Appendix 1

List of participants

Participants EFC WP15 virtual meeting 30th March 2023

Face to Face

NAME	SURNAME	COMPANY	COUNTRY
Bour Beucler	Valerie	Nalco Water	FRANCE
Cano moreno	Fransico	CEPSA	SPAIN
Corradini	Raffaele	Techint Engineering Construction	ITALY
De Landtsheer	Gino	Borealis	BELGIUM
Lobaton Fuentes	Militza	Borealis Chimie SAS	FRANCE
Makhoul	Roger	Spraying Systems Europe Co	BELGIUM
Monnot	Martin	Industeel	FRANCE
Noordink	William	Corrosion Radar	NETHERLANDS
Norling	Rikard	RISE Research Institutes of Sweden	SWEDEN
Rangel	Pedro	CEPSA	SPAIN
Ribes Salvador	Alberto	Nalco Water	SPAIN
Roguieg	Ghalem	IGS	FRANCE
Ropital	François	IFP Energies nouvelles	FRANCE
Tacq	Jeroen	SIRRIS	BELGIUM
Van Caelenberghe	Timothy	Fluves	BELGIUM
Van Hoestenberghe	Thomas	Fluves	BELGIUM
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Wijnants	Geert Henk	STORK Asset Management Technology	NETHERLANDS

Remote

NAME	SURNAME	COMPANY	COUNTRY
Andari	Fouad	Total Energies	FRANCE
Brandl	Ramona	OMV	GERMANY
Casu	Carlo	Istituto Italiano della Saldatura	ITALY
Cimatti	Arnaud	VARO Refining	SWITZERLAND
Claesen	Chris J	Nalco Champion	BELGIUM
Comas	José	Total Refining & Chemicals	FRANCE
Comel	Lorenzo	GMA Tech	ITALY
De La Paz	Joanna	Baker Hughes	SPAIN
Dodds	Patrick	Hexigone Inhibitors Ltd	UK
Dufour	Jerome	Nalco Water	FRANCE
Dupoiron	François	IDEMAC	FRANCE
Enegela	Philipp	INEOS Olefins & Polymers UK	UK
Ervik	Åsmund	SINTEF Energy Research	NORWAY
Farina	Carlo	CEFIT Corrosion Consultant	ITALY
Galliot	Ludovic	TotalEnergies	FRANCE
Goti	Raphael	Total Refining & Chemicals	FRANCE
Groysman	Alec	Israeli Corrosion Forum	ISRAEL
Hairer	Florian	Linde, Engineering Division	GERMANY
Hashemi	Farzad	Copsys Technologies	CANADA
Heider	Ben	Air Liquide Global E&C Solutions Germany GmbH	GERMANY
Helle	Henk	CorrosionControl.Nu	NETHERLANDS
Höwing	Jonas	Alleima	SWESEN
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Krabac	Lubomir	Borealis Polyolefine GmbH	AUSTRIA
Kus	Slawomir	Honeywell Process Solutions	UK
Leone	Antonino	Eni	ITALY
Maffert	Joerg	Dillinger Huttenwerke	GERMANY
Maguire	Michael	Currach Consulting Limited	CANADA
Reinders	Arjen	McDermott	NETHERLANDS
Santacruz	Beatriz	CEPSA	SPAIN
Schempp	Philipp	Shell Deutschland Oil GmbH	GERMANY
Schwemmer	Marcel	3M Deutschland GmbH	GERMANY
Sentjens	Johan	Temati	NETHERLANDS
Sharma	Prafull	Corrosion RADAR	UK
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Thornthwaite	Philip	Baker Hughes	UK
Vanacore	Alessandro	GMA Tech	ITALY
Vergani	Lorenzo	Wood plc	ITALY
Visgaard Nielsen	Anni	Kalundborg Refinery A/S	DENMARK
Vosecký	Martin	Nalco Water	CZECH REPUBLIC
Wold	Kjell	Sensorlink	NORWAY
Yuhei	Suzuki	Nippon Steel Europe GmbH	GERMANY
Zakeri	Hadi	PetroIneos	UK
Zhang	Jian-Zhong	SABIC	UK

Appendix 2

EFC WP15 Activities

(Francois Ropital)

EUROPEAN FEDERATION OF CORROSION

Welcome to the EFC Working Party Meeting

"Corrosion in Refinery and Petrochemistry" WP15

30 March 2023

EUROPÄISCHE FÖDERATION KORROSION
EUROPEAN FEDERATION OF CORROSION
FEDERATION EUROPEENNE DE LA CORROSION

EFC Working Party 15 « Corrosion in Refinery and Petrochemistry » Activities

Chairman: Francois Ropital Deputy Chairman: Johan Van Roij

Information Exchange – Forum for Technology

Sharing of refinery materials /corrosion experiences by operating company representatives.

Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2023 Brussels-Belgium, 2024 Paris-France)

In 2023 the Refinery corrosion session will on Monday 28 August 2023

In 2023 the Joint session on Biorefineries will be on Thursday 31 August 2023

In 2024 Eurocorr will take place from 1 to 4 September in Paris

WP Meetings

One WP 15 working party meeting in Spring (30 March 2023),

One meeting at Eurocorr in September in conjunction with the conference, this year it will be on Tuesday 30 August 2023 in Brussels (hybrid meeting ?)

Publications - Guidelines

Web site : https://efcweb.org/WP15.html

AGENDA EFC Working Party 15

Corrosion Refinery Petrochemistry Industry Meeting

9h30-9h45 Welcome - WP15 Activities

•Welcome - WP15 Activities

- Welcome by Nalco-Ecolab (Valérie Bour-Beucler)

- Eurocorr 2023 Brussels
  the Refinery corrosion session took place on Monday 28 August
  the Joint session on Biorefineries took place on Thursday 31 August morning

- Next business meeting during Eurocorr 2023 week on 29 August in Brussels

- Advancement of the guideline on corrosion on sea water cooling systems
  (Valérie Bour-Beucler, Antoine Surbled, Francois Ropital)

- Other points

EFC
EUROPEAN FEDERATION OF CORROSION
FÉDÉRATION EUROPÉENNE DE LA CORROSION
EUROPÄISCHE FÖDERATION KORROSION

Eurocorr 2023 “Refinery Petrochemistry” session: Monday 28 August: 13h30 – 17h40

Title	Last name	Company
A review on the characteristics and current results of VDM Alloy 699 XA: an alloy designed for applications in the petrochemical industry	Kremer	VDM Metals International GmbH
Developing 3D Models for Liquid Water and Vapor Transport and Condensation in Insulated Systems to Understand Corrosion Under Insulation	Ervik	SINTEF Energy Research
InnovateCUI – A Joint Industrial Initiative investigating Sensors and Coatings for improved management of Corrosion Under Insulation	Tacq	Sirris
Optimizing the Inspection of Corrosion Under Insulation in Badak LNG Plant by the Implementation of Risk-Based Method	Maulana	Badak LNG
Life Extension of Ageing Critical Process Assets	Bateman	IGS Europe sro
Advanced Sprayed Nanostructure Coatings Against Corrosion for Refinery Applications	Al Mutairi	Saudi Aramco Oil Company
Matching Welding Filler and similar welded joint for UNS S34752	Kurihara	
Defect-Free Commissioning: Challenges & Opportunities Amidst the COVID-19 Pandemic	Amin	
Structure and Related Effectiveness of Naphthenic Acid Corrosion Inhibitors	Zenasni	
Trouble Shooting of Crude Unit Overhead Unit Corrosion Using Ionic Equilibria Modelling - A CLSCC Case	Soundararajan	ADNOC REFINING
Enhancing reused lubricating oil performance using novel ionic liquids based on imidazolium derivatives (antioxidants, and anticorrosion agents)	Deyab	Egyptian Petroleum Research Institute
CORROSION RISK AND PROCESS SAFETY IN REFINING AND PETROCHEMICAL INDUSTRY	Groysman	Technion
Experimental Analysis of Alkoxide Corrosion in Biofuels	Arya	TU Darmstadt

Annual business WP15 meeting : Tuesday 29 August: 10h – 16h

Eurocorr 2023 Joint Session “Biorefinery”: Thursday 31 August: 8h40 – 10h00

Title	**Last name**	**Company**
Preventing Renewable Conversion Corrosion	Bateman	IGS Europe sro
Contribution of analytical techniques in understanding corrosion mechanisms by free fatty acids in vegetable and waste oils	Kittel	IFP Energies Nouvelles (IFPEN)
Corrosion performance of different alloys exposed to HTL conditions	Blücher	Sintef Industri
Experimental Analysis of Alkoxide Corrosion in Biofuels	Arya	TU Darmstadt

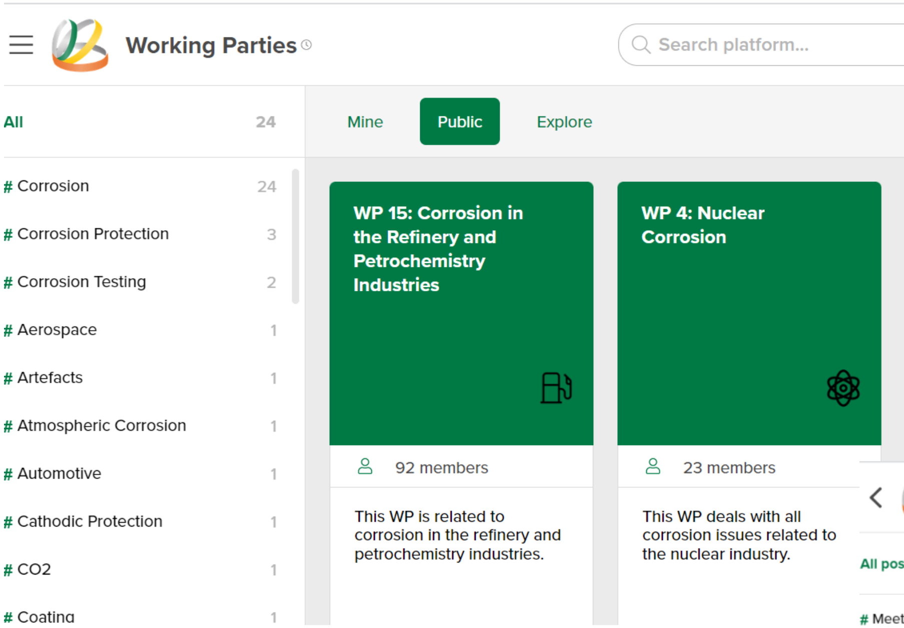
List of the WP15 spring meetings :

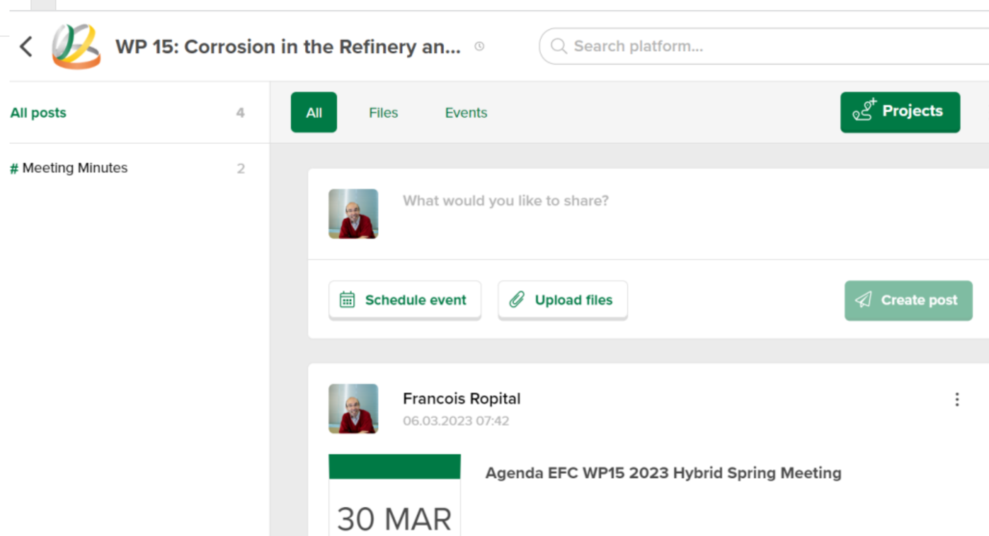
10 April 2003	Pernis - NL (Shell)
8-9 March 2004	Milan -Italy (ENI)
17-18 March 2005	Trondheim- Norway (Statoil)
31 March 2006	Porto Maghera - Italy (ENI)
26 April 2007	Paris - France (Total)
15 April 2008	Leiden -NL (Nalco)
23 April 2009	Vienna - Austria (Borealis)
22 June 2010	Budapest - Hungary (MOL)
14 April 2011	Paris - France (EFC Head offices)
26 April 2012	Amsterdam - NL (Shell)
9 April 2013	Paris - France (Total)
8 April 2014	Mechelen - Belgium (Borealis)
14 April 2015	Leiden -NL (Nalco)
26 April 2016	Paris - France (Total)
13 April 2017	Frankfurt - Germany (EFC Head offices)
3 May 2018	Dalmine - Italy (Tenaris)
10 April 2019	Roma - Italy (Rina CSM)
23 March 2021	Zoom meeting
24 March 2022	Zoom meeting

EFC Hub Platform

A Web forum platform on the EFC Hub platform has been created

https://efc.solved.fi/activities/wp/list

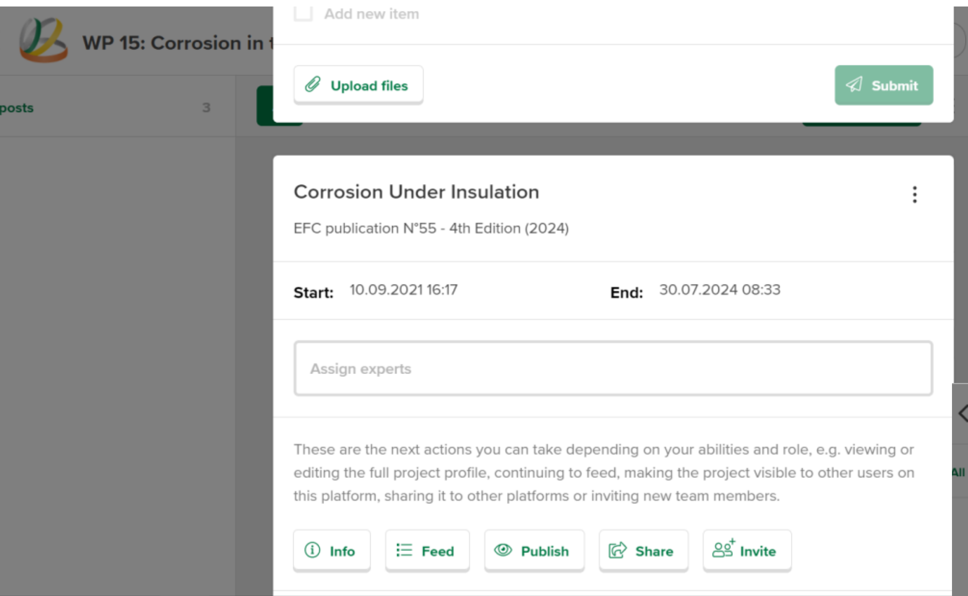


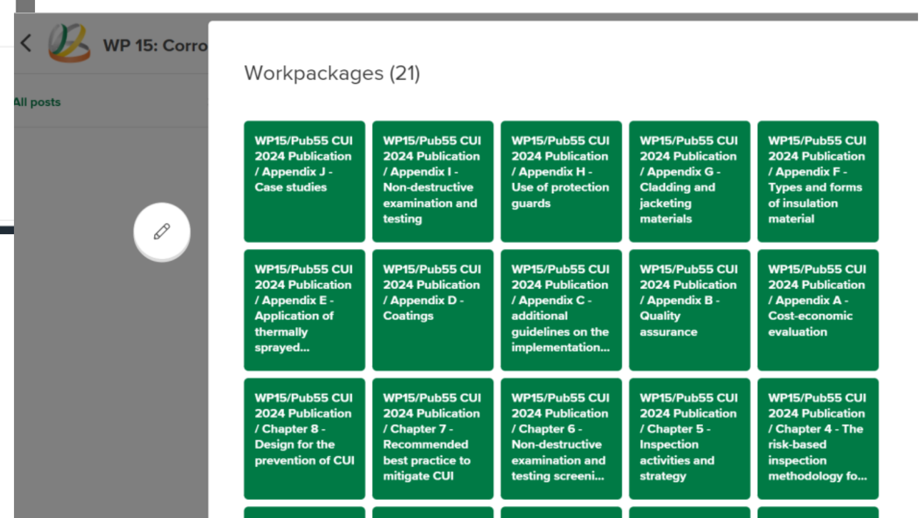


EFC Hub Platform: CUI Project

EFC CUI Web forum platform:

https://efc.solved.fi/activities/wp/feed/ef91a569-219e-444b-90f8-69c26945cdf7





Publications from WP15 – Forum Platform

•EFC Guideline n° 55 Corrosion Under Insulation Editor: Gino de Landtsheer
The 3rd revision is available

https://www.elsevier.com/books/corrosion-under-insulation-cui-guidelines/de-landtsheer/978-0-12-823332-0

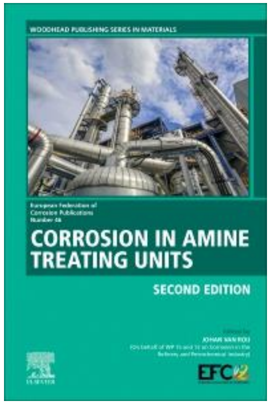
•EFC Guideline n° 46 revision on corrosion in amine units Editor: Johan van Roij
is now available

https://www.elsevier.com/books/corrosion-in-amine-treating-units/van-roij/978-0-323-91549-6

- Best practice guideline on corrosion in sea water cooling systems (joint document WP9 Marine Corrosion and WP15)

In progress by a task force

Thank you to all the contributors for their work



Advancement of the guideline on corrosion on sea water cooling systems

Chapter	Title	Chapter Leader	Chapter contributor
1	Introduction	Valerie Bour-Beucler	Jean-Nicolas Cordier
2	Heat exchanger systems	Valerie Bour-Beucler	Jean-Nicolas Cordier
3	Sea water environment	Valerie Bour-Beucler	
4	Forms of corrosion	Valerie Bour-Beucler	Antoine Surbled
5	Biocide treatments	Valerie Bour-Beucler	Philippe Bleriot
6	Inhibitors	Philippe Bleriot	
7	Materials	Antoine Surbled	
7.1	Carbon steel		Antoine Surbled
7.2	Stainless steels		Dominique Thierry Jonas Howing
7.3	Nickel alloys		Dominique Thierry Angela Philipp
7.4	Copper alloys		Dominique Thierry
7.5	Aluminium alloys		
7.6	Titanium alloys		Antoine Surbled
7.7	Concrete		Antoine Surbled
8	Corrosion protection	Jian-Zhong Zhang	
8.1	Material selection to avoid galvanic coupling		Jian-Zhong Zhang
8.2	Coatings		Jian-Zhong Zhang
8.3	Cathodic protection		Nicolas Larche Dominique Thierry
9	Maintenance and tube cleaning	Valerie Beucler	Jian-Zhong Zhang Antoine Surbled
10	Control monitoring inspection	Antoine Surbled	

Thank you to all the contributors for their work

Joining EFC WP15 activities

If you are not on the list of WP15 members and you want to join you can

- Fill the EFC Friend form: https://efcweb.org/friendsform.html

- Or send an email to francois.ropital@ifpen.fr

EFC Web site :https://efcweb.org/

EFC Hub Platform : https://efc.solved.fi/activities/wp/list

Information :
Future conferences related to refinery corrosion

27-31 August 2023
EUROCORR 2023 Brussels Belgium

3-7 March 2024
CORROSION 2023 AMPP New Orleans

1-4 September 2024
EUROCORR 2024 Paris France

7-11 September 2025
EUROCORR 2025 Stavenger Norway

Look at the Website: https://efcweb.org/Events.html

Thanks Valerie and Nalco Ecolab
For hosting the meeting

Thanks to every one for
her, his participation

See you
in another WP15 and EFC event……

Até a vista, Tot ziens, Arrivederi, Goodbye,….

Appendix 3

Chabel insulation system

(Laurent Eckebus)

CHABEL®

CLOSURE OF INWATERING POINTS

CHABEL®

OUR PRODUCTS

INSULATION

RUBBER

COATING

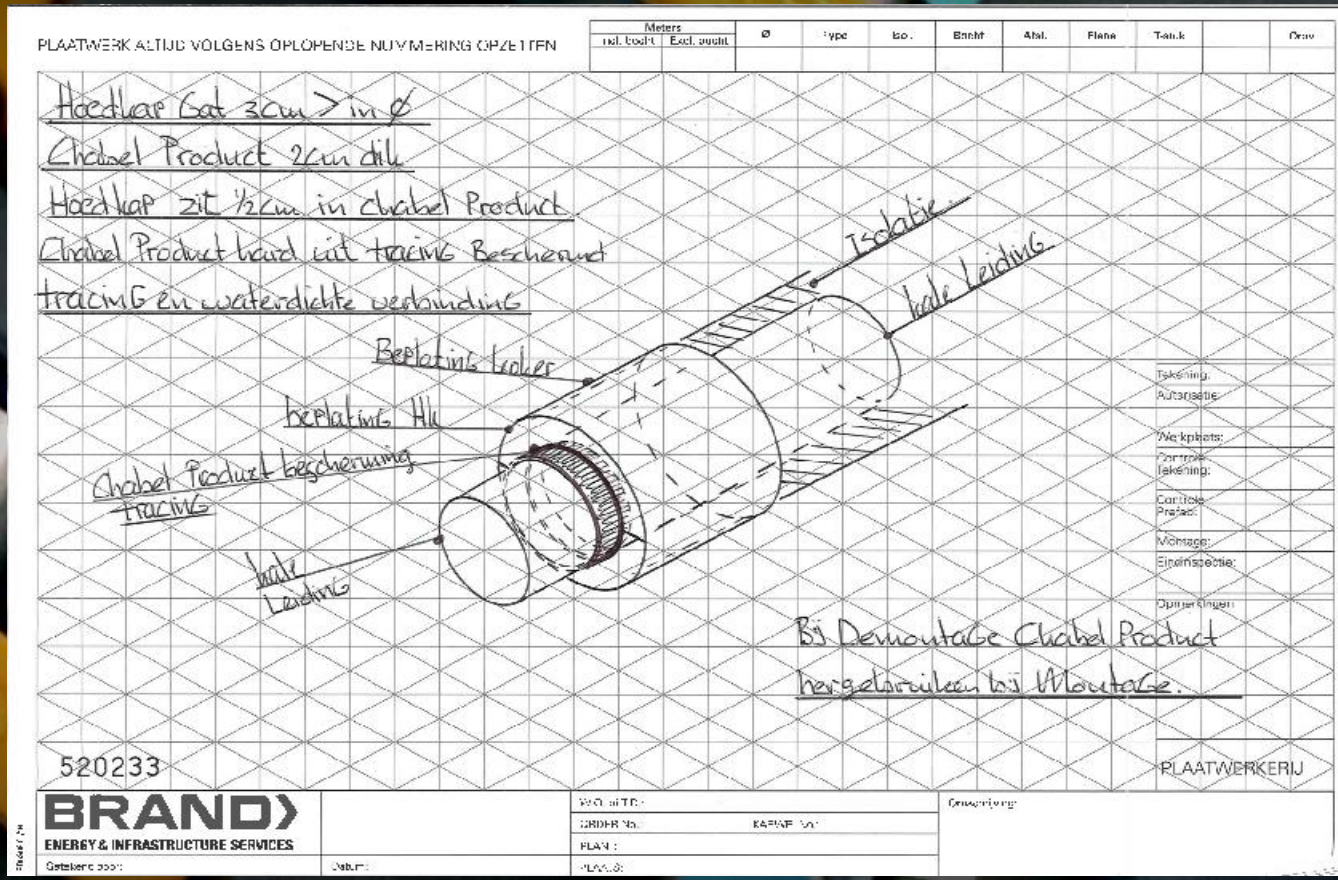
CHABEL

PURPOSE TODAY

How can we use Chabel CTP combined with existing insulation techniques to prevent CUI at potential water points?


CHABEL
WHAT IS CHABEL CTP?
A short product movie

HOW DID WE COME UP WITH THE IDEA ?



CHABEL®

Advantages Chabel CTP at water points

- Complete closure around tubules / T-pieces / H-pieces / water points
- All possible shapes can be wrapped with insulation because of the flexibility of CTP
- UV resistable
- Additional insulating effect of pieces
- Long shelf life (in aggressive environments)
- Closed cell structure, water/liquid repellent
- Sheet is pressed 3 or 5 mm in CTP, so that a water repellent construction is created
- Reusable
- Easy assembly/disassembly (inspection)

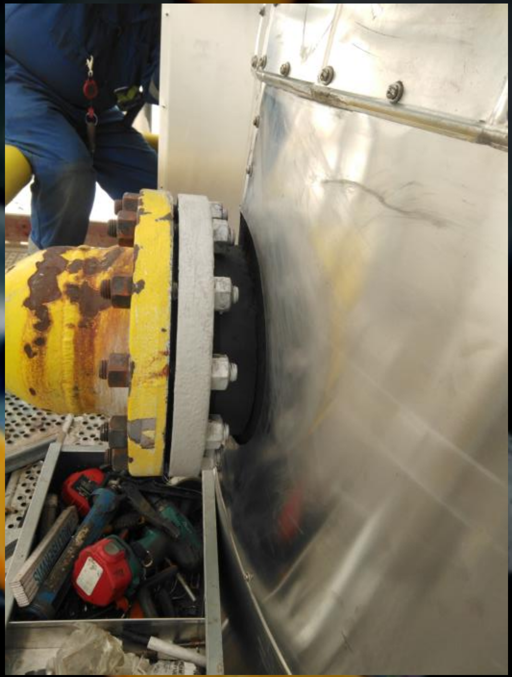
CHABEL®

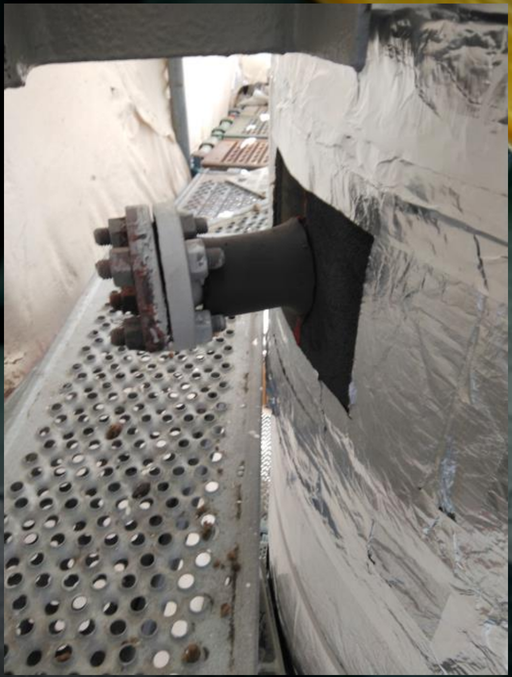
SHELL PERNIS

CHABEL

SHELL PERNIS

Installation CTP on various inwatering points before cladding





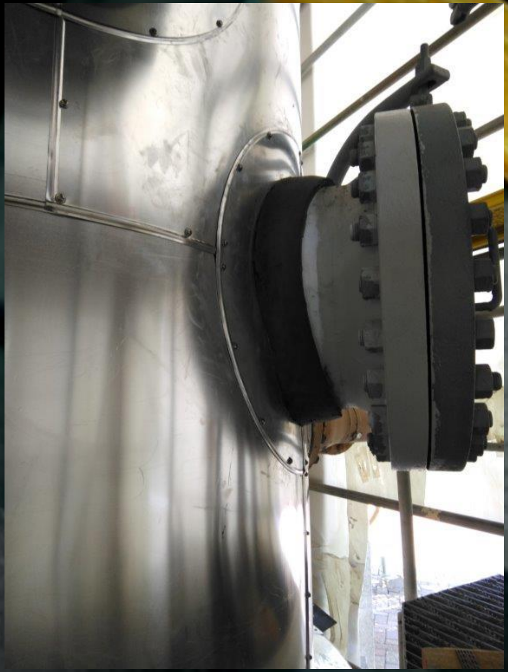
CHABEL

SHELL PERNIS

Installation CTP on various inwatering points before cladding

SHELL PERNIS

Installation CTP on various inwatering points after cladding


CHABEL

SHELL PERNIS

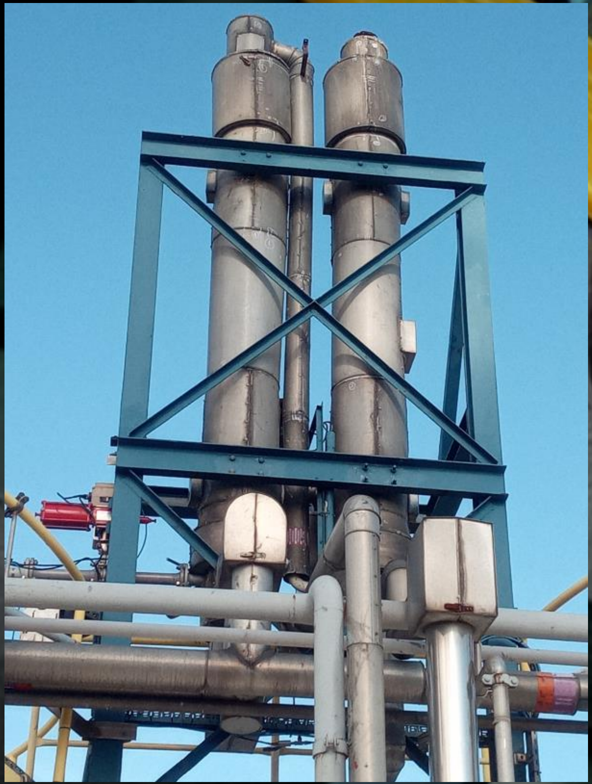
Installation CTP on various inwatering points after cladding

CHABEL®

DELAMINE

DELAMINE

Installation CTP on various implementations during next stop



CHABEL®

SITECH


CHABEL
SITECH
TESTS WITH SITECH AT INWATERING POINTS COLUMN

CHABEL®

SITECH

Installation CTP on various inwatering points before cladding

CHABEL

SITECH

Installation CTP on various inwatering points after cladding

CHABEL

SITECH

2 UPCOMING PROJECTS DURING THE STOP IN APRIL 2023

CHABEL

SITECH

2 UPCOMING PROJECTS DURING THE STOP IN APRIL 2023

CHABEL®

Questions or samples?

Appendix 4

Potential of distributed fibre optic sensing for corrosion monitoring

(Thomas Van Hoestenberghe)

NICE TO MEET YOU, WE ARE

FLUVES

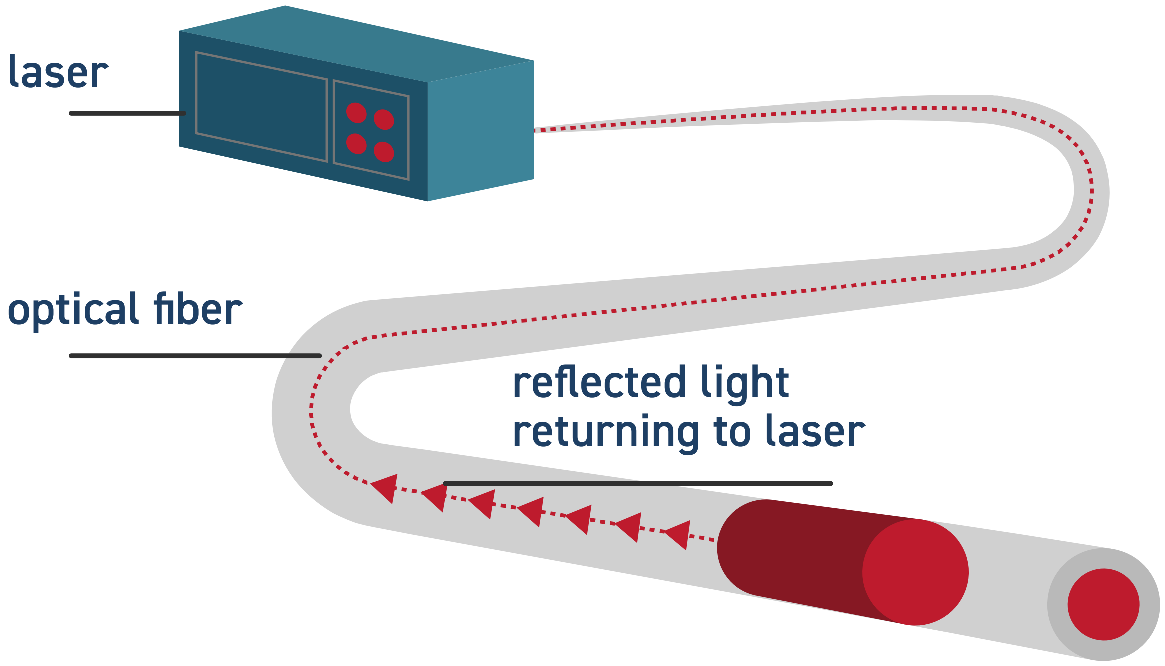
WE CARE ABOUT YOUR INDUSTRIAL ASSETS. WE MONITOR THEM.

FLUVES

FLUVES

HOW DOES FIBER OPTIC MONITORING WORK?

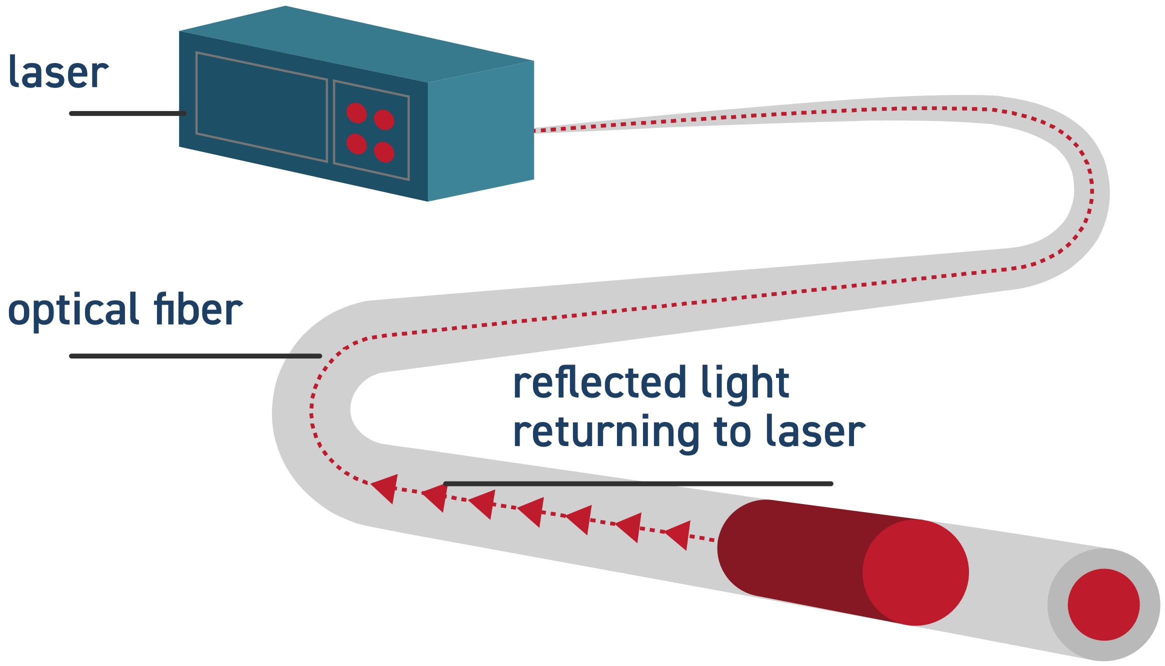
Sensing **temperature** & **acoustics**



FLUVES

HOW DOES FIBER OPTIC MONITORING WORK?

Sensing **temperature** & **acoustics**



ATEX PROOF

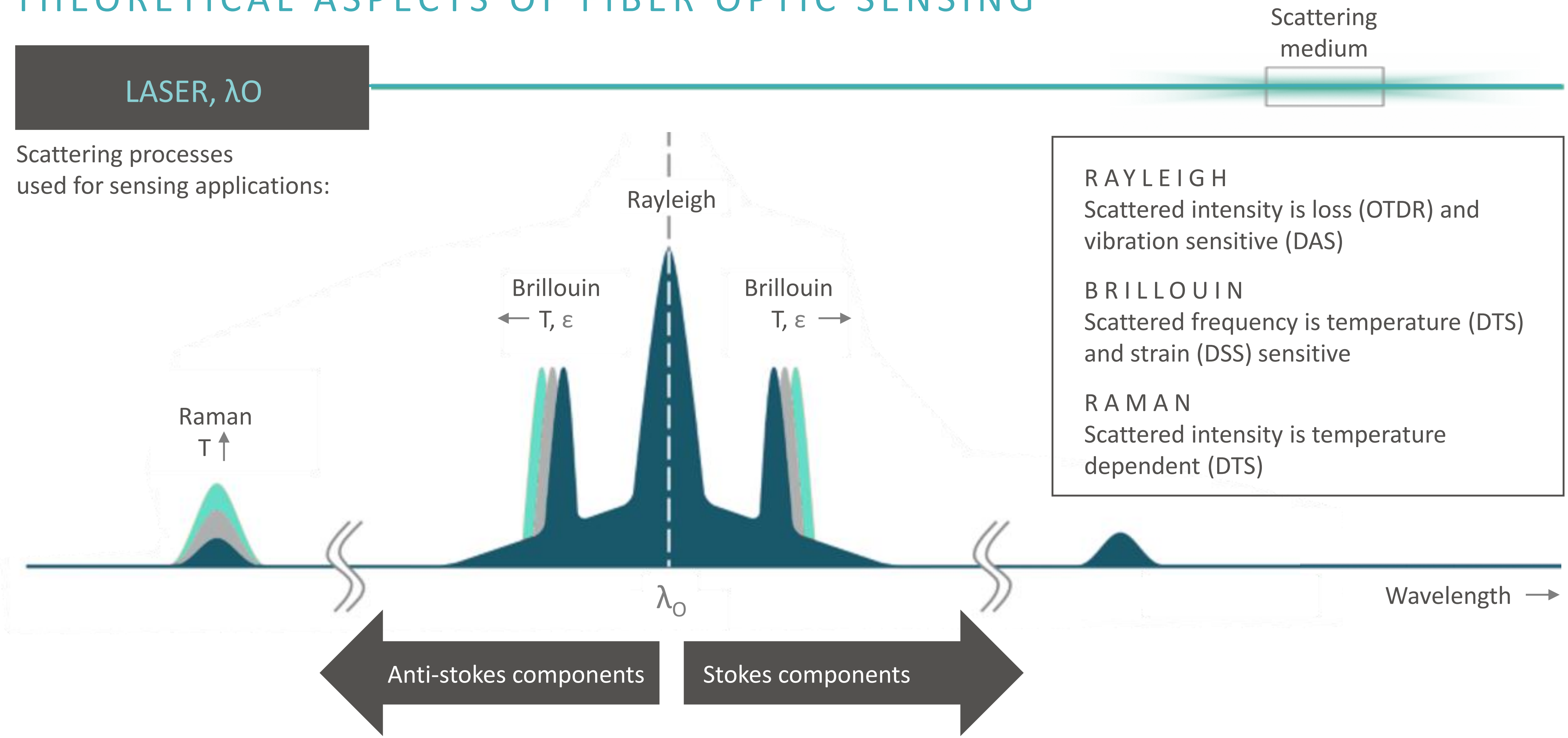
EXTREMELY LONG RANGES

HIGHLY ACCURATE

COST EFFECTIVE

THEORETICAL ASPECTS OF FIBER OPTIC SENSING

Scattering processes
used for sensing applications:



RAYLEIGH
Scattered intensity is loss (OTDR) and vibration sensitive (DAS)

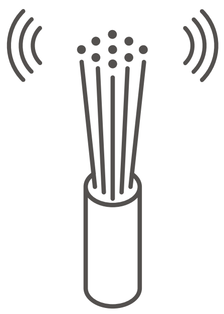
BRILLOUIN
Scattered frequency is temperature (DTS) and strain (DSS) sensitive

RAMAN
Scattered intensity is temperature dependent (DTS)

FLUVES

YOU’RE ALL SET WITH OUR

PREDICTIVE MAINTENANCE PLATFORMS



Fiber Optic Sensors

Gathering & analyzing data

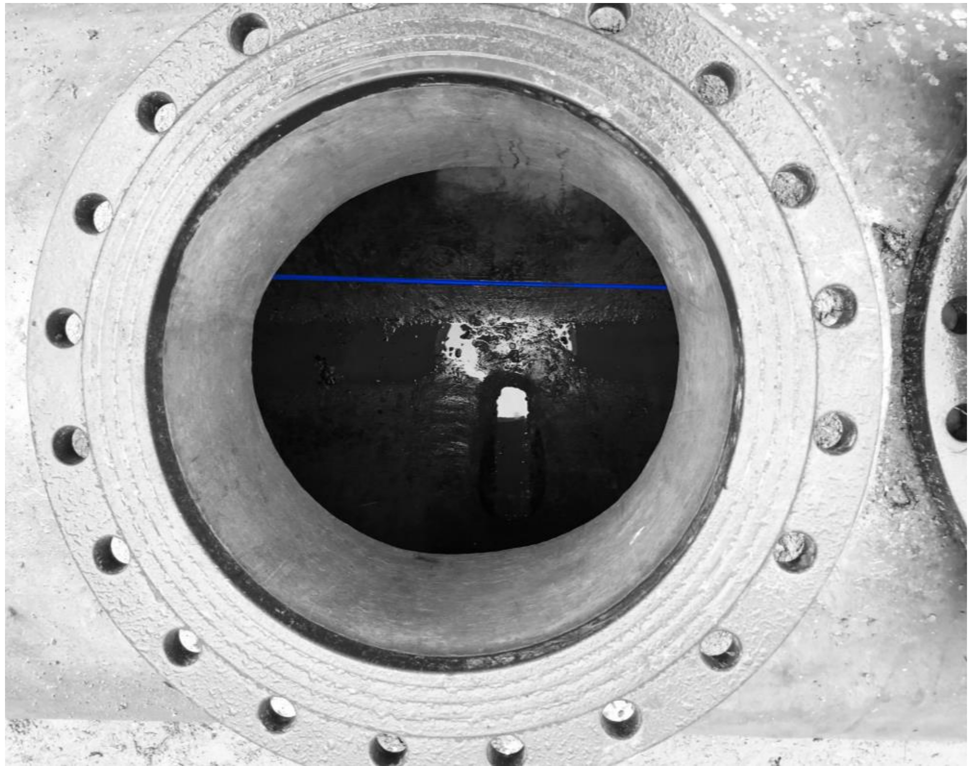
Understandable dashboards

FLUVES

HOW DOES FIBER OPTIC MONITORING WORK?

1) Place the fiber IN or ON the asset.

- Fiber is a **standard telecom fiber**:
  - Possible to use existing cables
  - They are easy to repair
- There is a cable for **ANY environment** (outdoor, high/low temperatures,…)



FLUVES

HOW DOES FIBER OPTIC MONITORING WORK?

2) Connect a sensing system (DTS, DAS).

- Can be placed anywhere

3) Computation server processes raw data and pushes results to the cloud via network or 4G.

FLUVES

HOW DOES FIBER OPTIC MONITORING WORK?

2) Connect a sensing system (DTS, DAS, DSS).

