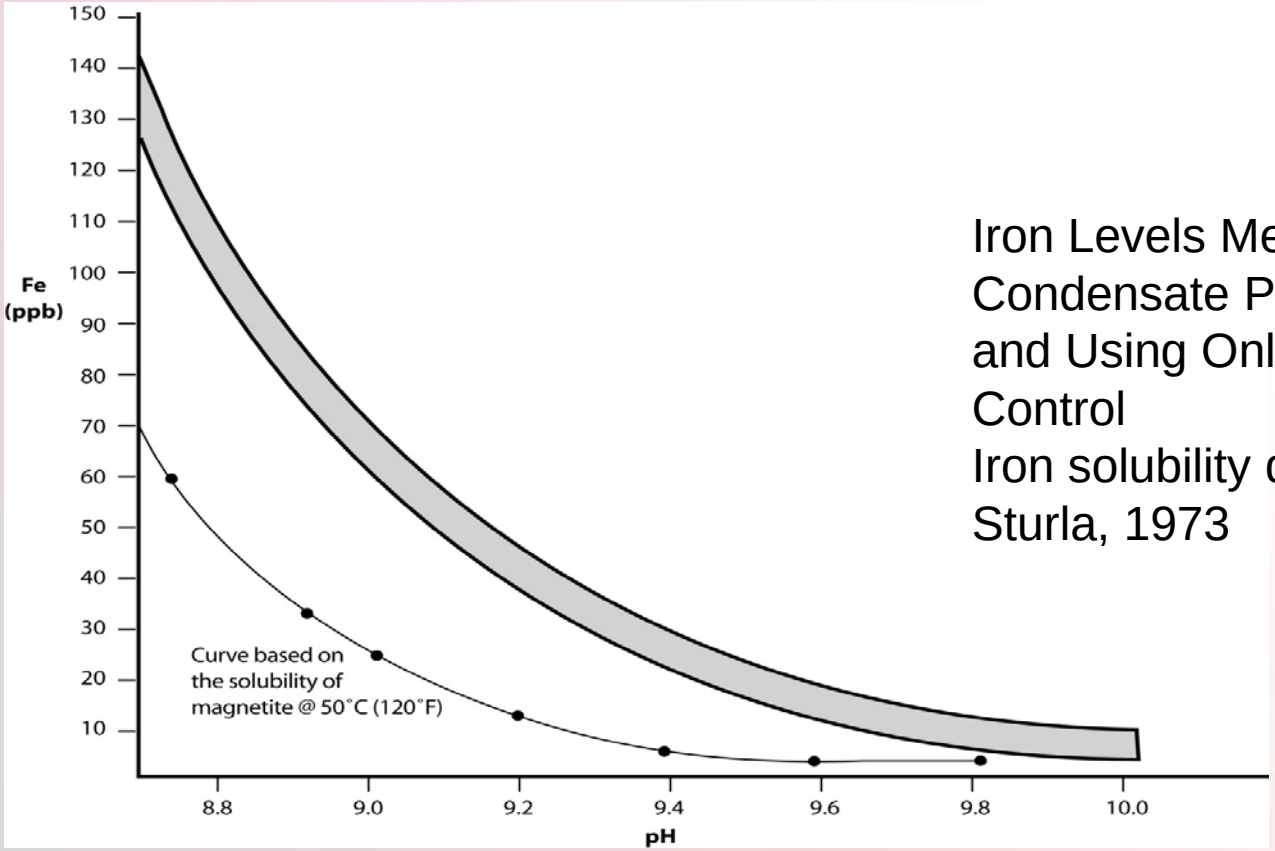
Typical ACC Damage

Corrosion/FAC in ACC and The Consequences

- High concentrations of iron around the cycle
  - Boiler/HRSG deposits (expensive chemical cleaning)
  - Boiler/HRSG Tube Failures (overheating and TF)
  - Steam Turbine Deposits (including aluminum)
- Need for Iron Removal Processes
  - Condensate Polishing and/or Filters
- Limitations around the cycle
  - Condensate polishing (may have to change mode)
- Overall an ACC “controls” the unit cycle chemistry
  - International Guidelines now available for ACC and two-phase flow (IAPWS Volatile Guidance 2010, 2015)

By 2008/9 Total Iron vs pH was Consistent Worldwide

(Dooley/Aspden pH Versus Iron Relationship)



Iron Levels Measured at Condensate Pump Discharge and Using Only Ammonia for pH Control

Iron solubility data extracted from Sturla, 1973

Dooley, Aspden, Howell & DuPreez, PPChem 2009

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By 2008/9 Needed an ACC Corrosion Index to Compare and Categorize Corrosion and Track Improvments

DHACI

(Dooley, Howell, Air-cooled Condenser, Corrosion Index)

DHACI for Tube Inlets

1. Tube entries in relatively good shape (maybe some dark deposited areas)
2. Various black/grey deposits on tube entries as well as flash rust areas, but no white bare metal areas
3. Few white bare metal areas on a number of tube entries. Some black areas of deposit
4. Serious white bare metal areas on/at numerous tube entries. Lots of black areas of deposition adjacent to white areas
5. Most serious. Holes in the tubing or welding. Obvious corrosion on many tube entries

Examples included on later slides

DHACI for Lower Ducts

A. Ducting shows no general signs of two-phase damage
B. Minor white areas on generally grey ducting. Maybe some tiger striping with darker grey/black areas of two-phase damage
C. Serious white bare metal areas in the hot box and at numerous changes of direction (eg. at intersections of exhaust ducting to vertical riser). White areas are obvious regions of lost metal.

Now We know what the Corrosion Looks Like

DHACI 3

DHACI 4

DHACI 3

The FAC / Corrosion damage is the same worldwide with all cycle chemistries

and what Holes at Tube Entries Look Like

DHACI 5

Inspections Worldwide show the same Features

Combined Cycle with ACC after ~ 15,000 hrs.

