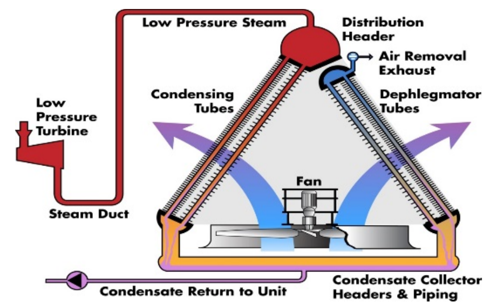
Air Cooled Condenser Users Group

Introduction for ACC FAC and Cycle Chemistry Session



Barry Dooley

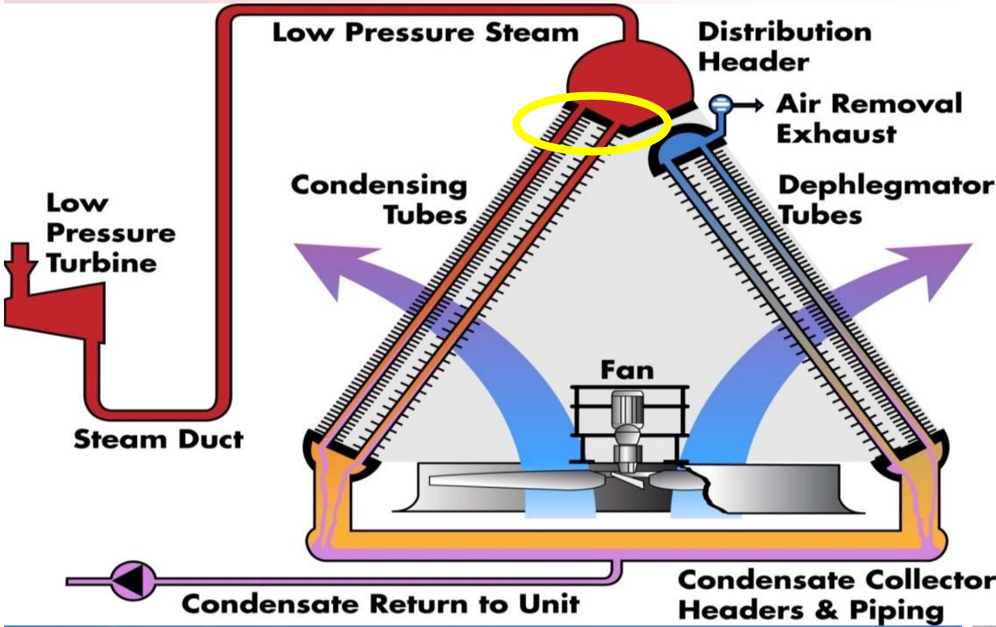
ACCUG 2018

Colorado Springs, USA

9th – 11th October 2018

Structural Integrity Associates, Inc.

ACC Come in Many Sizes



But the FAC / Corrosion damage is the same worldwide with all chemistries and plant types **(Based on assessment/inspection work conducted in Australia, Canada, Chile, China, Cote d'Ivoire, Dubai, India, Ireland, Mexico, Qatar, Abu Dhabi, South Africa, UK and US)**

Typical ACC Damage

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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)

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The 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.

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 plant types

and what Holes at Tube Entries Look Like

DHACI 5

Inspections Worldwide show the same Features

Combined Cycle with ACC after ~ 15,000 hrs, pH 9.1.