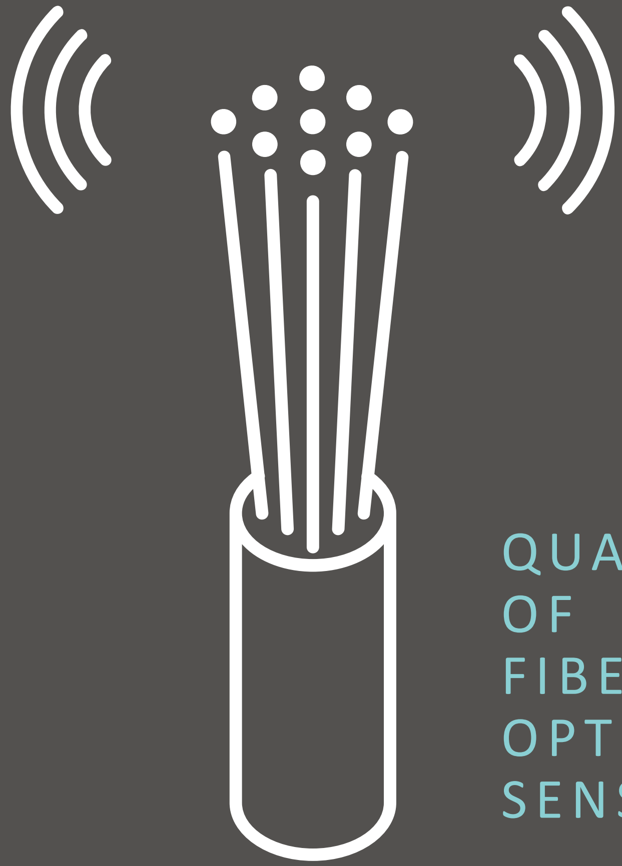
- Can be placed anywhere

3) Computation server processes raw data and pushes results to the cloud via network or 4G.

4) Our in-depth analytics software converts the raw data into understandable metrics.

5) An online dashboard visualizes the insights and alarms the user when a problem were to arise.

FLUVES



QUALITIES OF FIBER OPTIC SENSING

ONE ROBUST TELECOM FIBER EQUALS 1000 OF POINT SENSORS

Point sensors aren't bad, but fiber optic sensing is just way better.

- **Stable set-up and technology**
- **Can stand the test of time**
- **Designed for harsh environments**
- **All sensitive hardware is installed remotely**

FLUVES

OUR FLUVES ENGINEERS ARE SETTING UP THE HARDWARE.

Once installed, there is no need anymore for manual site inspections

FLUVES

WE CAN MONITOR EVERY METER

⇒ Complete coverage of large assets

WITH PRECISE LOCALISATION AND INSTANT ALERTS YOU CAN TAKE IMMEDIATE ACTION

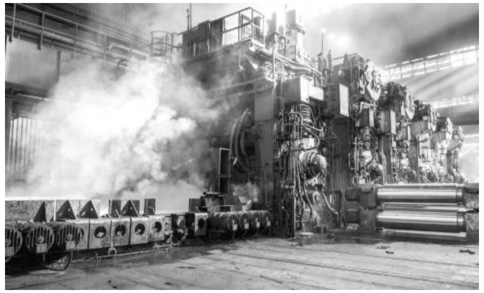
⇒ This keeps the **cost** and **downtime** to a **minimum**

FLUVES

USE CASES OF FIBER OPTIC SENSING

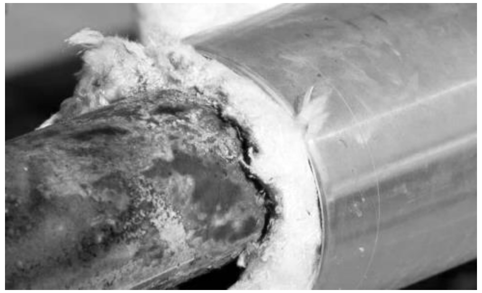
INDUSTRY

FURNACES



TANKS & REACTORS

CORROSION



PIPELINES

STEAM TRAPS

CABLE

UTILITY

PIPELINE LEAKS

PIPELINE INTRUSION

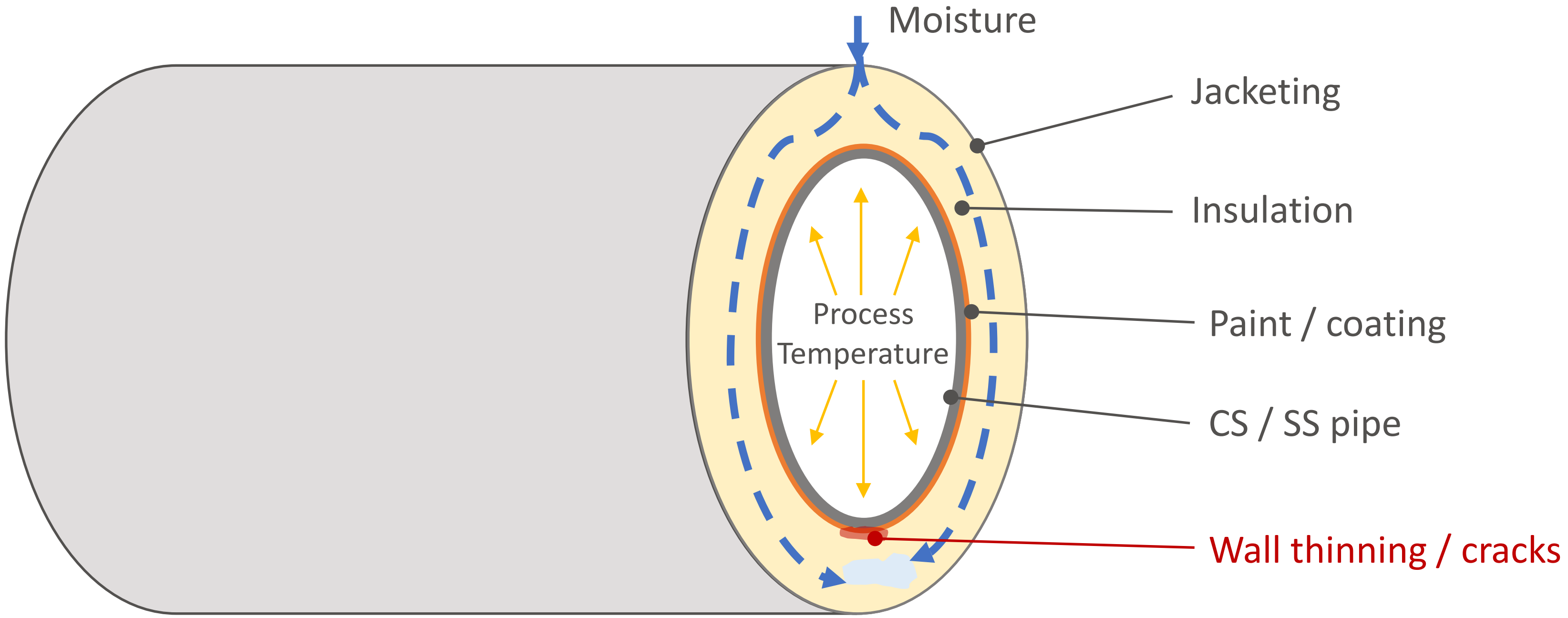
FIBER OPTIC MONITORING TO PREVENT

CORROSION UNDER INSULATION – CUI

FLUVES

WHAT IS CUI?

Corrosion Under Insulation can occur on insulated pipes and equipment.



CUI - DEALING WITH A HIDDEN THREAT

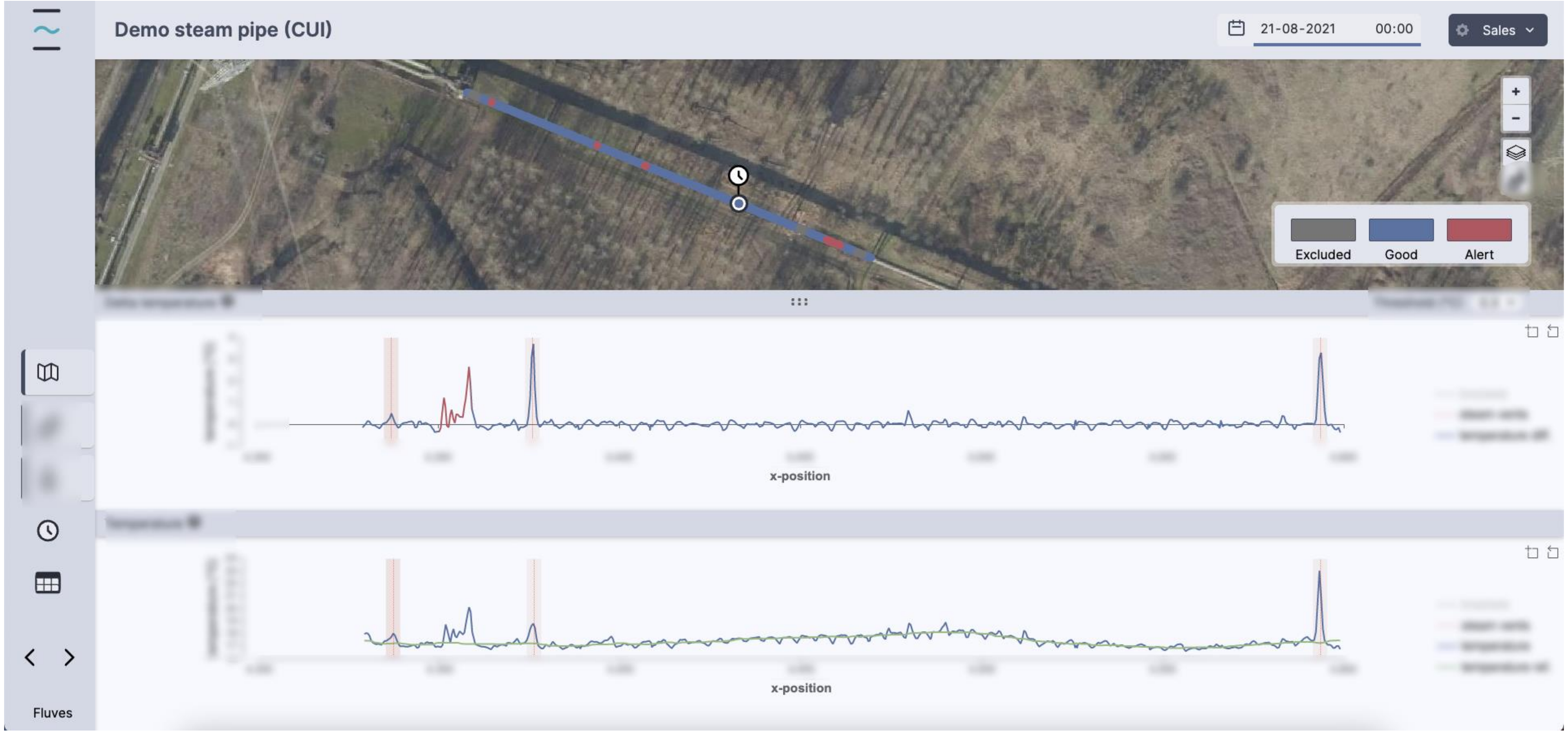
- “Prevention is better than cure”
- Awareness at all levels in the organization is required
- A total approach is needed

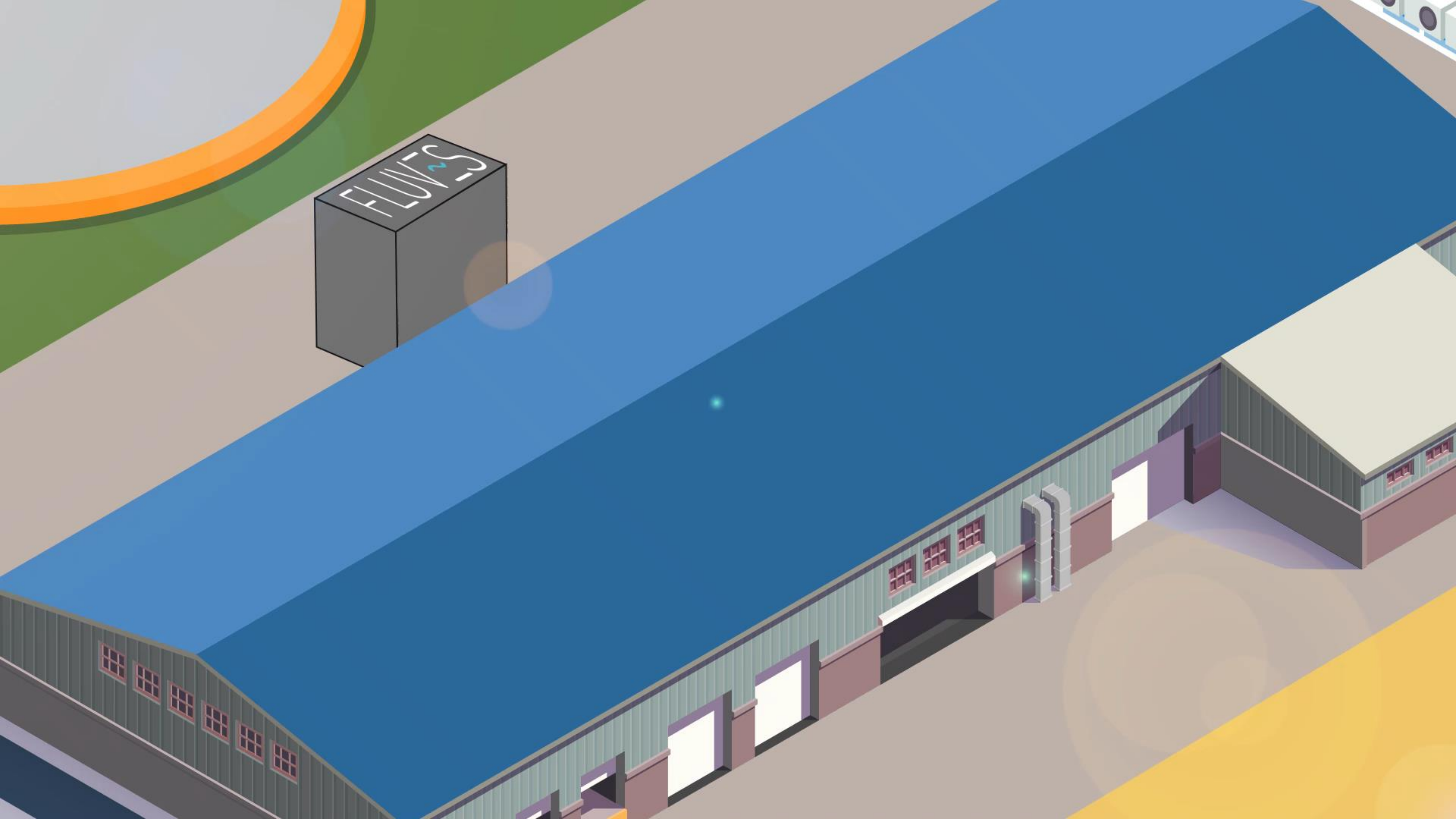
CUI
INSTALLATION OF THE FIBER

- A specialty optical fiber is attached along the whole length of the pipeline

- It can be placed on the outside of the cladding. No need to dismantle anything

CUI – DASHBOARD





CUI – FOCUS POINTS FOR INSPECTION

Email us: sales@fluves.com
Call us: +32 9 346 85 30

By talking to our clients, we are still discovering new industrial problems where fiber optic sensing seems to be the best solution.

SO LET'S TALK!

FLUVES

WE CARE ABOUT YOUR CRITICAL EQUIPMENT. WE MONITOR IT.

Appendix 5

Copsys intelligent digital skin

(Michael Maguire)

COPSYS

Copsys Intelligent Digital Skin

Disrupting Corrosion

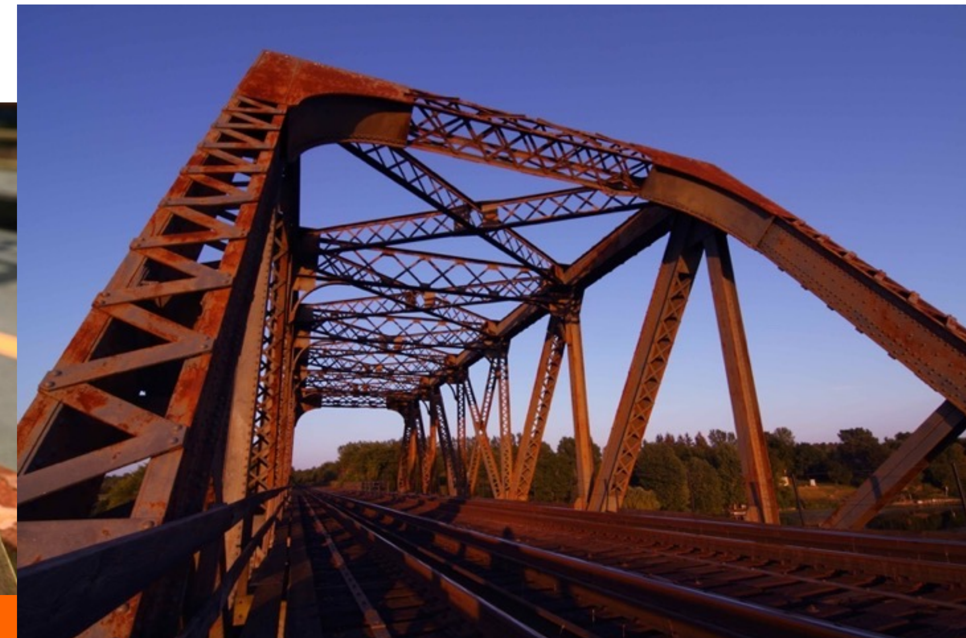
Presentation to:

i-tech

12 Jan 2023

Rust Never Sleeps…

5 tons of steel lost through corrosion every second!



Cost 3.4% global GDP = **$2.5 trillion**/year

COPSYS

Corrosion Under Insulation (CUI)

Serious process safety incidents	**20%**
Process systems maintenance cost	**40% - 60%**
GHG Emissions	**5% - 10%**

$10 Billion

Offshore oil and gas production

COPSYS

UK Health and Safety Executive (Q3 2022):

- "CUI continues to represent a major safety threat, having been responsible for a number of major hydrocarbon releases and presenting industry with a range of business assurance and continuity challenges that carry with them significant costs each year.
- Despite promising developments in managing CUI over recent decades, ***it remains a challenging issue that requires a fresh approach".***

Corrosion Under Insulation (CUI)

COPSYS

Disrupting CUI

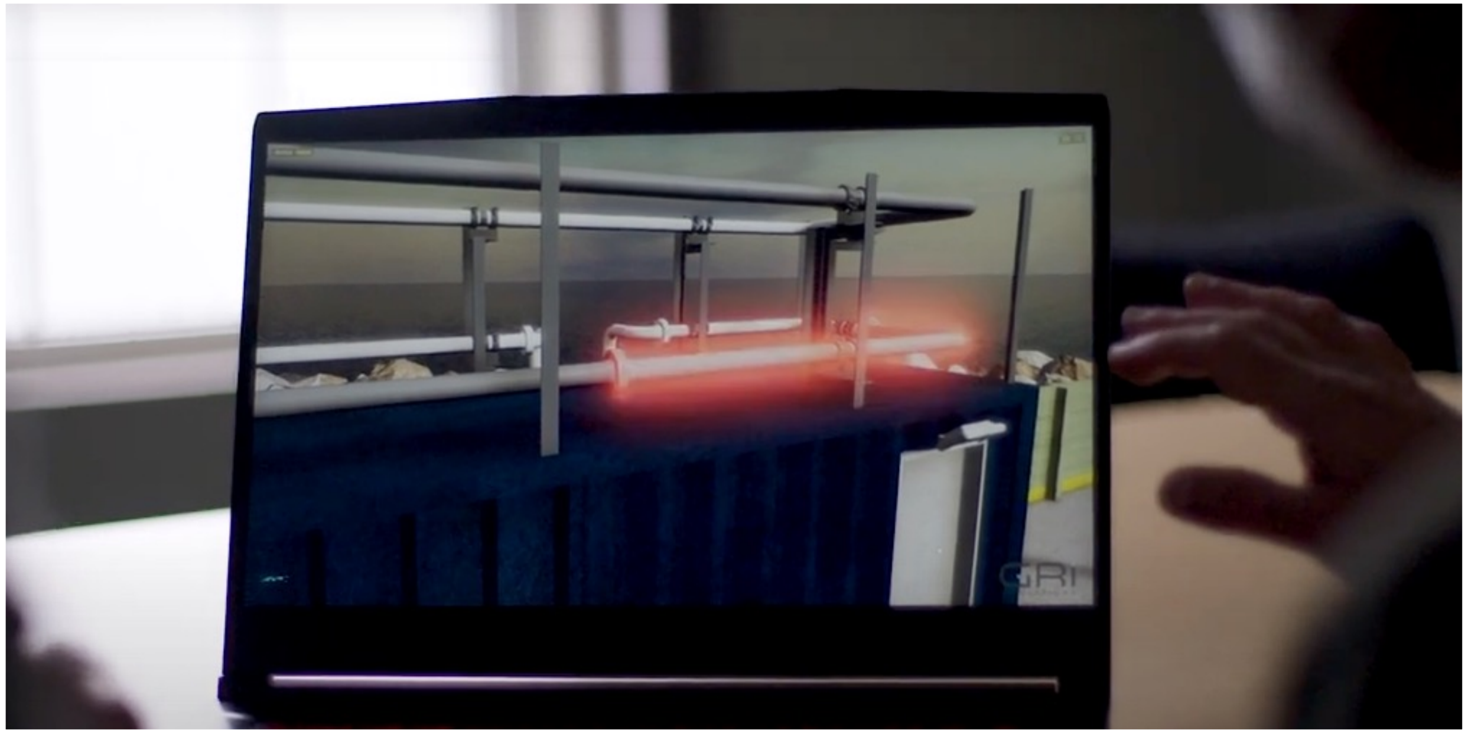
Manual Hunting – Visual / NDE Inspection

Persistent Digital Presence

COPSYS

Copsys Intelligent Digital Skin (CIDS)

- Paint-based digital “feeling” skin detects and locates coating barrier damage (CUI hotspots) in real time before corrosion damage can occur
  - New category of paint-based, full-surface digital sensor



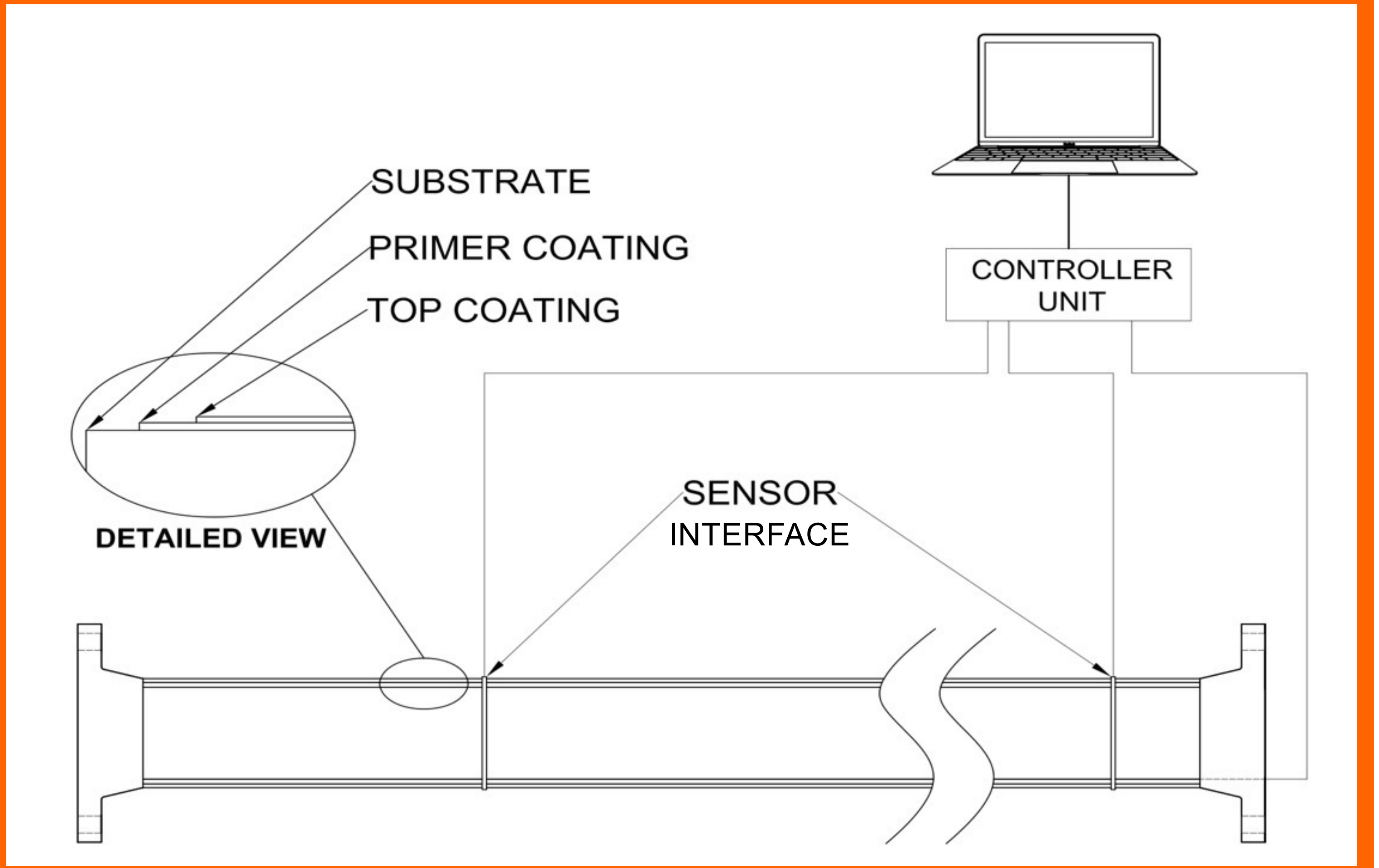
- Coating-integrated Impressed Current Cathodic Protection (ICCP)
  - Prevents Corrosion damage even after coating failure
  - Asset surface health digital visualization First Time!

COPSYS

CIDS System Overview

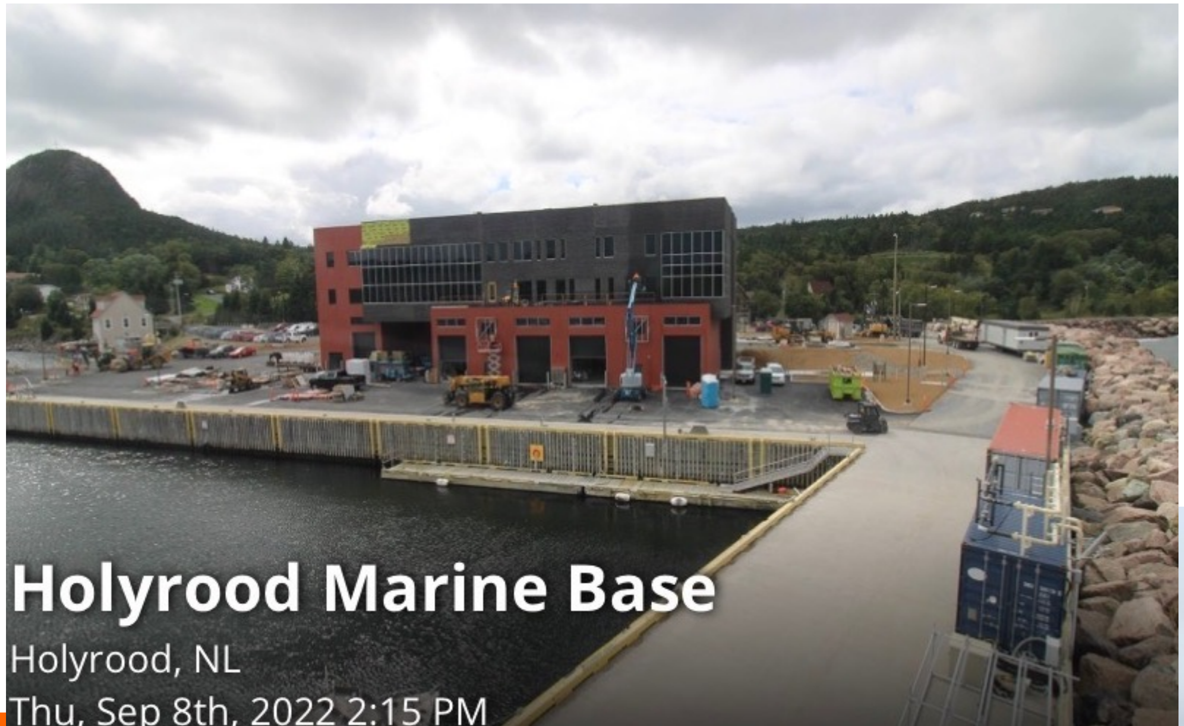
Coating Integrated ICCP – Foundational Innovation

- First ICCP Disruption
- Combines advanced polymer, electronic and digital technologies
- Cost and performance competitive with conventional CUI Coatings
- Simple data / analytic feed
  - Easy enterprise or cloud integration
- 4 patent applications +2 proposed
- Core Science Innovation
  - Deep product/application pipeline
- Technology Readiness Level (TRL) 7



COPSYS

Field Trials
@
MI's The Launch



CIDS Demo Challenges

- Contractor substandard Coating Application
- Experimental Flowloop Overheating Event

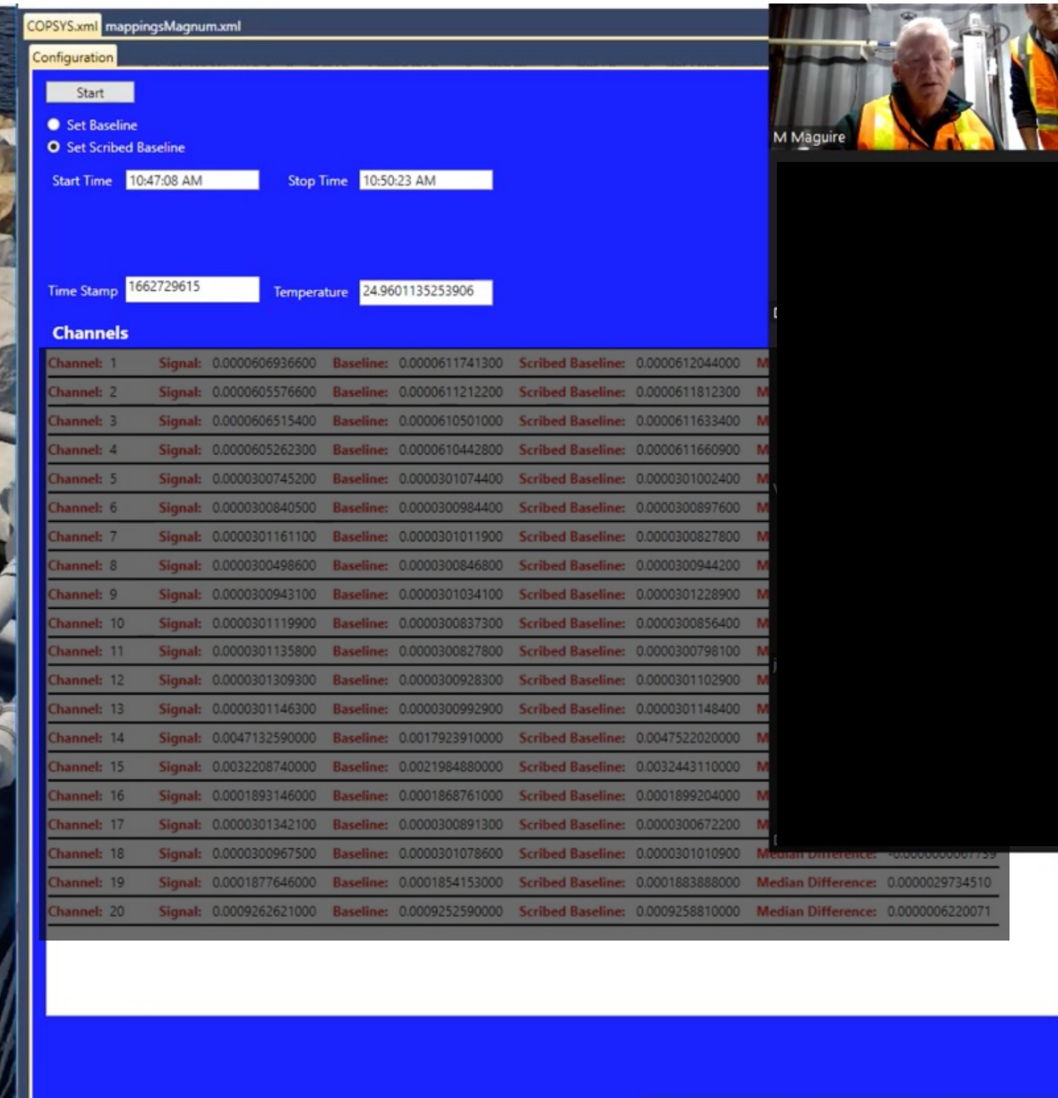
Commercial Control Coating
- Overheating damage

Tarpaulin Residue welded to CIDS coating
- CIDS coating – same exposure remained intact

COPSYS

CIDS Live Demonstration

9 Sep 2022



Paint Scribe

COPSYS

Coating Integrated ICCP

Exposure to electrolyte under insulation

COPSYS

CIDS as CUI Corrosion Protective Barrier Coating

Comparative Coating Testing to ISO 19277

- CIDS vs leading commercial CUI Coating
- Daily Cyclic Thermal Loading to 500 ^{o}C x 6 weeks under wet insulation
- CIDS superior performance: Overall better corrosion protection
- Equivalent or better mechanical performance
- Independent validation @ Memorial University
- LR Type Approval pending

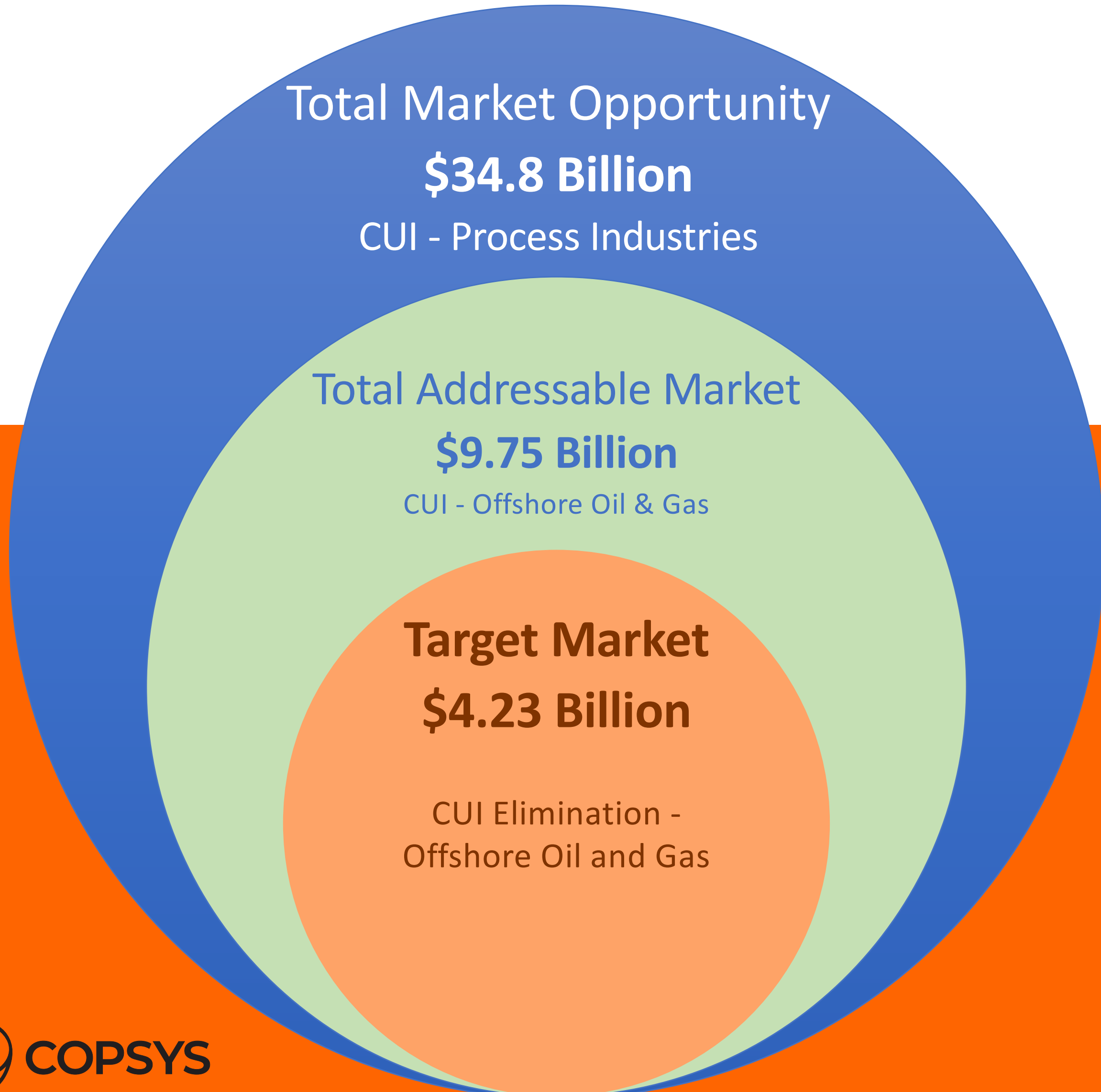
Global Competition Asset Integrity

Redefining the competitive landscape!

	Barrier Protection	Cathodic Protection	Digital Integration	Damage Detection & Location	No UEP Signature	Stray Current Control	Hydrogen Damage Control
COPSYS	✓	✓	✓	✓	✓	✓	✓
Barrier Coating	✓						
ICCP		✓					

COPSYS

CIDS Market Potential



6000 Offshore Platforms Producing Globally

12.4% annual market growth through 2025

Digital Asset Integrity Intelligence SaaS Solution

Copsys Team

Farzad Hashemi

Co-Founder

Metallurgic Engineer

30+ years Industrial Integrity Management

7 x Serial Entrepreneur

- Industrial Corrosion Management
- Powder metallurgy, die & mould manufacturing
- Domestic appliance manufacturing/distribution
- Medical equipment manufacturing
- Consumer paint manufacturing

Mike Maguire

Co-Founder

Naval Architect - Ocean Engineer

30+ years Energy & Technology Leadership

- Safety, Risk and Compliance
- Innovation & Project Management
- Board and Technical Committee experience
- Global network technical experts and decision makers

Bernardo Faragalli

Project Manager

Mechanical Engineer

18+ years Offshore Oil and Gas Leadership

- Facilties Engineering and Reliability
- Hibernia Team Lead for equipment integrity, fabric maintenance and corrosion remediation; regional lead for pressure equipment integrity
- Project manager for Atlantic Canada GHG Emissions Reduction R&D initiatives

Next Steps

- CIDS refinements at component and system level to advance the technology to commercial application
  - **TRL 7/8 → TRL 9 + Market** (ISED TRL Scale)
  - Productization: Minimum Viable Product (MVP) offering
  - Electrical Certification (ATEX / IEC Ex)

- Industry CUI Pilot Deployment
  - Targeting planned maintenance turnarounds with recoating/replacement across a variety of insulated equipment/assets, geometries and locations

COPSYS

Next Steps

Other Value-added Applications

- Naval and Marine
- Offshore Renewables
- Subsea Assets
- Remote infrastructure sensing and asset integrity

COPSYS

Net Zero Technology Centre
Technology Driving Transition

CIDS provisionally approved for funding from

NZTC Asset Integrity (CUI) Challenge

"Our vision is to eliminate failures due to CUI by 2026 and we need new technology to make this a reality. We are looking for innovative ideas and technology for the detection, inspection and mitigation of CUI. Eliminating CUI will enhance safety, improve production efficiency and reduce fugitive emissions.