DHACI 4

Concentration of Two-phase FAC beneath Supports

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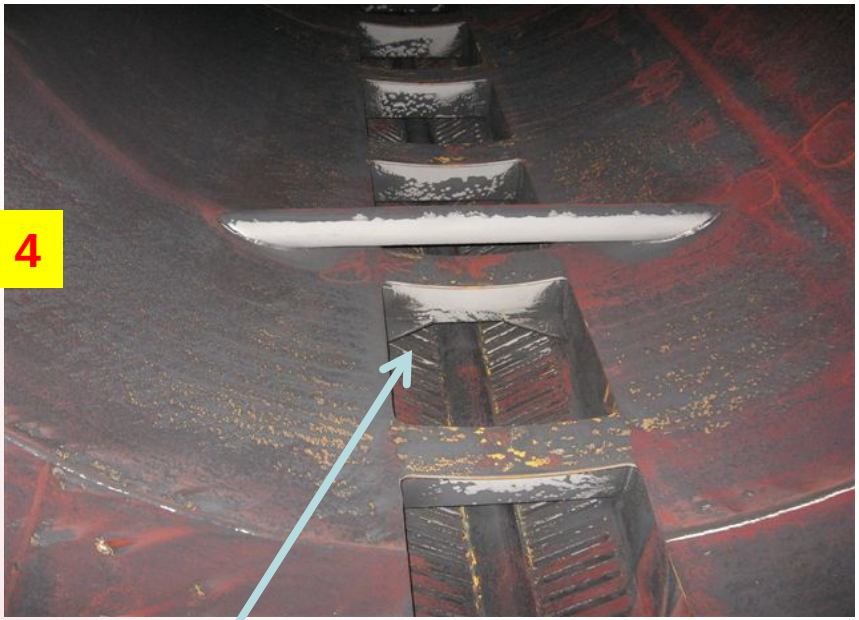
Inspections Worldwide show the same Features

750 MW Supercritical on OT at pH 9, ~4,000 hrs.

DHACI 4



Concentration of Two-phase FAC beneath Supports

Source: Richardson and Joy, ACCUG 2011

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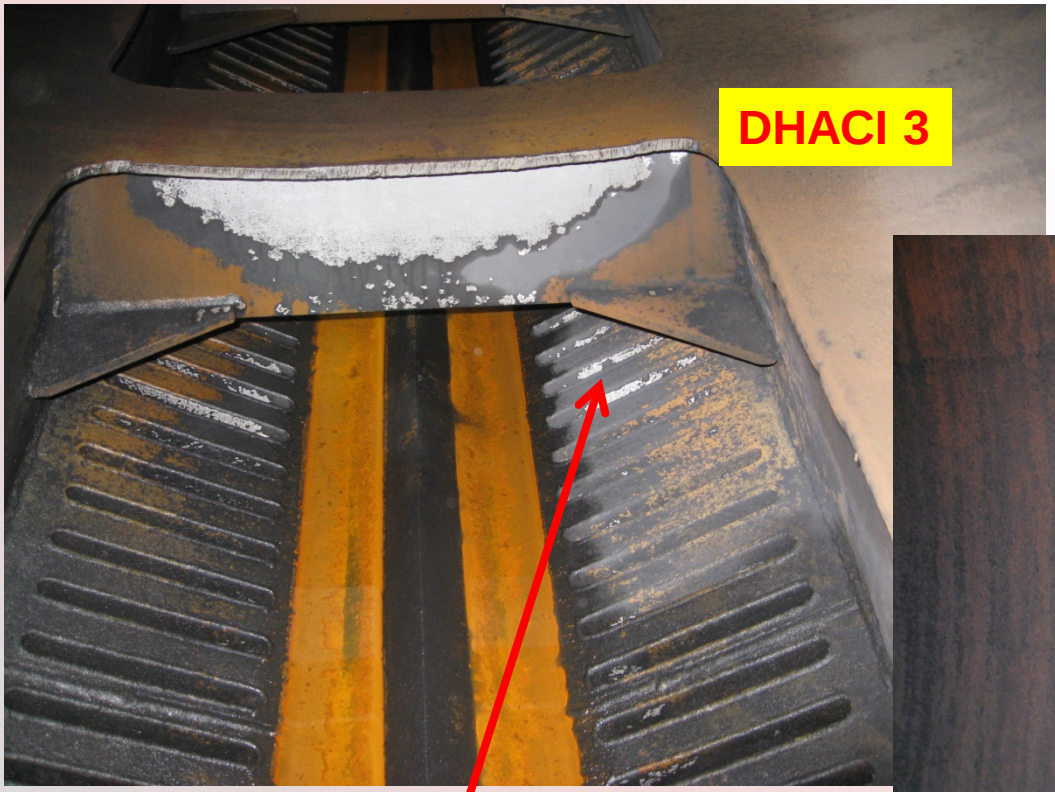
Inspections in China

650 MW Supercritical with Shuang Liang ACC. 15 Months.



So is the ACC Corrosion Mechanism Low Temperature Two-Phase FAC?