DHACI 4

Concentration of Two-phase FAC beneath Supports

DHACI – Dooley, Howell Air-cooled Condenser Index

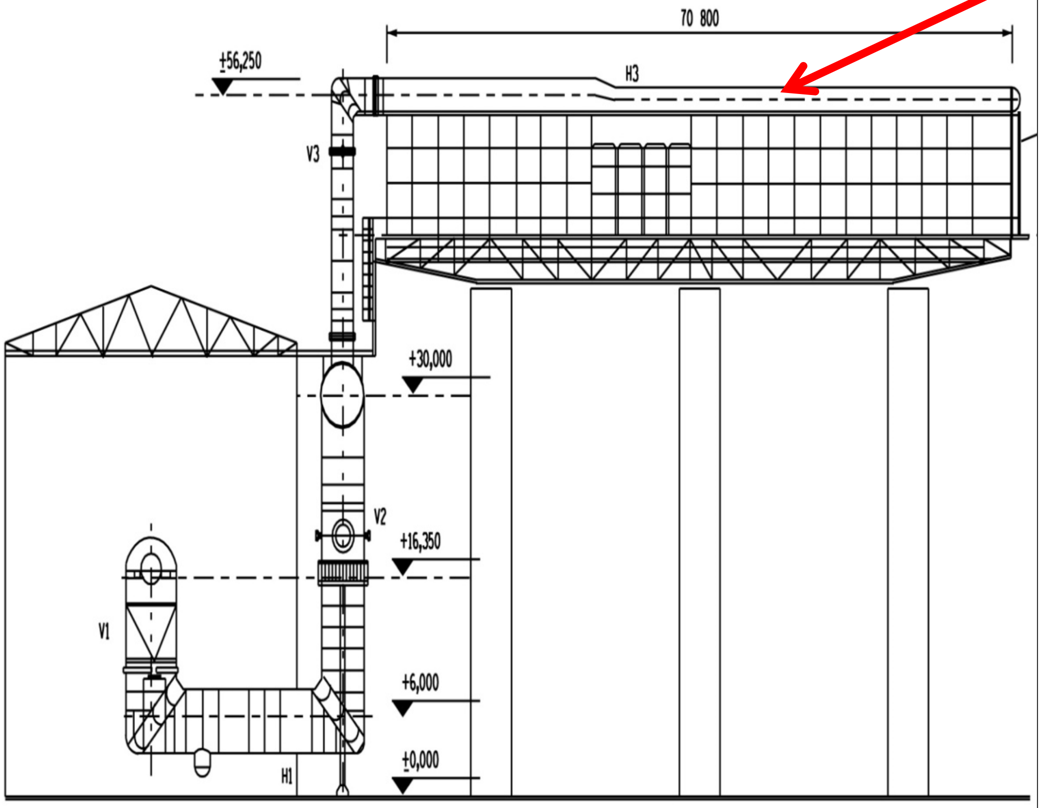
Inspections Worldwide show the same Features

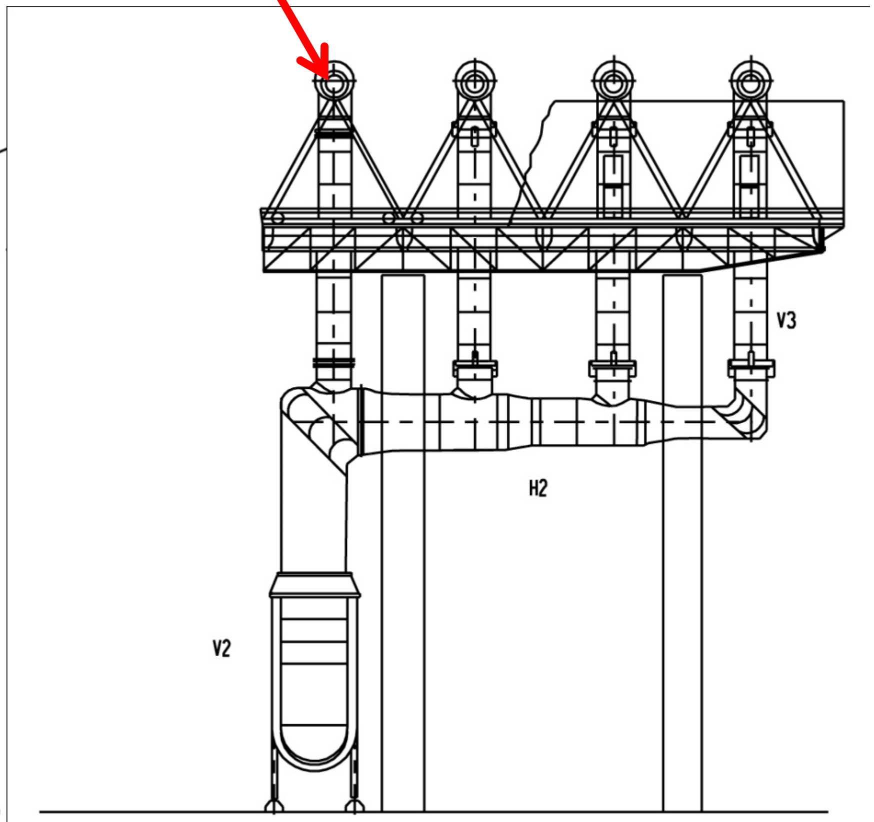
750 MW Supercritical on OT at pH 9, ~4,000 hrs.