CIDS Delivers on all aspects of NZTC CUI Problem Statement

- √ **Detection** Detects CUI Hotspots before corrosion damage can occur
- √ **Inspection** Replaces manual inspection processes with persistent digital presence
- √ **Mitigation** Coating-integrated ICCP prevents corrosion even after barrier system failure

COPSYS

UN Sustainable Development Goals

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Resilient Infrastructure

Asset life extension

13 CLIMATE ACTION

Measurable GHG Emissions Reduction

14 LIFE BELOW WATER

Clean Quiet Hulls

Zero Toxicity

Marine Invasive Species

Other SDG

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

8 DECENT WORK AND ECONOMIC GROWTH

15 LIFE ON LAND

COPSYS

Copsys Partners

Natural Resources Canada / Ressources naturelles Canada

Canada

Suncor Energy

energy research & innovation
NEWFOUNDLAND & LABRADOR

MI

Dalhousie University

Memorial University

innovacorp
EARLY STAGE VENTURE CAPITAL

GRi SIMULATIONS

COVE Start-Up Yard

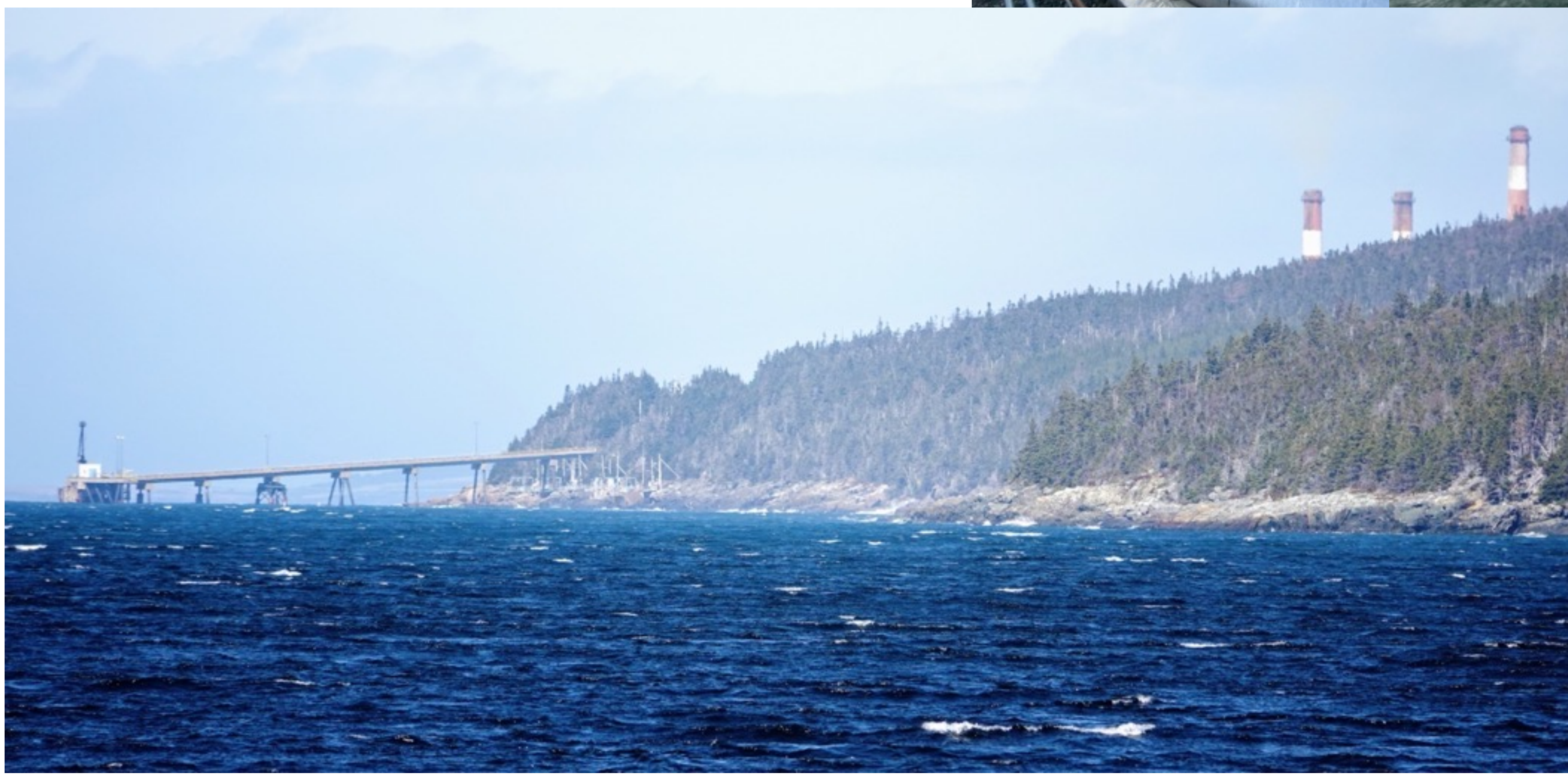
Lloyd's Register

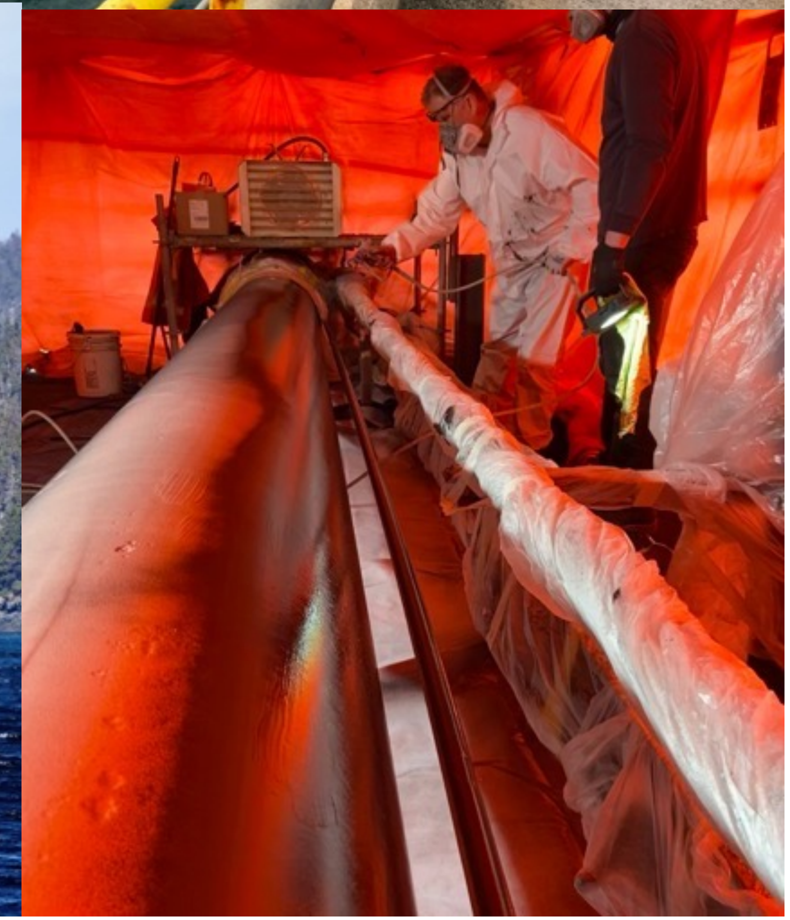
Safinah Group

Net Zero Technology Centre
Technology Driving Transition

COPSYS

Long Term Harsh Environment Exposure





Appendix 6

CUI monitoring of a heat exchanger: case study

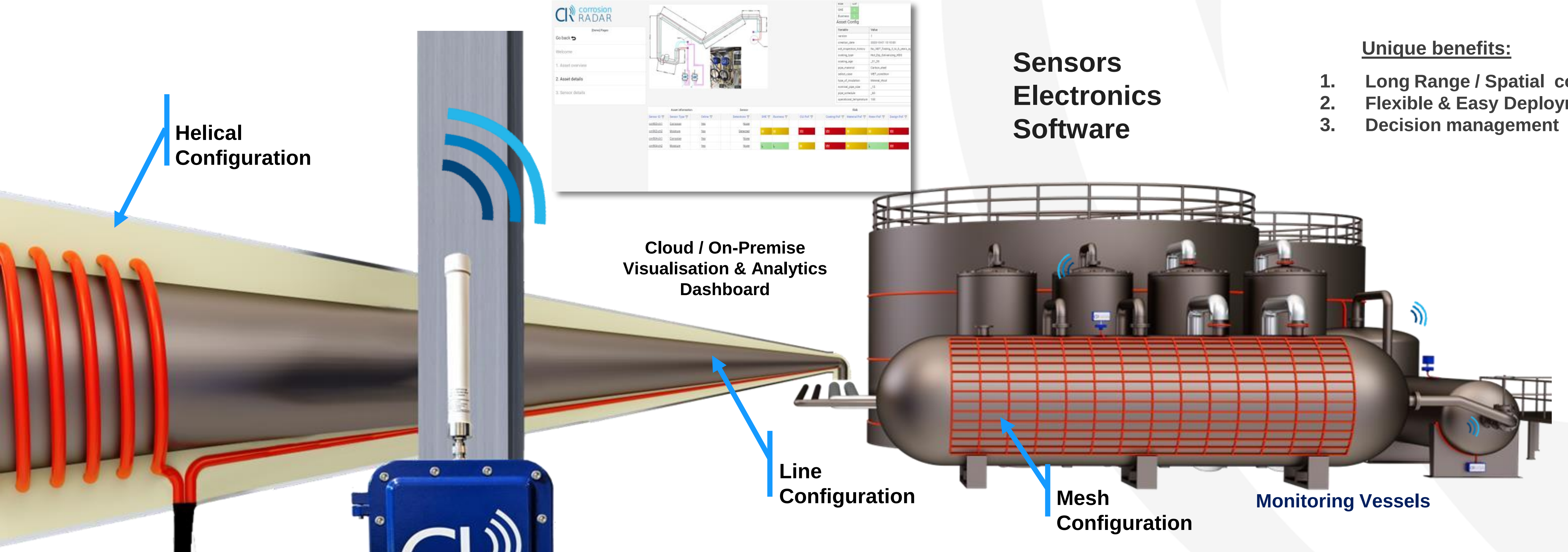
(Philip Enegela)

INEOS

CUI Monitoring of a Heat Exchanger

Philip Enegela
INEOS O&P UK

CUI Risk Monitoring system - Moisture and Corrosion Sensing



Sensors
Electronics
Software

Unique benefits:

1. Long Range / Spatial coverage
2. Flexible & Easy Deployment
3. Decision management

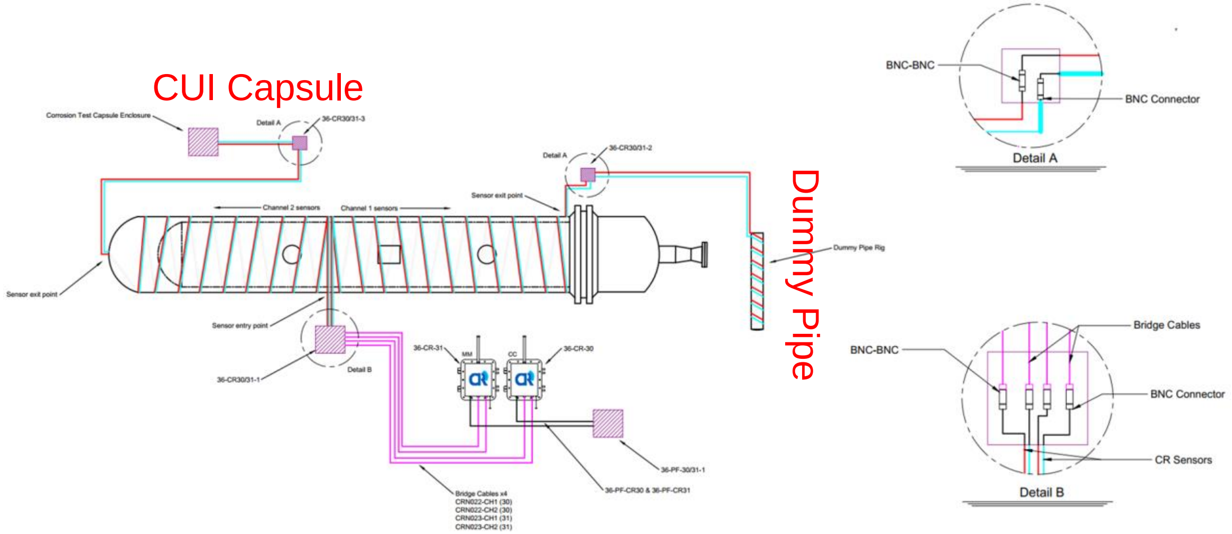
CR Node (electronics)

ATEX/IECEx /UL Certification	Ex - Zone 1 and Zone 2 USA - Class 1 Div 2 (C1D2)
Ingress Protection	IP66
Power Source	Battery (optional 24V DC or 110V AC)
Communications	Wireless: Cellular/WirelessHART/LoRa Manual data transfer: BLE Tablet / USB

Sensors

Sensor Types	Moisture Corrosion
Sensor Length	Up to 100 m (per node)
Temperature Range (°C)	- 190 to +300 °C - -310F to 572F

Heat Exchanger Details



Asset -
HEX 36-E-80 (Distillate Stripper Reboiler)
Hot insulation
Shell side fluid: Stripper feed
Tube side fluid: Steam
Material of construction: CS

Objective-
Shell side is operating within the CUI susceptibility range

CR monitoring design-
Two (2x) monitoring systems have been installed
Sensors cover the shell side of the asset
On either side of the HEX a test set-up is provided

Outcome-
Moisture detected after the introduction of brine solution to both of test set-ups

Moisture detected under insulation on the asset in historical data

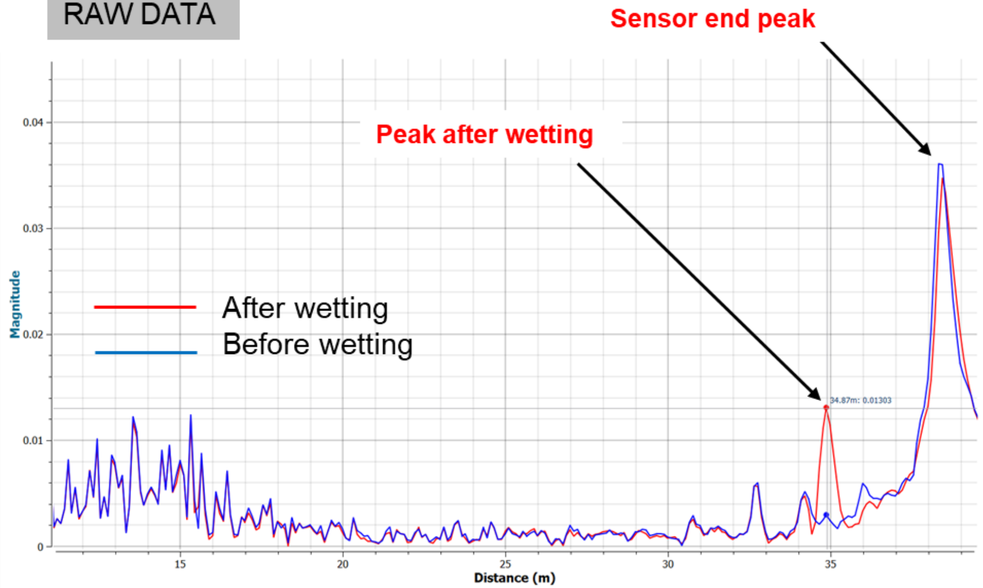
Moisture Detection - Trials

Detection Trials

CUI Test Capsule

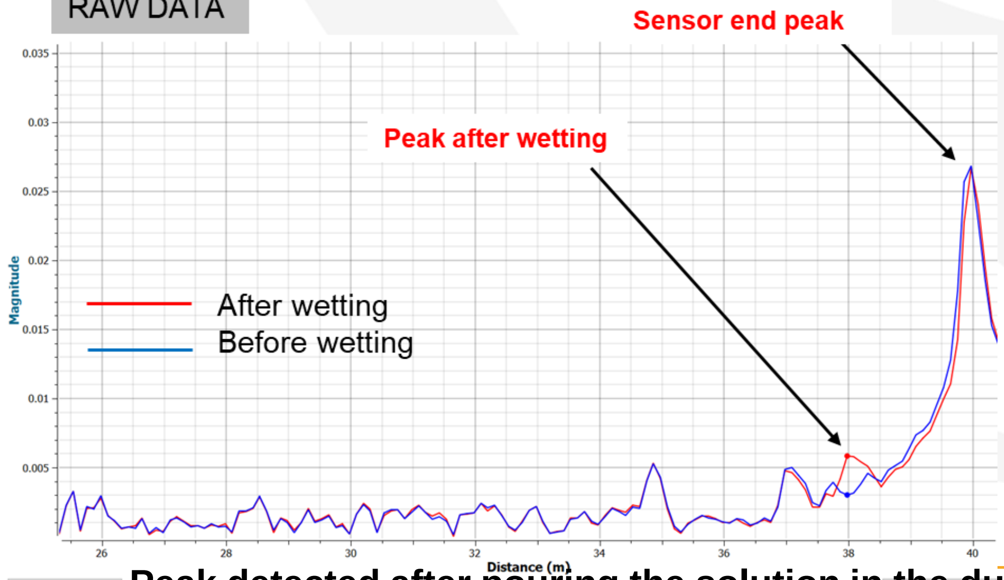
Dummy Pipe Test

RAW DATA



Peak detected after pouring the solution in the capsule

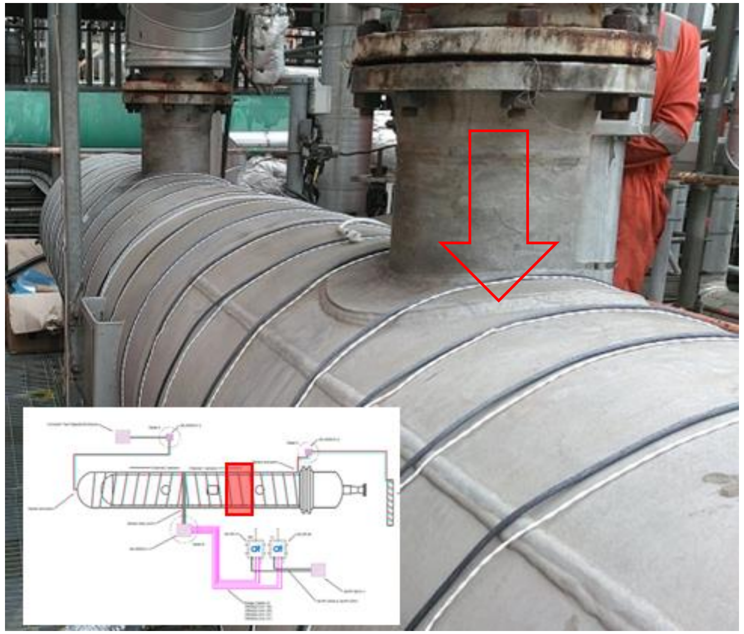
RAW DATA

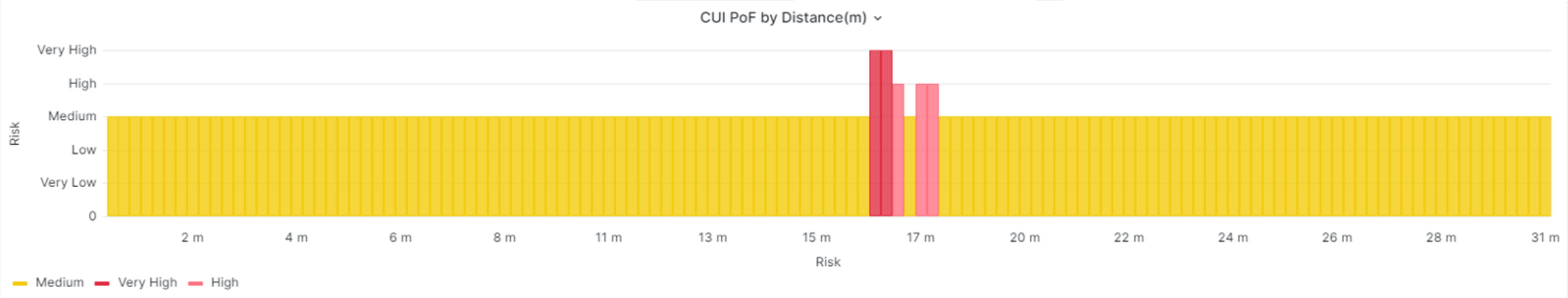


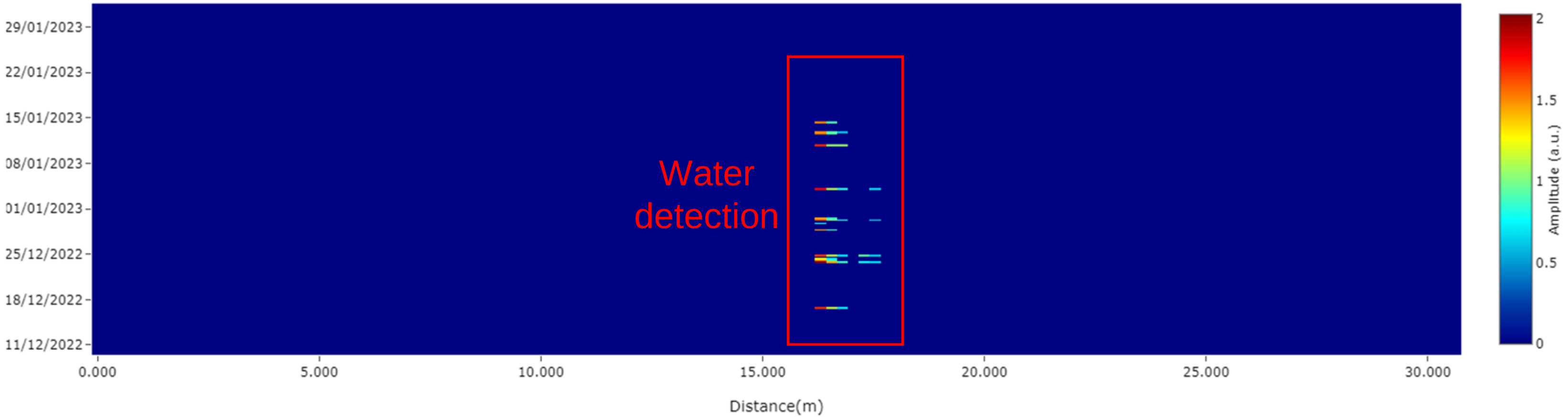
Peak detected after pouring the solution in the dummy pipe

Heat Exchanger monitoring

Historical Data Analysis







- The collected data is from 9th of December 2022 to 1st of February 2023.
- Water has been detected on channel 1 of CRN031. The location of the water is at 16m and 17m of the moisture sensor (excluding the bridge cable) on the west part of the HEX shell.
- The location of water ingress is at the shell outlet nozzle as shown with an arrow in above picture. This is thought to be due to poor mastic application during insulation installation

INEOS

Appendix 7

Sirris joint industrial project on CUI

(Jeroen Tacq)

InnovateCUI

Joint Industry Project

Sensors
Coatings
Insulation
Energy losses

Jeroen Tacq, Sirris

EFC-WP15 Meeting, Lille, 2023-03-30

Participants (8 confirmed)

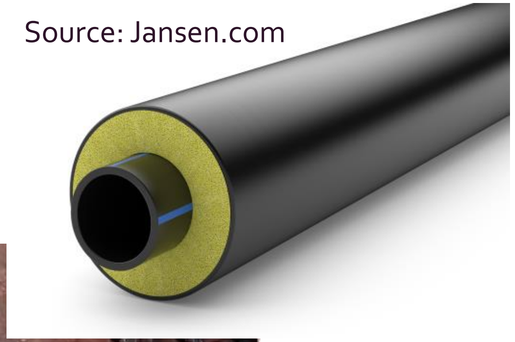
Possible additional participants

+ others?

Corrosion Under Insulation

SAFETY, COSTS, REPUTATION

Source: Jansen.com



CUI Failures: left, Petroplus (Src: BBC); right, Brae Alpha (Src: IMCA)

Development of a realistic CUI test environment

Develop and demonstrate CUI Management Solutions

KIK | MPI
Kennis- en innovatiecentrum
Maintenance Procesindustrie

Corrosion LABS

Interreg
EUROPESE UNIE
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

Realistic CUI Test Environment for Sensors, Coatings and Insulation

Realistic CUI Test Environment for Sensors, Coatings and Insulation

Provide system test for different company owners

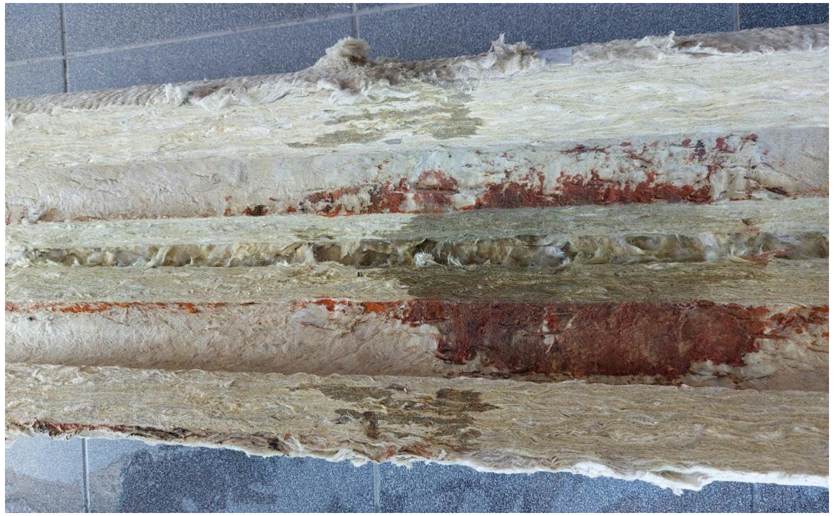
- ➢ Testing of measuring devices, sensors, insulation systems, coatings, etc.
- ➢ Sensor response times, detection thresholds, etc.
- ➢ Live measurements
- ➢ Impact of operating conditions on CUI

Result after 12 days (cyclic T, start with wet insulation)

First results - Location of water retention

12 days
80 ml/h
20°C
+ 120g

12 days
80 ml/h
82°C
+ 1500 g



Effect of Temperature on Water repellent properties

Dry weight
approx. 1500 g

First results - Location of water retention

RT, 5ml/h, 4 weeks

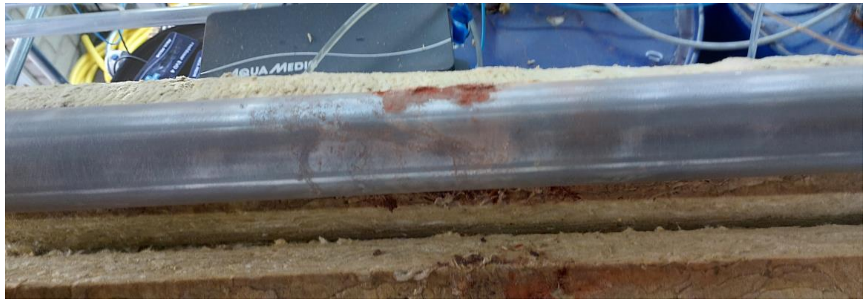
82°C, 5ml/h, 4 weeks

Take away: Small amounts of water have a more corrosive effect on cold pipes

Influence of temperature cycling

Cyclic (82/22°C), 5ml/h, 13 weeks

82C°, 5ml/h, 13 weeks



<u>Take away:</u> Cyclic temperature regime results in corrosion that is much more spread along the length of the pipe (further study of corrosion needed).

Evaluation of CUI Sensors

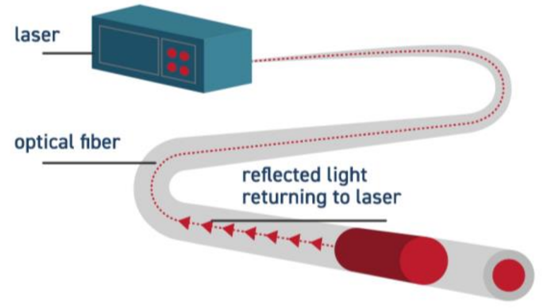
EVALUATION AND TRAINING OF CUI MONITORING TECHNIQUES – FLUVES

senspro Data Under Insulation

Electrical Capacitive Measurement

FLUVES

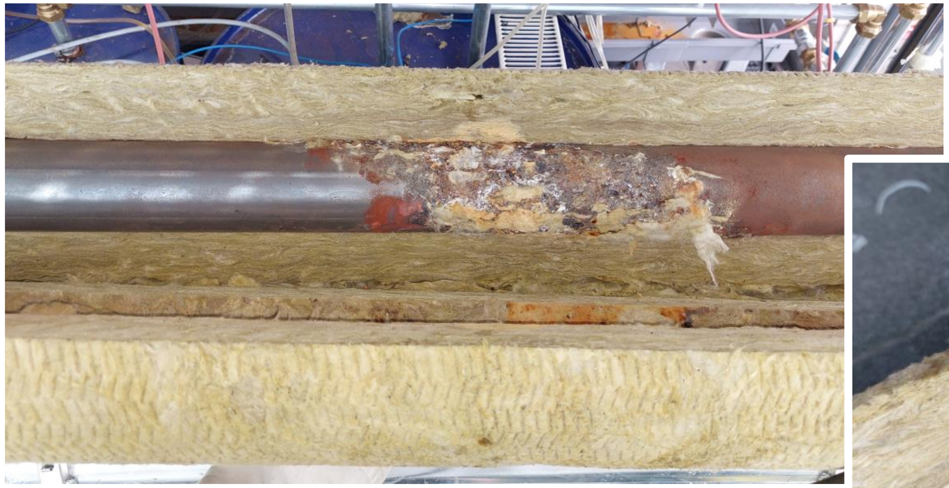
Optical Fibre Monitoring



Dry-out

82°C, 40ml/h, inspection after approx. 24h dry-out

Wet on the outside



Dry pipe

- If you want to use moisture in insulation as a input parameter in models, you may need to know where the moisture is. (Intended purpose of CUI Sensors…)
- What is ‘dry’ for one sensor may not be ‘dry’ for another one.

- Incorporation of sensor data in CUI Management programs.

Realistic CUI Test Environment for Sensors, Coatings and Insulation

Corrosion LABS

Dec 2022

Phase 1

Phase 2

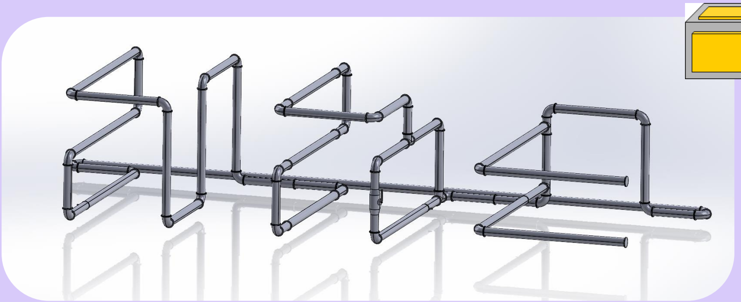
Durable industrial CUI research program

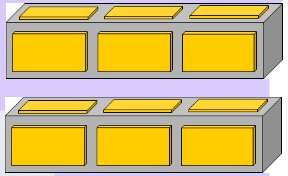
Interreg
EUROPESE UNIE
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

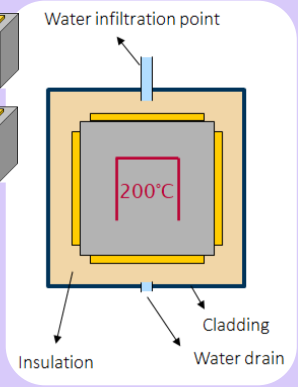
€400k, 2 year learning trajectory

InnovateCUI-JIP

Financed by the industry







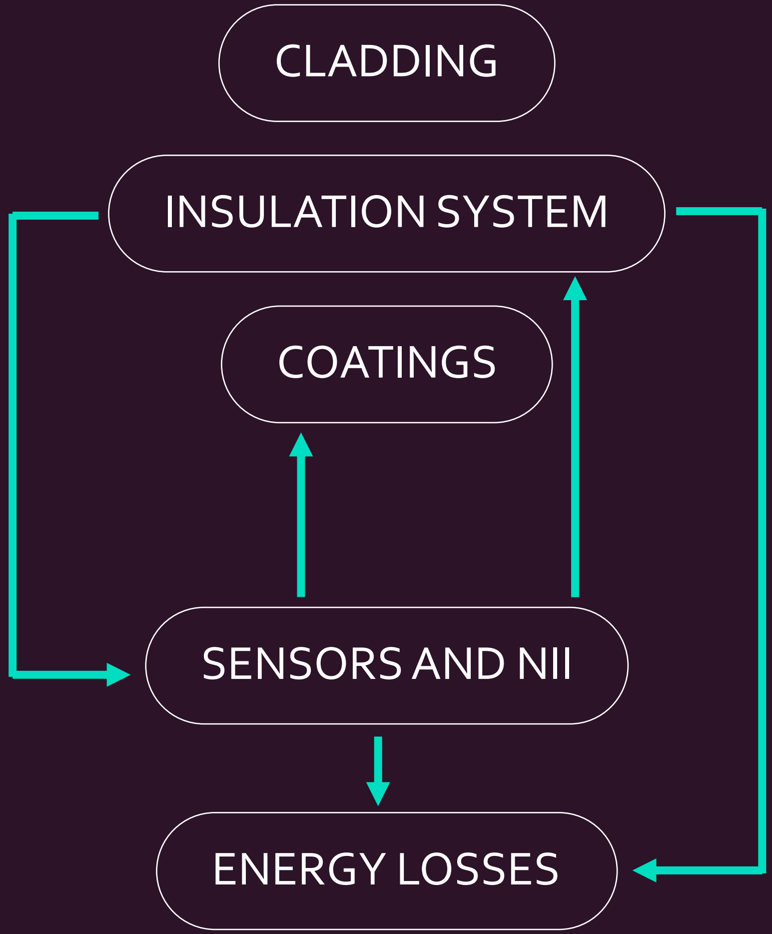
InnovateCUI-JIP

OBJECTIVES

- ✓ Reduce cost and increase safety
- ✓ Increase understanding of CUI and how to manage it
- ✓ Independent testing of CUI management solutions
- ✓ Present clear insights and guidance on what combination of CUI Management solutions provides the most cost-effective approach for various situations

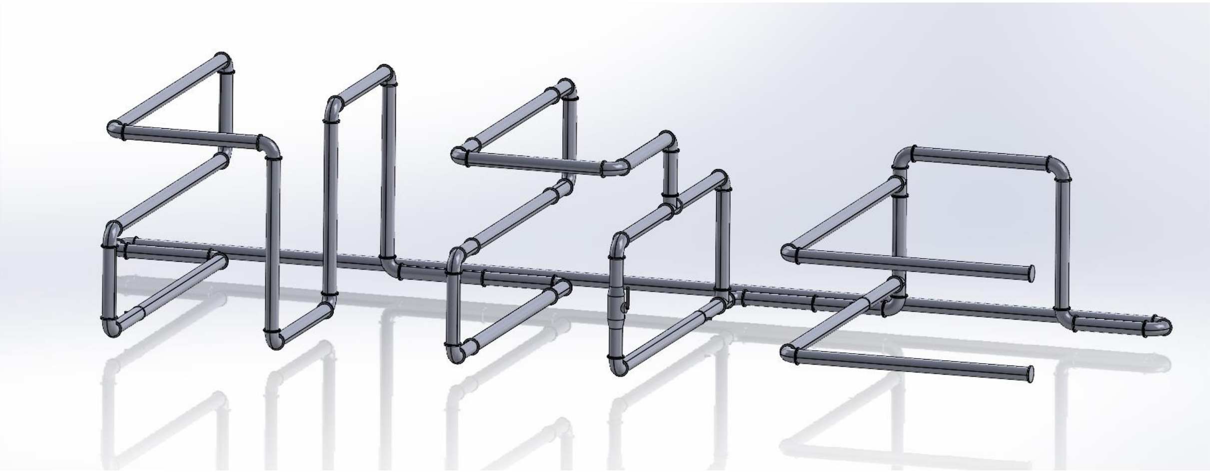
O1	Evaluate the performance of CUI sensors.
O2	Understand the data from CUI sensors and the information contained within that data, providing guidance on implementation of sensors, and how their output can be used in management decisions.
O3	Develop a methodology that can link accelerated testing of CUI Coatings to actual field performance and use it to evaluate an accelerated CUI coatings test.
O4	Study the feasibility and possible methodology for the development of CUI coating degradation forecasting models.
O5	Evaluate the impact of insulation system design on sensor (and coating) performance (subject to prioritisation of the project scope by the Industrial Partners).
O6	Evaluate the feasibility to correlate data from CUI Moisture sensors and Energy Losses.

A System Approach to CUI



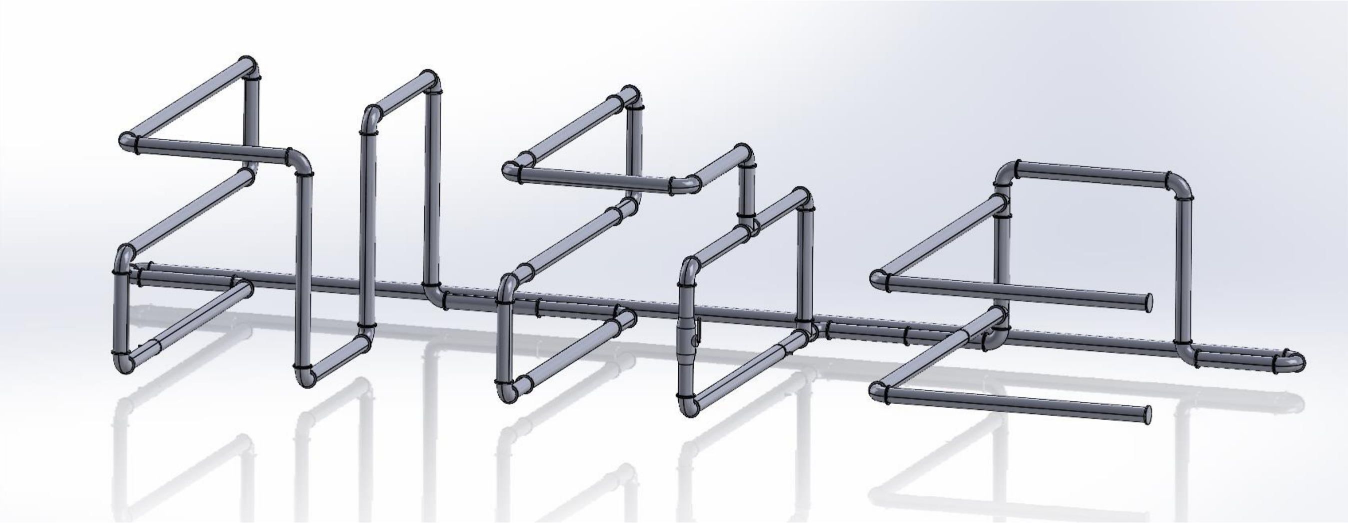
InnovateCUI - Sensors

Decision based on voting by JIP Partners - status on 21/03/23		
Air humidity sensor	**Trisense**	Include if possible to combine
	Indusenz	
	Wi-corr Proximity	
	Kaefer BLU	Include in testing
Water accumulation sensor	**Bernax**	
	H2O Obvious	
Fuse wire	**COSASCO**	
	CUISpotter	
	CorrosionRADAR	
Electromagnetic waves through a wire	**CorrosionRADAR**	Include in testing
Pop-out fuse wire	**REPCO CORROTEX**	Include if possible to combine
Capacitive moisture measurement	**isenspro**	Include in testing
Optical fibre moisture measurement	**Fluves**	Include in testing
	Senergetics	
Radio wave antenna's	**Wi-corr Quanta**	Include in testing
Percolation sensor (wire)	**PercoSens**	Include if possible to combine



Approximately 55m of piping

InnovateCUI - Sensors



Approximately 55m of piping

sirris innovation forward

Antwerpen • Brussel-Bruxelles • Charleroi
Gent • Hasselt • Kortrijk • Leuven • Liège

JIP-InnovateCUI

Sensor testing objectives and relation to the test rig design

What questions do we want to see answered about the sensors and their capabilities?

- [redacted] [All]
- [redacted] [Module 1, W1, W2 + return pipe] [redacted]
- [redacted] [All]
- [redacted] [Module 1, W1, W2 + return pipe]
- [redacted] [All]
- [redacted] [All]
- [redacted] [W6 or W7, possibly not wetting at the same time]
- [redacted] [Module 2]
- [redacted] [Module 2, W5 to W7]
- [redacted] [W1, W2, W8, W9; W8 and W9 NOT wetting simultaneously]
- [redacted] [Module 3, W8, W9, W10; NOT wetting simultaneously] [redacted]
- [redacted] [Module 2, W3 to W5]
- [redacted]

Possible objectives not directly related to the type of sensor:

- Obtain information on corrosion rates as a function of humidity.
- Obtain information on dry-out capacity of insulation.
- Learn about the effectiveness of drain-holes (start test without drain holes, check if drain holes make a difference towards water retention and dry-out).

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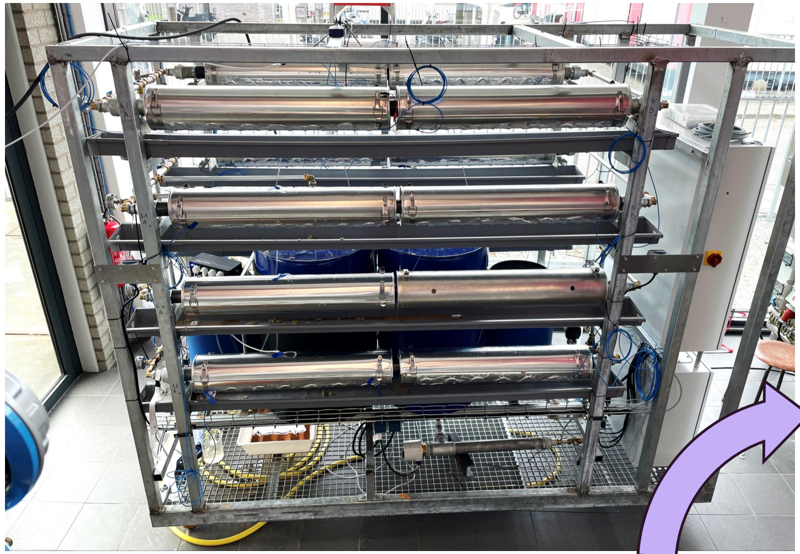
3001 Heverlee • België

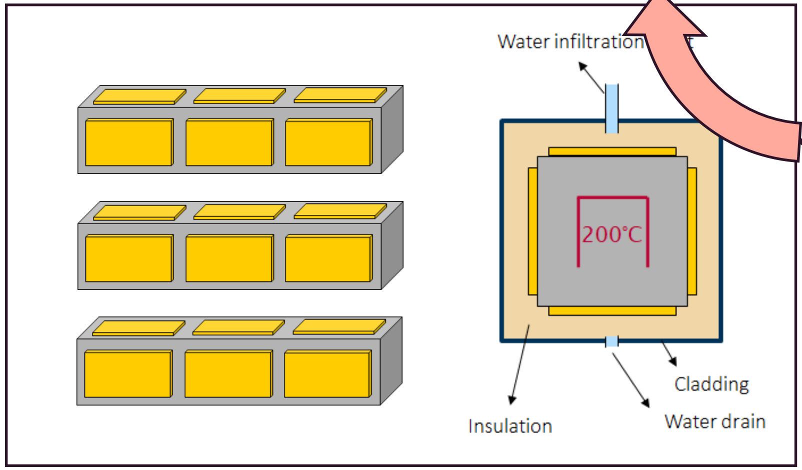
CUI JIP - Coatings

Long duration coating test (1.5 yrs)



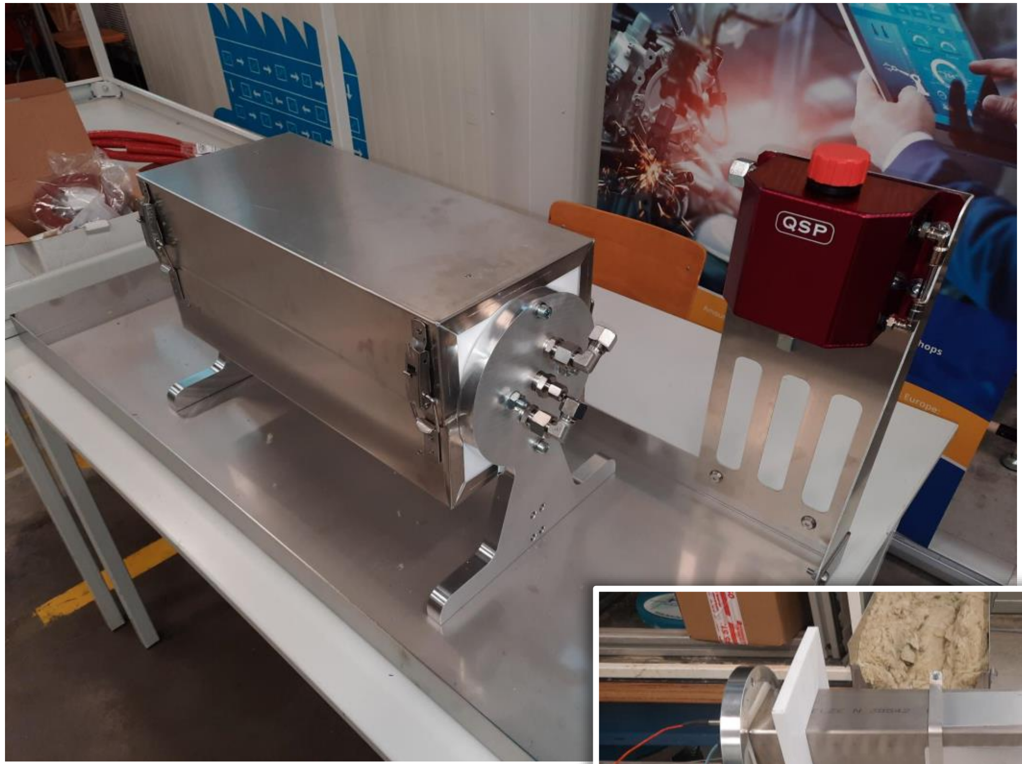
In-field measurements

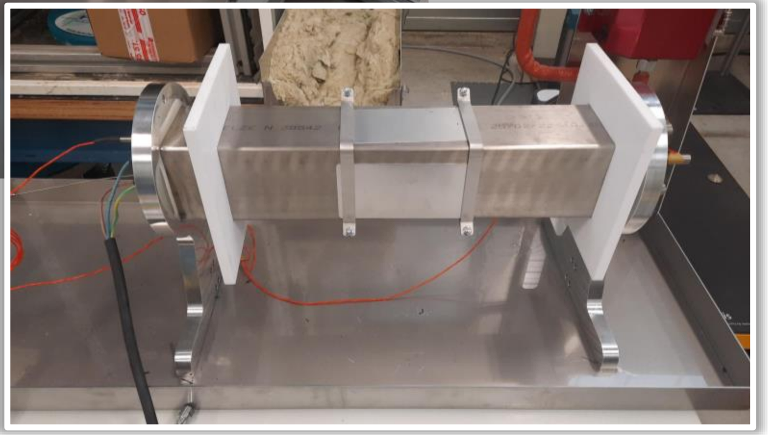
Accelerated coating test



Combined interpretation to get insights about real-field performance based on accelerated testing.