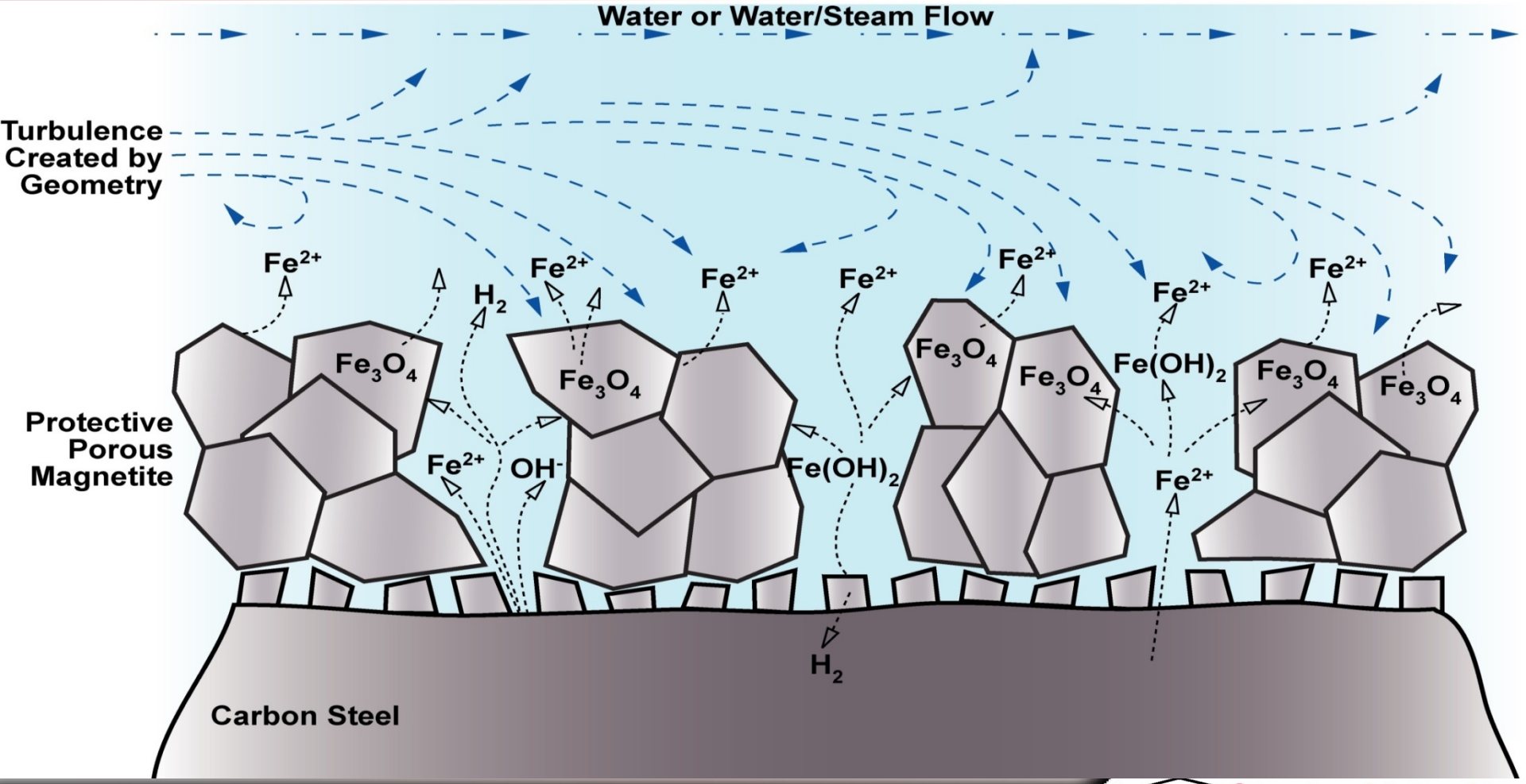
which is

Dependent on Removing the Saturation of Fe_3O_4 at the Surface and Precipitating/Depositing it Adjacently

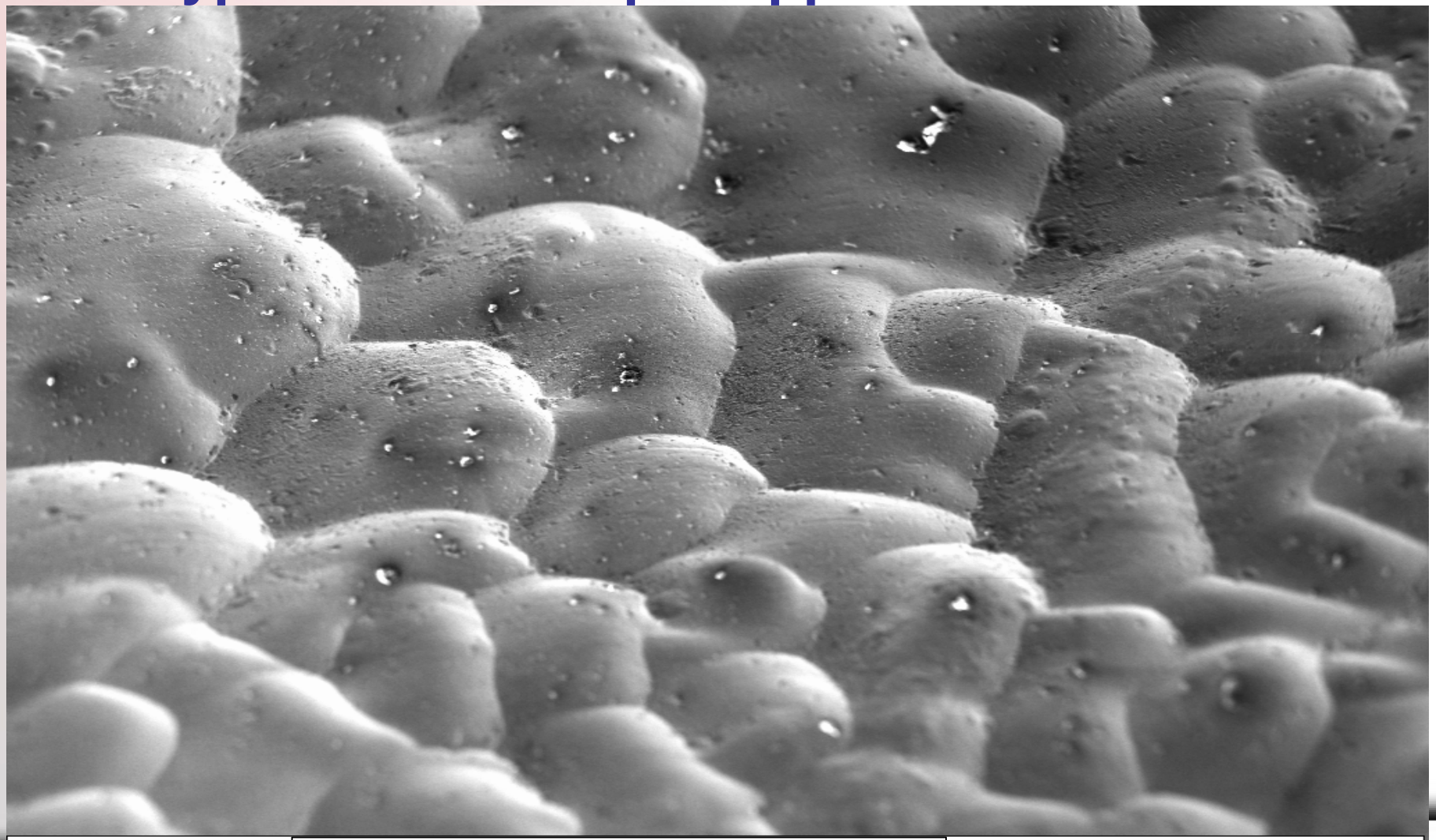
(Two ACC Tubes with damage (white areas) have been analyzed)