DHACI 4

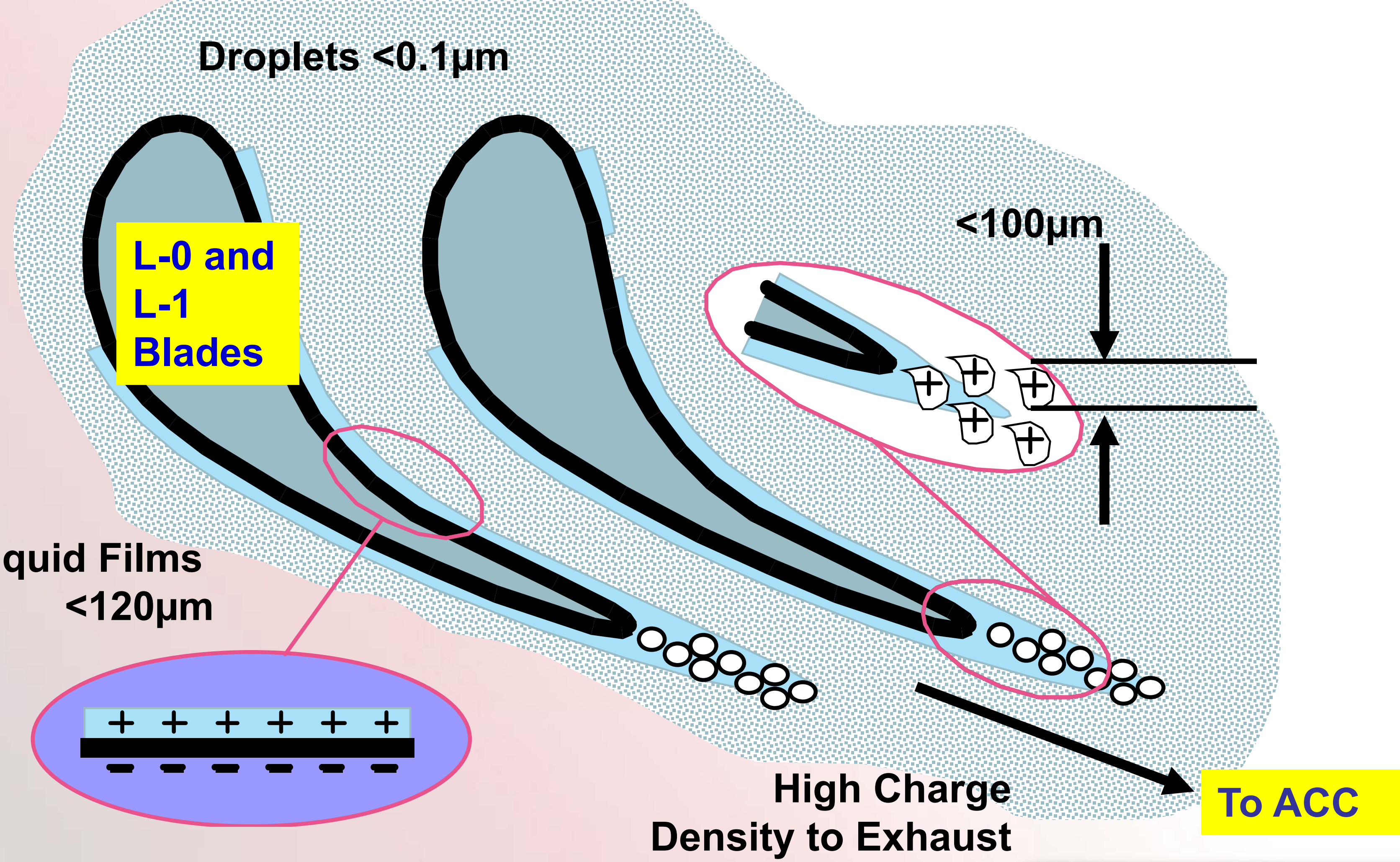
Concentration of Two-phase FAC beneath Supports

To Understand the Corrosion Here we need to Understand the Environment in the PTZ





Generation of the ACC Environment is in the PTZ



We Fully Understand the Environment but Can we Prevent the Corrosion Mechanism?