CUI JIP - Coatings



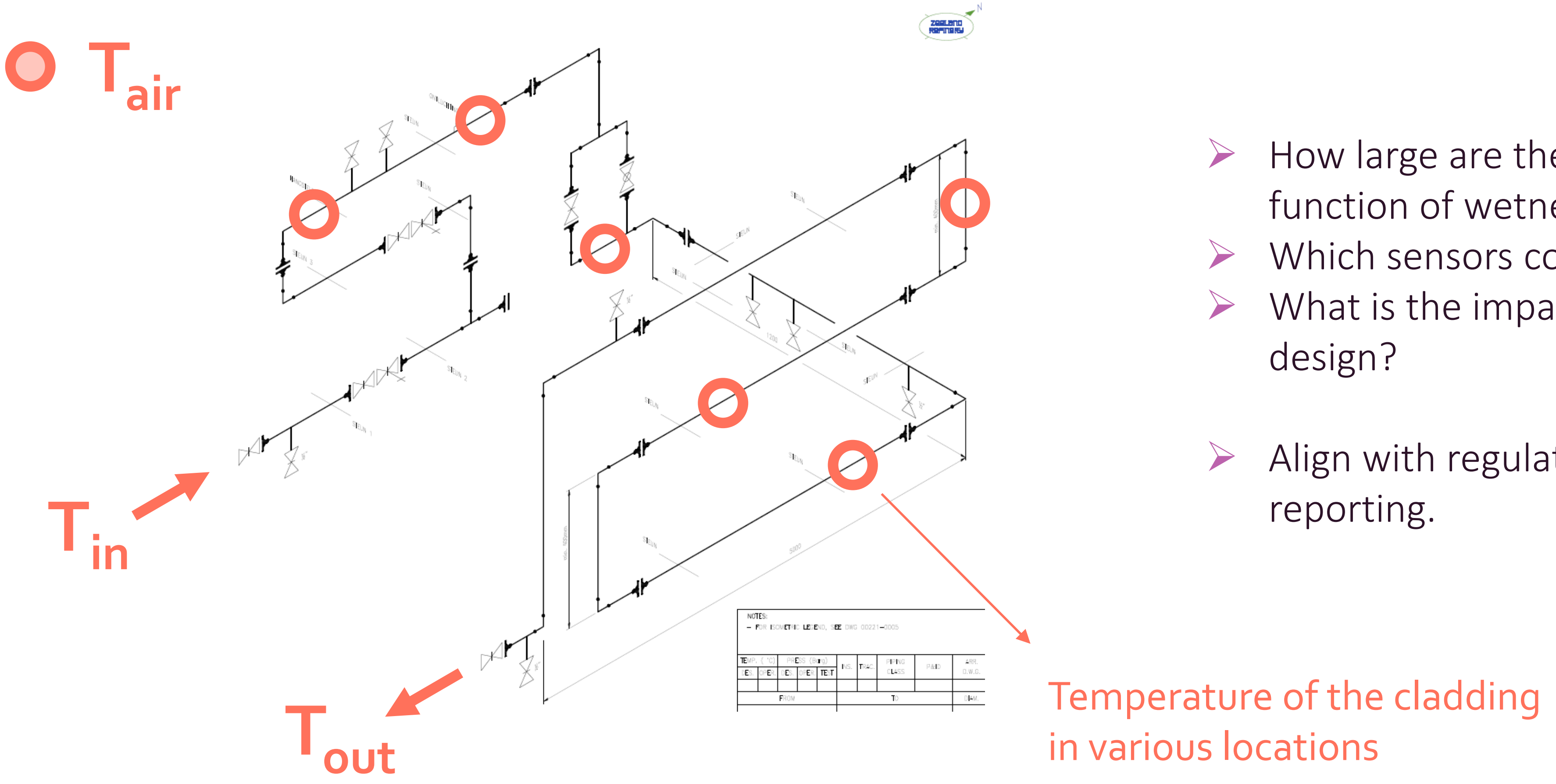


- Coating Classification according to Norsok M-501 and SP0198 (CS-1, CS-3, CS-4)

- Possible coating systems for testing (TBD)
  - High build Epoxy on Carbon Steel
  - Norsok 1D Epoxy Phenolic on Carbon Steel
  - Norsok 1D Epoxy Novolac no Carbon Steel
  - Norsok 1B, Zinc epoxy on Carbon Steel

CUI JIP – Insulation System

INVESTIGATIONS ON ENERGY LOSSES DUE TO WET/DEGRADED INSULATION



- How large are the energy losses are as a function of wetness?
- Which sensors correlate with energy losses?
- What is the impact of insulation system design?

- Align with regulatory obligations on energy reporting.

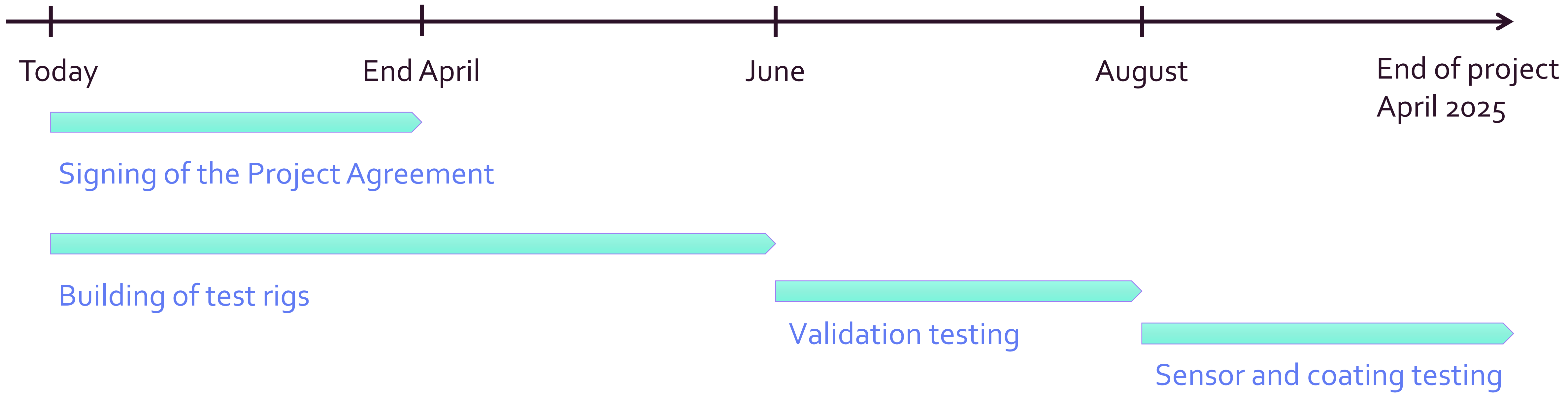
InnovateCUI-JIP

DELIVERABLES

D1	Report on CUI sensors' technical capabilities, disadvantages and advantages based on a desktop survey.
D2	Report on the performance of CUI sensors, based on the test data obtained within the project. This may include the type of data measured by the sensors, the measured data itself (data output as would be the case in a commercial setting), location accuracy, detection thresholds, ease of installation, ability to measure at/past flanges, etc.
D3	Input for the further development of existing guidelines (for example: EFC55 – Corrosion under Insulation (CUI) guidelines) on how sensors may be used in a CUI Management program.
D4	A proposed methodology to evaluate the performance of CUI Coatings.
D5	Data of coating test results in accelerated and slow ageing tests, in agreement with the definition and use of Results as outlined in the Project Agreement.
D6	Report on the feasibility and possible methodology for the development of CUI coating degradation forecasting models.
D7	Report on the feasibility to correlate data from CUI Moisture sensors and Energy Losses.

CUI JIP – Contribution and timeline

- Project duration: 2 year
- Financial Contribution: €18.000/yr



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Arantxa Penninger

Coating test coordinator

Bart Teerlinck

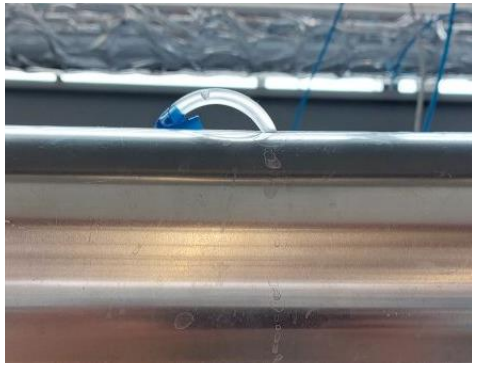
Program lead

Realistic CUI Test Environment for Sensors, Coatings and Insulation

WHAT ARE WE DOING?

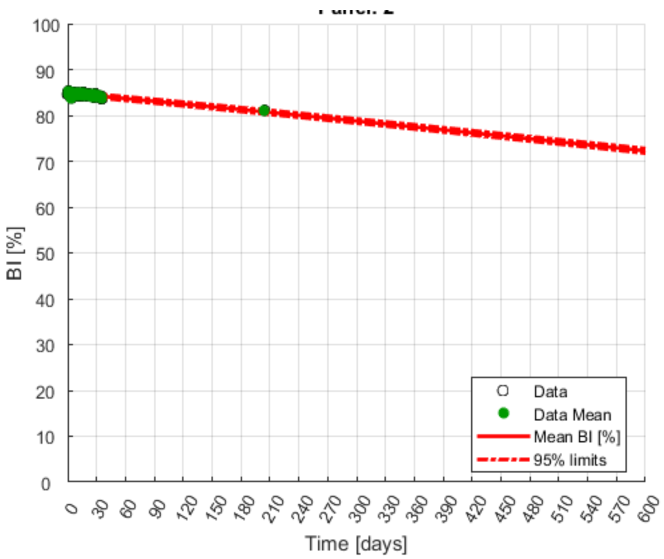
Testing rigs for CUI

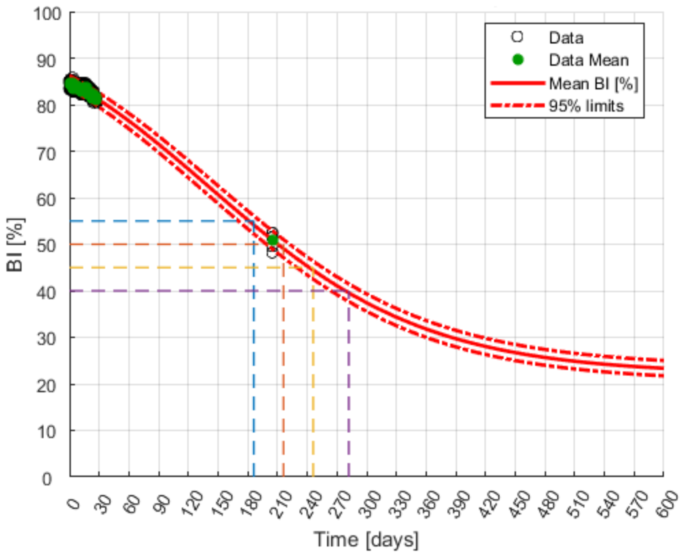
- Plant trials are challenging to control and face safety & environmental issues
- Test rigs offer realistic environment, safe and controlled
- Test rigs managed by independent research institute can bridge the gap between innovation and implementation



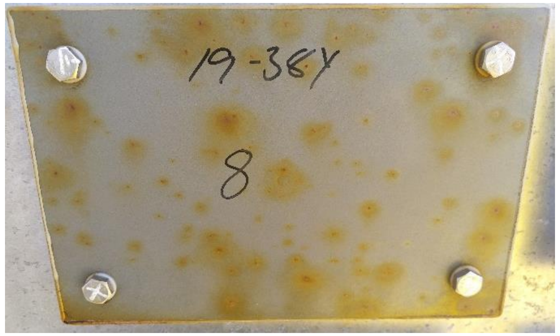
Comparative testing of coating systems

COATING QUALITY EVALUATION AND LIFETIME FORECAST USING FIELD-EIS MEASUREMENT METHOD FROM C-CUBE





C-Cube
International bv



Appendix 8

Recent development of CUI management

(Geert Henk Wijnants)

Recent developments in CUI management

Geert Henk Wijnants
Principal Consultant, STORK Asset Management Technology

Corrosion Under Insulation

WORLD CLASS MAINTENANCE

Corrosion Under Insulation

roadmap

Call for Action / Business Driver
- Prevention is better than correction.
- Save on failure costs.
- Investing in a cost-effective approach from TCO.
- Recognisability from management structure
- Preventing “trial and error” approach

CUI solution:
- Modular approach based on maintaining what is good, improving what can be improved.
- Using generally proven concepts with regard to predicting corrosion, assessing damage, determining risk, estimating lifespan, controlling costs.
- Transparency through independent approach from WCM; a supplier-independent concept.
- With the involvement of KINT, ION, VNCI, RVO, SDN

Business model:
- Risk-oriented, so investment in those areas where it yields best profits.
- Taking into account the continuation of those concepts which are already doing well.
- Improve together by using each others individual experiences for the better good.

(Potential) partners:
- Asset-owners from “BRZO” sector
- Isolation and coating industry
- Inspection- and service suppliers

Development CUI Awareness tool
- Self assessment tool.
- Awareness wrt CUI
- Evaluation level of robustness in terms of being prepared for CUI

Development Best Practice
- Modular set of tools for implementation of CUI management
- Risk based approach
- Based on the ISO HLS structure
- Standard based on hands-on experience of involved companies and the current state of the art in this matter.

Innovations project
- Development moisture-sensoring
- Development sustainable coatings with enhanced CUI resistance
- Development Best Practise CUI conscious insulating
- Determination of earning capacity CUI program for the industry.

Knowledge & Validation Project
- Performance of new detecting techniques
- Performance of new coatings
- Performance of improved insulation techniques
- Performance optimised CUI management as per industry branch

Upgrade feasible innovations
- Branch oriented innovations for proven performance blockers as per industry.
- Implementation service concepts for integrated CUI performance management (isolation, coating, inspection, energy efficiency)

Sustainable Control on CUI.

RISC

2018 2019 2020 2021 2022 2023

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Corrosion Under Insulation

Status quo:

- Best practise CUI management.
- Tools for implementation (XLSX; PPTX)
- Gap analysis for optimisation

Modular setup. Elements:

- ➢Standardized Risk Assessment Method
- ➢Decision model for coating lifetime with risk(t)
- ➢Corrosion rate CUI over time with valuation in risk
- ➢Assessment of the condition of insulation, effect on risk
- ➢(Cost-)Effectiveness of NDT, influence on "control on risk"
- ➢Awareness presentation regarding impact CUI management program with costs/benefits.
- ➢The best practice description according to "ISO high level structure" for RBI CUI.

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Corrosion Under Insulation

Ongoing:

Innovation along the following tracks:

- Develop decision tool based on inspection costs
- Standardization in terms of condition determination
- Building a database with CUI related incidents
- Establishing a coating monitoring program
- Development of a cost-effective moisture monitoring program
- Wider application of the CINI standard.

Background:

- Best Practise available since end 2019.
- Setup according to ISO HLS structure (MSS).
- Audit points applied from the start.
- Assessment along two lines:
  - o Management line (HLS/MSS)
  - o Discipline line (Critical elements)
  - ➔ Failure chance; average / max. / min.
- Consequences as per std. Risk model EN16991.
- ➔ Risk assessment AND earning capacity.

www.wcmvector.com (NL –to be converted to EN)

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Results from the development:

- Limited detail in advance:
  "Traffic Light" : Good/Medium/Bad.
  It's about understanding, not about debate whether it is a 4 or a 7.
- Big differences in one company
  Dep. of role/position
- Characteristic: "no policy yet"
- Communication is essential.

A	B	C	D	E	F	
	1: Gap-analyse ten opzichte van de BP Risk Based CUI management; tooling				2: Gap-ana	
Toetsings kader:		Risicobeoordeling zoals verwerkt in "Best Practise voor Risk Based CUI Management".			Kader:	Bec
	Bij de toetsing wordt geverifieerd in hoeverre de volgende elementen aanwezig zijn:					
	Management framework: (gericht op verbetercyclus met evaluatie etc.)		5.0		[△1]	Bec
		Kent een structuur met eigenaarschap en verbetercyclus (conform ISO HLS):	1		[△2]	Bel
		Heeft een planmatige aanpak met verdeling van activiteiten over de jaren:	1		[△3]	Ver
		Bevat een budgetopbouw die gebaseerd is op de benodigde besteding:	1		[△4]	Beh
		Evalueert afwijkingen waarbij het toegepaste systeem heeft gefaald:	1		[△5]	Sco
	Risicobeoordeling:		5.0		[△6]	Toe
		Risicobeoordeling kwantitatief met berekening kans x kosten:	0		[△7]	Aan
		Risicobeoordeling bevat wettelijk perspectief op fataliteit (< 10^-4):	1		[△8]	Dire
		Bepalen risico op basis van beschikbare corrosie marge:	2		[△9]	Er is
	Corrosie snelheid:		1.7		[△10]	Het
		Onderscheid staal / RVS:	2		[△11]	Bev
		Op basis van temperatuur:			[△12]	Wijz
		Op basis van aantal wisselingen:			[△13]	Doe
		Afhankelijkheid van soort milieu (omgeving):			[△14]	Doe
		Afhankelijkheid van soort isolatie:			[△15]	Bes
		Afhankelijk van conditie (toestand) van isolatie (lekdicht):			[△16]	Ben
	Levensduur coating:		5.0		[△17]	Bet
		Onderscheid coating / TSA:	2		[△18]	Con
		Beoordeeld op basis van bewezen ervaring:	2		[△19]	De
		Inbreng generatie van de coating:	2		[△20]	Doo
		Inbreng van conserveerbaarheid vanuit ontwerp:			[△21]	De
		Inbreng werkproces én mate van ervaring applicateur:			[△22]	Eise
		Wijze van beheer van de isolatie:			[△23]	Exte
	ND() Effectiviteit:		4.3		[△24]	Uitg
		Inbreng soort van de onderzoeken object (typical):	2		[△25]	Wijz
		Maakt gebruik van overzicht van effectiviteit van toe te passen technieken:	2		[△26]	Kwa
		Verwerkt vereist niveau van dekking (onderzoeks percentage):	2		[△27]	Ben
		Verwerkt vereist niveau van risico reductie:			[△28]	Bev
		Onderscheid screening (corrosie detectie), vocht detectie, wanddikte (conditie):			[△29]	Pre
		Onderscheid naar te onderzoeken diameter:			[△30]	Aan
		Onderscheid naar te onderzoeken wanddikte:			[△31]	Aan
	NDO Doelmatigheid:		7.5		[△32]	Bev
		Hanteert afweging van meest kosteneffectieve methode:	2		[△33]	Dire
		Kent opties stralen/schilderen, screening en vervolg, RTF, upgrade:	1		[△34]	Act
					[△35]	Toe
	Bevindingen: (algemeen geconstateerde aspecten m.b.t. methode)				[△36]	Cor
					Bevindinge	

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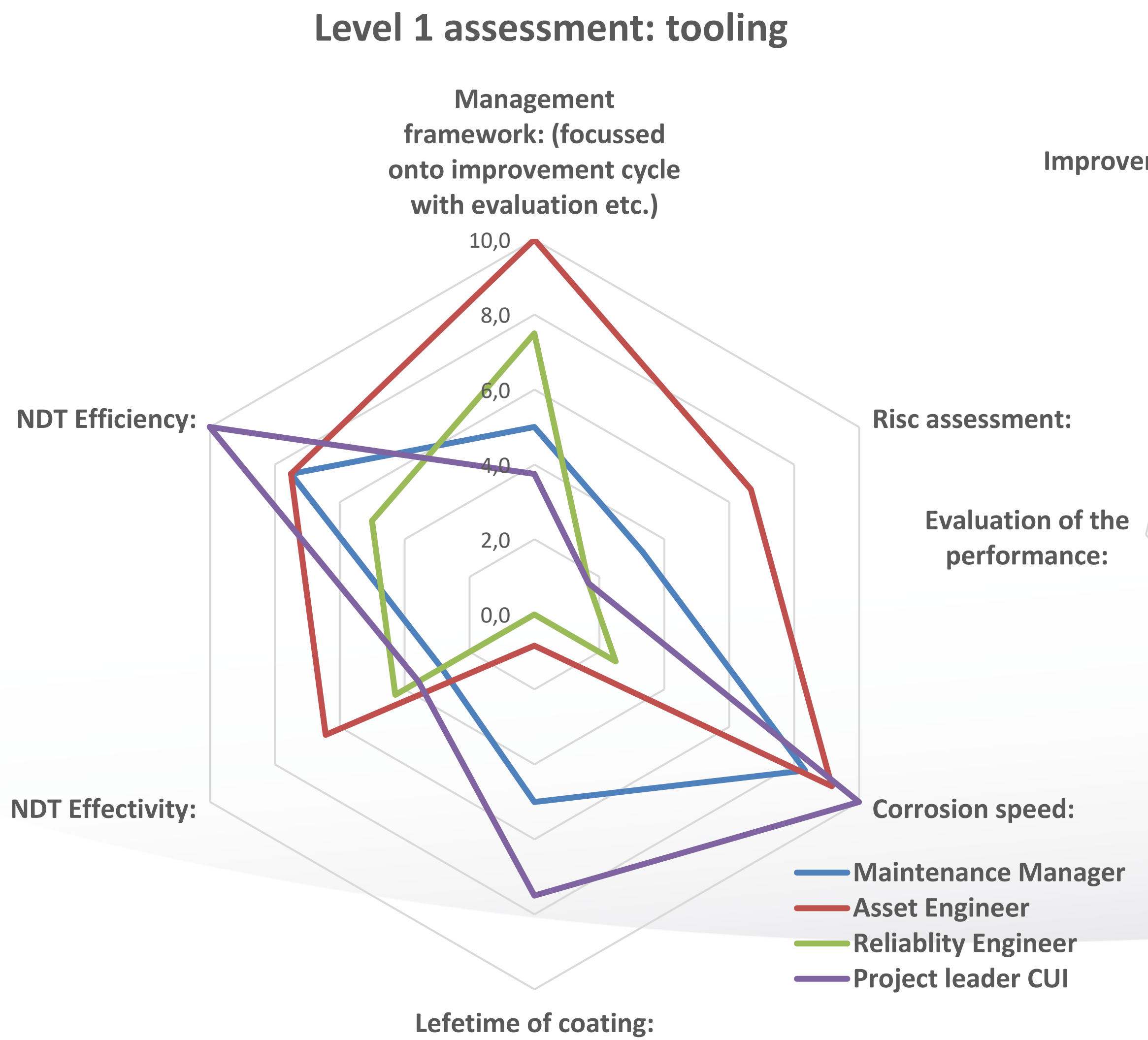
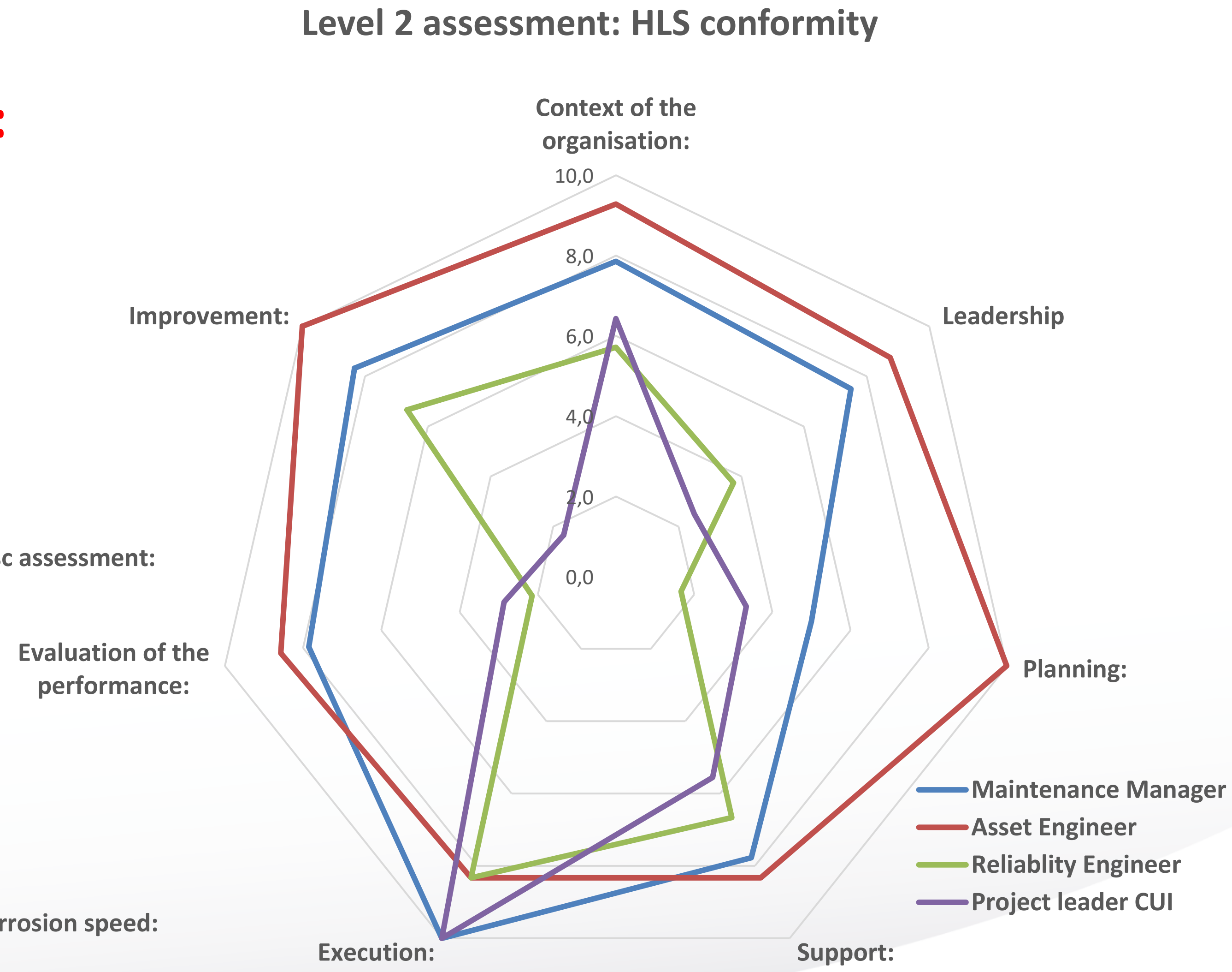
Recent findings from GAP Analysis:

Typical findings within one plant:





Recent findings from GAP Analysis:

Typical findings for a sector:

GAP-Analysis tooling: 4 companies; 5 audits; all “Chemicals”.

Benchmark score: 4+; *exception* **Leadership** and **schedule** (planning). => First profit to be obtained.

Level 1 assessment: Tooling

Level 2 assessment: HLS Conformity

Recent findings from GAP Analysis: within one plant….

Main results:

- Lack of joint perspective and awareness on key features. Therefore:

✓ Enhance interaction by regular meeting with knowledge sharing for those involved. (so create additional value; it's not just on progress and "ticking the boxes").

✓ Promote exchange on idea's of what could be improved (PDCA acc. To HLS).

✓ In general: create focus on the effects of the results achieved!

➢ Note that CUI is NOT just the issue of the production facility / asset manager.

Recent findings from GAP Analysis: over various plants……

Main results:

- In general, lacking continuing focus on CUI management (leadership/planning). Therefore:

✓ Facilitate the use of a common strategic approach, in order to create preventive structure, planning and prioritization (the 3 P's).

✓ Treat the subject as a major topic (which it usually is), NOT as "an add-on on the other activities" (which usually tend to be positioned on the long stretch).

➢ Note that CUI is a MAJOR (costs-)issue for the total production facility (TCO).

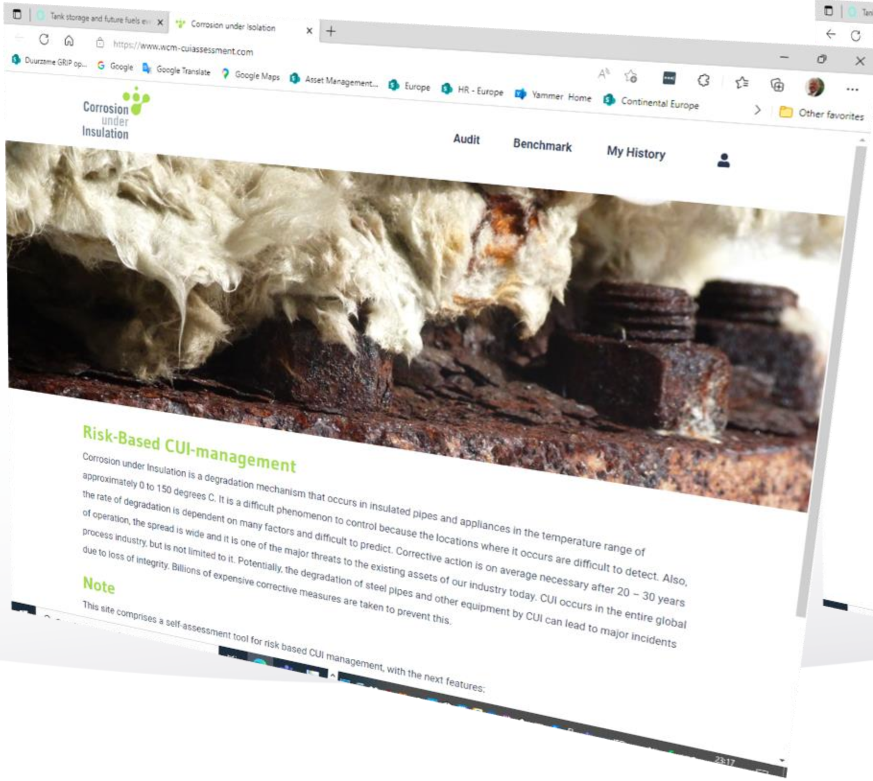
Additional findings from GAP Analysis:

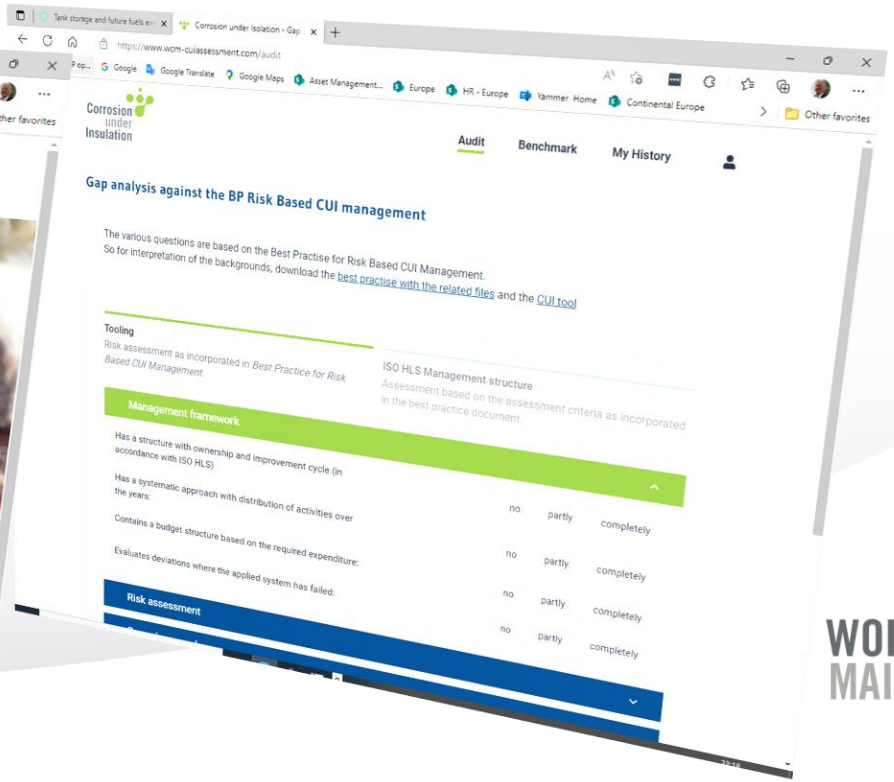
Comparing yourself with the results from others, helps to get to the next level.

Enhanced insight that an eye for details is simply required.

For this the internet site www.wcm-cuiassessment.nl had been created.

- ✓ Anonymized
- ✓ Free
- ✓ Report download





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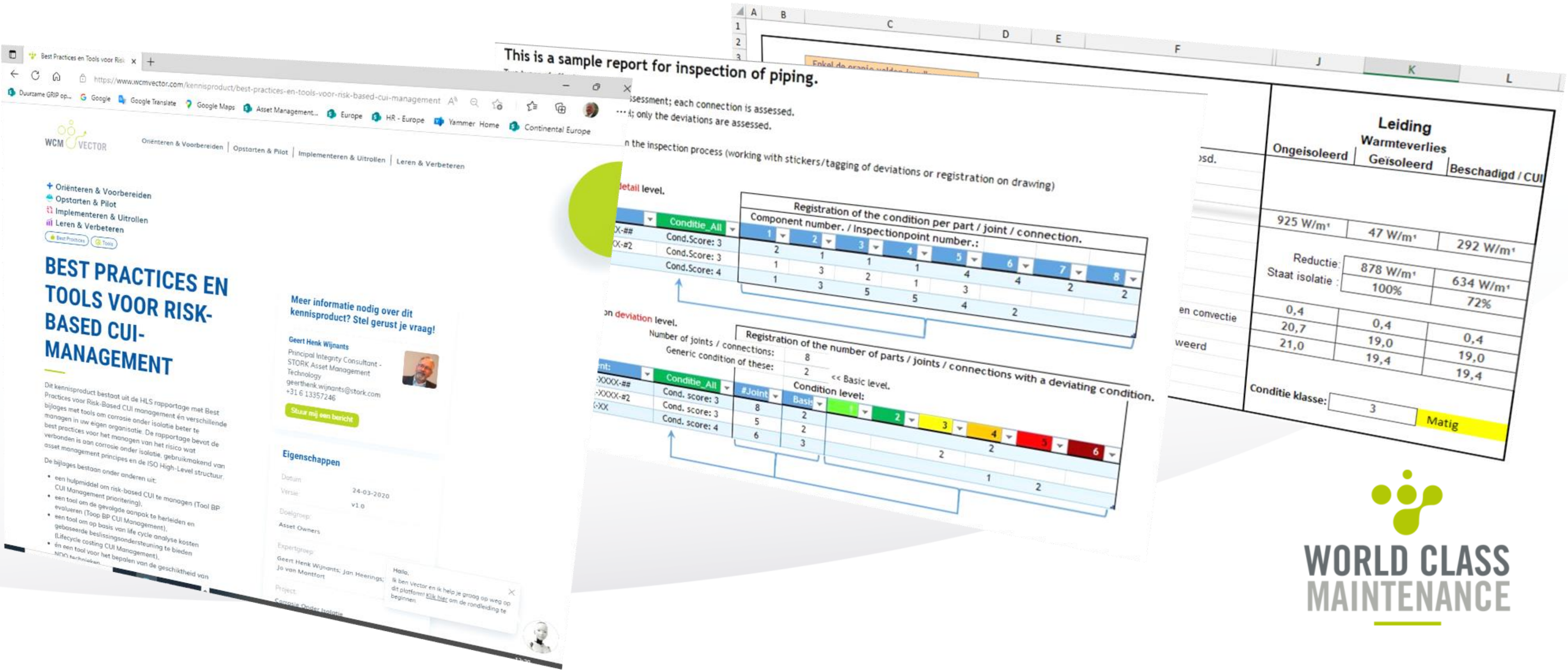
Other recent developments:

- All tooling now available for free download via www.wcmvector.com
- Tool for condition assessment of insulation has been adapted to included energy efficiency assessment (EED directive).

✓ Acc. CEN 17385

✓ Free

✓ Report download



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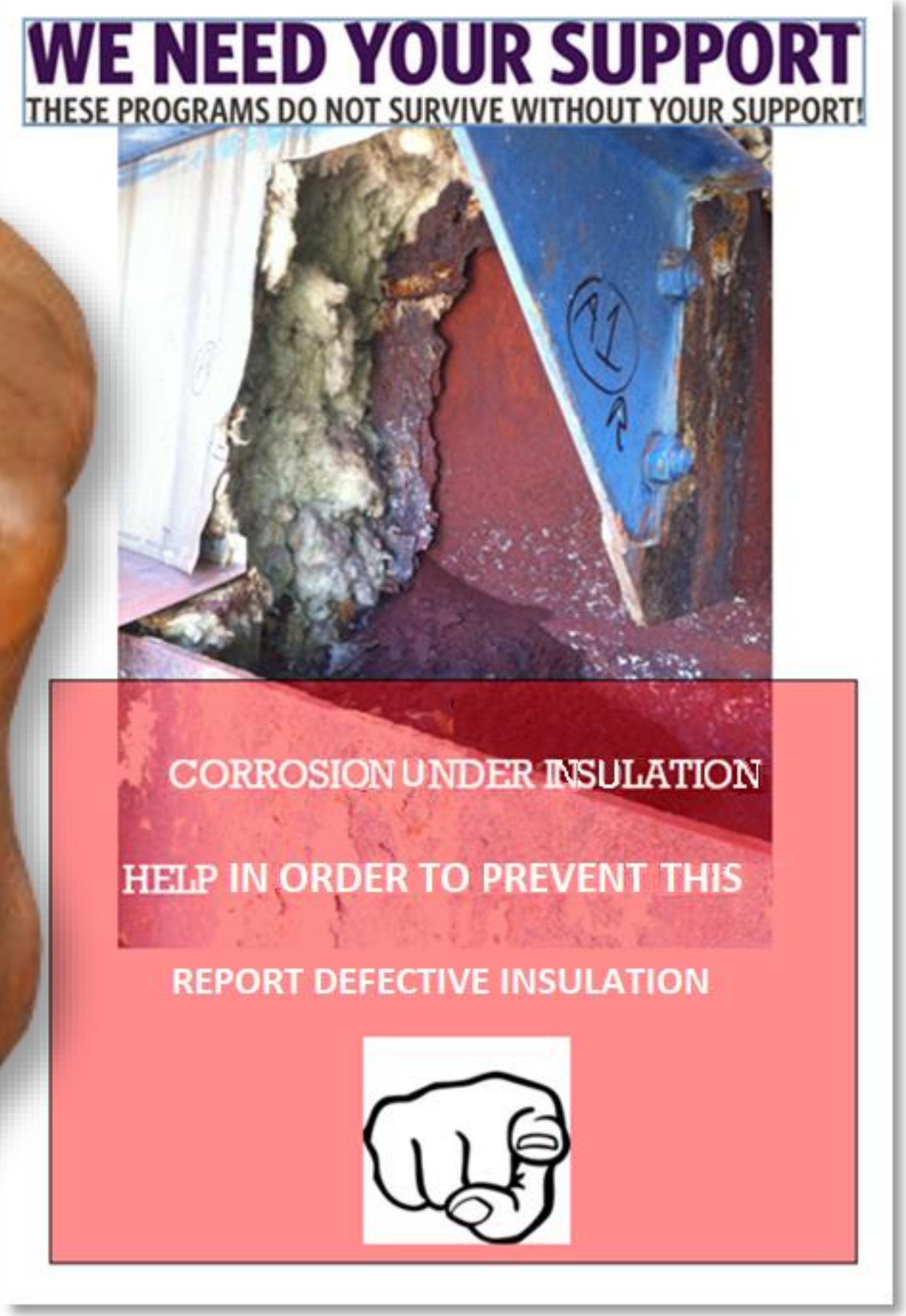
It's a joint effort!



Track the involvement!

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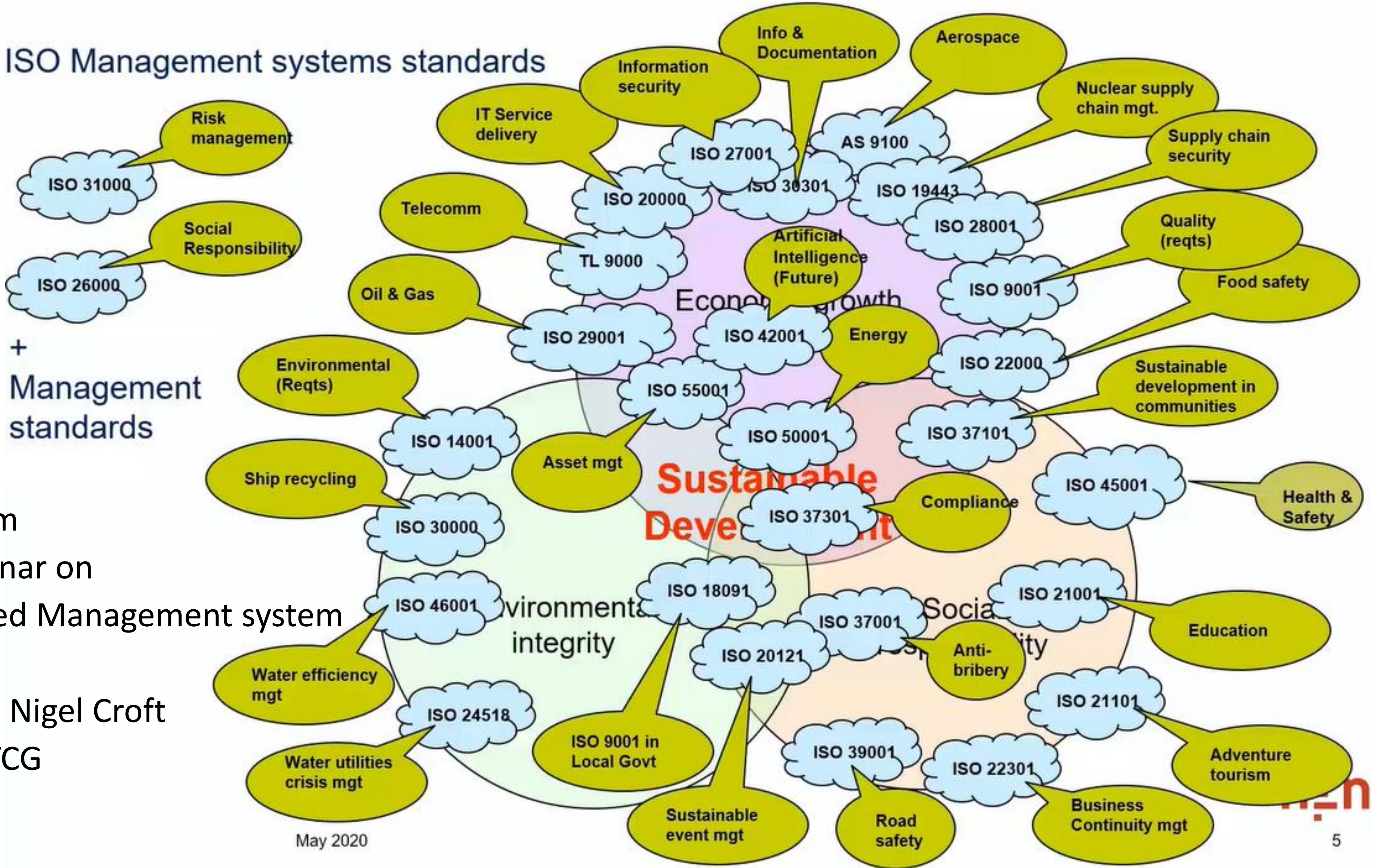

Image from
NEN Webinar on
Harmonized Management system

Section by Nigel Croft
Chair of JTCG

Appendix 9

Phencote protective coating for heat exchanger tubes protection from corrosion and fouling

(Lorenzo Comel)

30.03.2023 EFC WP15 "Corrosion in refinery and petrochemistry" spring meeting

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Lorenzo Comel, Process Engineer
NACE lev. 2 Coating Inspector

Alessandro Vanacore, Project manager
3rd Lev. ISO 9712 VT-PT-MT-UT-PAUT-ET-AE-LT;
2nd Lev. ISO 9712 RE,ME,TT.

GMA COMPANY

G.M.A. is specialized in customized solutions used to restore original properties of industrial pressure equipment and optimize their performances.

The company has over 30 years of international experience in thermal power plants, oil refineries and petrochemical plants.

The R&D Department carries out a wide range of technical & chemicals tests for our clients in order to continuously improve and innovate our products and technique

The quality management system of G.M.A. is ISO 9001 certified.

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OUR MAIN CLIENTS

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EDISON
Electrabel
GDF SUEZ
Enel
burgo
DAIKIN
eni
power
PROKON
EKON GROUP
FINCANTIERI
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TRANE
SOLVAY
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ALSTOM

30.03.2023 EFC WP15 "Corrosion in refinery and petrochemistry" spring meeting

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Phencote protective coating patented family from GMA for heat exchanger internal tubes protection from corrosion and fouling

Lorenzo Comel, Process Engineer
NACE lev. 2 Coating Inspector

Alessandro Vanacore, Project manager
3rd Lev. ISO 9712 VT-PT-MT-UT-PAUT-ET-AE-LT;
2nd Lev. ISO 9712 RE,ME,TT.

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INTRODUCTION

Heat exchangers and pressure vessels are some of the most important equipment in refineries, petrochemical and power generation plants. These are critical parts, and their correct operation is strictly related to the reliability and efficiency of the complete production process.
The anticorrosion resin systems used by G.M.A. allow to optimize the materials used and to correct and restore corrosion problems that may occur during their operation, such as galvanic and bimetallic corrosion, erosion, over velocity and cavitation.

COMPANY AND SERVICES

Possible solutions (covered by international patents and tested with decades of experience on the field) include the high thickness coating of condensers tube sheets, the full-length internal lining of tube bundles using epoxy and phenolic resins, the protection and strengthening with high performance materials of internal surfaces of water boxes and process piping.

SERVICES

- NDT tests for HEX using APR acoustic technology
- Hydro-mechanical and high pressure tube cleaning for condensers
- Tube ends coating
- Anticorrosion coating for tube sheets
- Full length internal tube protection for condensers and HEX
- Anticorrosion coating for different components, including carbon fiber strengthening of piping and vessels
- Coating and tanks, vessels, water boxes etc.