"Normal" Two-phase FAC in Flowing Turbulent Flow

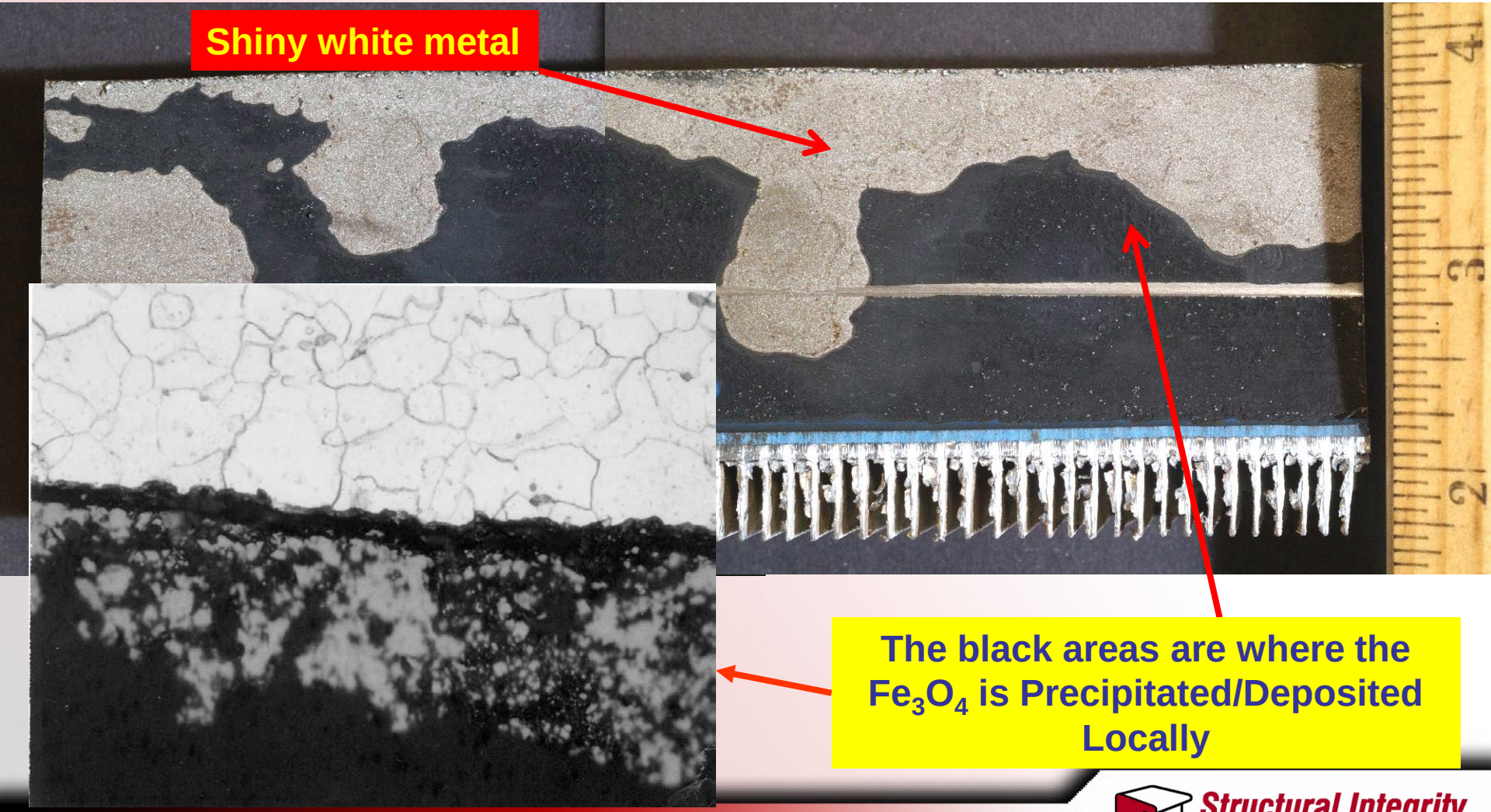
(Removes the Saturation of Fe_3O_4)



Typical Microscopic Appearance of FAC



Inside diameter surface of an ACC Tube



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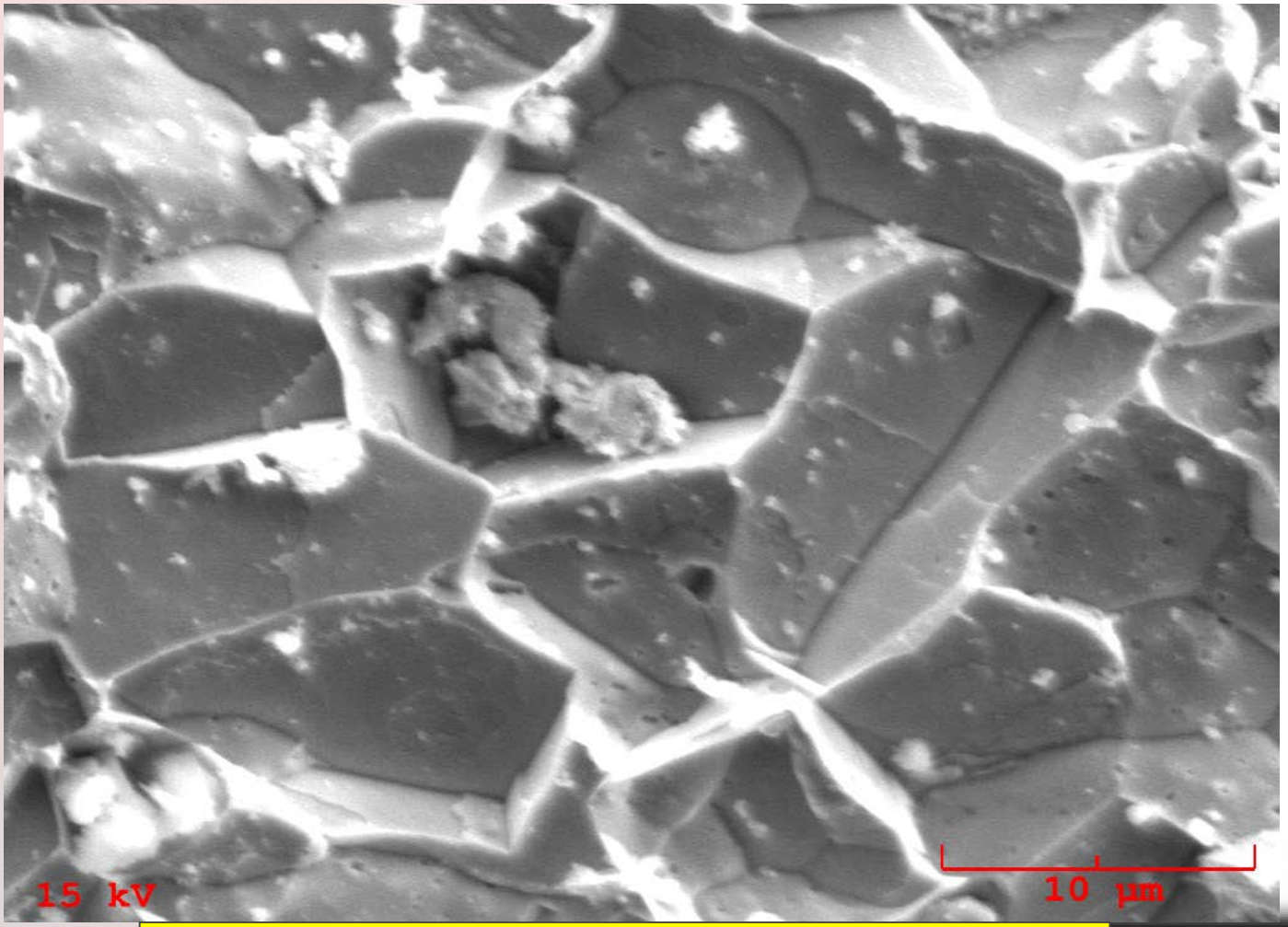
SEM Image of Corroded ACC Surfaces