"Solutions" are being applied

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

Increase local pH (including FFS) – Appears to work but science not fully understood/explained

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

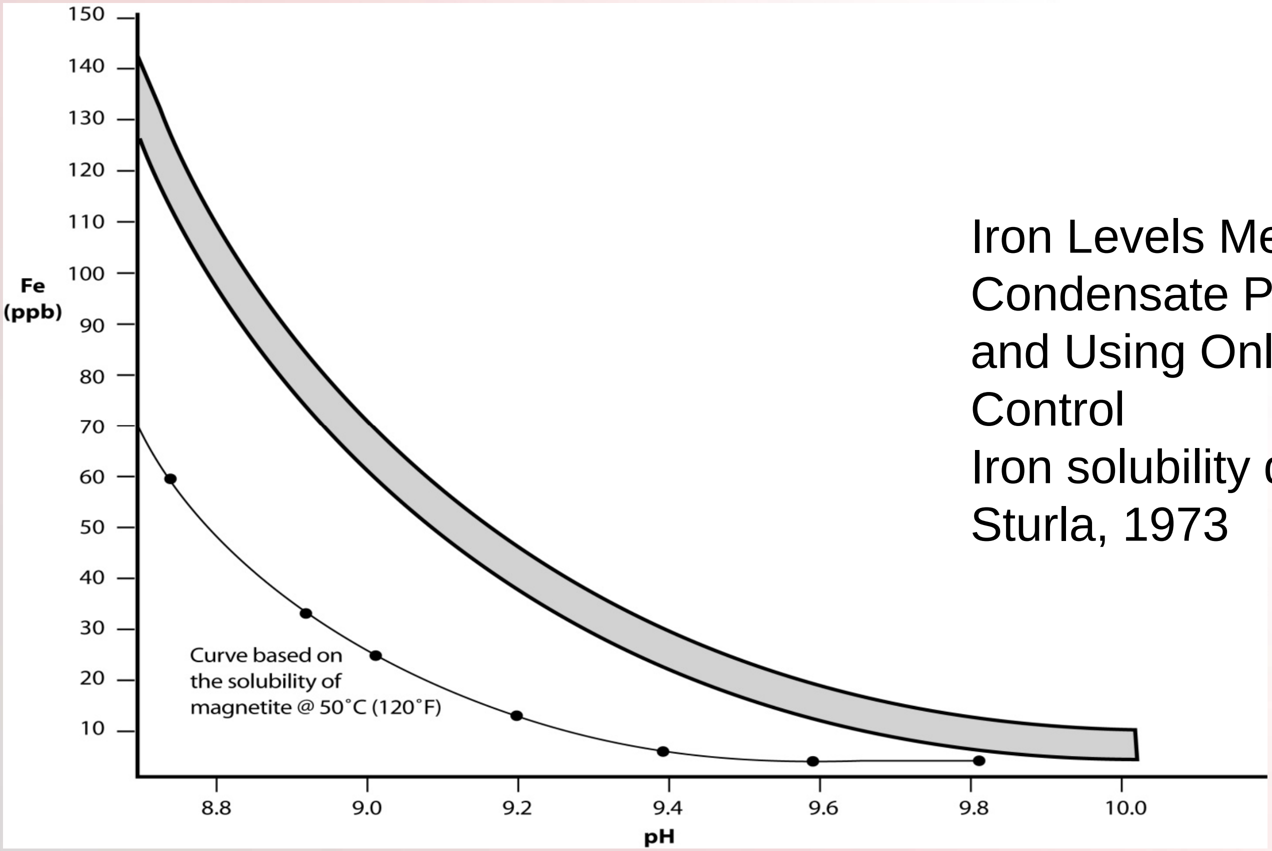
Coatings (epoxy), Sleeves, Inserts – Not sufficient information

Alternate Materials to CS – very few cases and no validation

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

The Total Iron vs pH is Consistent Worldwide

(Dooley/Aspden pH Versus Iron Relationship)