CORROSION IN HEAT EXCHANGERS AND CONDENSERS

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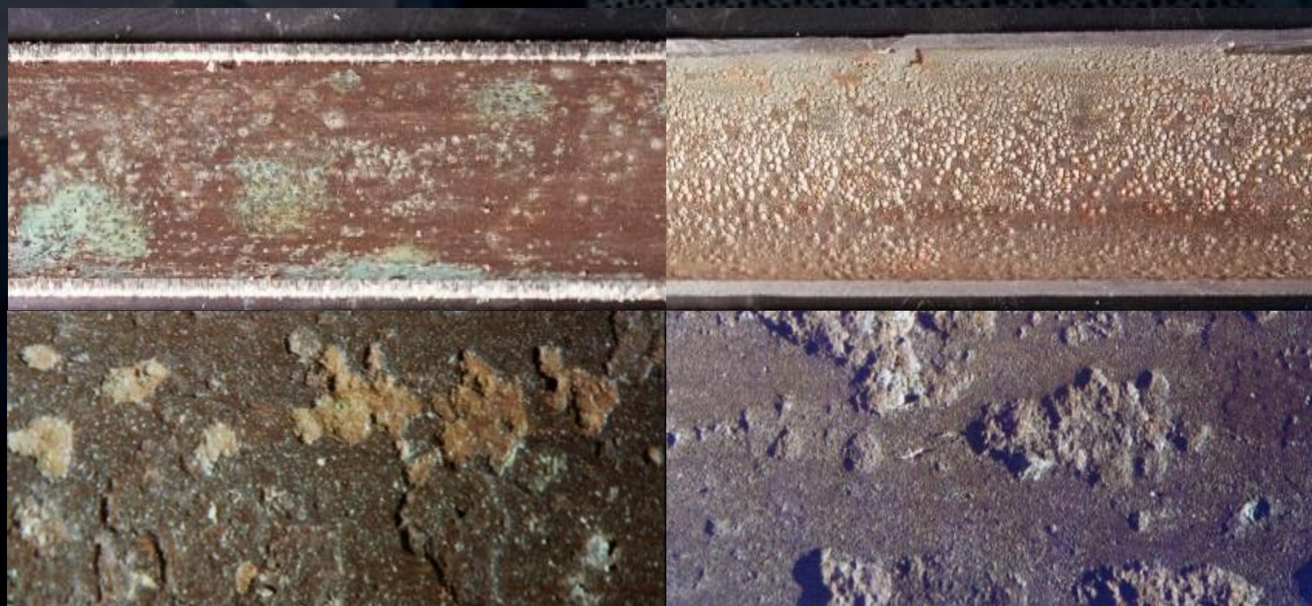
CORROSION THEORY

Heat exchangers are continuously exposed, from the refrigerant side, to a dirty and aggressive environment (chlorides, sulphides, sand and mud), and are particularly susceptible to corrosion and erosion of the tubes. Fouling increases resistance to thermal exchange, decreasing the performance of the equipment and triggering corrosive processes under deposit.



Corrosion in a tube of 70/30 Cu-Ni after three years of exercise in brackish water, with evidence of pitting filled with corrosion products

CORROSION THEORY

Uncontrolled corrosion causes loss of thickness, structural weakness, and damages to tubes with holes. In addition, copper alloy tubes are also subject to erosion. This is caused by a turbulent flow, which can be caused by overflow due to excessive velocities, or by foreign bodies blocked inside the tubes.

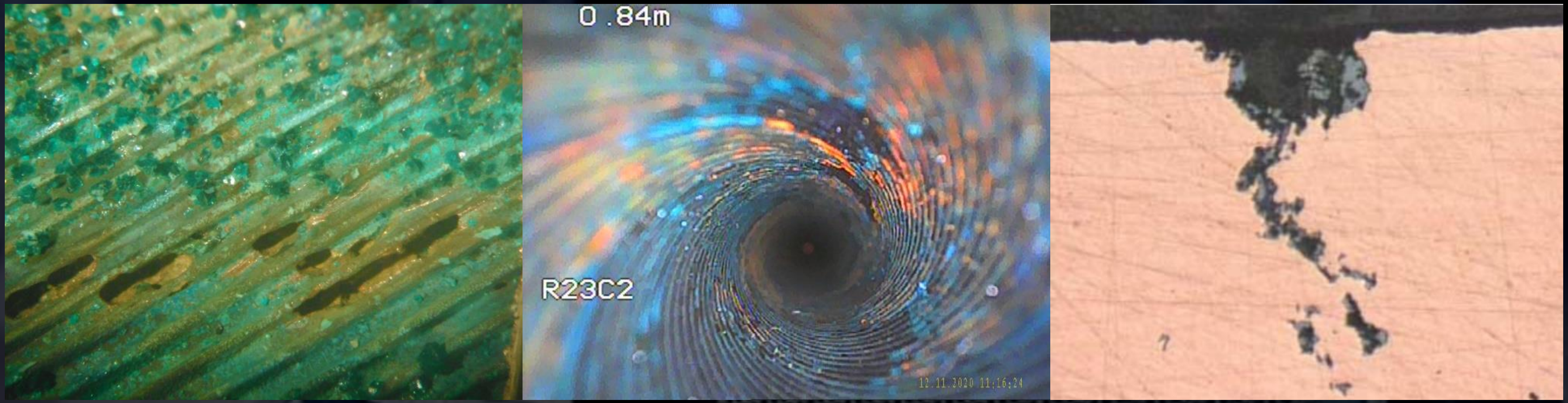
Left, hole caused by the presence of a barnacle in a Cu / Ni condenser tube; right, severe erosion / corrosion in a brass tube

CORROSION THEORY

Turbulence phenomena at the tube outlet on Al-brass and Cu-Ni

Over velocity erosion in copper tube due to presence of foreign materials

CORROSION THEORY



Localised corrosion (probably ant-nest) in copper tubes of chillers

Erosion in Cu-Ni tubes due to presence of sand

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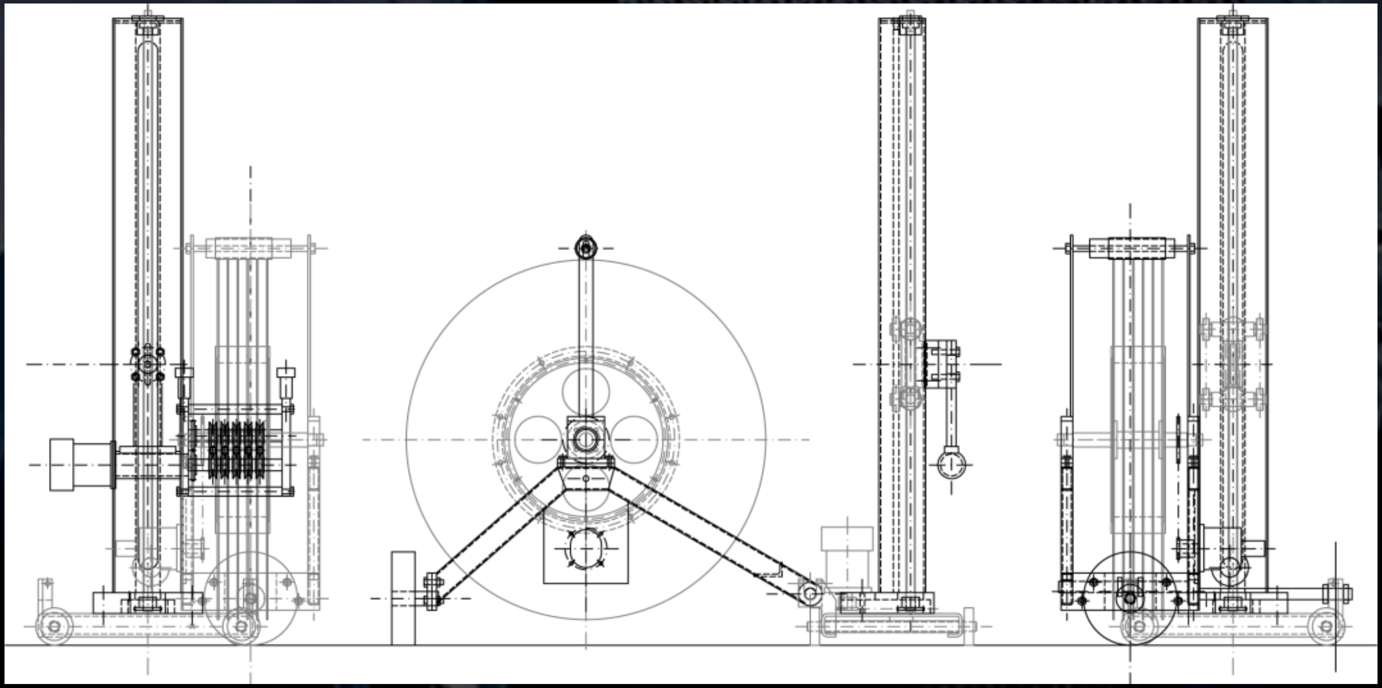
CORROSION THEORY

Corrosion due to interaction between metals with different potentials

Interaction between bundle in titanium and chambers in carbon steel

COATING TECHNOLOGY



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INTERNAL TUBES COATING

Phencote is a fast and durable solution to any internal tube surface problem; it prevents damage caused by fouling, corrosion, erosion and cavitation

Suitable for immersion in all kind of water services

Operating temperatures up to 100°C (epoxy resin Phencote HR60TL) or 180°C (phenolic resins Phencote 11 and 19DR)

Compact machinery for easier accessibility through manholes

Internal tube diameter starting from 13 mm and tube length up to 25 m

Time of application: within duration of a normal maintenance outage

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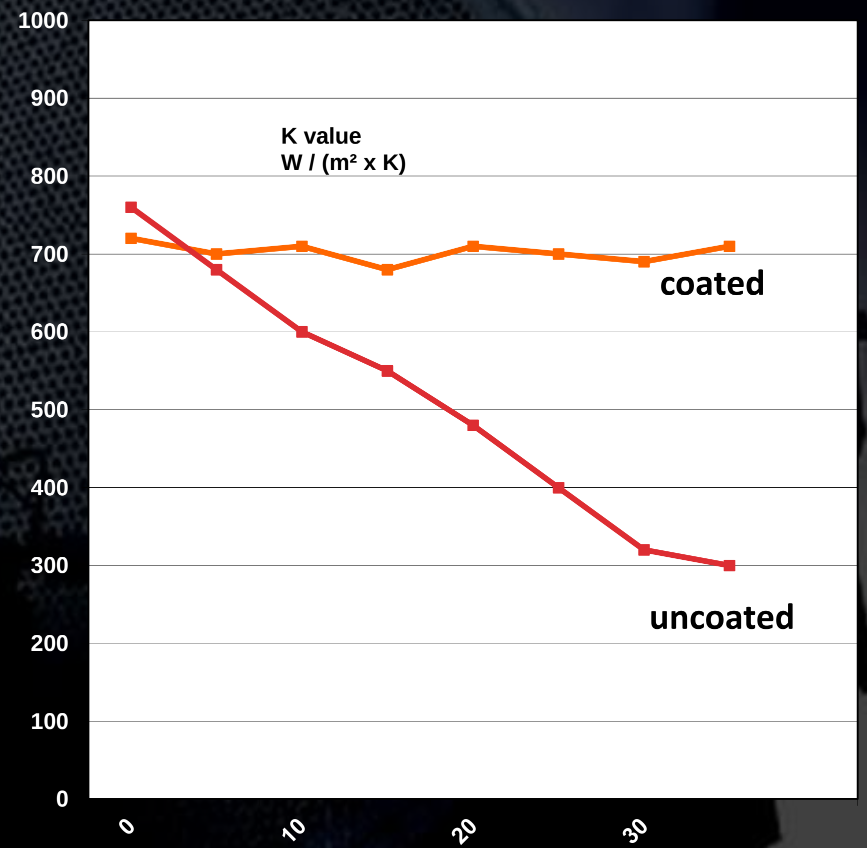
INTERNAL TUBES COATING: THERMAL EXCHANGE

Studies and tests have shown that the overall medium-term effect of the Phencote coating is positive for heat exchange.

G.M.A. carried out in-plant test campaigns to compare the performance of an uncoated and coated heat exchanger; the data deriving from the experimentation were then processed by the engineers of the University of Trieste.

Experience has resulted in a reduction in heat exchange of about 2% due to the presence of the coating.



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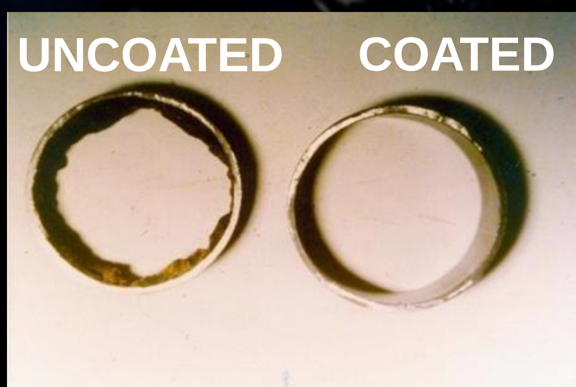
INTERNAL TUBES COATING: THERMAL EXCHANGE

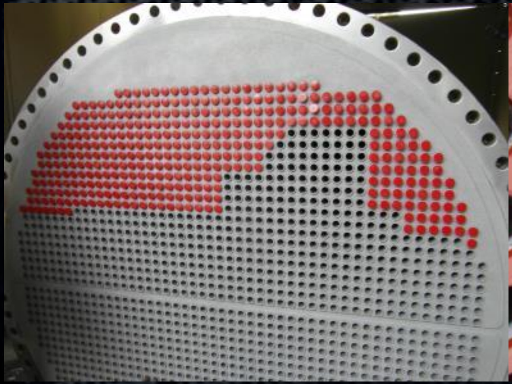
We should also consider that after 6-12 months, the overall effect due to the presence of the lining is positive, as the coating itself makes more difficult the adhesion of debris and fouling, reducing the need to perform costly outages for cleaning activities (images after 2 years of service)

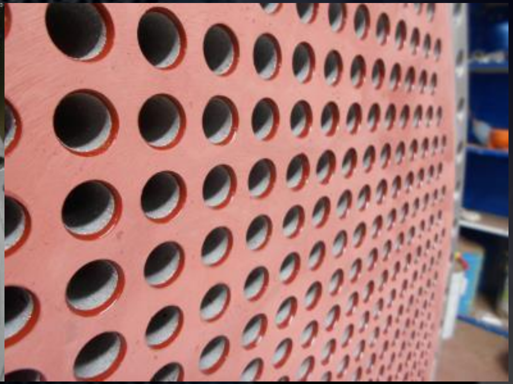


EXPERIENCE ABOUT ANTI-FOULING PROPERTIES

A complete anticorrosion coating has been applied on 10 big bundles for a Lybian refinery owned by an important Italian group.

High thickness coating of tube sheets in order to protect tube rollings





Application of 200 micron of Phencote HR60TL at full length of tubes

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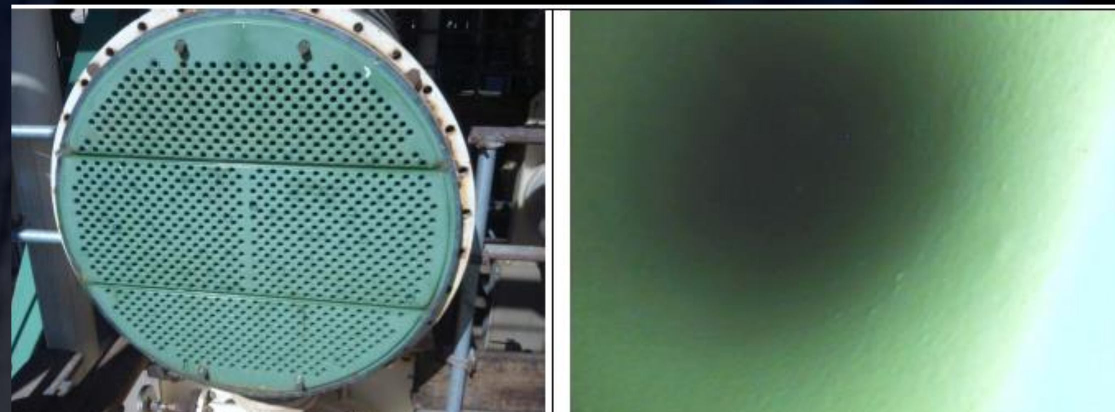
An official inspection report has been issued from the client after 4 years of operation, comparing the behavior of the coated bundles with others uncoated working in the same conditions.



Coated

Uncoated

The coated bundles shows optimal conditions of resins with no fouling, while the uncoated ones reveal massive corrosion and deposits

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TUBE SHEET HIGH THICKNESS COATING

- Application of a 3-5 mm thick Phencote 2000 T.S. resin
- Restores damaged tube sheets and blocks corrosion
- Electrical insulation of the plate
- Optimized tube inlet profile to reduce cavitation
- Ideal completion of the tube ends lining system

CERTIFIED QUALITY

The inspectors have earned the following international certifications

- Coating inspector INAC (Italian association for anticorrosion)
- Coating inspector NACE (National association of corrosion engineering)
- FROSIO coating inspector
- NDT technician according to ISO9712 method VT

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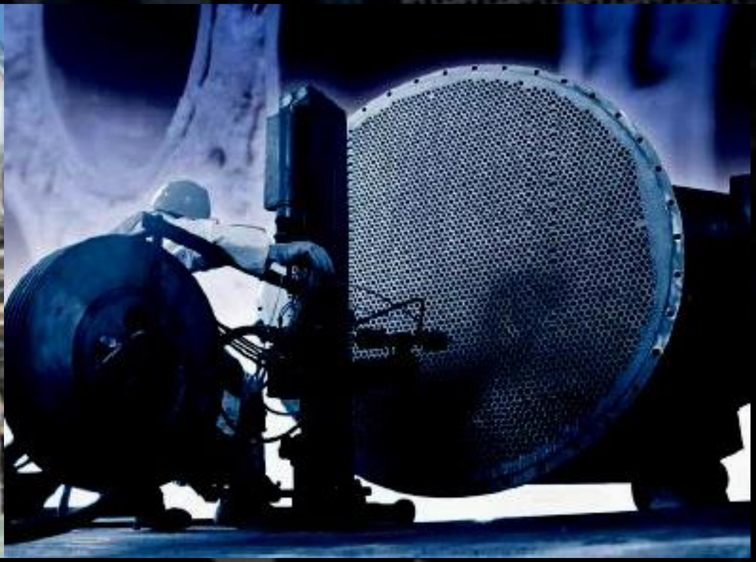
CONDENSERS AND HEAT EXCHANGERS: CASE STUDIES

PREVENTIVE MAINTENANCE



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The plant shutdown due to unforeseen corrosive problems during its operation is a serious problem, feared by maintenance technicians, as it often results in serious production and economic losses, and involves safety issues.

G.M.A believes that early diagnosis of possible problems is the correct approach to optimize the operation of the plants and to prevent the occurrence of malfunctions and failures.

During his experience, G.M.A. has allowed the client to prove the benefits of this philosophy, accompanying it from the diagnosis of the (existing or potential) issues, the proposal for their resolution, the implementation of the intervention, and the maintenance of the measures implemented over time.

In the next slides we will present some situations where this approach has been rewarding for the customer, analyzing the technologies used in the different cases.

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AIR COOLERS FOR COMPRESSORS

An anticorrosion lining can be a solution to increase corrosion resistance and reduce fouling adhesion, resulting in an optimization of costs and efficiency:

- **Full length internal lining @ 100 microns**

Cleaning and surface preparation by abrasive blasting

Application of 3 layers of Phencote resin on internal surfaces of tubes

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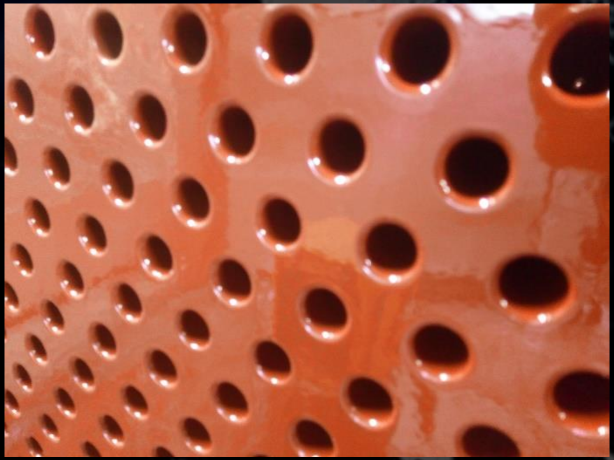
AIR COOLERS FOR COMPRESSORS

Final NDT and inspection, including endoscope analysis, porosity check and thickness detection



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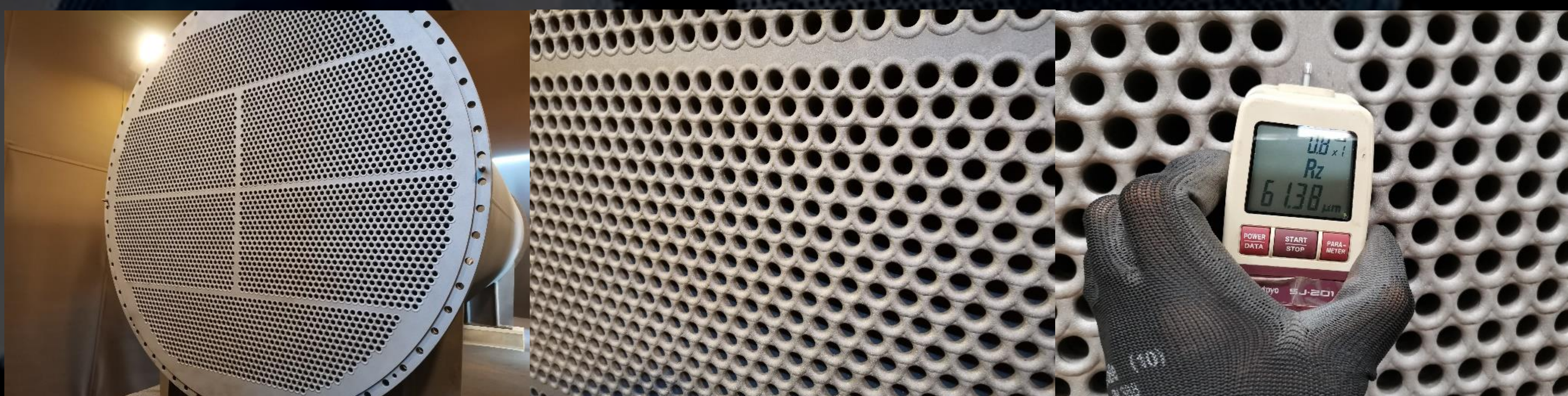
HEAT EXCHANGERS FOR SEA WATER APPLICATION

In order to allow the use of less expensive materials in aggressive environment, internal lining of heat exchanger is a common approach in Italian petrochemical plants

- **Carbon steel tubes with 200 microns internal lining of epoxy/phenolic resin**

Cleaning and surface preparation by abrasive blasting



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HEAT EXCHANGERS FOR SEA WATER APPLICATION

Internal application with air-mix system of 180 microns of Phencote thermosetting resin; intermediate heating and final curing in the oven

Final tests, including thickness, 100% pinholes and video inspection

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If it is too late to implement a predictive approach and issues related to poor design and / or severe working conditions have already caused damages, it is possible to propose solutions to solve the problems and extend the life of equipment

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REFINERY

Steam condenser with tubes in brass and tube sheets in carbon steel: massive corrosion at tube sheets, support plates…

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REFINERY

High pressure cleaning and abrasive blasting of bundle and chambers with steel grit at SA2,5 standard
NDT vacuum test

REFINERY

Reprofiling of tube sheets with high resistance epoxy mastic
Temporary plastic plugs installation
Phencote primer resin application by airless spraying
Trowel application of Phencote 2000 high thickness epoxy resin

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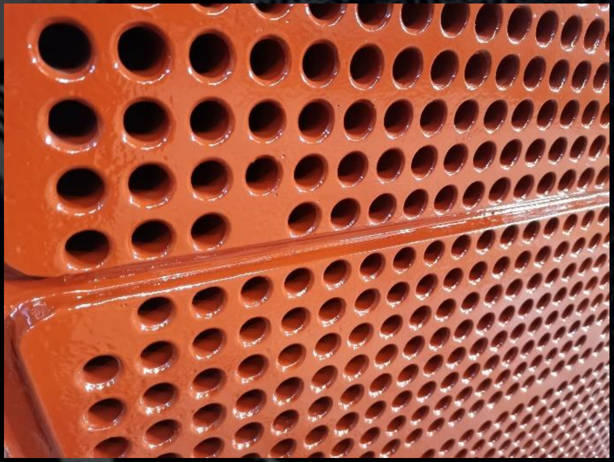
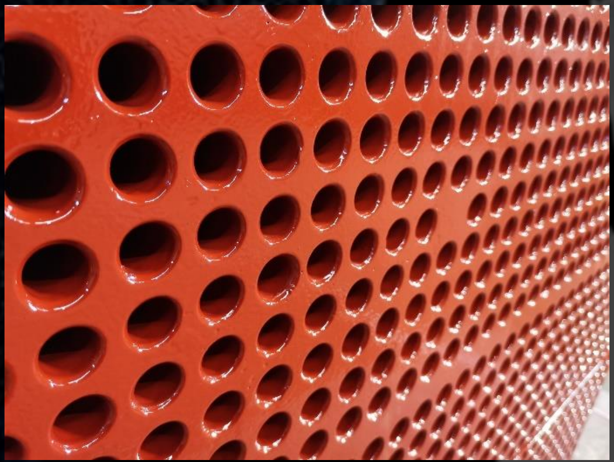
REFINERY

Grinding of tube sheets and removal of plugs
Application of 200 microns of Phencote HR60TL at tube ends (250 mm)





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REFINERY

Reprofiling of water chambers with epoxy mastic
Application of 800 microns of Phencote HR60 resin



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REFINERY

One way condenser

756 rolled tubes

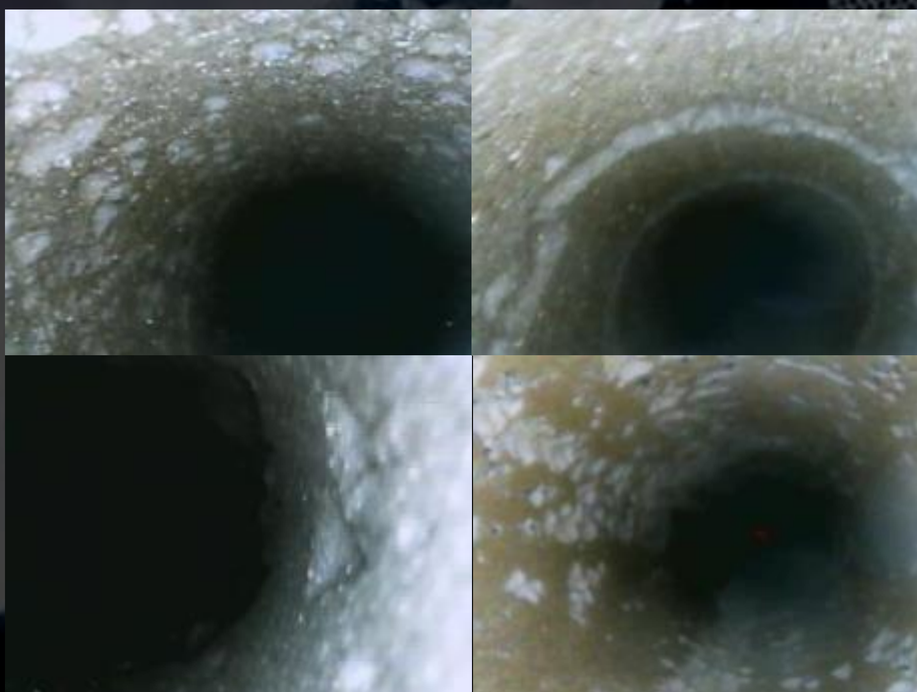
Temperature (S/T): 120/80° C

Tubes material ASTM B111

The preliminary inspection shows erosion problems due to over velocity, together with pit phenomena within the pipes. There are also problems at tubes expansion and the condenser is also affected by massive fouling

REFINERY

Non-destructive control of the 100% tube bundle with acoustic technique combined with endoscopy to exclude serious defects in the pipes and evaluate the preventive plugging



The control highlights the presence of numerous erosive and corrosive defects: a complete restoration treatment with Phencote resins appears to be the ideal solution to stop corrosive phenomena in progress and prolong the useful life of the condenser

REFINERY

Gritblasting to Sa 2 ½ standard tube sheets and inner tubes and inspection of the results achieved (endoscopy, roughness, visual appearance)

Phencote 2000 high thickness coating on tube sheets

REFINERY

Application of two layers of Phencote HR60 T.L. resins at tube ends using air-mix gun with special radial nozzles and extension

Application with semi-automatic machine of 2 layers of Phencote HR60TL on full length of tubes

Final checks: 180 micron thickness on tube ends and 80 micron inside the tubes: work completed in 8 days

DISCUSSION

www.gma-tech.com

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THANKS FOR YOUR ATTENTION

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GMA

PERFORMING SOLUTIONS

Appendix 10

HVTS solution to upgrade existing metallurgy to higher alloys against corrosion and/or erosion

(Ghalem Roguieg)


SURFACE TECHNOLOGY SOLUTIONS FOR MISSION CRITICAL EQUIPMENT
Integrated Global Services (IGS)
igs
www.integratedglobal.com

Presentation Contents

IGS at a Glance

35+ Years
Experience

300+
Employees

$100+ Million
Turnover

8/10 Top Oil and Gas Companies
are our Clients

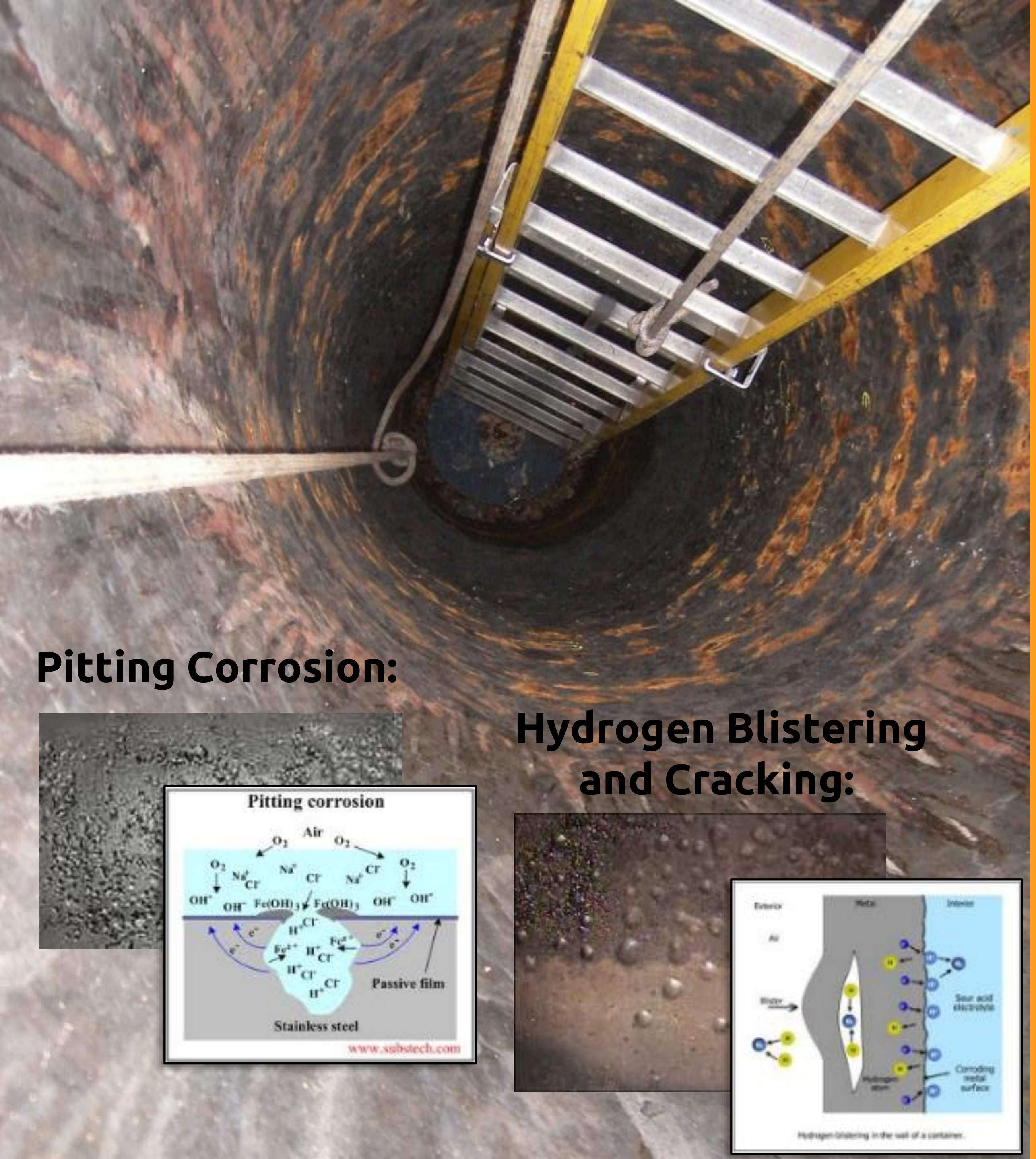
6000
Projects

1500+
Vessels

About IGS

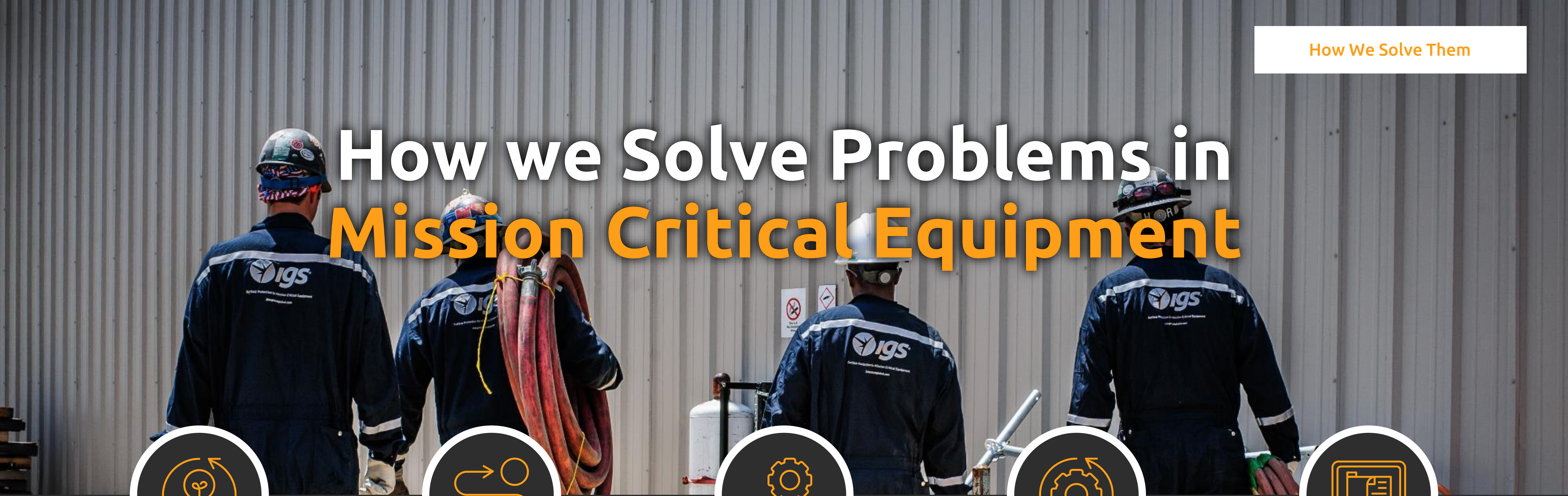
Strong Global References

- Amine and Caustic Units
- Separators
- KO Drums
- Heat Exchangers & Piping
- Other Mission Critical Equipment



GENERAL DAMAGE MECHANISMS WE ENCOUNTER

- AMINE CORROSION
- CAUSTIC CORROSION
- CO_2 CORROSION
- GENERAL CORROSION & PITTING
- CORROSION UNDER INSULATION (CUI)
- ATMOSPHERIC CORROSION
- FLUE GAS DEW POINT CORROSION
- GALVANIC CORROSION
- H_2S CORROSION
- HEAT AFFECTED ZONE CORROSION
- MICROBIOLOGICALLY INFLUENCED CORROSION (MIC)
- ENVIRONMENTAL CORROSION
- METAL DUSTING
- SOUR WATER CORROSION (ACIDIC)
- SULFURIC ACID CORROSION
- CARBURIZATION/DECARBURIZATION
- FUEL ASH CORROSION
- OXIDATION
- SULFIDATION
- NAPHTHENIC ACID CORROSION (NAC)
- STRESS CORROSION CRACKING
- DELIQUESCENT CORROSION
- CORROSION FATIGUE WET H_2S DAMAGE (BLISTERING/HIC/ SOHIC/ SCC)
- SULFIDE STRESS CRACKING



How we Solve Problems in Mission Critical Equipment

1. Understand the problem
2. Specify a solution
3. Select a material
4. Turnkey application
5. Report

an IGS Solution

HVTS

- High Velocity Thermal Spray
- Robust Corrosion and Erosion Alloy Cladding
- Applied Turnkey in Situ
- Adopted by Major Refineries and Chemical Plants Globally

CASE STUDY 1

Refinery Avoided Column Replacement

Est Life Cycle Cost Saving - $7.95M

(inspected in 2014 and 2018)

aramco

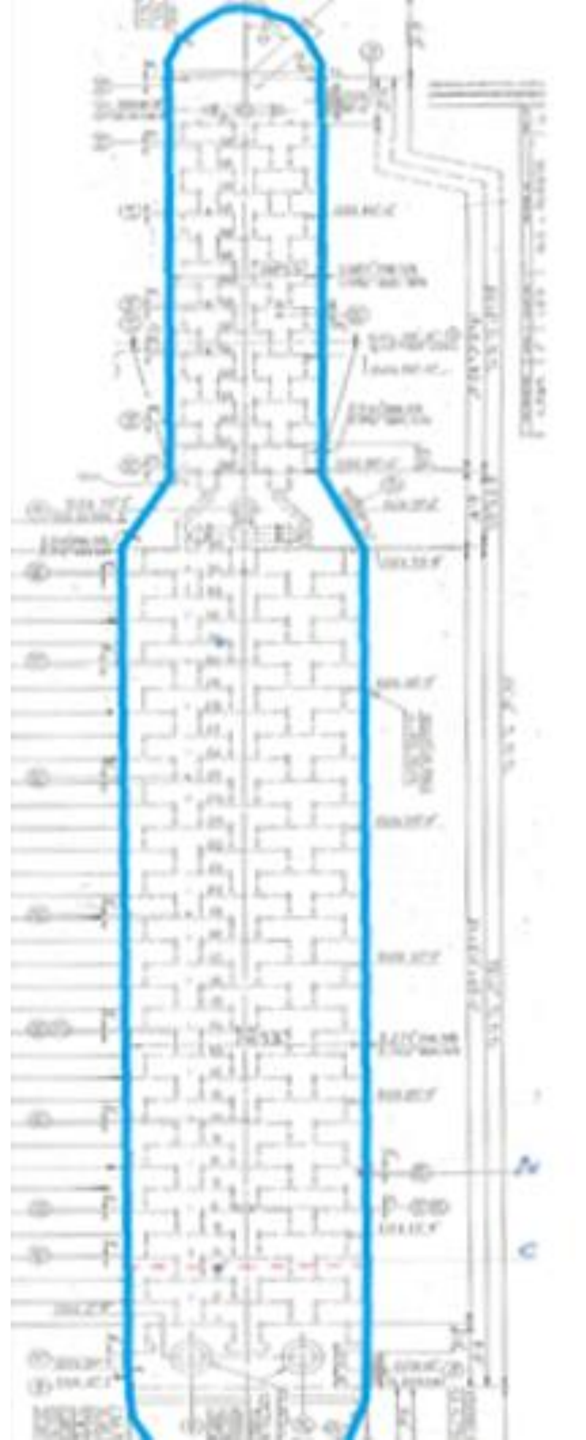
Case Studies

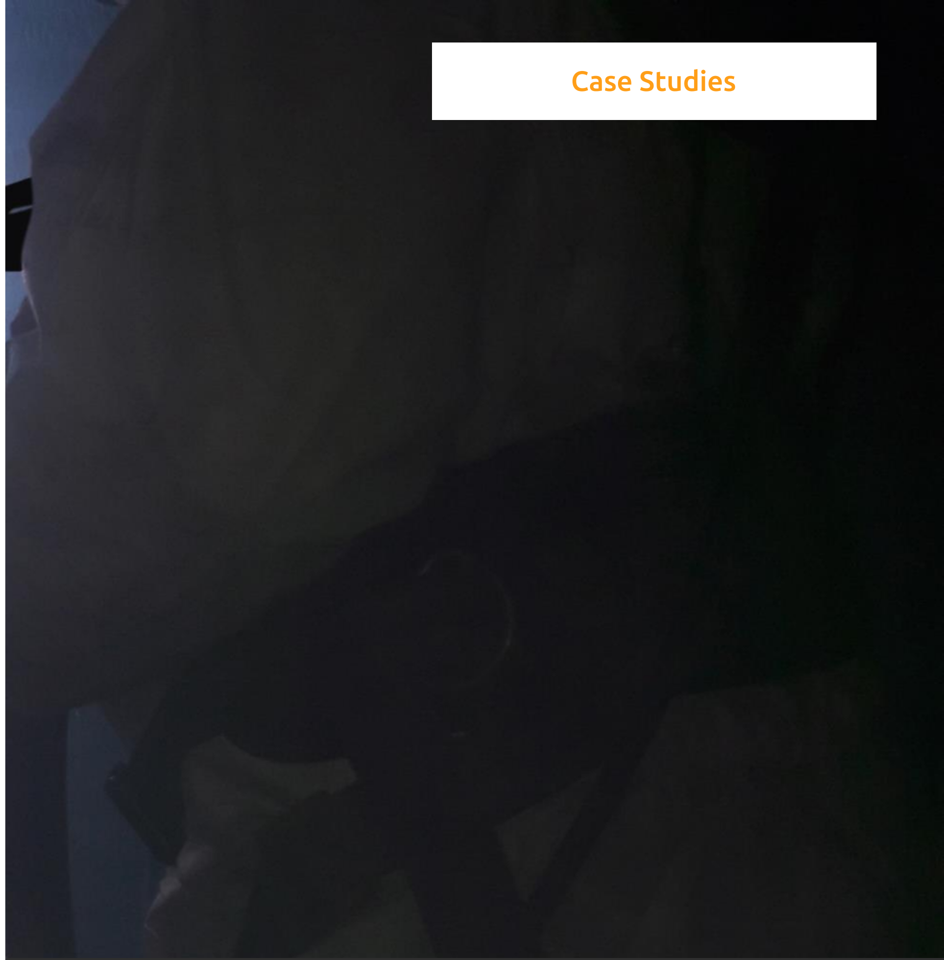
De-Ethanizer Column

SUFFERING FROM HIC

Built in 1975, suffering from Sulphide Stress Cracking (SCC) of repair welds applied in 2004 (poor initial PWHT).

- Internal corrosion activity generating atomic Hydrogen and embrittled steel beginning to crack due to Hydrogen Induced Cracking (HIC).





HVTS Project

STRESS RELIEVING NOT VIABLE

Existing hydrogen blisters could extend to form stepwise cracking and the column would have to be removed and laid down horizontally to conduct stage wise repairs

- Once cracks had been excavated and repaired, internal cladding with HVTS of all pressure bearing surfaces and welds was applied to protect the surfaces from further degradation.

Flow Splitter Vessels 2022

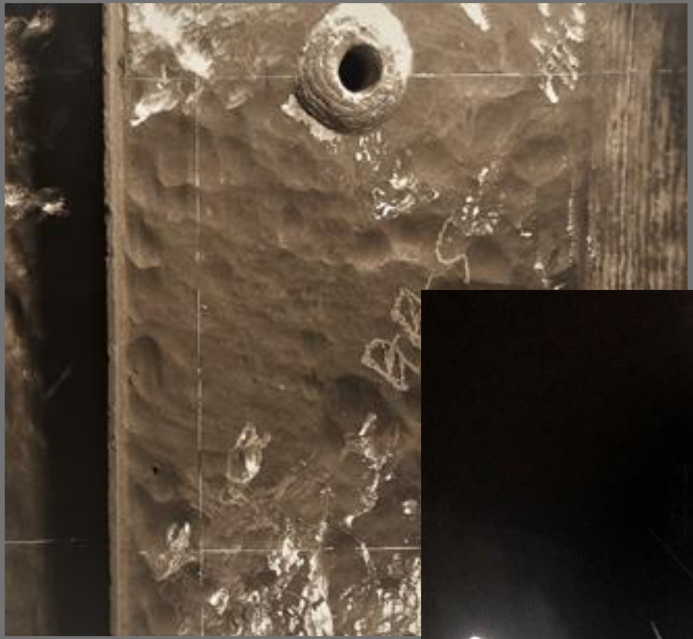
Flow Splitter Vessels

Scope of Work

IGS HVTS applied to Bottom Half of Vessel - 180 Deg from 3 O'clock to 9 O'clock and to identified 17 nozzles.