Preferential grain boundary corrosion attack

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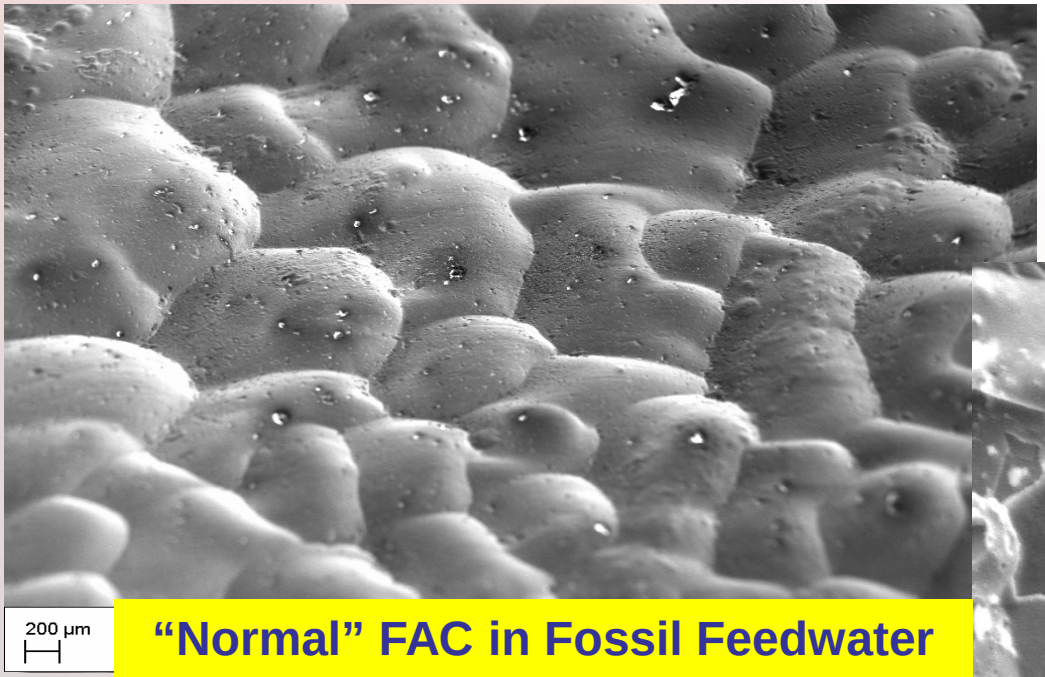
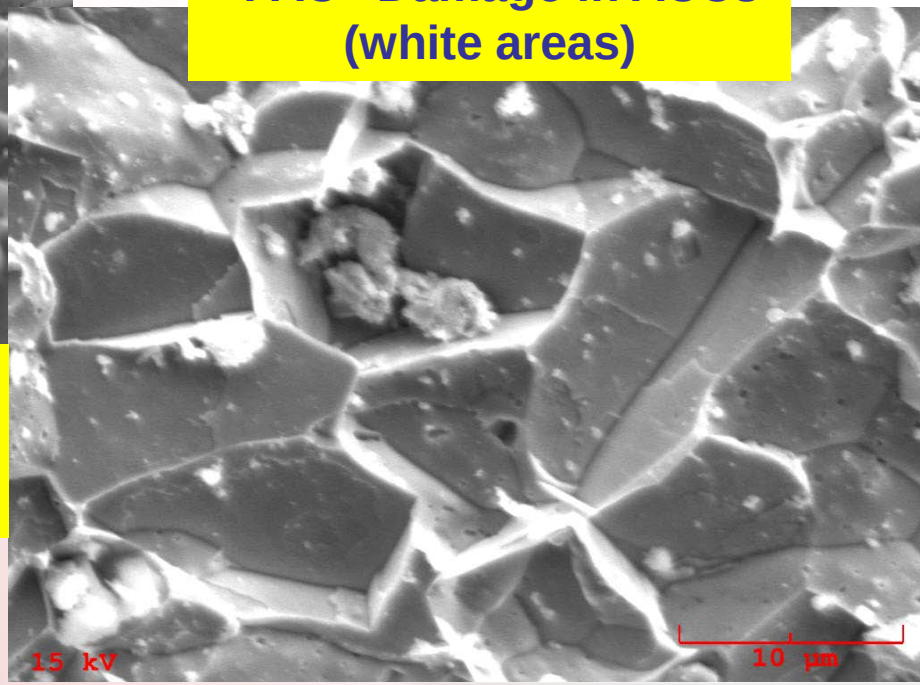
Comparison of the Microscopic Appearance of FAC and ACC Corrosion



"Normal" FAC in Fossil Feedwater and in Combined Cycle/HRSG Circuits

"FAC" Damage in ACCs (white areas)



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So do we Fully Understand the Environment and the Corrosion Mechanism and how to Prevent?

Solutions are already being applied

Increase bulk condensate pH up to 9.8 – Works and is Validated

Increase local pH (amines including FFP) – Appears to work but science not completely understood/explained