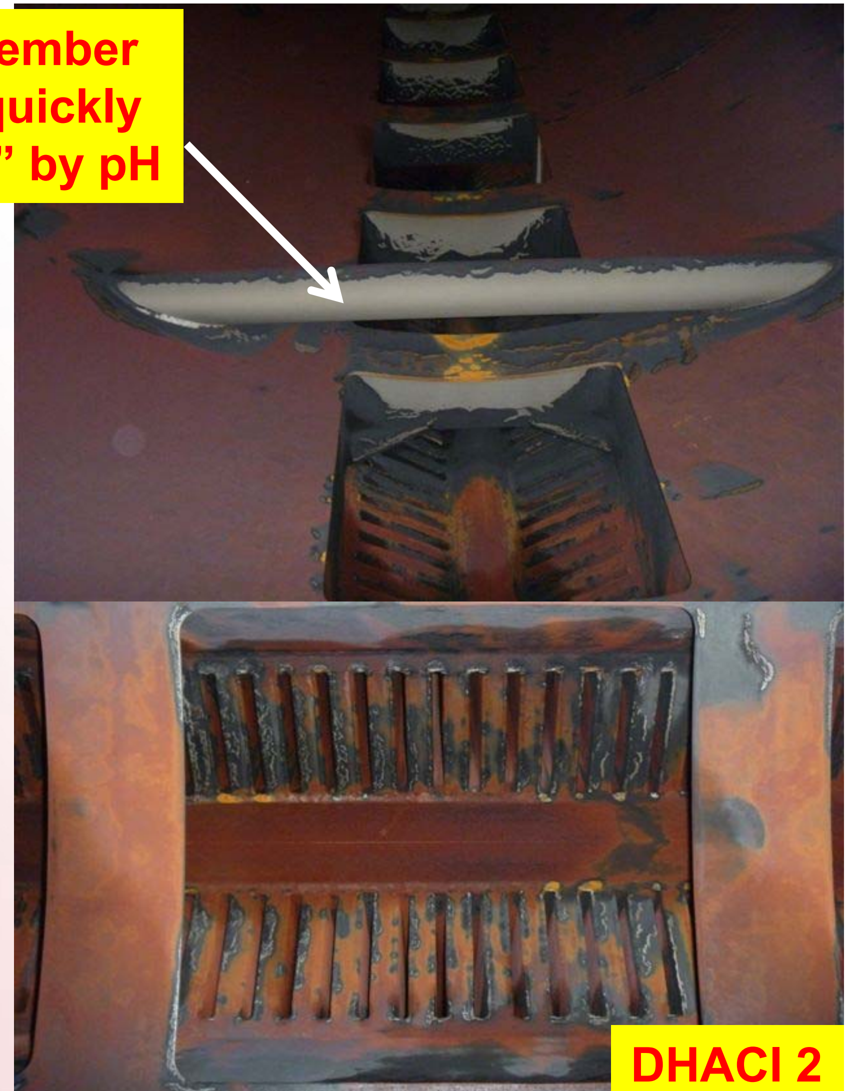
Iron Levels Measured at Condensate Pump Discharge and Using Only Ammonia for pH Control

Iron solubility data extracted from Sturla, 1973

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

Cross member LDI not quickly "arrested" by pH

DHACI 4



DHACI 2

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

DHACI 4

DHACI 2

What Guidance is Currently Available?

Air Cooled Condenser Users Group

http://acc-usersgroup.org/

ACC.01

Original Issue: May 12, 2015

Revision due: May 12, 2018

Guideline for Internal Inspection of Air-Cooled Condensers

Structural Integrity Associates, Inc.

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)

Structural Integrity Associates, Inc.

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 FFS 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

Technical Guidance Document

Monitoring and Analyzing Total Iron in Fossil and Combined Cycle Plants

Consensus of 24 Countries

Latest Revision Issued 1st May 2014

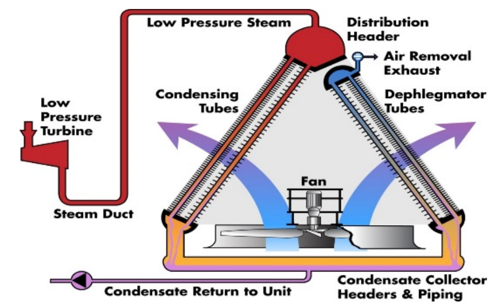
Achievable Total Fe & Cu Levels – Different Plant Types/Optimized Chemistry

(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)