The initial condition of the internal surface of the vessel was severely corroded and pitted, showing signs of metal loss due to an erosion corrosion mechanism.

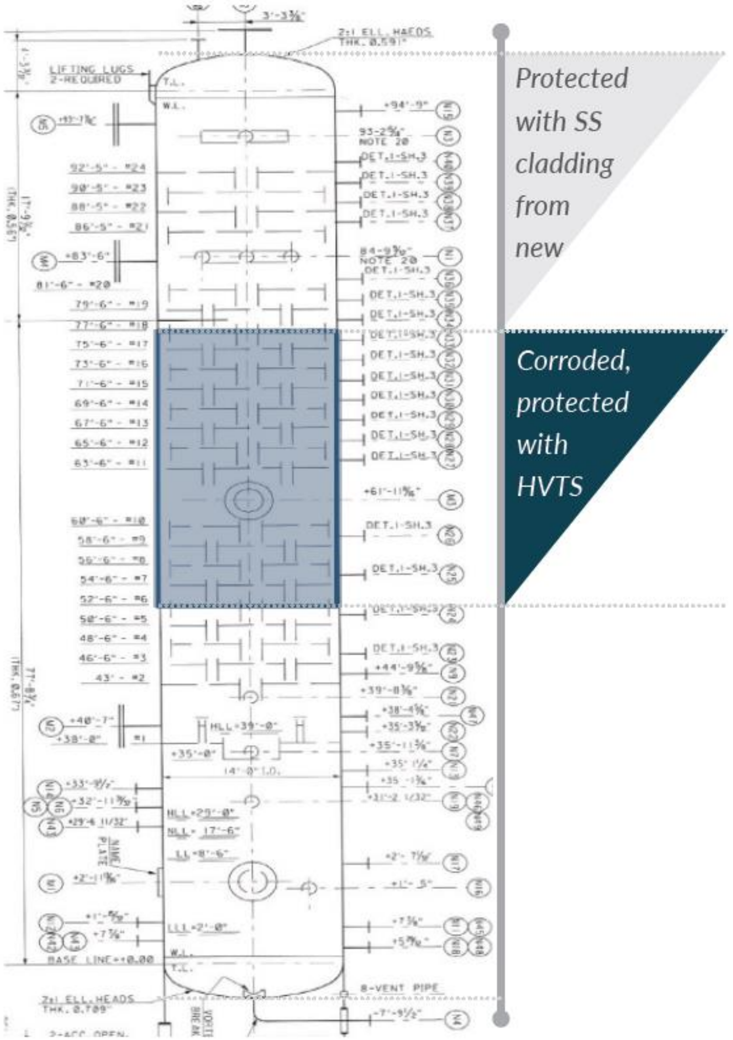
Surface prepared through weld buildup and grinding.


DGA AMINE STRIPPER COLUMN - Localized Deep Pitting Corrosion

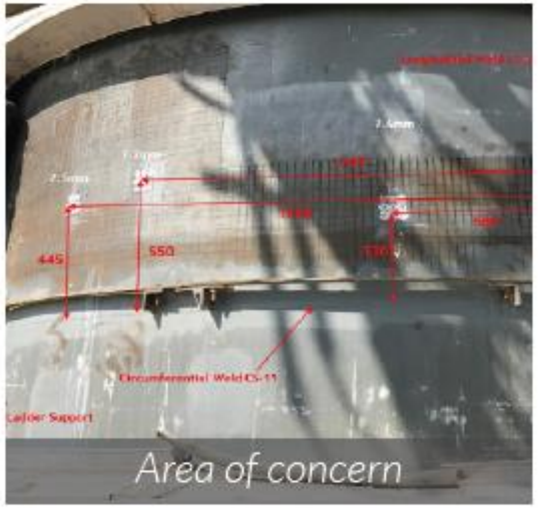
- Stopped critical column replacement or field weld overlay, PWHT and an extended T&I (2 to 3 week extension).
- HVTS TA impact – 1 week
- Amine column experiencing large scale corrosion, including deep pitting in the central section of the column, trays number 6 to 18, initial application in 2015/2016.
- Warranty provided through to next planned shutdown.

Scheduled external UT/NDT inspection in 2018 indicated wall thickness loss.



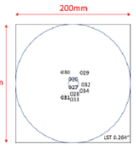
External inspection service prevented unplanned shutdown

IGS performed an external inspection to prove the integrity of the internal HVTS cladding and prevented the client from shutting down the unit. In 2020 IGS returned to extend HVTS to tray 1 and internally inspected the column to prove HVTS performance.



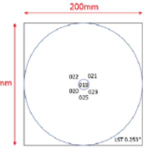
Area of concern

Area	Location	Signal	Readings			
B	026	CI	16	mils	406	um
B	027	CI	20	mils	508	um
B	028	CI	13	mils	330	um
B	029	CI	15	mils	381	um
B	030	UI	-			
B	031	CI	13	mils	330	um
B	032	CI	13	mils	330	um
B	033	CI	20	mils	508	um
B	034	CI	18	mils	457	um
B	Center	CI	0.264	inches	6.7	mm



Area A measurement

Area	Location	Signal	Readings			
A	019	CI	14	mils	356	um
A	020	CI	14	mils	356	um
A	021	CI	20	mils	508	um
A	022	CI	20	mils	508	um
A	023	CI	19	mils	483	um
A	024	CI	13	mils	330	um
A	025	CI	18	mils	457	um
A	Center	CI	0.253	inches	6.4	mm



Area D measurement

In 2018, scheduled external NDT/UT readings between trays 15 and 17 indicated a loss of shell thickness.

An emergency forced shutdown was considered to enable internal inspection to verify the IGS HVTS cladding integrity.

IGS Proprietary NDT Inspection Performed to verify the internal cladding integrity.

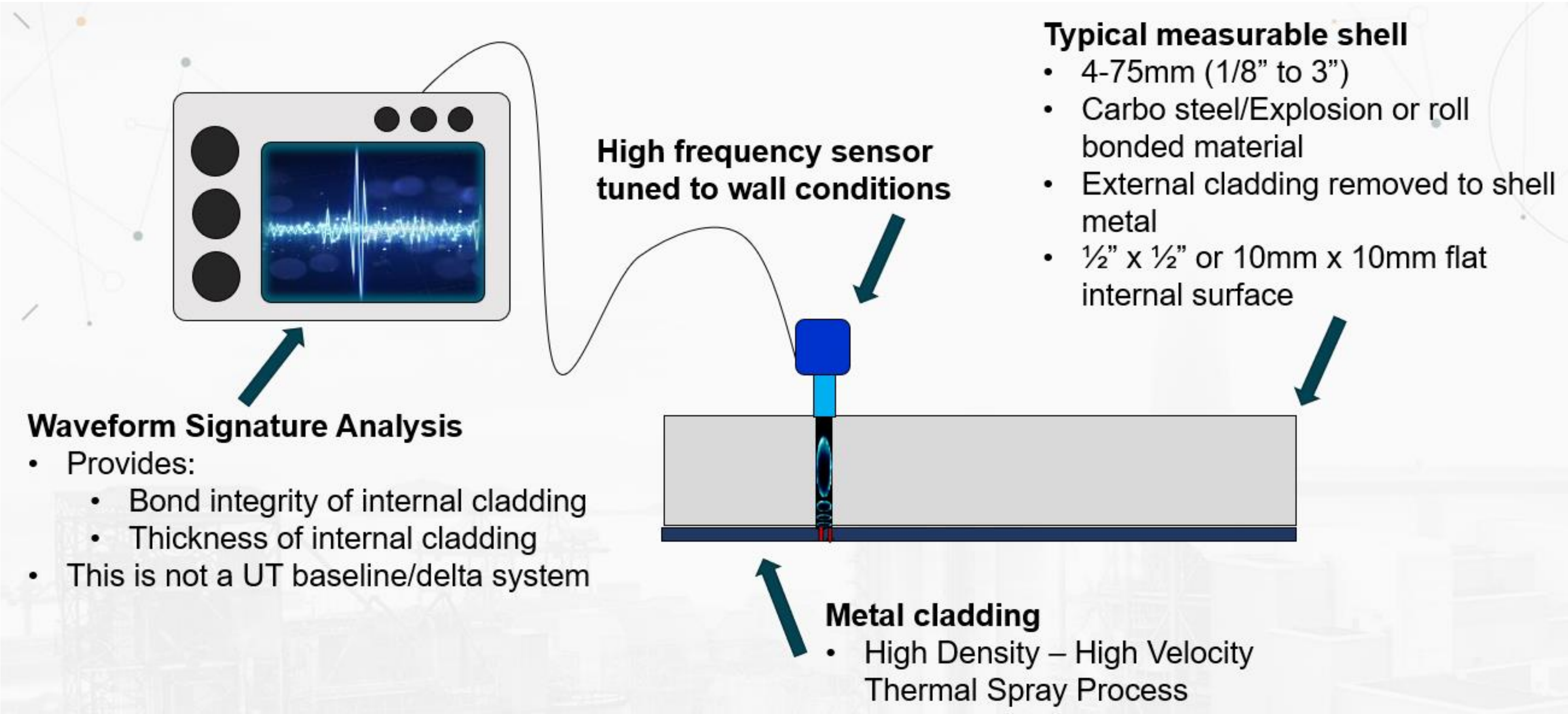
Asset owner cancelled the emergency shutdown, maintaining operation through to the 2020 planned turnaround.

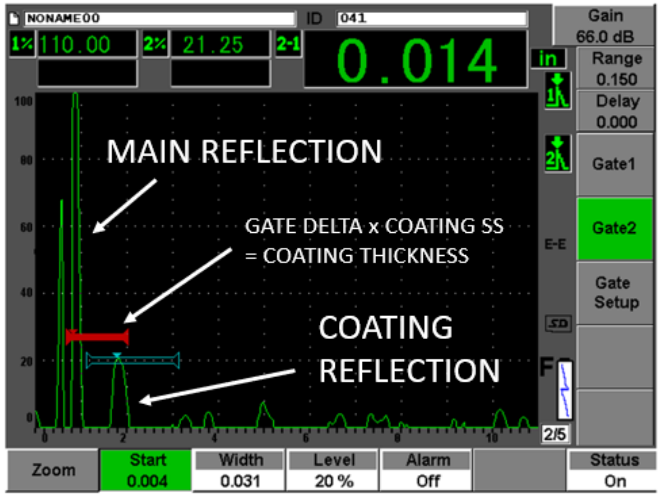

HVTS alloy cladding - tray 15

The internal inspection results in 2020 confirmed the findings of the external IGS inspection.

IGS | *www.integratedglobal.com*

Condition Monitoring:
On-Line Evaluation of IGS HVTS Cladding Integrity

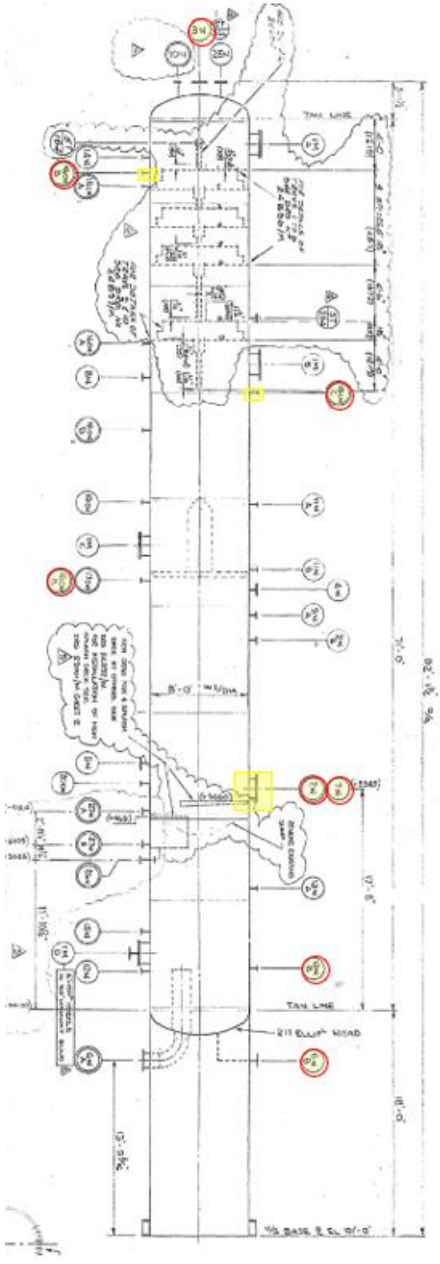




CASE STUDY 4

From Problem to Solution in 7 Days

Emergency Response



DELAYED COKER FRACTIONATION COLUMN

- The refinery in the United Kingdom identified localized corrosion in their delayed coker fractionation column during a planned turnaround.
- This vessel was built in the 1970s and had an internal type 400 stainless steel cladding installed from new.

WELDING?

- Upon initial inspection, refinery maintenance personnel planned to weld it up.
- Welding would create heat-affected zones, and it would not be possible to do post-weld heat treatment without putting too much heat into the local area, leading to further cracking of the existing internal cladding.
- They considered evaluating field weld overlay with a specialized weld overlay process. Still, due to the short-term notice of the discovery scope, it was not possible to consider setting this up in time without extending the critical path of the outage. They had an issue.

HVTS APPLICATION

- IGS (Integrated Global Services) had the equipment and materials in the country and was able to support the refinery with a fast application.
- HVTS was applied to seamlessly connect the alloy 625 overlay on the new insert and the existing type 400 cladding in the vessel by overlapping both CRA materials.
- All IGS safety and quality control procedures were followed, including monitoring the surface preparation, cleanliness profile, and taking thickness measurements of the HVTS during application.


About IGS
OUR PURPOSE AND VISION
Partner with our customers to solve challenging problems in mission critical equipment
Be the global source for reliable surface protection
igs
www.integratedglobal.com

How can we support your activities?

Appendix 11

Effect of temperature instability on Neslon curves

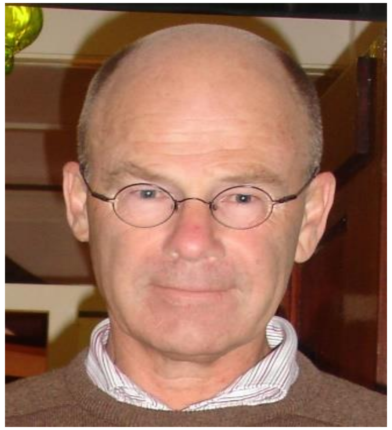
(Henke Helle)

Effect of temperature instability on Nelson curves

The Antero-Anacortes catastrophy reviewed

Henk Helle

Corrosion & Integrity Management Consultant



Experience Summary

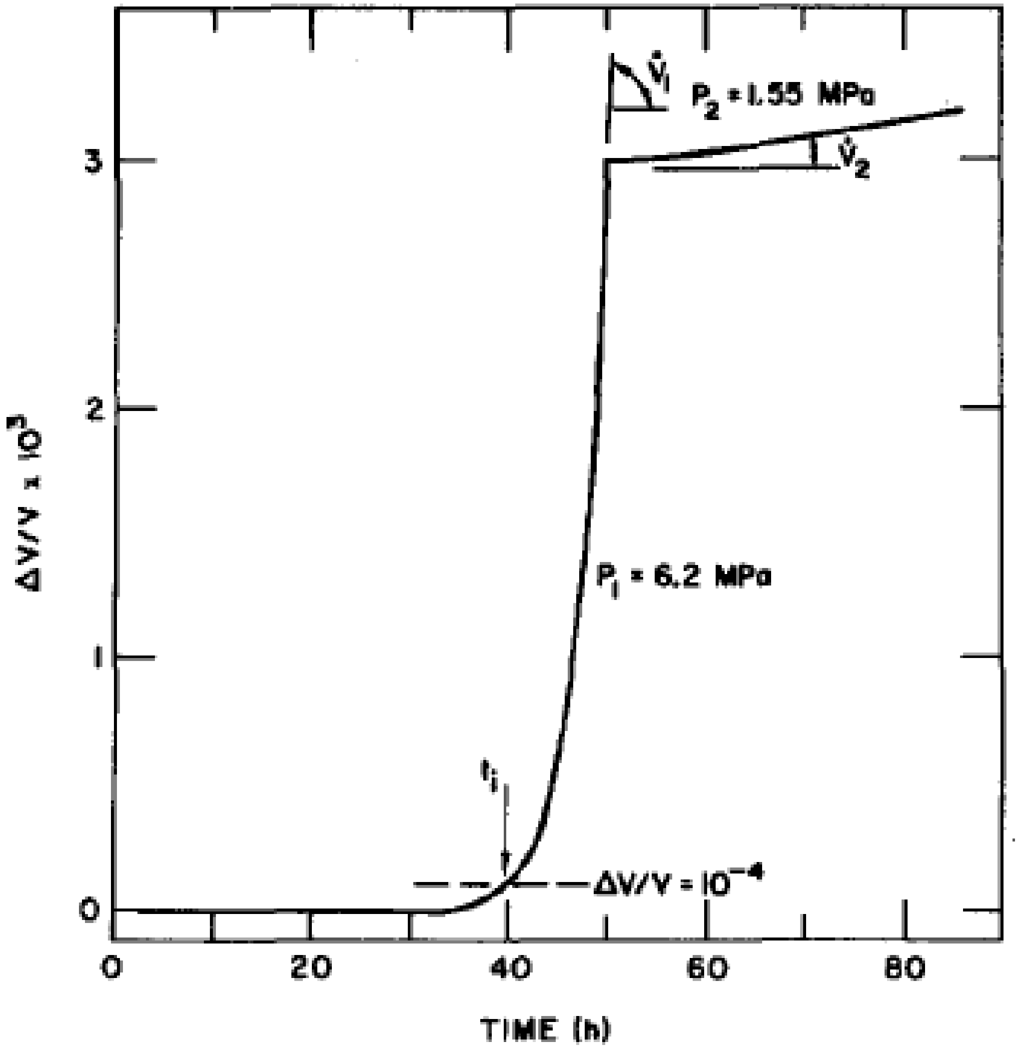
I spent over40 years in the field of material science, integrity management and corrosion, becoming a world-class technical expert in corrosion and integrity management in the Refining and Oil & Gas industry.

I publish from time to time on Refinery Corrosion and Integrity, Corrosion Control in Crude Units and Integrity Management in HF-Alkylation Units.

Credentials
Technical University Delft; Lips BV; Shell; CorrosionControl.Nu BV

Areas of Specialization
Corrosion phenomena's, Integrity Management, Risk-Based-Inspection, Corrosion Control in Crude Units, HF-Alkylation units, Asset Integrity Review's, Root Cause Investigation, Troubleshooting and Training

The nature of HT-hydrogen attack: incubation and void growth



Swelling as a function of time for a specimen exposed to hydrogen at 475°C. After ~50 H, the H_2 pressure was reduced from 6.2 to 1.55 MPa.

hydrogen solubility in steel

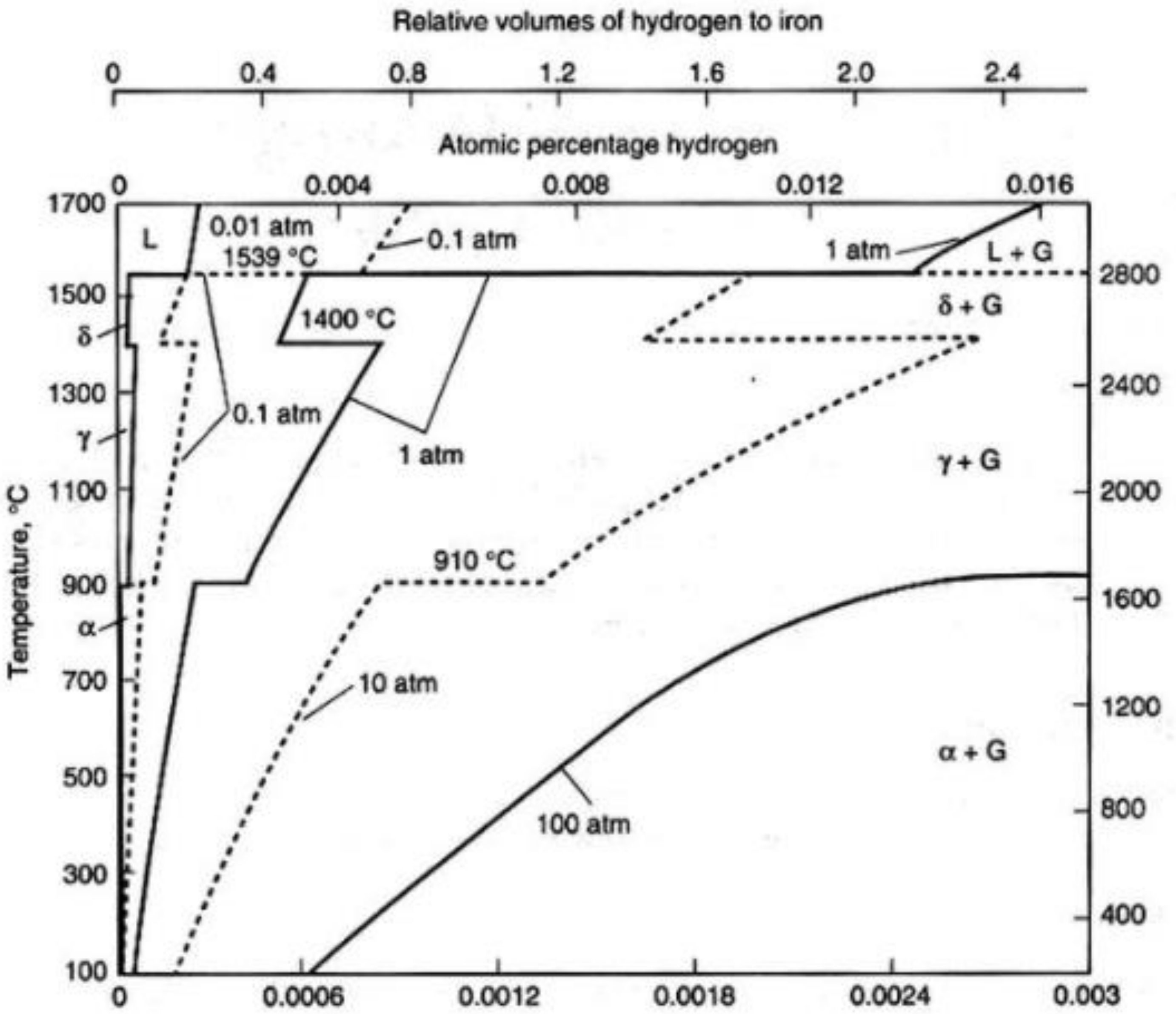
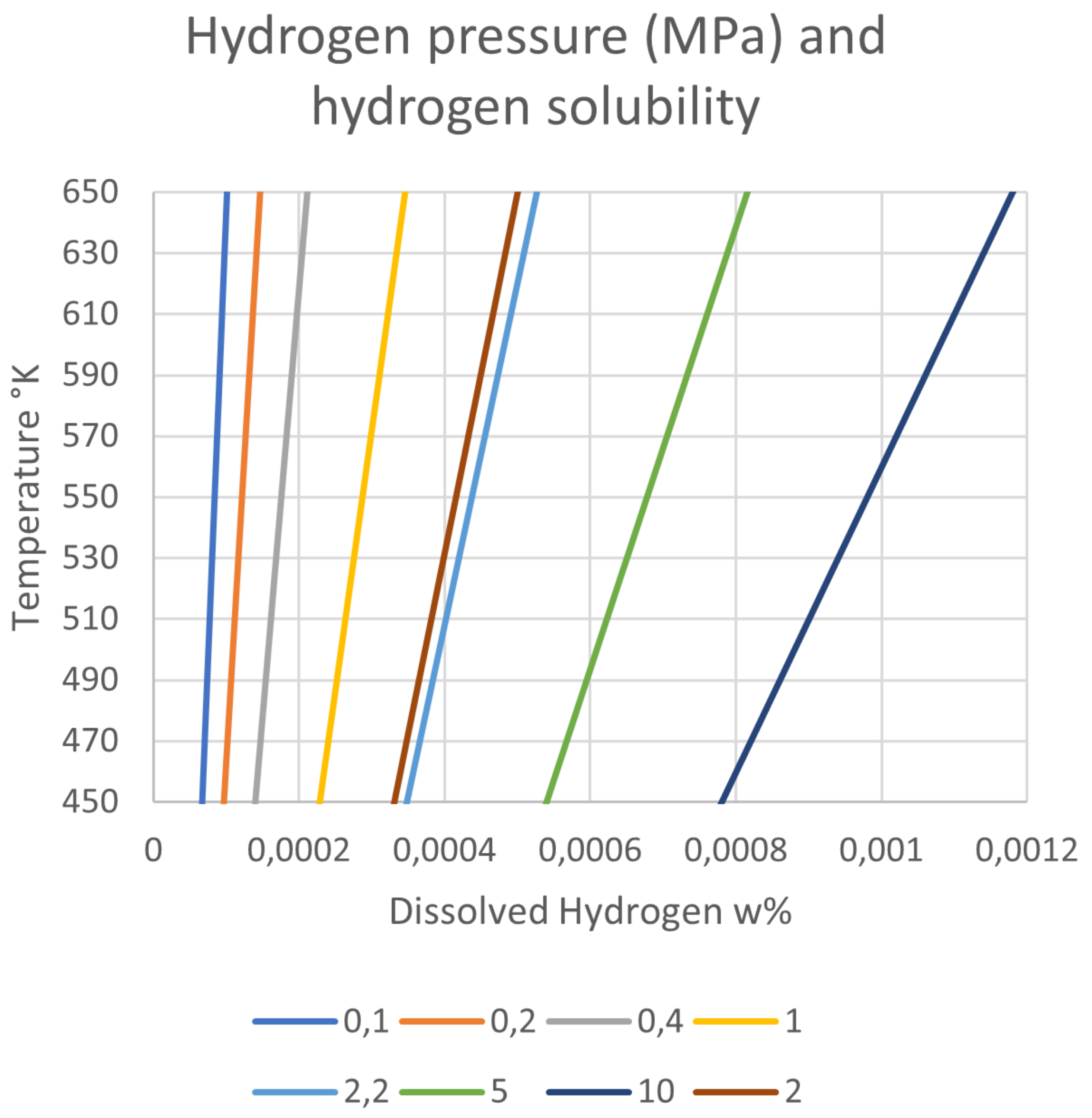


Figure 2: Dissolved hydrogen concentration (w%) in iron with temperature, hydrogen pressure and metal phase.

hydrogen solubility in ferritic steel and external H_2 pressure levels (Mpa)

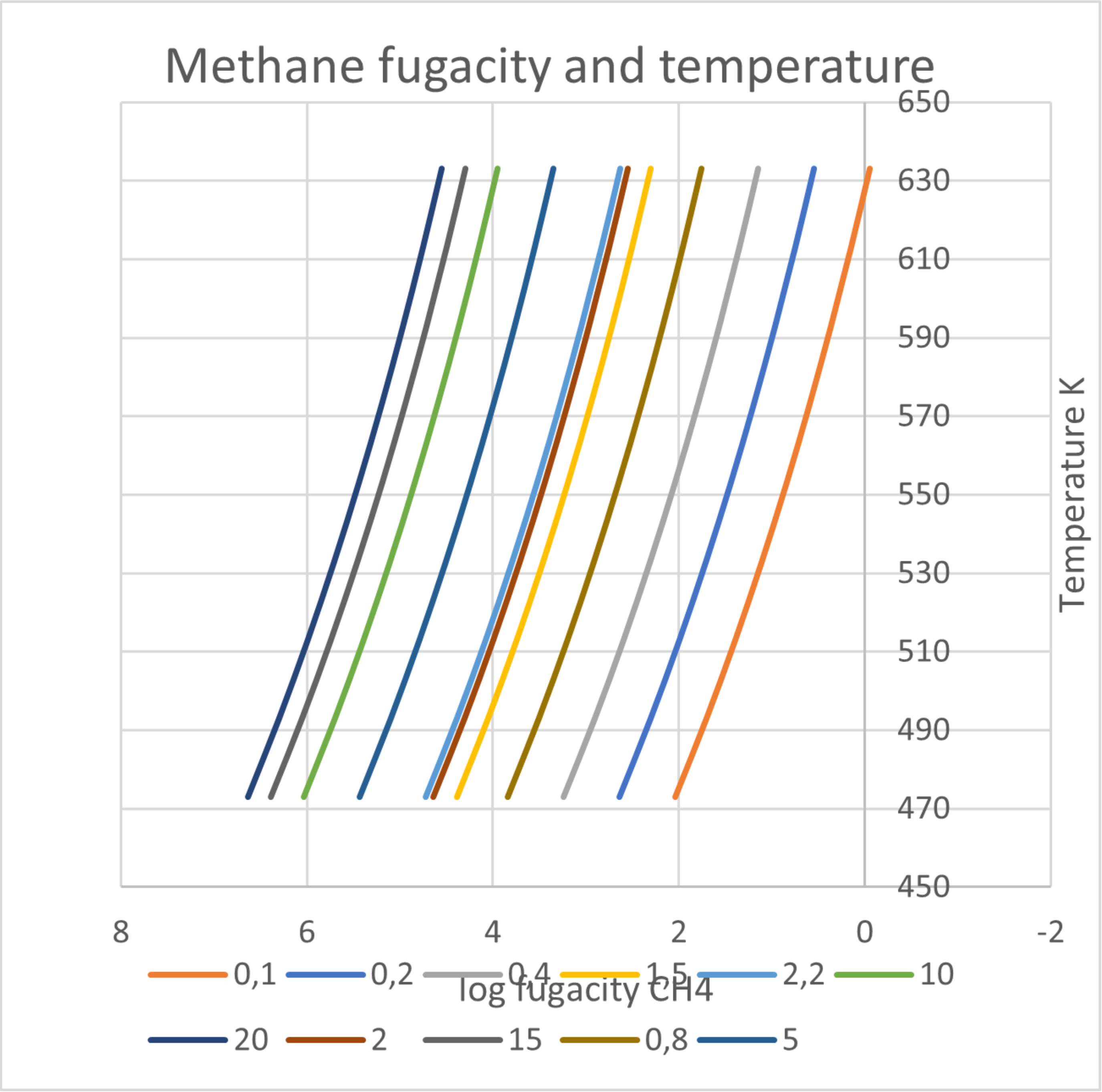


$$C + 4H \rightarrow CH_4$$

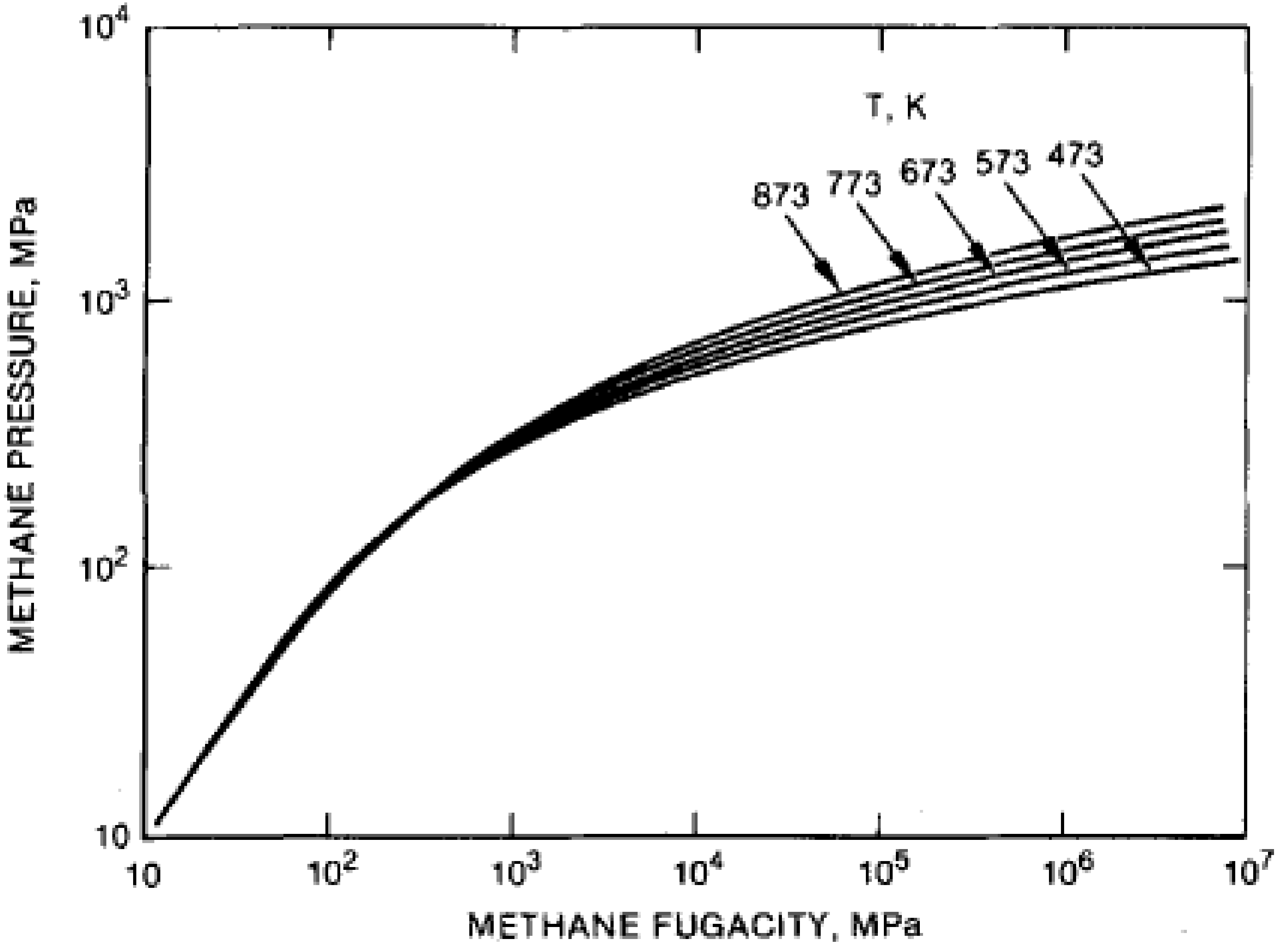
$$K = \exp(-\Delta G/RT)$$

$$P_{CH4} = p_H^{\,4} * \exp(-\Delta G/RT)$$

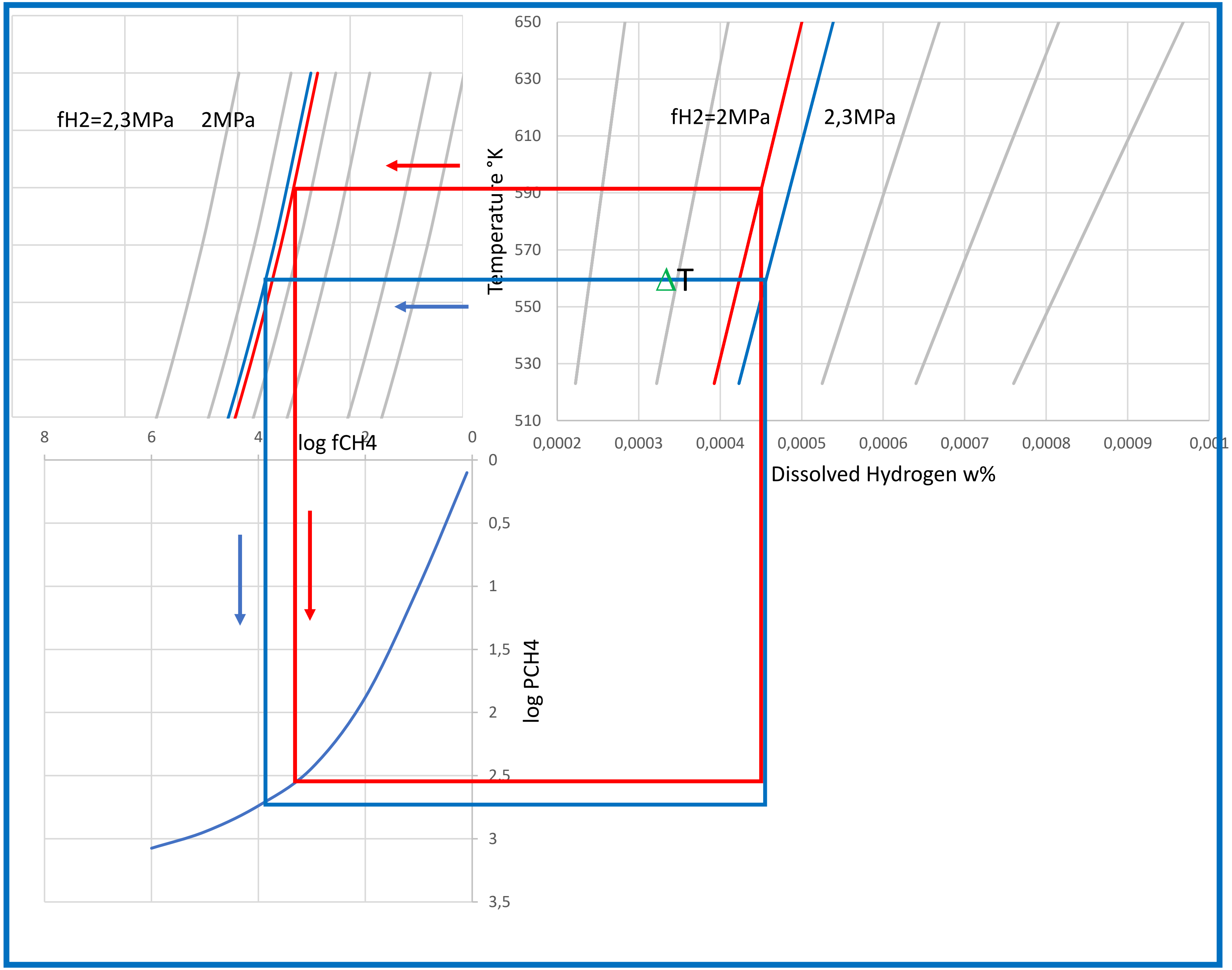
Methane fugacity vs. temperature. Parameter is hydrogen fugacity (Mpa)



Methane pressure in voids vs. methane fugacity.

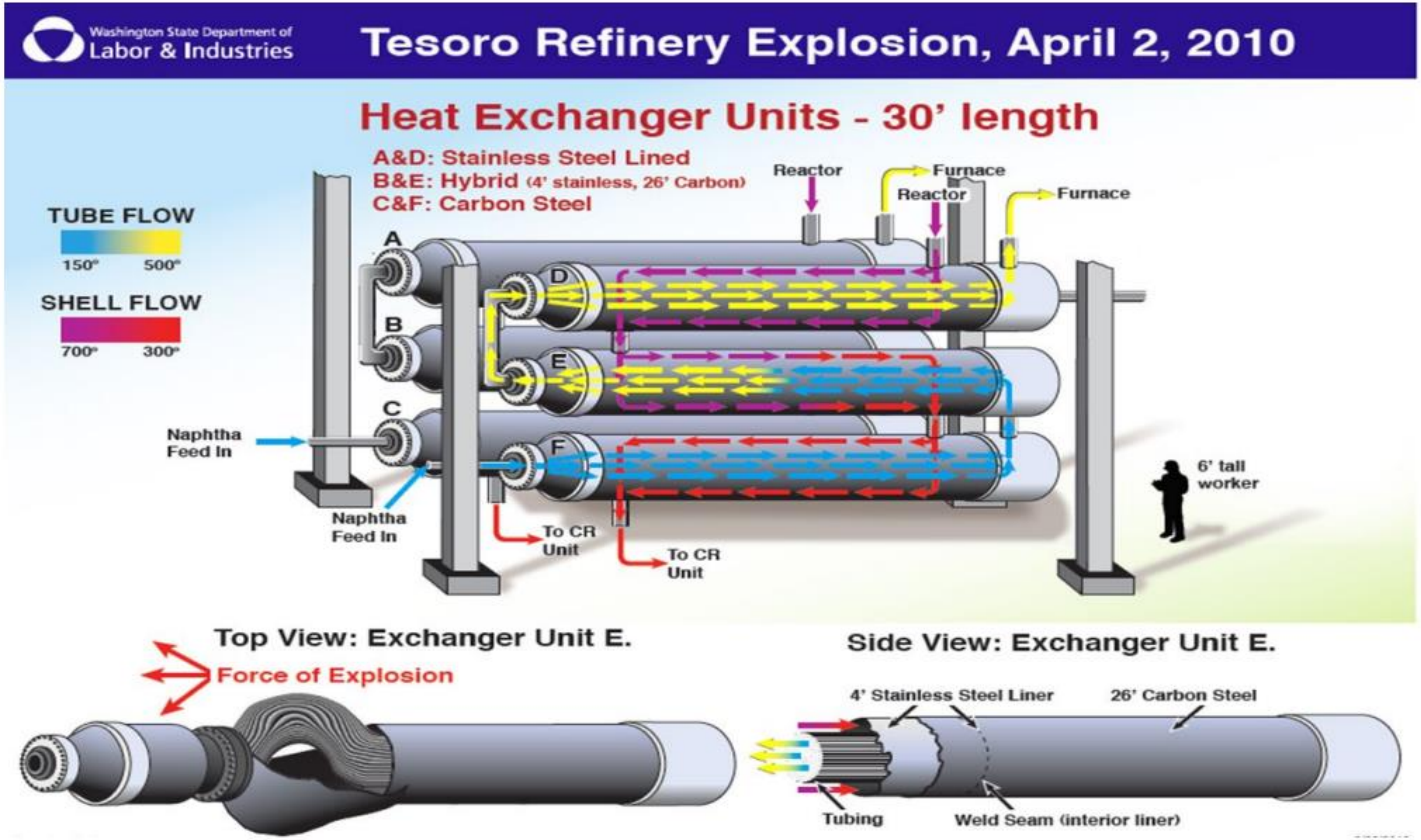


Escalation of effects due to temperature drop.



1. A 30°K drop from 580°K and 0,00045 w% hydrogen will raise the hydrogen fugacity from 2 MPa to 2,3 MPa.
2. Those changes correspond to a doubling of methane fugacity from 5480 MPa to 12216 MPa.
3. Methane void pressure increase is less spectacular but significant: from ~300 MPa to ~500 MPa.