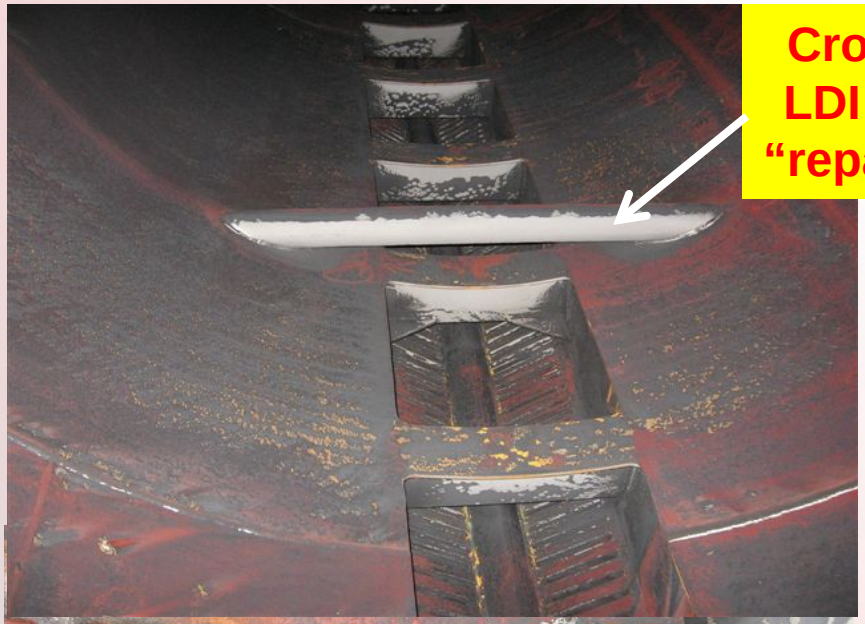
Filters (average and absolute) and condensate polishers – Can lower total iron but doesn't stop FAC/Damage

Coatings (epoxy), Sleeves, Inserts – Not sufficient information

Alternate Materials to CS – very few cases and no validation

Designs –various have been applied but FAC/Damage still occurs

Damage takes time to repair (ex. 2 Years with pH 9.8)



Cross member LDI not quickly "repaired" by pH

DHACI 4

DHACI 2

Source: Richardson and Joy, ACCUG 2011

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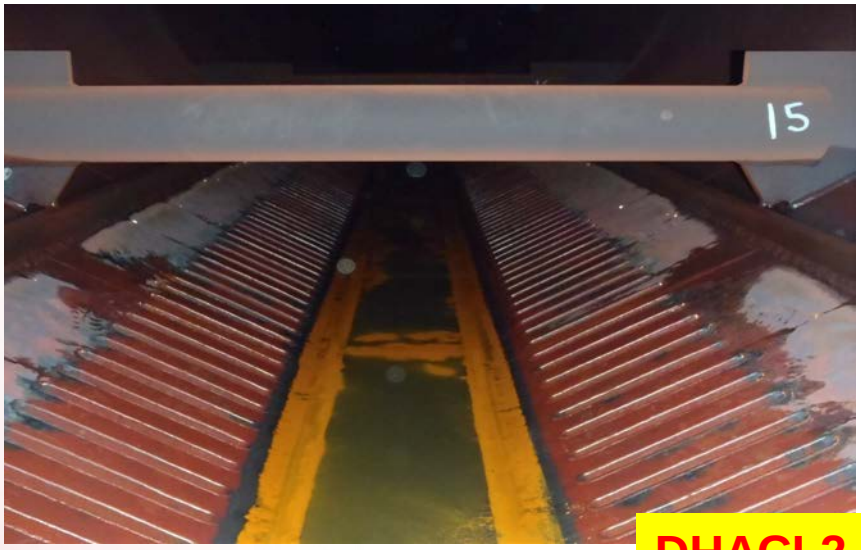
Damage takes time to repair (15 Months with pH 9.8)

DHACI 4



DHACI 2

Source: Barnett & Olszewski, 2013 FAC Conf. Washington

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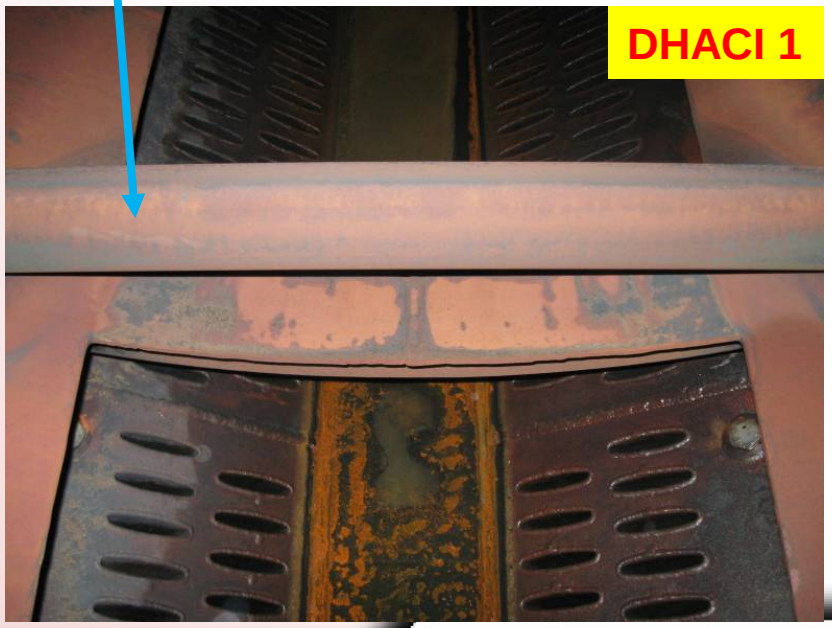
ACC “Repairs” with FFP

DHACI 4

Cross member appear to repair using FFP

DHACI 1



Courtesy Bill Stroman

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ACC Operation with FFA

Image courtesy of Anodamine Incorporated. Combined Cycle with ACC's, treatment with Anodamine HPFG

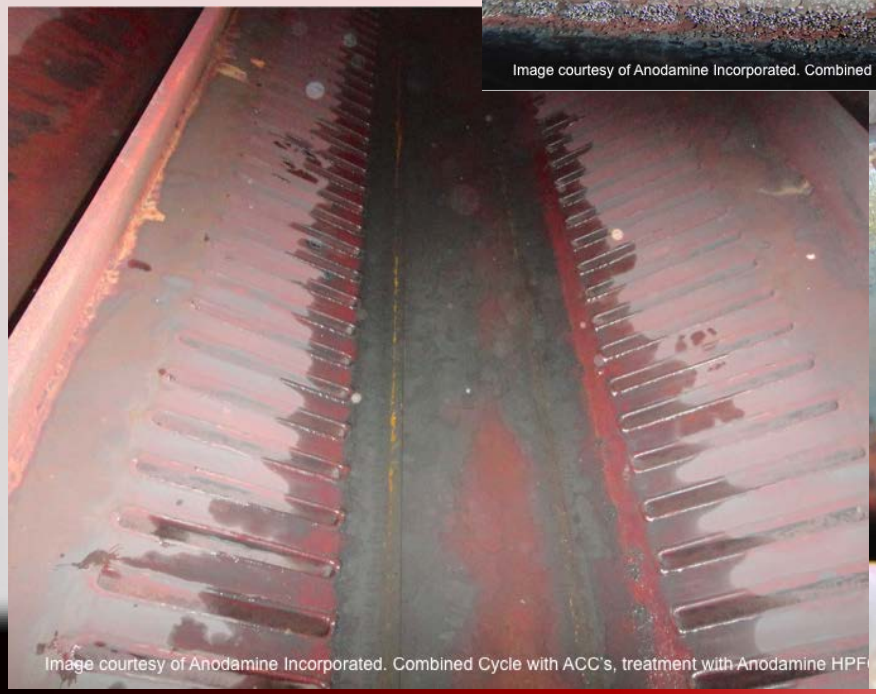


Image courtesy of Anodamine Incorporated. Combined Cycle with ACC's, treatment with Anodamine HPF