Air Cooled Condenser Users Group

Discussion Items for ACCUG 2018



Film Forming Substances (FFS)
Air In-Leakage

ACCUG 2018

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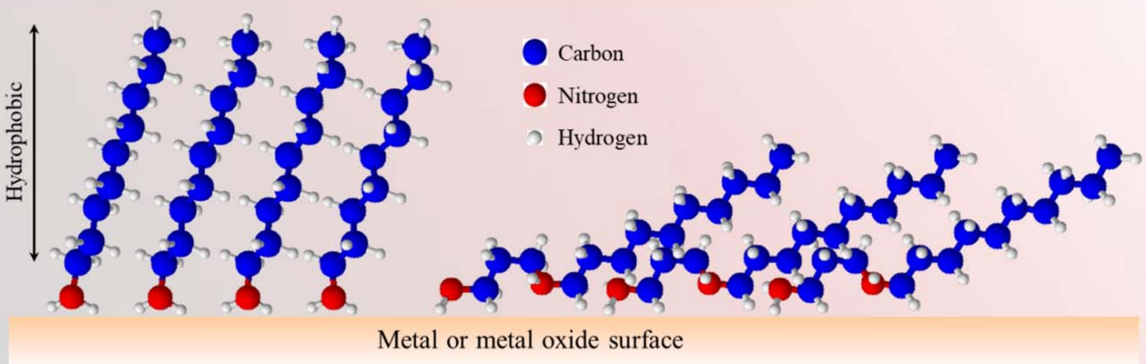
Structural Integrity Associates, Inc.

Film Forming Amines (FFA)
Octadecylamine – ODA
Oleyamine – OLA
Oleyl Propylenediamine - OLDA

Film Forming Substances (FFS)



New International Nomenclature

Lots of confusion worldwide on amine (FFA/FFAP) and non-amine (FFP) based substances. IAPWS introduced the new nomenclature for FFS

Film Forming Substances (FFS)

FFA/FFAP **FFP**

IAPWS

Structural Integrity Associates, Inc.

ACC "Arrests" with FFAP

Cross member appear to repair using FFAP

Courtesy Bill Stroman

Film Forming Substances

Possible Benefits of FFS

- Suitable for all-ferrous and mixed-metallurgy feedwater systems
- Optimum pH control in water and steam
- Lower corrosion product generation and transport
- Cleaner steam turbines
- Possible Improvement of steam turbine efficiency
- Benefits for oxidizing and reducing chemistries
- Avoids BTF / HTF due to Under-deposit Corrosion & Corrosion Fatigue
- Shutdown protection under wet and dry conditions
- Shorter startup times
- Reduced or arrested FAC (single- and two-phase)
- Improved or eliminated ACC corrosion / FAC

Film Forming Substances

Numerous "reported" problem as well as some major open issues

- Deposits in Boilers (tubes, drums) and Turbines
- Tube failures due to heavy deposits
- Decomposition of added alkalizing amines
- Elevated CACE in condensate and steam
- Mis-identification of the real contaminants
- Numerous proprietary mixes and blends
- Analysis of FFS and amount to use
- Increased boiler / HRSG evaporator deposition
- Increased levels of deposits in tubes, headers, drums
- BTF / HTF due to UDC and Overheating
- No rugged application processes
- Very variable ("poor") detailed documentation of FAC
- Variable detailed documentation of ACC corrosion/FAC

Film Forming Substances

Goals for Understanding

- Plant studies have not been definitive enough and very simple to show reduced corrosion products
- There is a need to raise the bar providing the world with answers on the main failure / damage mechanism and processes. (Apply Section 8 of the IAPWS TGD)
- Can we avoid BTF / HTF due to UDC & CF?
- Can we reduce /eliminate single- and two-phase FAC?
- Can we provide shutdown protection in steam & PTZ
- Shutdown protection under wet and dry conditions
- Basic understanding for attachment of hydrophobic FFS film to iron (magnetite and hematite) and copper oxides (cuprous and cupric)

International Association for the Properties of Water and Steam

Technical Guidance Documents

Film Forming Substances

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

Structural Integrity Associates, Inc.

Technical Guidance Document - FFS

Base Case Guidance

1. Operation. All-ferrous fossil, combined cycle and biomass plants. "Section 8"
   - 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)