Anacortes NHT explosion


Washington State Department of Labor & Industries
Tesoro Refinery Explosion, April 2, 2010
Heat Exchanger Units - 30' length
A&D: Stainless Steel Lined
B&E: Hybrid (4' stainless, 26' Carbon)
C&F: Carbon Steel
TUBE FLOW
150° 500°
SHELL FLOW
700° 300°
Reactor
Furnace
Reactor
Furnace
A
B
C
D
E
F
Naphtha Feed In
Naphtha Feed In
To CR Unit
To CR Unit
6' tall worker
Top View: Exchanger Unit E.
Force of Explosion
Side View: Exchanger Unit E.
4' Stainless Steel Liner
26' Carbon Steel
Tubing
Weld Seam (interior liner)

Background

- Feed/effluent heat exchanger of a naphtha hydrotreater
- Commisioned in 1971, failed due to HTHA in 2010
- Failed exchanger was C-steel, non-PWHT
- Never inspected for HTHA due to safe margin with Nelson curve.
- Temperature fluctuations are inherent with F/E exchanger service
- The exchanger ruptured, gases ignited; 7 people died.
- CSB report provides further details

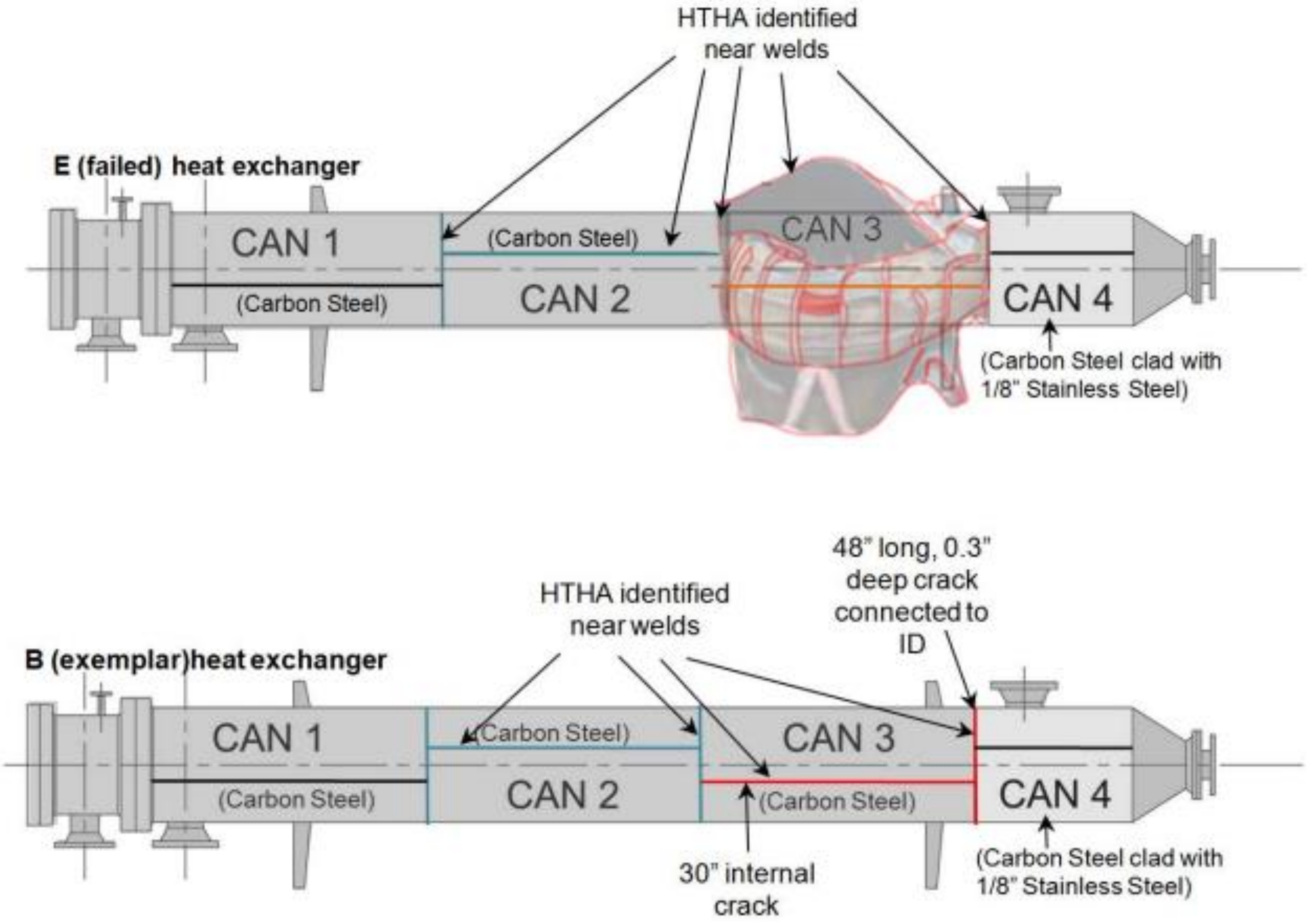


Figure 22. Comparison of Damage Locations in the B and E Heat Exchangers. Severe HTHA damage is found in the B heat exchanger in the same locations where the E heat exchanger ruptured.

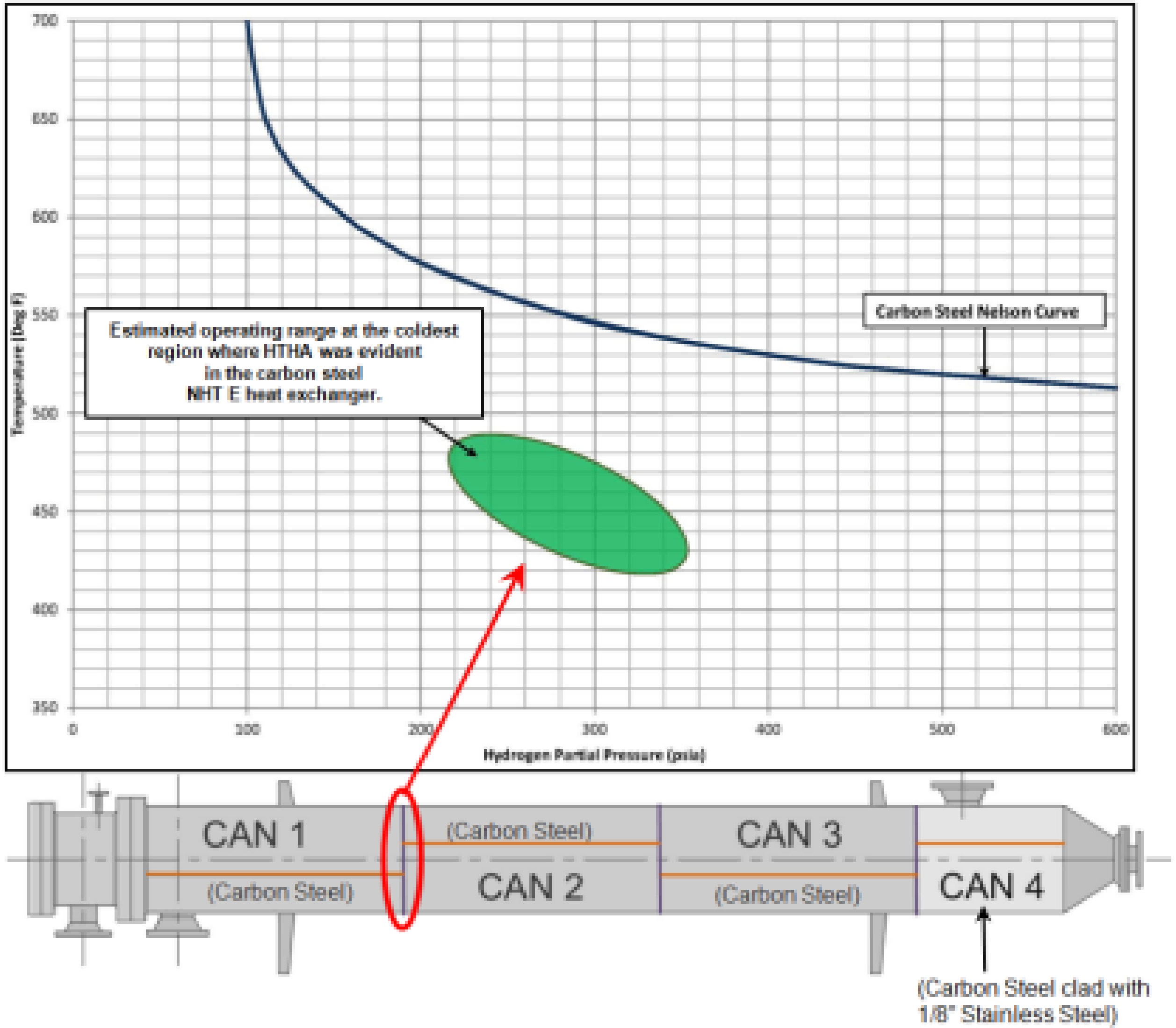


Figure 27. Model Results for the Coldest Region of the E Heat Exchanger. The coldest region of the E heat exchanger with evident HTHA was estimated to operate as much as 120 °F below the carbon steel Nelson curve.

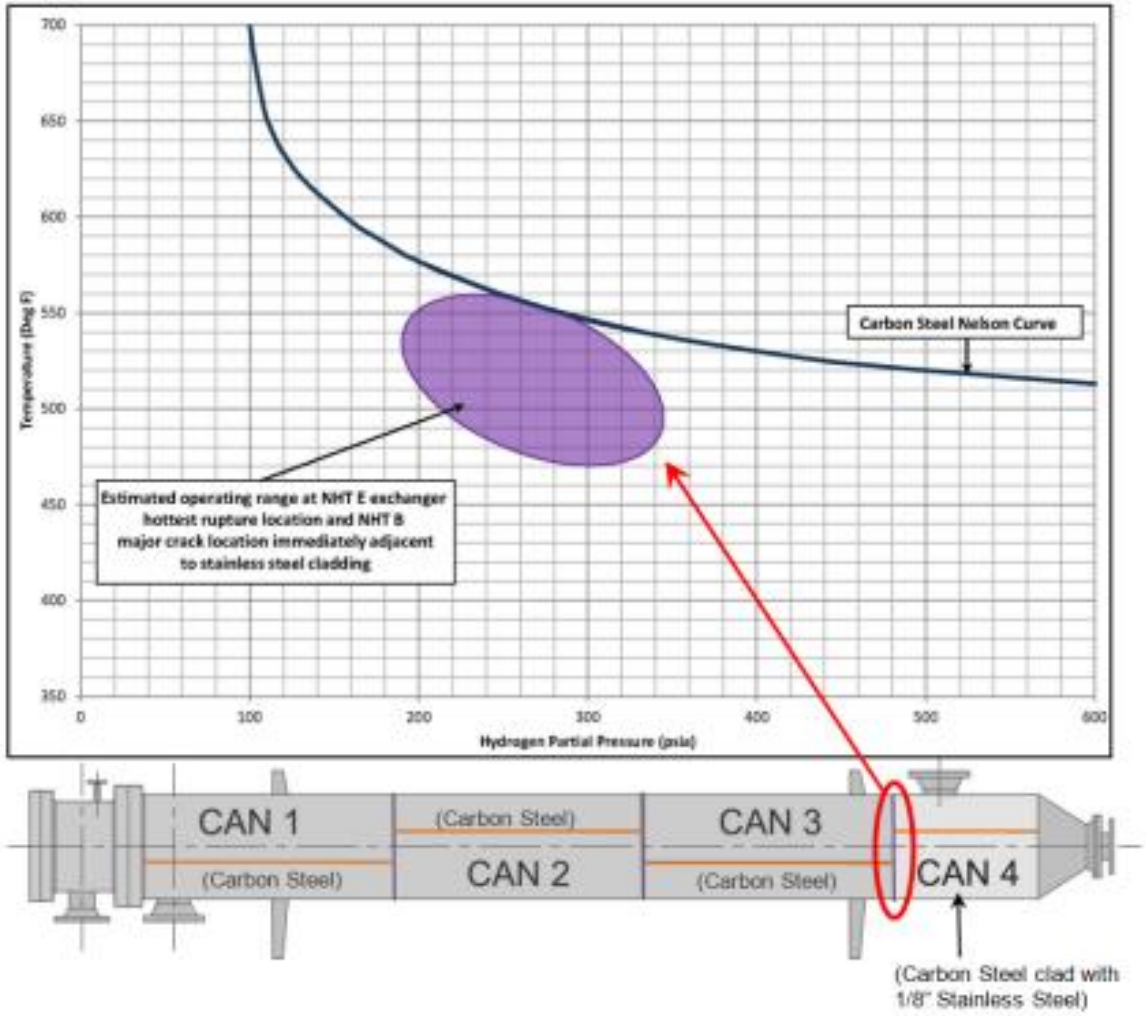


Figure 26. Model Results for the Weld Downstream of Can 4. The circumferential weld immediately downstream of the stainless-steel-clad portion of the carbon steel B and E heat exchangers was estimated to operate just below the carbon steel Nelson curve. Extensive HTHA was found in this region, the hottest rupture location of the E heat exchanger and the major crack location of the B heat exchanger.

Conjectures

1. Temperature drops increase the hydrogen fugacity and hence the methane fugacity and hence the methane void pressure in steel that is exposed to hot hydrogen gas.
2. Therefore, temperature instability probably reduces the incubation time of HTHA and lowers the incubation threshold.
3. The rates of cooling and subsequent heating probably influence the effect.

Appendix 12

Corrosion case histories in biorefinery plants/ from feedstock to reaction

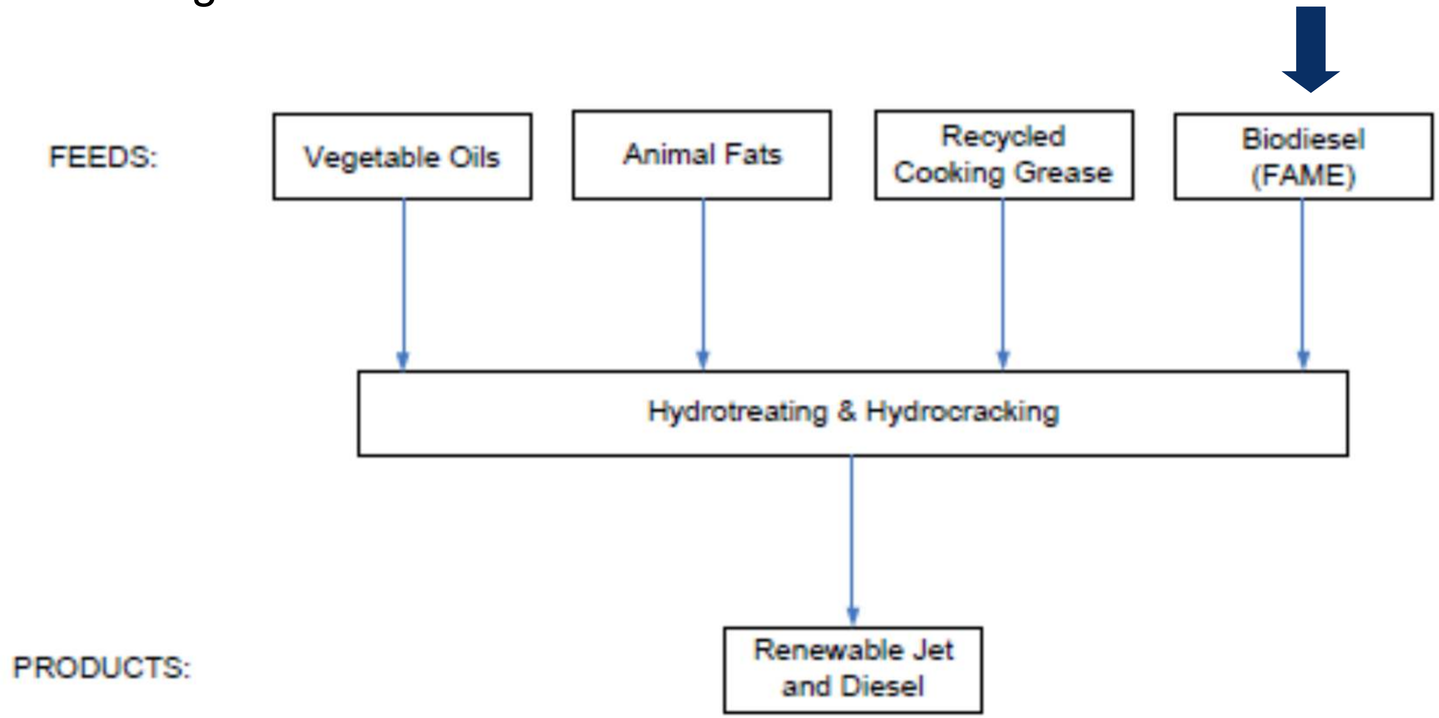
(Carlo Casu, Marco de Marco)

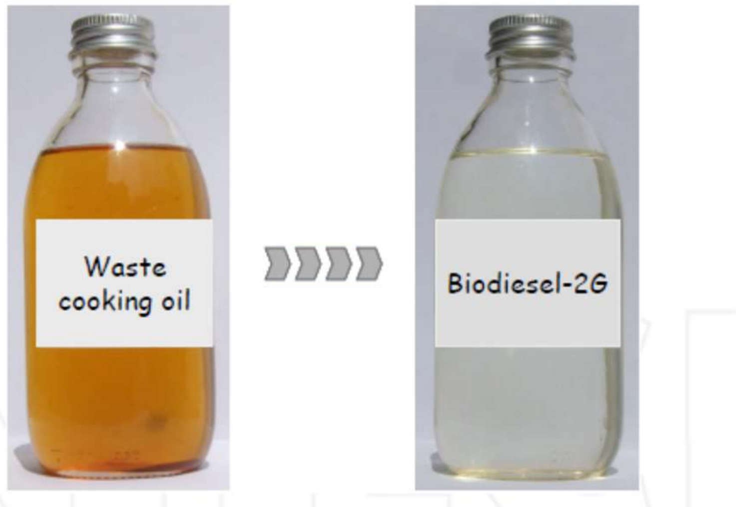
Corrosion Case Histories in Biorefinery

M. De Marco – IIS
C. Casu - IIS

ISTITUTO ITALIANO DELLA SALDATURA
ente morale

Need to create **"drop-in" renewable fuels** (second generation) practically interchangeable with those of fossil origin.





Certain reactions and certain processes present in the production of **biofuels/renewable fuels** are familiar to corrosion and materials engineers working in the refining field (**hydrotreatment, hydro-conversion, isomerization, distillation**, etc.).

Raw materials and intermediates change!

- **"Fossil" refinery:** hydrophobic hydrocarbons with sulfur (sulfides, mercaptans, etc.), nitrogen compounds and small quantities of oxygen.
  - ***By-products from processing***: hydrogen sulfide, ammonia and only small quantities of water.

- **Bio-based fuels:** starting with species with a high oxygen content (carbohydrates, triglycerides, Free Fatty Acids – FFA, etc.).
  - ***Products and by-products***: oxygenated species such as alcohols, CO_2 , organic carboxylic acids and water as a by-product.
  - High Acidity Numbers (TAN)
  - The presence of **water** increases corrosion problems.

The widespread presence of **aqueous phase** makes the process fluids in any case potentially more corrosive than hydrocarbons of fossil origin.

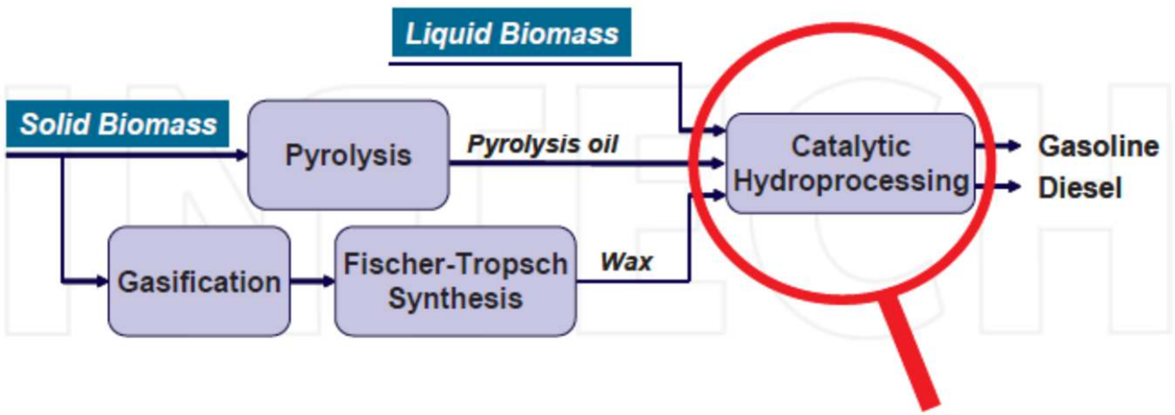
H_2O solubilizes numerous corrosive agents present

→ ***Organic acids***
→ ***Inorganic acids***
→ ***CO_2***
→ ***Chlorides***

and promotes **MIC.**

The refinement process by hydrotreating allows to eliminate the oxygenated species (organic acids) and refine the molecular structure (saturation, isomerization, etc.).

✓ **"Drop-in" fuels – Renewable Fuels - RF**



Overview of corrosion issues

- The transport, storage (raw materials and finished products), production and combustion phases of biofuels/renewable fuels could present **different corrosion problems than fossil fuels.**
- The presence of greater quantities of **oxygenated species**, **water and organic acids (also FFA)** entails variable risks of corrosion.
- **CO_2 and chlorides** may also be present which dissolve in the **aqueous phase ("low T" corrosion)**
  - **CO_2** corrosion requires SS
  - Process fluids with **organic acids** in the aqueous phase require SS with Mo (e.g. 316, 317, 2205)
  - If **chlorides + organic acid** are present → Ni-Cr-Mo alloys (e.g. alloy 625 or, in aggressive conditions, C276)
- In **anhydrous streams with organic acids at T> 100 ° C** corrosion problems due to **"high T"** are triggered (similar to NAP Acid): need to use steels with high Mo type 317 825, 625
- **Hydrogen mixing** mitigate corrosion at high T (lowering the TAN) ? → standard 300 SS cab fit, but less **data than petroleum refining unit!**

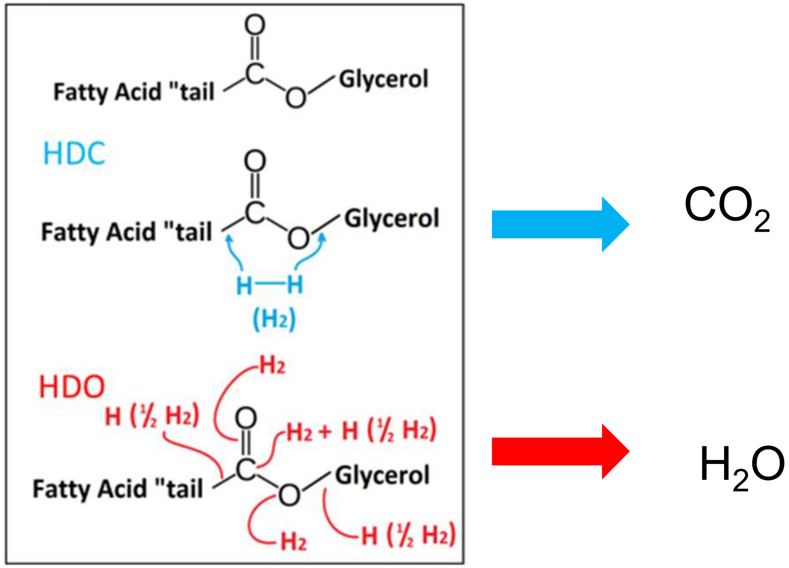
Effluent systems

- Effluent from reactor (hydrotreating) processing **pure bio-oils** and biomass-oil contains high content
  - CO_2 from HDC reactions
  - H_2O from HDO reactions

- CO_2 corrosion on CS in effluent systems (low pH)

- **Feedstock rich in chlorides (**organic and inorganic) produce HCl in effluent (high risk of corrosion in CS and traditional SS → Mo containing Ni-alloys needed (injection of neutralizer?)

- **Mixed feedstock (petroleum + bio)** induce the presence of NH_3 → buffering effect pH in effluent but increases risk of NH_4Cl deposition and corrosion



* Sutton, Kirkham - Converting Hydroprocessing Equipment to Produce Renewable Diesel from Soybean and Corn Oil: Corrosion and Materials Considerations

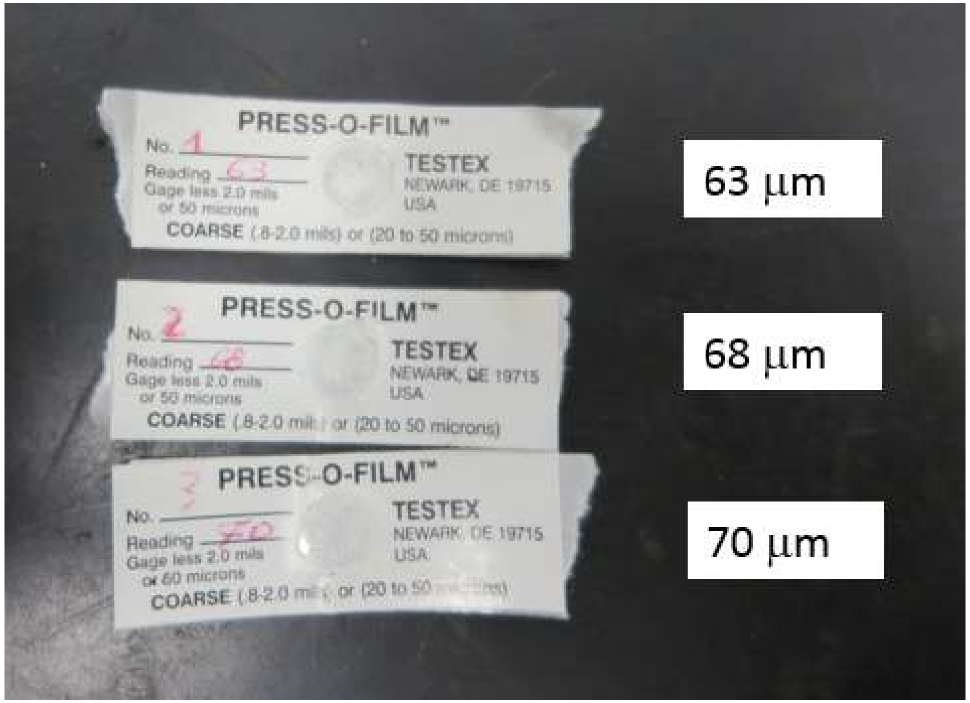
Coating failure in feedstock tanks

- Regenerated Used Cooked Oil (RUCO) tank
- Internal coating polyamide cured epoxy coating
  - 60 µm primer
  - 300 µm topcoat
- T maintained at 70 °C by heating coil
- Extensive exfoliation of the shell coating

ISTITUTO ITALIANO DELLA SALDATURA

- Shell coat
- Adhesive failure from substrate

- Surface profile not anomalous (replica tape)

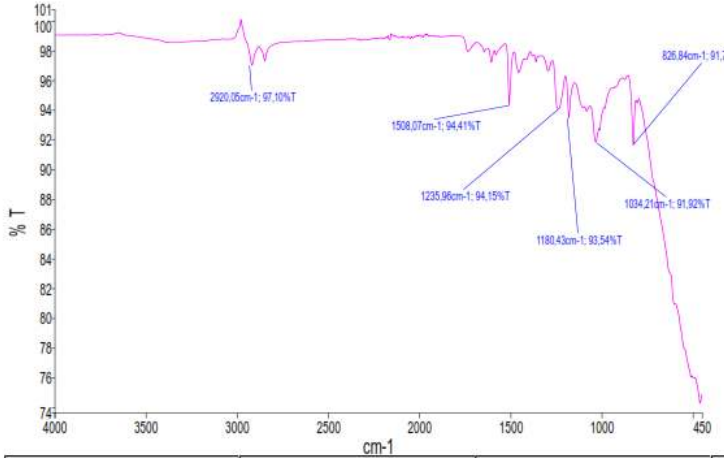


- View of the bottom
- Detachment of top coat from inner coat

- Shell coating sample
- Adhesive decohesion of the primer from substrate
- Measured thickness slightly greater that specified

FTIR – Epoxy resin as expected

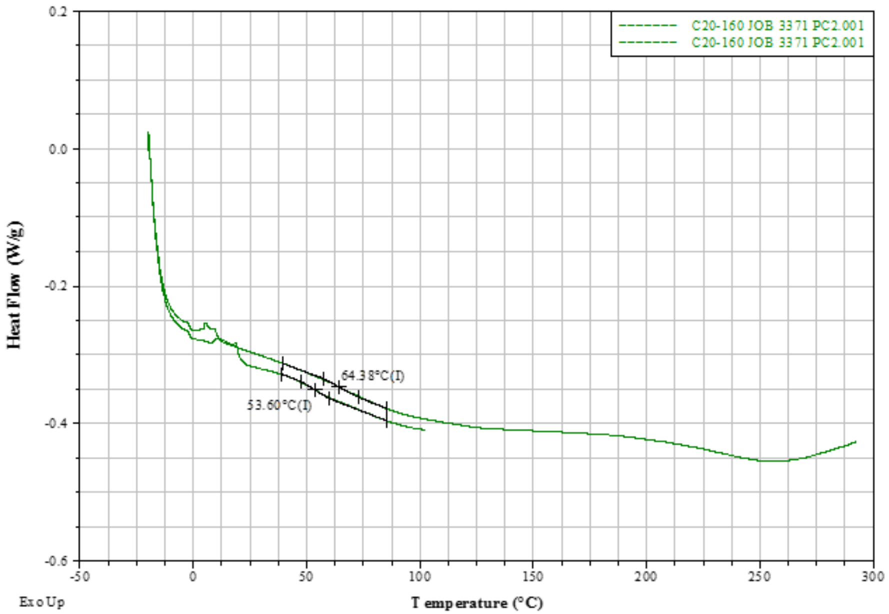
Analyst	Administrator
Date	giovedì 5 novembre 2020 16:18



Sample Name	Description	Quality Checks	Search Score
PARETE 2	Parete	The Quality Checks give rise to a Bande deboli warning for the sample.	0,792364

Search Best Hit Description
100% RESINA EPOSSIDICA

DSC – No evident deflection – Coating degradation



Coating products (max 60 °C T op) not suitable to sustain RUCO temperature maintained in the TANK (around 70 °C for viscosity)

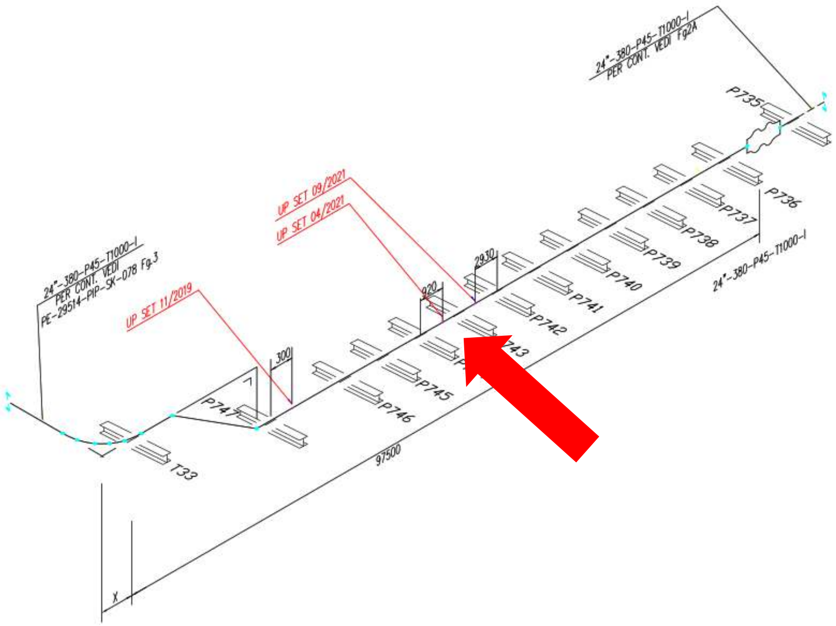
Select an epoxy-phenolic coating suitable to T> 100 °C

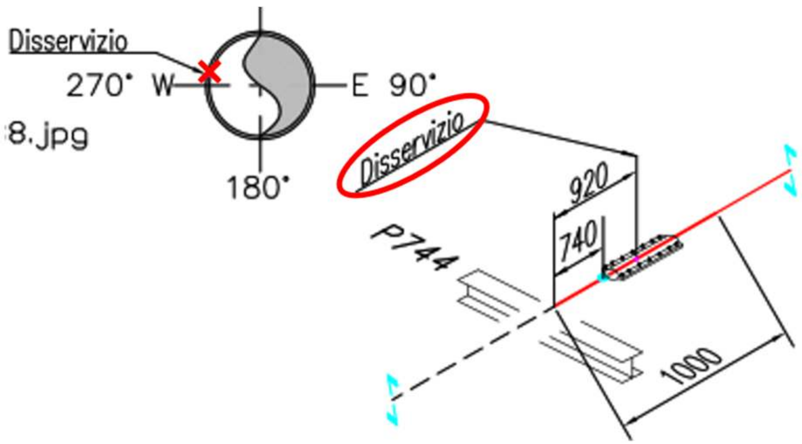
ISTITUTO ITALIANO DELLA SALDATURA

Localized corrosion pipeline – rapeseed/soybean oil

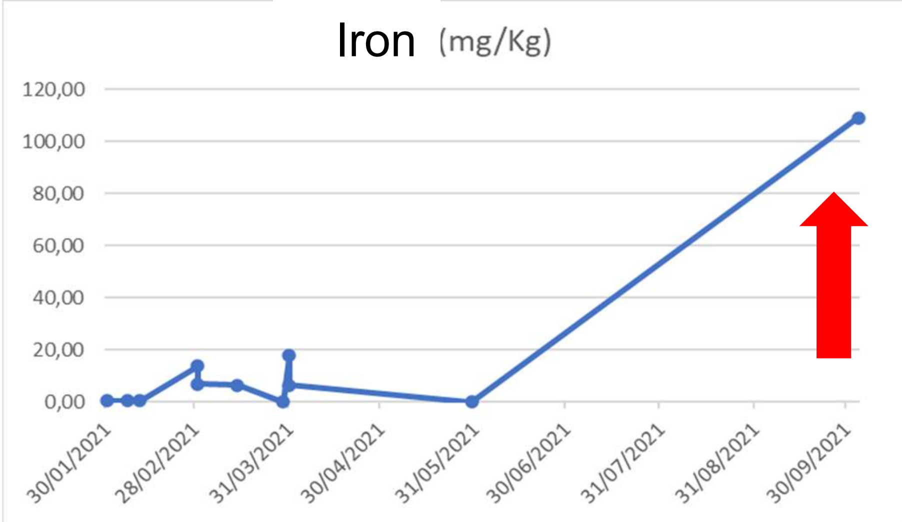
- Very localized corrosion phenomena
- Fluid : rapeseed/soybean oil
- T= 50 °C
- Intermittent service

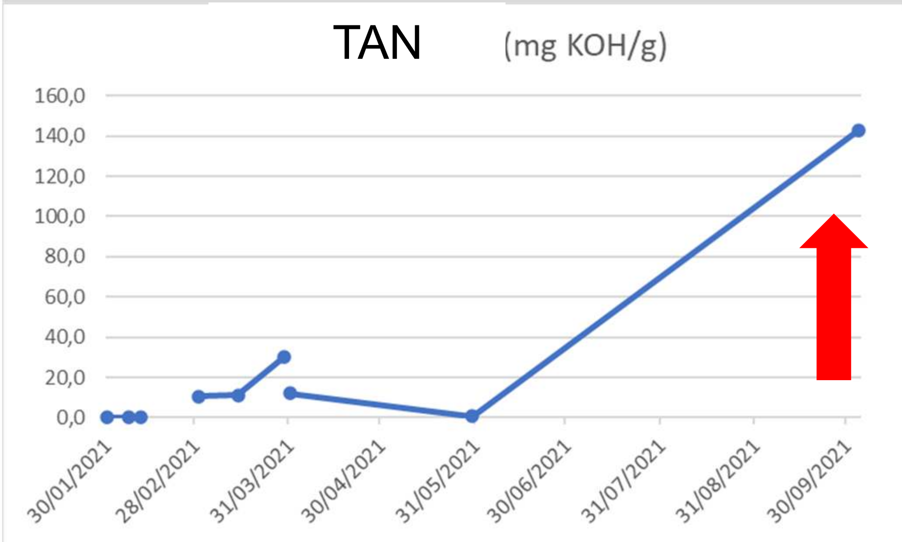
Piping layout – localization of damages
Low points





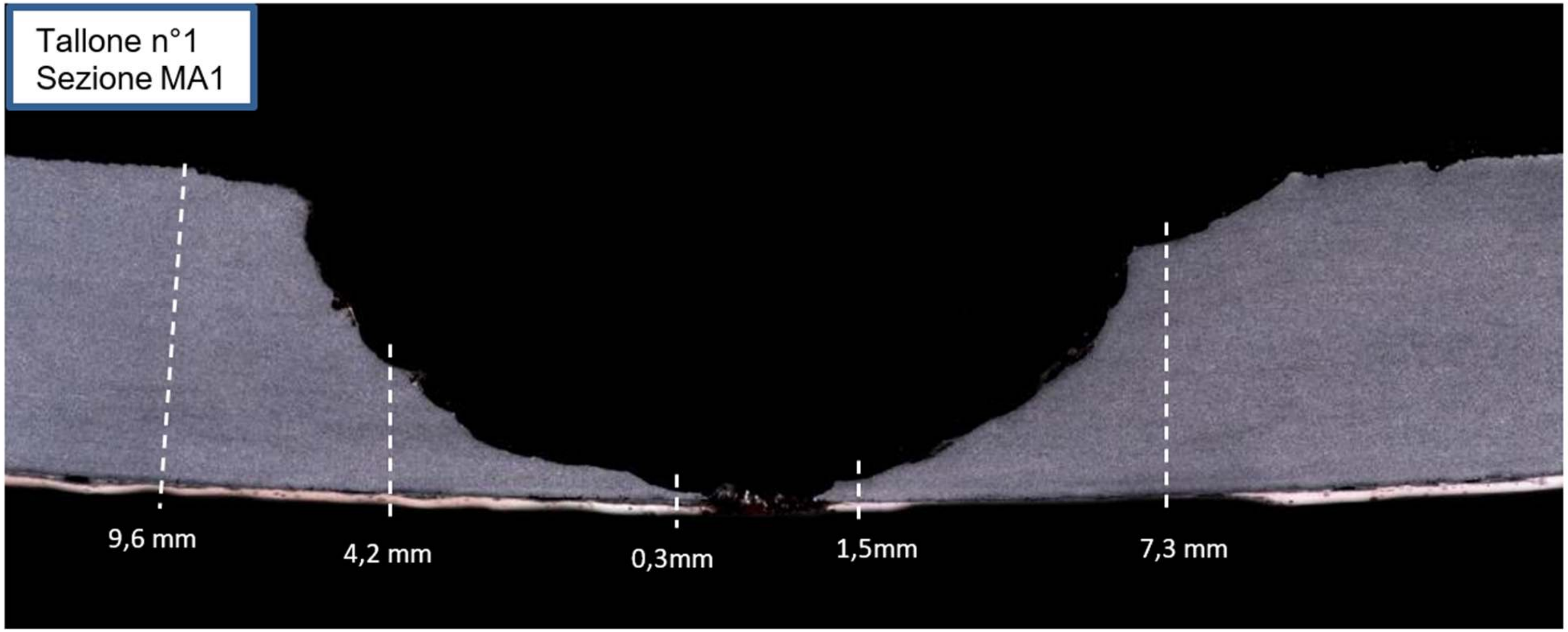
Feedstock analysis



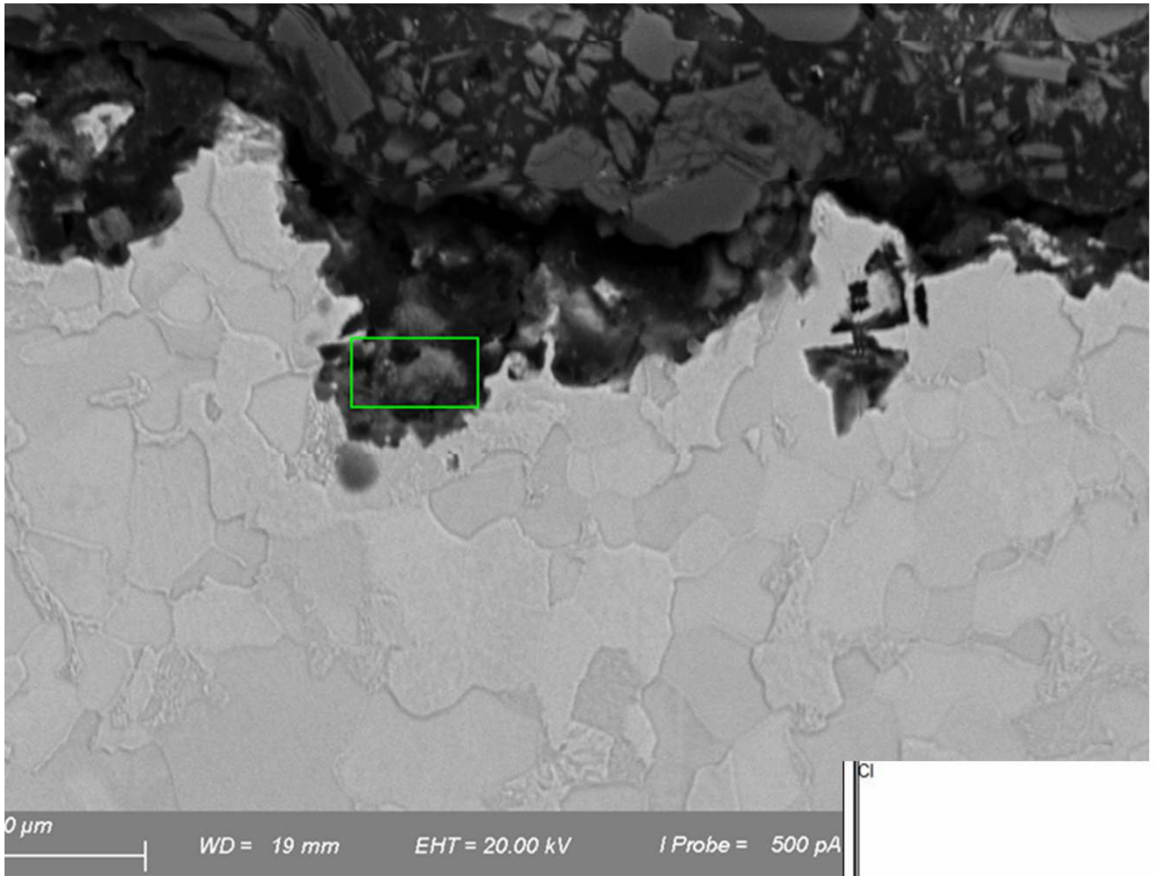


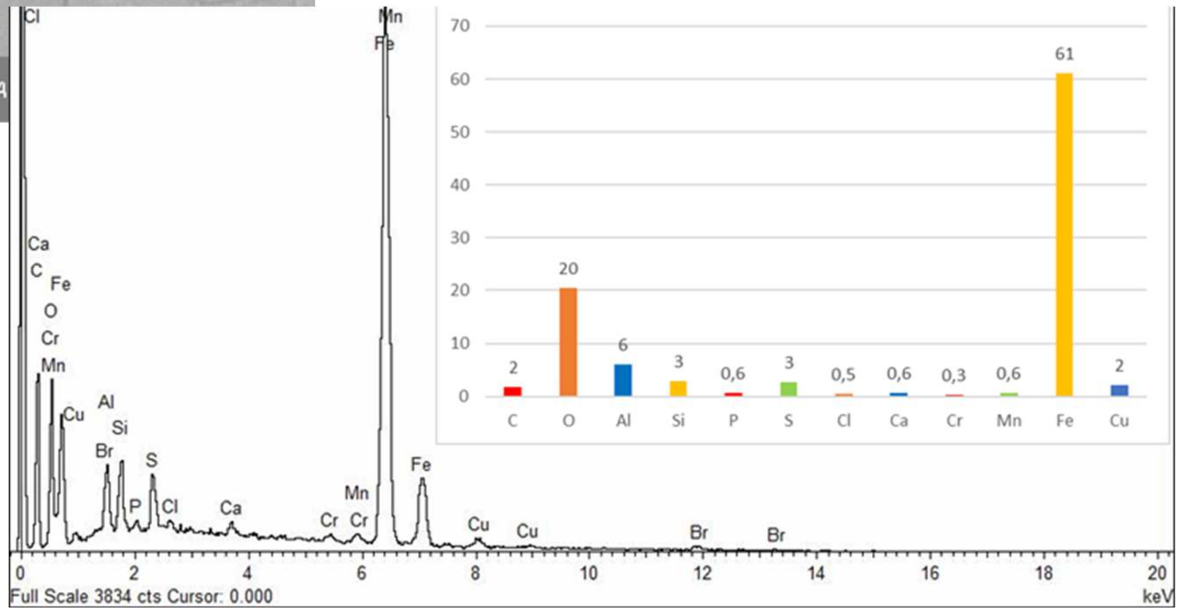
ISTITUTO ITALIANO DELLA SALDATURA

Corrosion Morphologies – Hemispherical pitting



Corrosion Morphologies – Shallow pitting





ISTITUTO ITALIANO DELLA SALDATURA

MIC analysis on solid samples (sessile bacteria)

Sampling code	001 (cells/g)	002 (cells/swab)
Sample specific detection limit	4.9×10^3	1.7×10^3
Total Bacteria	9.5×10^8	7.0×10^8
Total Archaea	2.0×10^4	5.4×10^4
Iron oxidizing bacteria (*Gallionella* spp.)	n.d.	n.d.
Iron reducing bacteria (*Geobacter* spp.)	n.d.	1.3×10^4
Sulphate reducing bacteria	n.d.	n.d.
Sulphur oxidizing bacteria	n.d.	4.7×10^5
Sulphur cycling related bacteria	n.d.	n.d.
Methanogene archaea	n.d.	n.d.