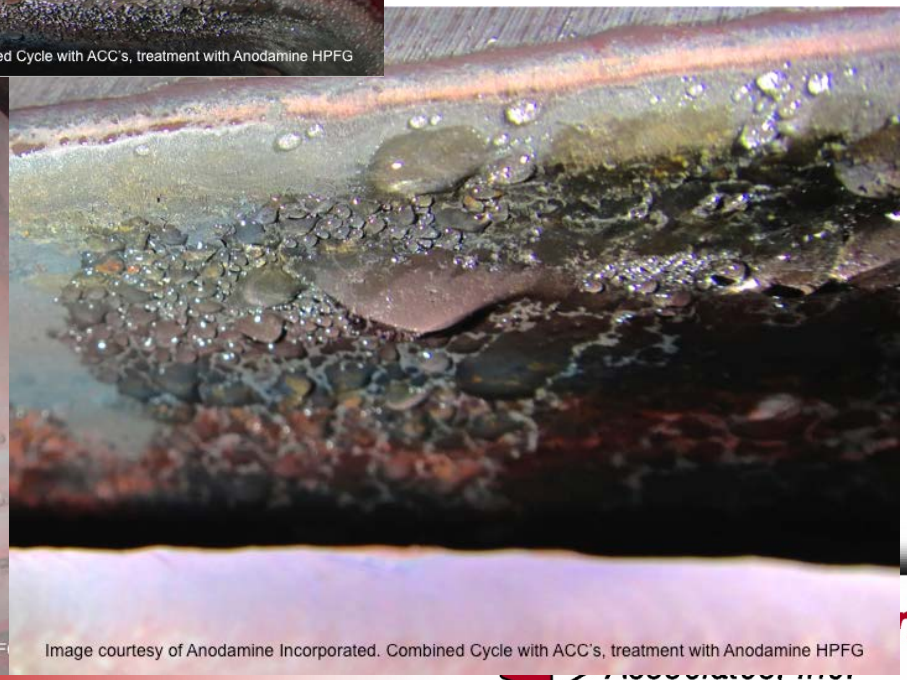
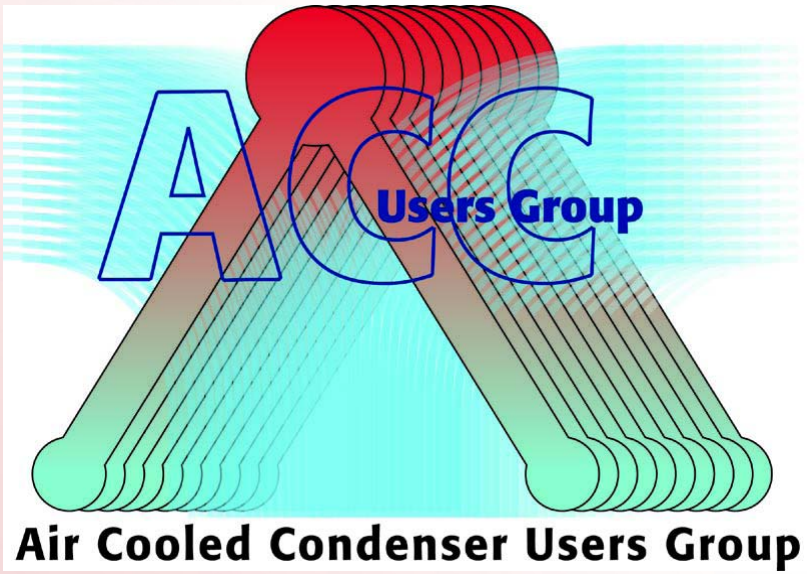


Image courtesy of Anodamine Incorporated. Combined Cycle with ACC's, treatment with Anodamine HPFG

What Guidance is Currently Available?



http://acc-usersgroup.org/

ACC.01

Original Issue: May 12, 2015

Revision due: May 12, 2018

Guideline for Internal Inspection of Air-Cooled Condensers

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International Association for the Properties of Water and Steam

IAPWS
Technical Guidance Documents
for
Fossil and Combined Cycle Plants

(with particular relevance for plants with ACC)

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IAPWS Technical Guidance Documents (TGD) for Plants with ACC

- **Procedures for the Measurement of Carryover of Boiler Water and Steam (September 2008).** This document includes the procedures to measure carryover from drum boilers to assist in preventing steam turbine failure/damage.

- **Instrumentation for monitoring and control of cycle chemistry for the steam-water circuits of fossil-fired and combined-cycle power plants (September 2015)**. This document includes a table that can be used to determine the minimum key level of instrumentation required for any fossil or combined cycle/HRSG plant.

- **Volatile treatments for the steam-water circuits of fossil and combined cycle / HRSG power plants (July 2015).** This document includes the basis for AVT and OT for all plants with customization for plants with ACC and using ammonia and amines. Recently added guidance for fast start and frequently started HRSGs.

Freely available and downloadable on IAPWS website www.IAPWS.org

IAPWS Technical Guidance Documents (TGD) for Plants with ACC

- **Phosphate and NaOH treatments for the steam-water circuits of fossil and combined cycle / HRSG power plants (Oct 2015).** This document includes the basis for selecting the optimum boiler/HRSG evaporator water treatment for (phosphate and NaOH treatments) for all drum plants including customization for plants with ACC.

- **Steam Purity for Turbine Operation (Sept 2013).** This document covers guidance for a wide range of turbines (fossil, nuclear, industrial, geothermal, etc) and failure mechanisms. It includes customizations for plants using amines and with carbon dioxide.