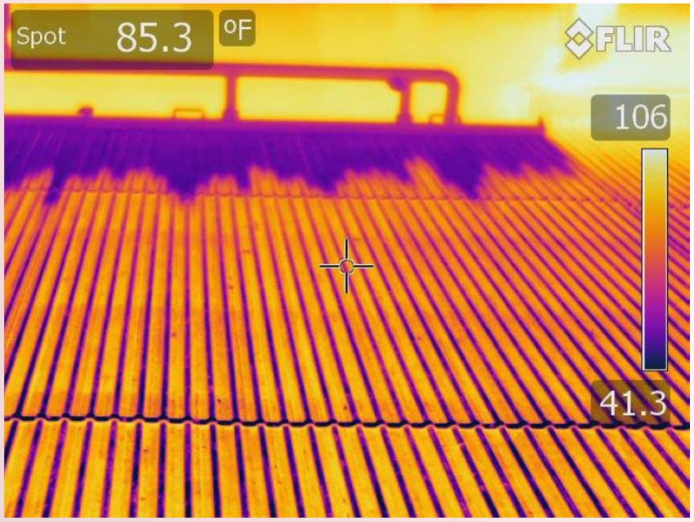
Customization Guidance

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

Air In-Leakage

Previous Presentations at ACCUG in 2010, 2013 and 2016



Sources of AIL on Plants without ACC

- Low pressure steam turbine / condenser expansion joints
- Low pressure steam turbine shaft seals
- Low pressure steam turbine instrumentation lines
- Steam turbine district heating heat exchanger in hot well
- Low pressure feedwater heaters (including piping, drains, valves, etc.)
- High pressure feedwater heaters (emergency drains out of service)
- Condenser drains
- Condensate pump seals
- Turbine gland steam condenser
- Condensate polisher (possibly when shut down)
- Makeup water lines if left open during operation
- Vacuum breakers
- Rupture disks
- Safety valves
- Condenser tube sheet to shell joints

Source: IAPWS TGD to be published 2018

Sources of AIL on Plants without ACC

- Condenser wall cracks
- Condenser instrumentation and connections (sight glasses, level transmitters, etc.)
- Air removal equipment suction components (such as steam jet air ejectors)
  - o Condensate drain seals
  - o Drains
  - o Isolation valves
  - o Flanged and threaded connections
  - o Air jets
  - o Shaft seals
- Orifice flanges, piping flanges
- Valve stems
- Condenser manway covers
- Suction side of boiler feedwater pumps (pump seals)
- Flash tanks, desuperheating tanks, and connections

Source: IAPWS TGD to be published 2018

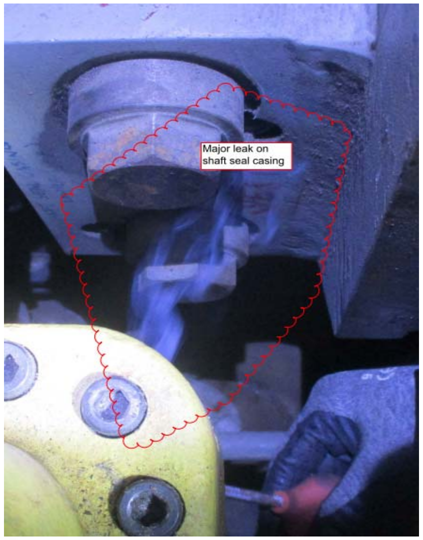
Sources of AIL on Plants with ACC

* Cracked welds (often due to freezing and/or poor quality welds)
  - Lower distribution section (ACC)
  - Upper distribution duct (ACC)
* Open valves
* Leaking flanges (from factory or field)
  - Flanges on steam turbine crossover piping
  - Steam turbine rupture disks
* Low pressure turbine exhaust (ACC)
* Loose instrument fittings/connections
* Condensate Receiver Tank
* Inter-condenser (IC) drain
  - Expansion joints in ACC ductwork
  - Riser duct isolation valve packing
  - Dephlegmator (air removal) tube section
  - Internal / external HX tube corrosion
  - Expansion-type rupture disks on main ACC exhaust duct

Source: IAPWS TGD to be published 2018

Detection & Measurement of AIL

- Instrument-based Methods
- Online Cycle Chemistry vs. AIL
- Tracer-based Method
- Smoke Detection
- Acoustic Testing
- IR Surveys
- Shaving cream



IAPWS TGD - Air In-leakage (AIL)

- Definition & Background Science of AIL
- Sources of AIL
- **Locating & Measuring AIL**
- Impact on Thermal Performance
- Impact on Cycle Chemistry
- **How to Limit Effects of AIL**
- Customization Needs

IAPWS TGD on AIL to be published 2018

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. FFS also work but not sufficient detailed documentation before and after application.

Damage on cross members is not "arrested" as quickly by increasing pH. Is this LDI caused by the larger droplets leaving the PTZ of the LP Steam Turbine?

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)
- **"Arrested" 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 FFS**
  - But need more fully documented cases (before and after, total iron levels,)