- **Corrosion Product Sampling and Analysis (May 2014).** This document covers the optimum procedures and techniques for monitoring iron and copper. Includes a table of achievable iron levels for plants with ACC

Freely available and downloadable on IAPWS website www.IAPWS.org

IAPWS Technical Guidance Documents (TGD) for Plants with ACC

- **HRSG HP Evaporator Sampling for Internal Deposit Identification (Sept 2016).** This document includes the locations where to take samples from HGP and VGP HRSGs, how to analyze the samples, and a new IAPWS map to assist in determining whether the HRSG HP evaporator needs to be chemically cleaned.

- **Application of FFA in Fossil, Combined Cycle and Biomass Plants (Sept 2016).** This document covers optimum application guidance for FFA / FFAP in all-ferrous plants. It also includes customizations for shutdown/layup, multiple pressures, mixed-metallurgy feedwater systems, condensate polishing, and air cooling.

Freely available and downloadable on IAPWS website www.IAPWS.org

International Association for the Properties of Water and Steam

A few examples of IAPWS Guidance for Fossil and Combined Cycle Plants

(with particular relevance for plants with ACC)

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Technical Guidance Document

Monitoring and Analyzing Total Iron in Fossil and Combined Cycle Plants

Consensus of 24 Countries

Latest Revision Issued 1st May 2014

Structural Integrity Associates, Inc.

Introduction and Rationale for Corrosion Product Sampling (CPS)

Significant problems with reliable and effective corrosion product sampling observed worldwide in fossil & combined cycle gas turbine (CCGT) plants. Particularly needed in plants with ACC

Corrosion product levels critical to determining effectiveness or otherwise of cycle chemistry programs - Total Fe and Cu levels key aspects of IAPWS cycle chemistry Technical Guidance Documents (TGD)

Critical activity either not done at all or conducted incorrectly

Achievable Total Fe & Cu Levels – Different Plant Types/Optimized Chemistry

(Indicative that FAC/Corrosion is "under control")

Feedwater		
OT:	Total Fe =	< 1 µg/kg
AVT:	Total Fe =	< 2 µg/kg
AVT (Mixed):	Total Fe & Cu =	< 2 µg/kg
HP/LP Heater Drains:	Total Fe & Cu =	< 10 µg/kg
HRSG Evaporators/Drums		
AVT/PT/CT:	Total Fe =	< 5 µg/kg
Air - cooled Condenser (ACC)		
ACC Outlet:	Total Fe =	< 10 µg/kg (ppb)
Post Condensate Filter:	Total Fe =	< 5 µg/kg (ppb)

Analytical Methods for Total Iron

Suitable methods

- **Post sample digestion UV-Vis (Ferrozine) with a 5 cm cell - Fe only**
- **Graphite Furnace Atomic Absorption spectrometry (GF-AA) post sample digestion**
- **Inductively coupled plasma mass spectrometry (ICP-MS) post sample digestion**

Key points are:

1. **Full digestion for all samples required**
2. **Detection limit of < 2 µg/kg required (lower the DL the better)**

International Association for the Properties of Water and Steam

Technical Guidance Documents

Film Forming Products

Received final review and approval from 24 countries involved in IAPWS. Reviews have included most of the chemical supply companies and most of the Steam Turbine, Boiler & HRSG Manufacturers

Published at IAPWS Meeting, September 2016
Dresden, Germany

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Technical Guidance Document
Film Forming Products

Task Group Members (Chairs: Hater, Lendi & Dooley)

("The only source of knowledge is experience")

Chemical Supply Companies

- Kurita
- GE Water
- Anodamine
- ChemTreat
- Helamin
- Nalco
- Reicon
- Aminotek (Russia)

Companies

- Laborelec
- Areva
- Siemens
- GE / Alstom
- CMI
- Swan
- IAE Japan
- Eskom

Manufacturers

- HRSG
- Steam Turbine
- Instruments

IAPWS Members Worldwide from 21 Countries

IAPWS TGD will be non-commercial and contain no proprietary items

Technical Guidance Documents
Film Forming Products

Questions that Fossil and Combined Cycle Plants were Asking and that the IAPWS TGD has Addressed

- **Information on what FFA / FFAP are and what they can do. Operationally and for shutdown and/or layup?**
- **How to determine which to use for which application and how to determine the amount to use and optimize?**
- **Are they applicable to different metallurgies (all-ferrous, mixed metallurgy and aluminium containing systems)?**
- **How to analyze and confirm content? What instrumentation is needed? Is there a need for additional instruments than included in IAPWS TGD?**
- **How to determine if successful? Monitoring of Total Iron / Copper? Is there a need for additions to the IAPWS TGD?**
- **How to use in Boilers, Feedwater, Steam Turbines, ACC?**

IAPWS TGD will be non-commercial and contain no proprietary items

Technical Guidance Document
Film Forming Product

Base Case Guidance

1. Operation. All-ferrous fossil, combined cycle and biomass plants
   - Which FFA to use
   - “Monitoring 1” baseline before use
   - How much to dose and where
   - How to analyze content of FFA in cycle
   - How to determine optimum use (Monitoring 2)

Customization Guidance

2. Shutdown/Layup
3. Different FFP and Combinative Mixtures
4. Major Components with Copper or Aluminum
5. Different Temperature / Pressures
6. Systems with ACC and Condensate Polishers
7. Seawater cooling and Desalination
8. Industrial Plants (hints only)

IAPWS TGD will be non-commercial and contain no proprietary items

Some Final Thoughts on “corrosion” in ACC

Based on work conducted in Australia, Canada, Chile, China, Cote d’Ivoire, Dubai, India, Ireland, Mexico, Qatar, Abu Dhabi, South Africa, UK and US

- **Increasing condensate pH to 9.8 will gradually eliminate the FAC damage at the tube entries and iron levels will reduce to IAPWS suggested levels (5 - 10 ppb). Documented by reducing the DHACI. FFP also work but not sufficient documentation.**

- **Damage on cross members is not “repaired” as quickly by increasing pH. Is this LDI caused by the larger droplets leaving the PTZ of the LP Steam Turbine?**

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Summary

- **Some aspects relate to (LT Two-phase) FAC**
  - Adjacent black and white areas in severe turbulent areas
  - Increasing local pH reduces damage
- **But some aspects don't (normal FAC scalloped appearance and white areas on cross members is probably LDI)**
- **Environment is known and has been measured**
  - Two-phase mixture formed in PTZ of the steam turbine
  - Concentrating liquids **(Higher in chloride/sulphate, organics)**
  - Lower in pH (0.5) and very low in dissolved oxygen (close to zero)
- **"Repaired" two-phase FAC areas turn red slowly**
  - Mechanism in ACC is thus not totally understood & what are amines doing?
- **Some good results using amines and FFP**
  - But need more fully documented cases (before and after, total iron levels,)