MIC Related corrosion!

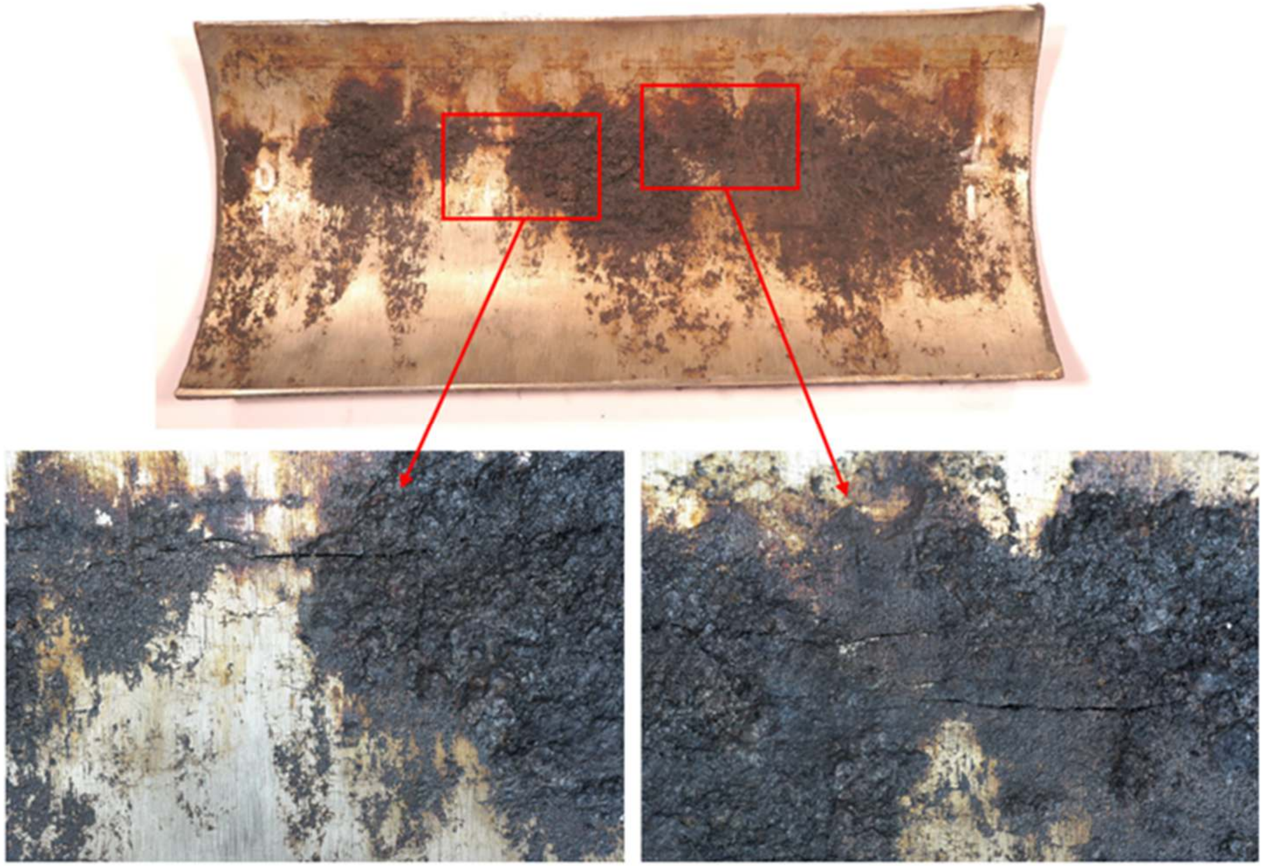
Stagnant fluid during intermittent service

ISTITUTO ITALIANO DELLA SALDATURA

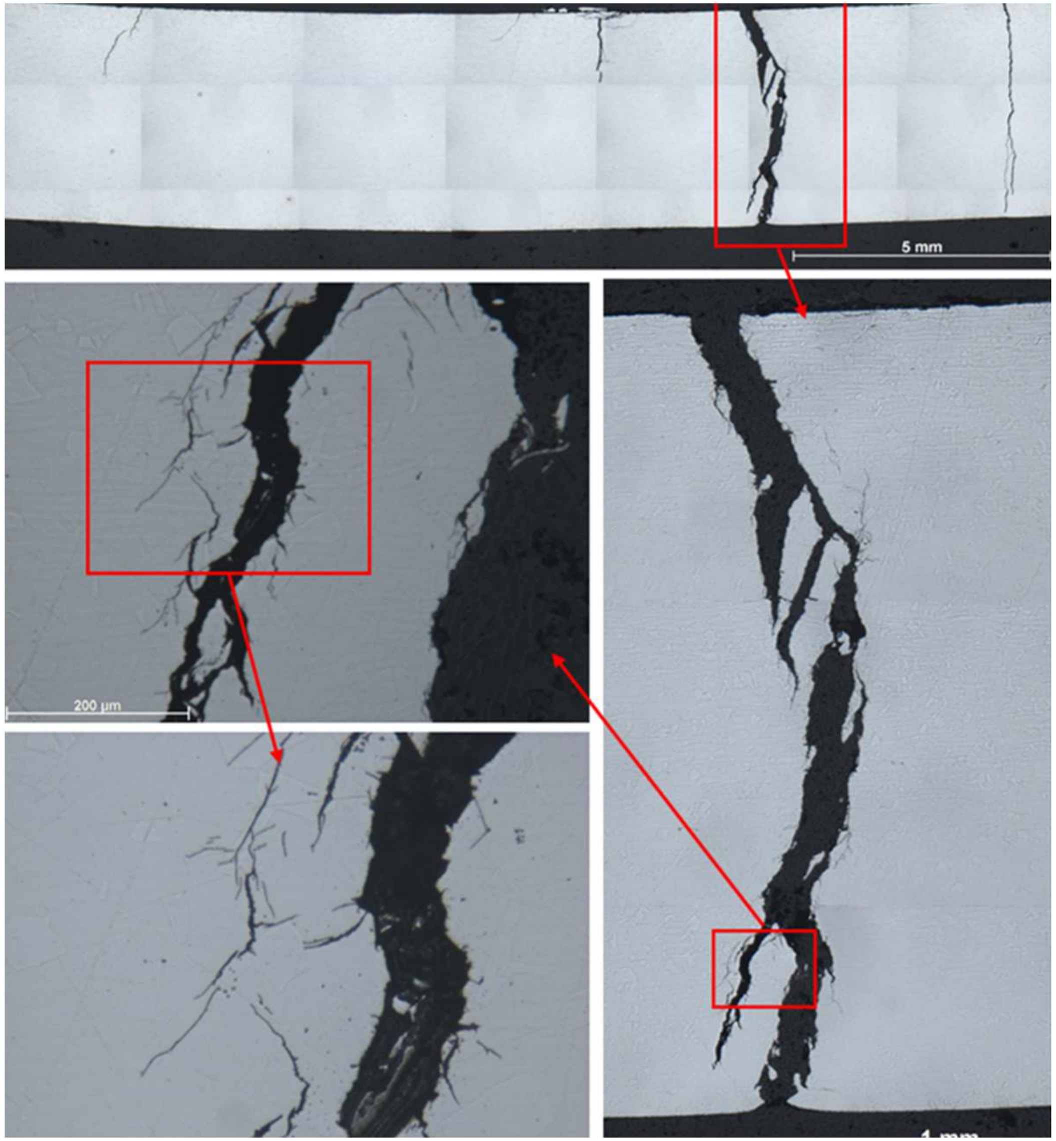
SCC on piping from pretreatment plants

- Fluid: biomass (palm oil and waste products)
  - From phosphoric acid and NaOH treatment.
- P= 1,5 bar
- T= 55-60 °C
- Age: 8 months
- Material: AISI 304 L

- Longitudinal cracks and black oily deposits

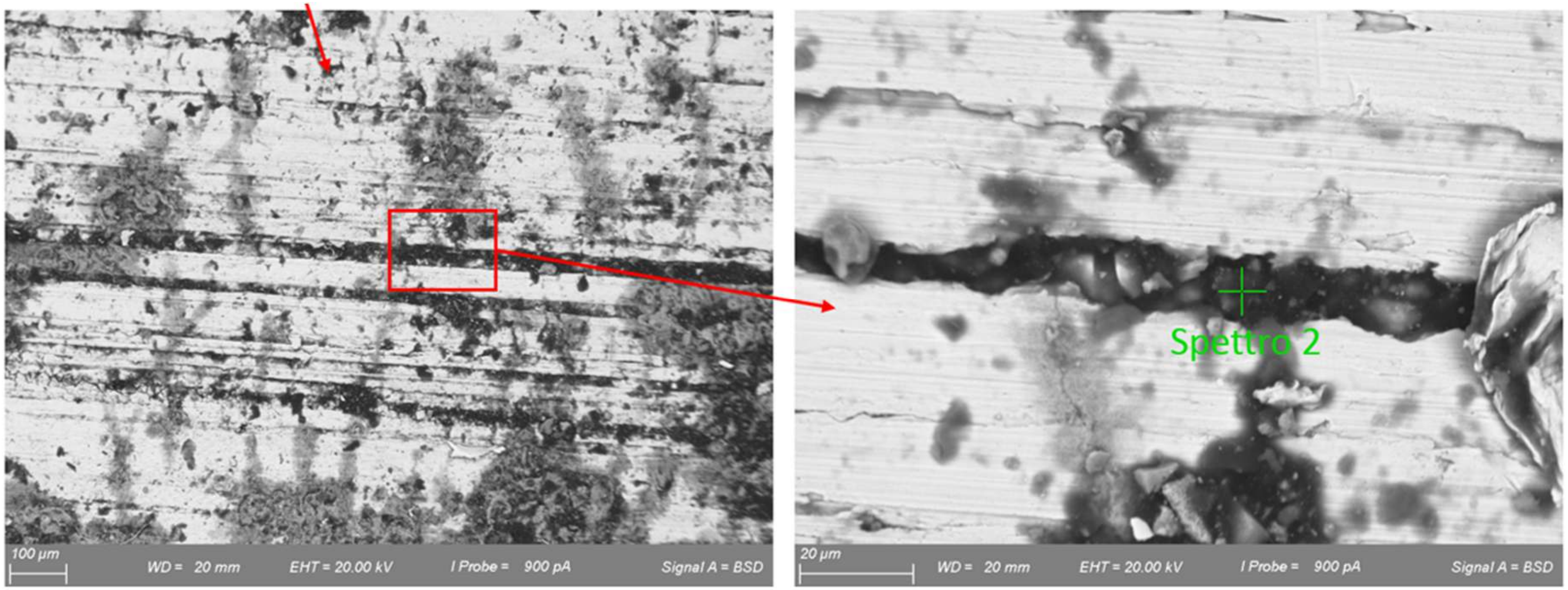


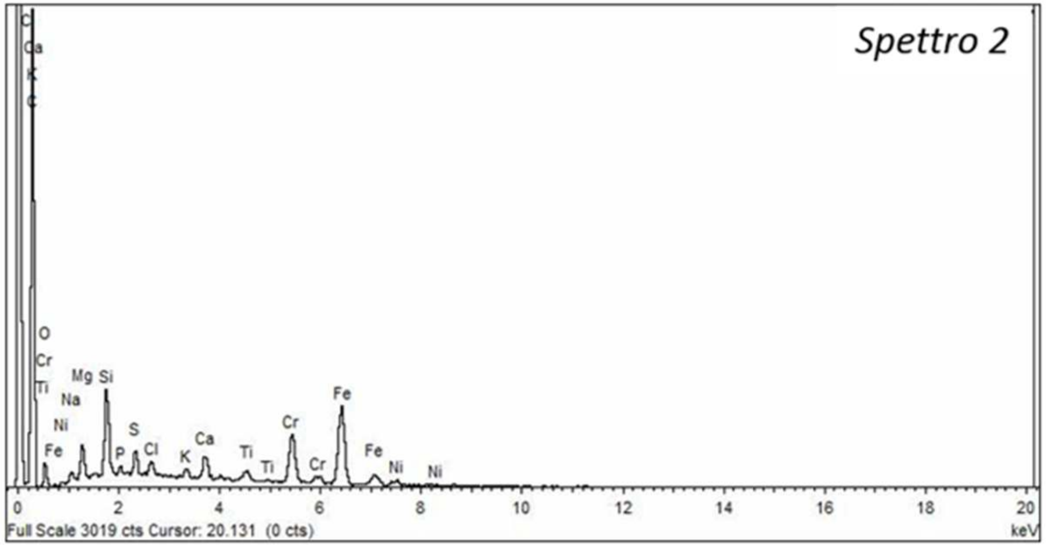
- Transgranular branched cracks form internal surface

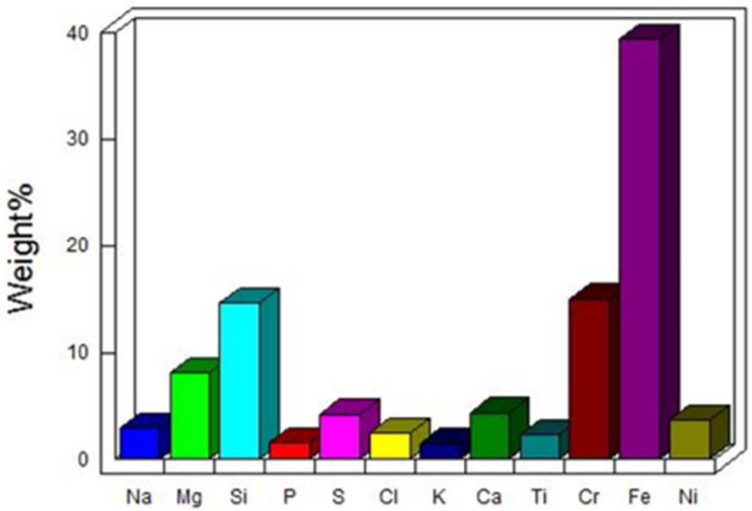


ISTITUTO ITALIANO DELLA SALDATURA

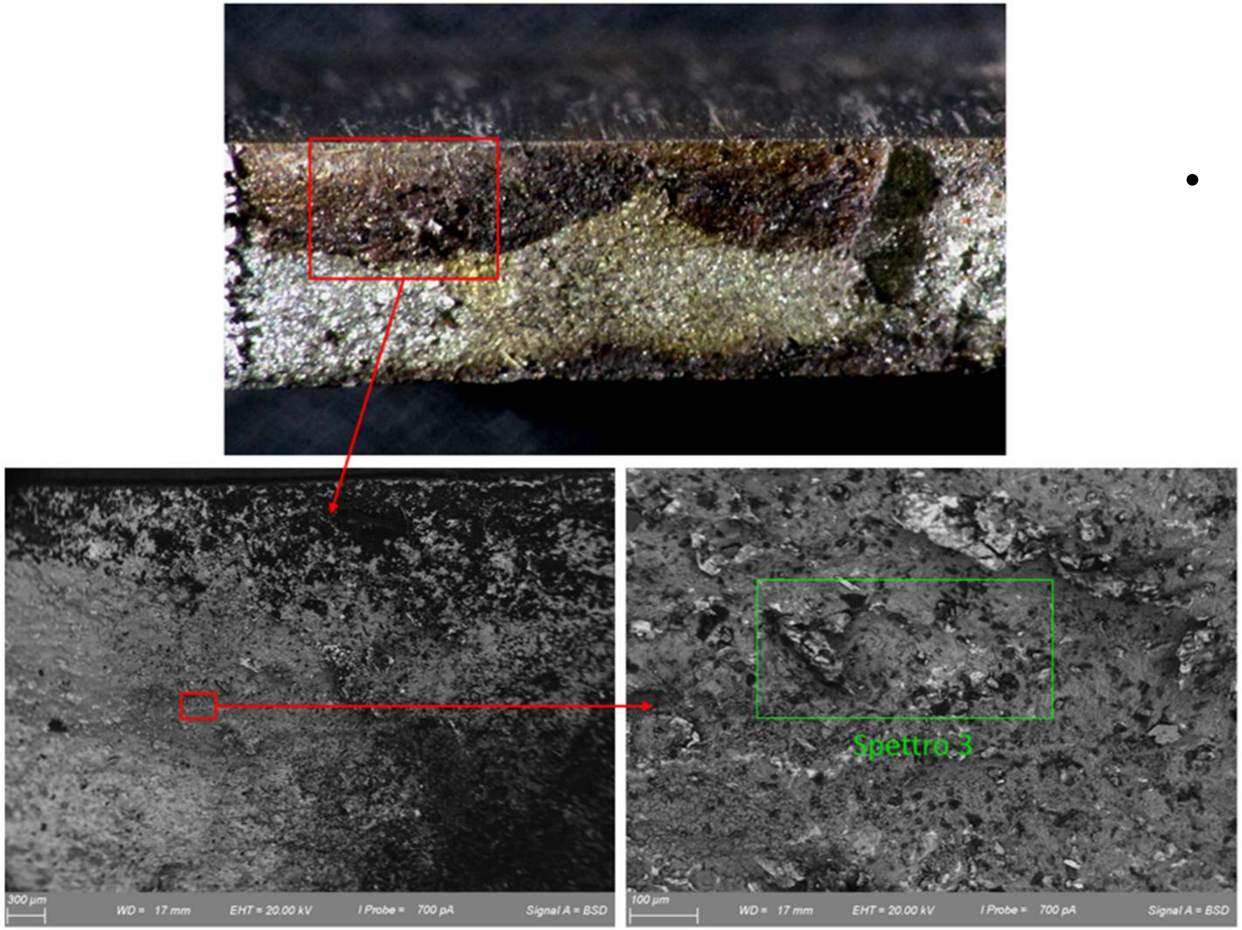
- SEM+EDS analysis

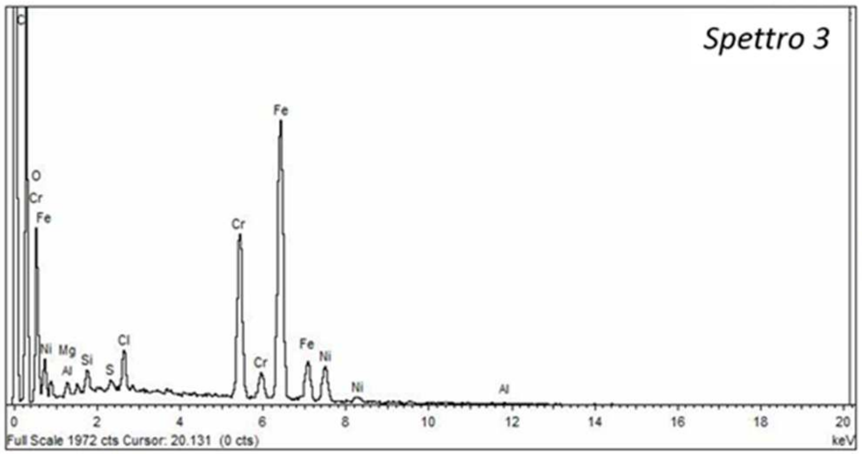


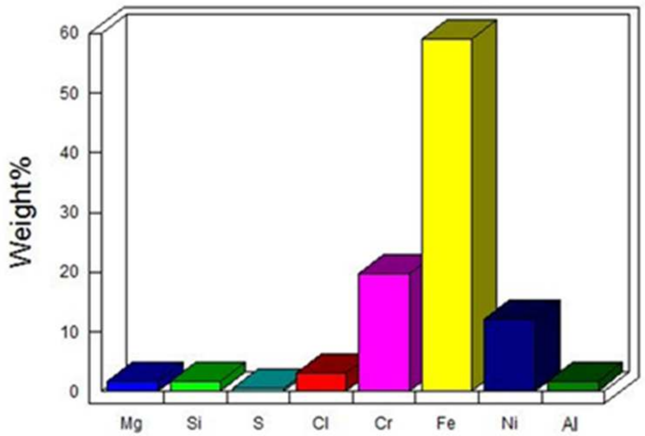




- SEM+EDS analysis







- Deposits Water extract

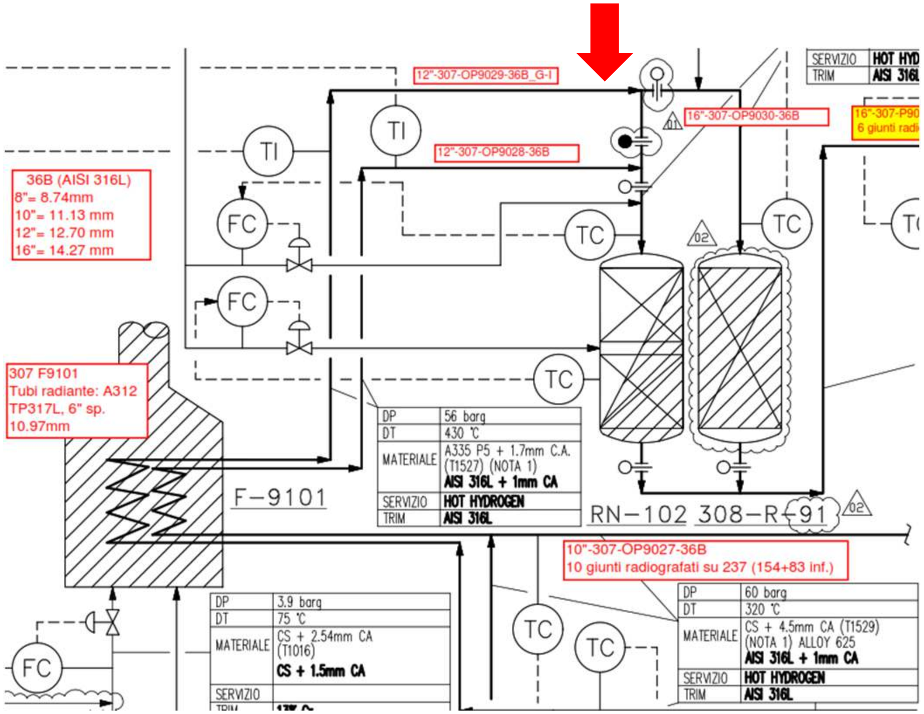
Parameter	Value
pH (upH)	6,70
Chlorides (mg/kg)	918
Fluorides (mg/kg)	< 0.5
Phosphates (mg/kg)	< 1
Sulphates(mg/kg)	1671
Nitrates (mg/kg)	9,43
Nitrites(mg/kg)	< 1
Ammonium (mg/kg)	14,5
Calcium (mg/kg)	287
Magnesium(mg/kg)	49
Potassium (mg/kg)	73
Sodium (mg/kg)	370

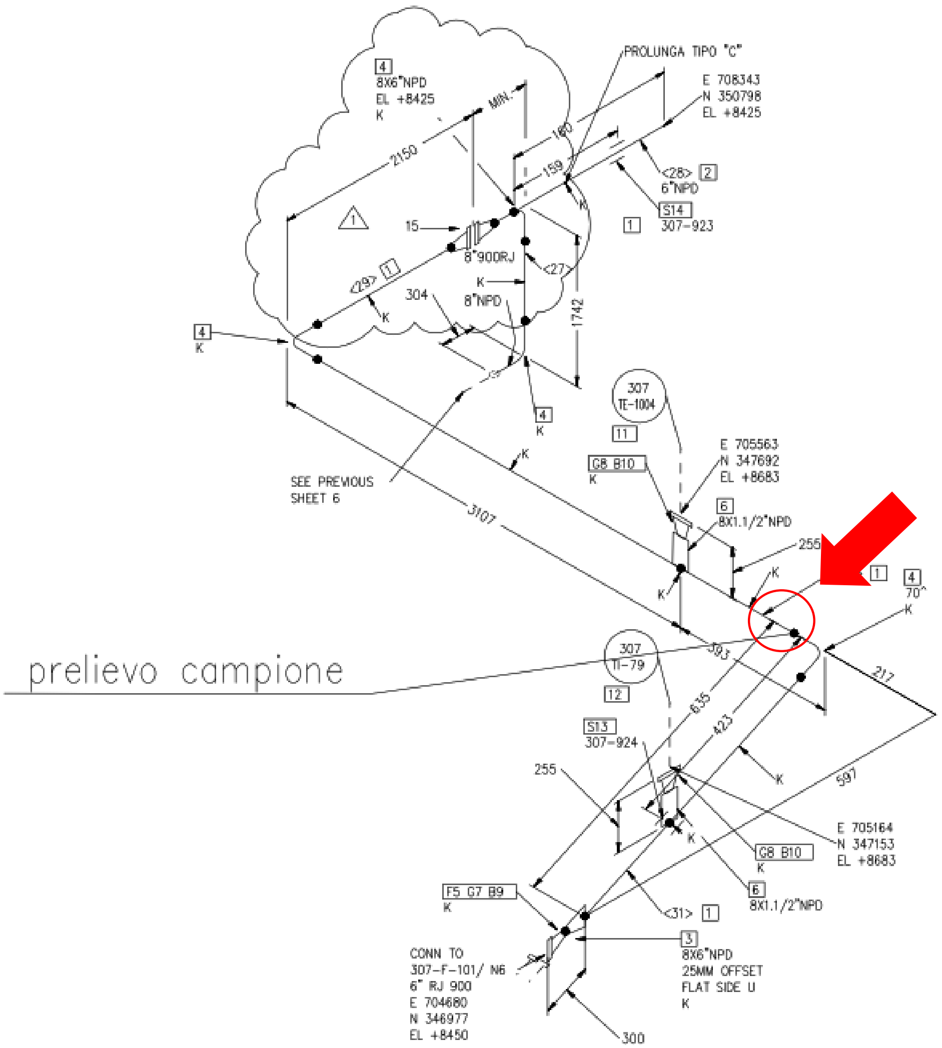
Chlorides-SCC from water and chlorides entrapped in the treated biomass

→ Materials selection!

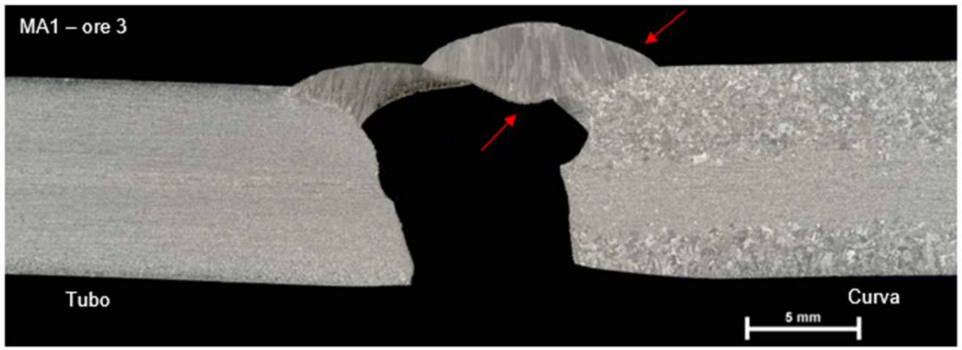
Selective corrosion of weld in Hydroprocessing reactor feed piping

- Hot feed piping from furnace to hydrotreating reactor
- Downstream H_2 injection
- Material : AISI 316 L
- T: 300 °C; P: 56 barg
- Age: 3 years
- Fluid: vegetable oil, hydrogen

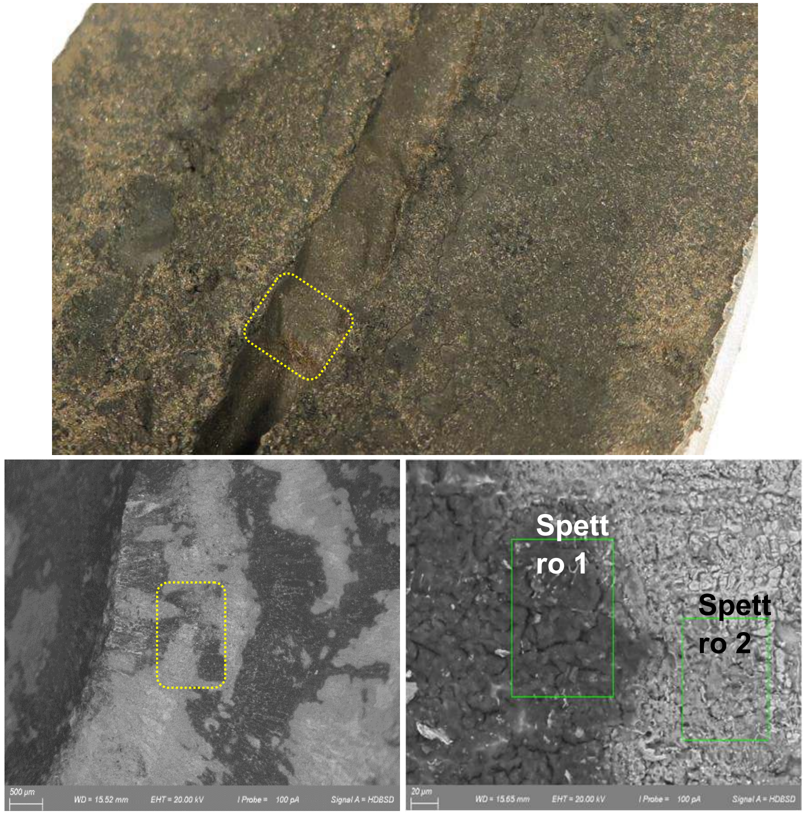


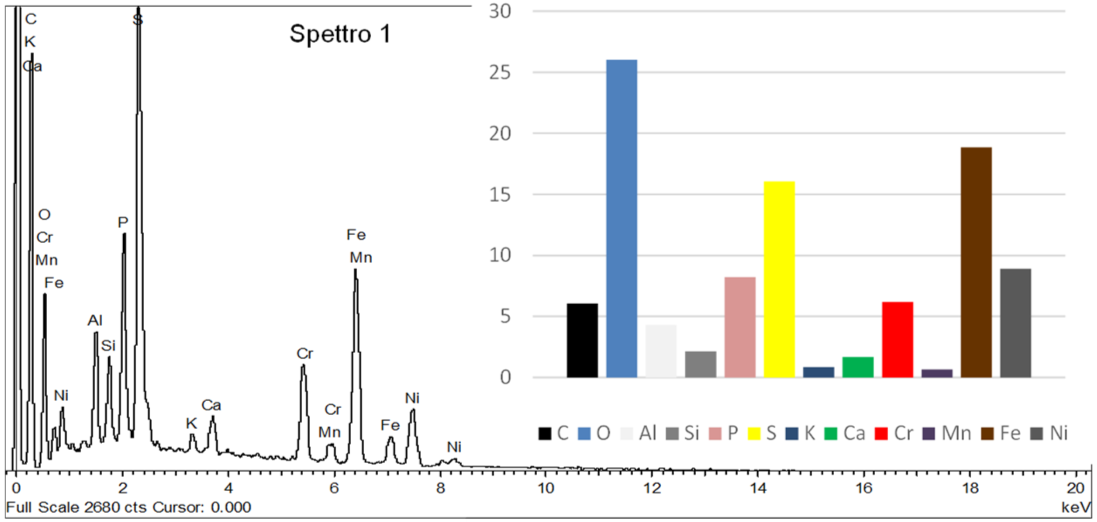


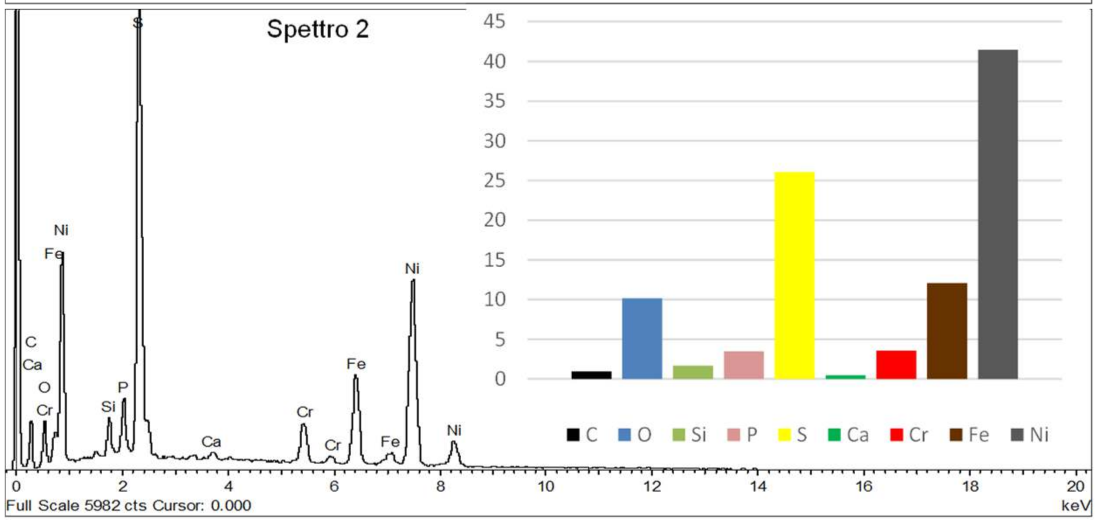
- Localized selective corrosion of weld from internal side



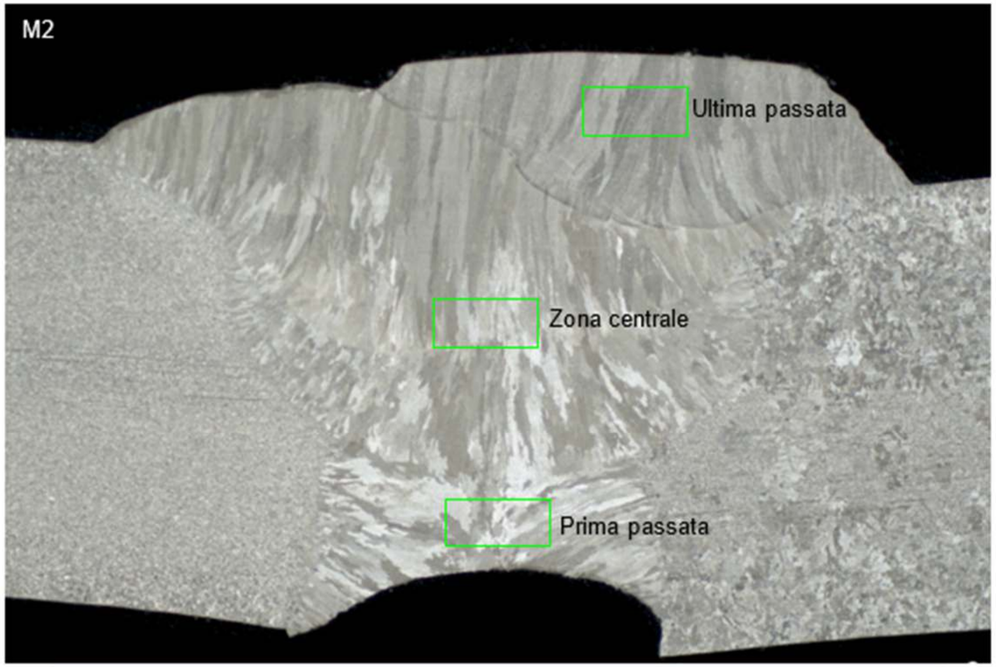
- SEM + EDS
- High sulfur and phosphorous



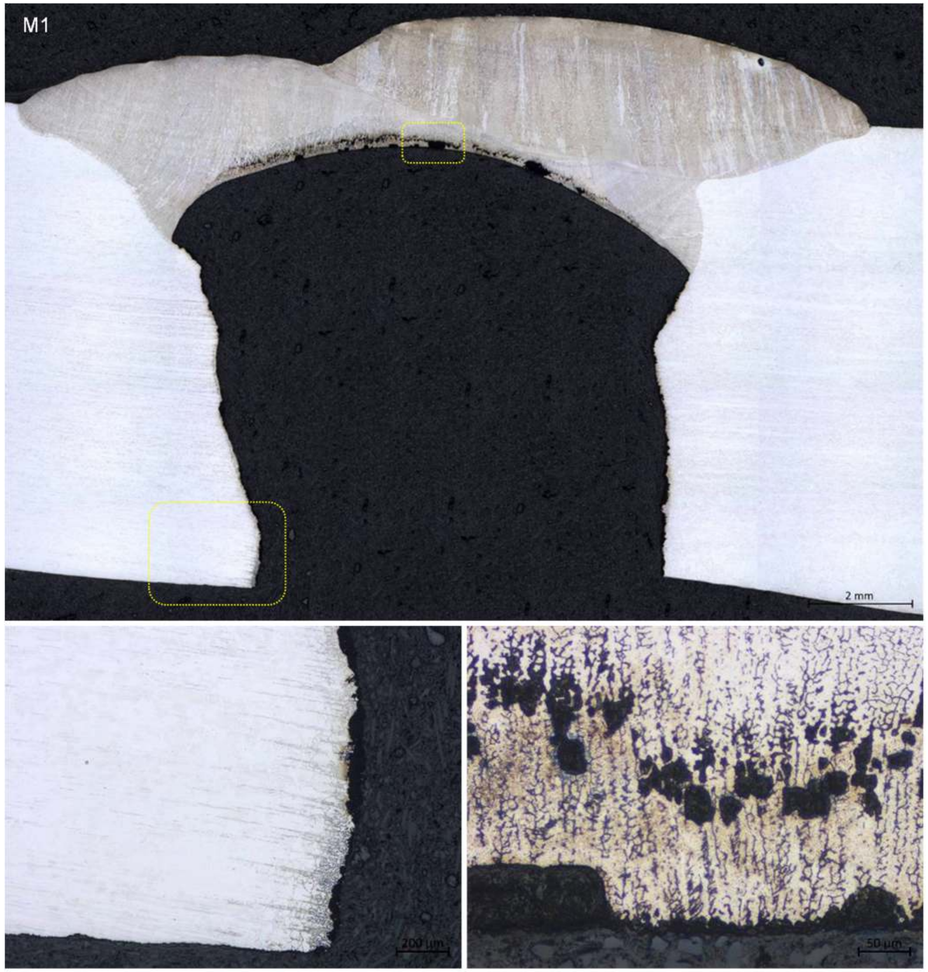




- Wrong filler metal → 304 type SS



	Si	Cr	Mn	Ni	Mo	Fe
Ultima passata	0,4	19	1,3	12	3,0	64
Zona centrale	0,5	18	1,5	10	0,7	69
Prima passata	0,5	18	1,6	10	1,3	69



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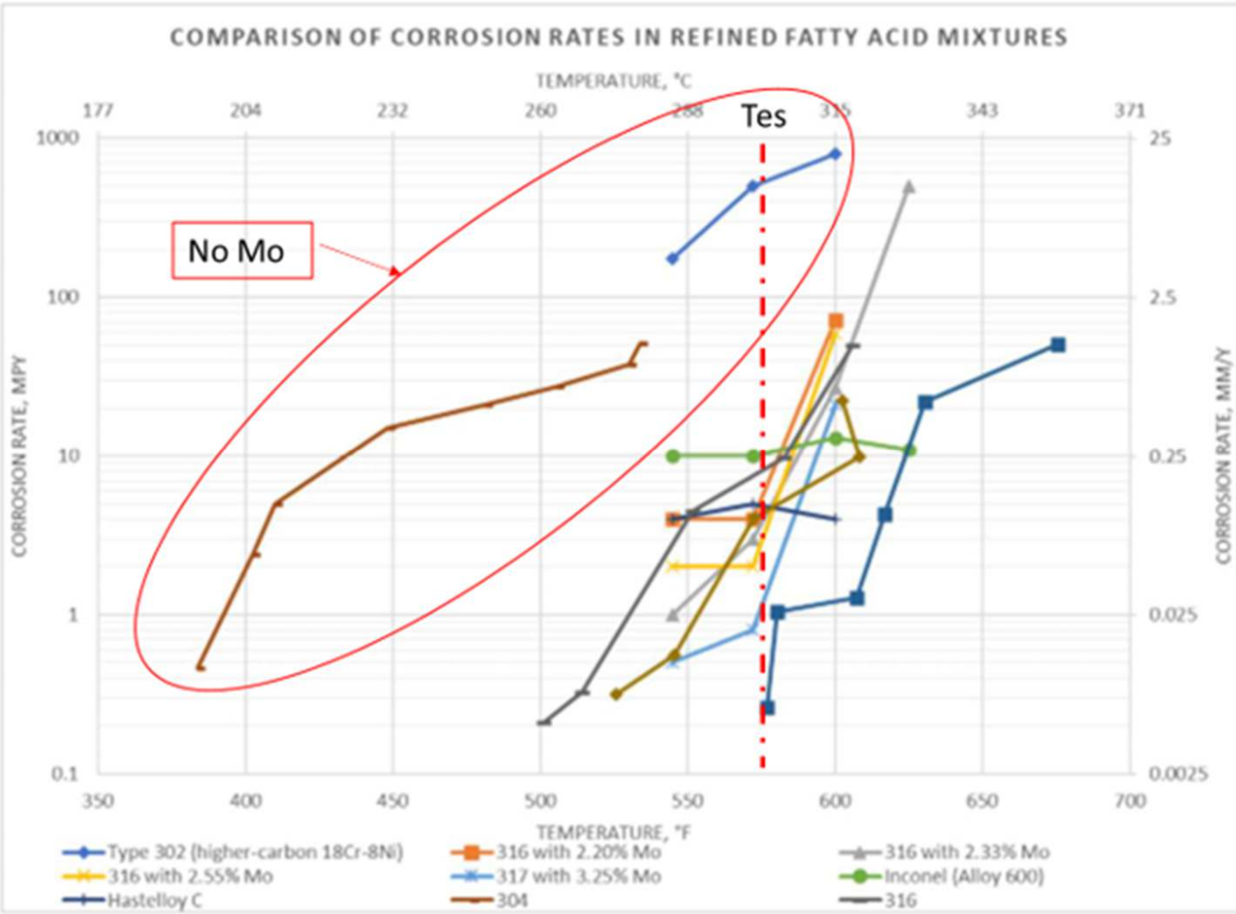
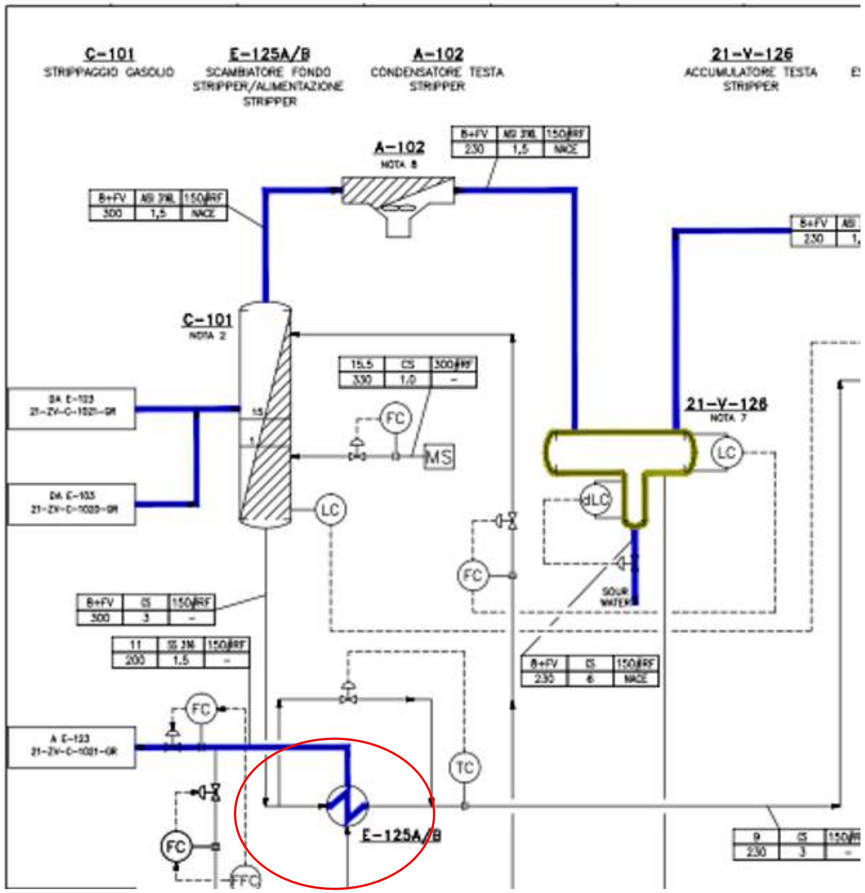
- **High temperature corrosion from organic acids (FFA?)**
- **Wrong Welding filler metal (304 SS) without Mo → less corrosion resistance**
- **Downstream H_2 injection → H_2 does not inhibit high T corrosion from organic acid → needs for Mo containing materials also with H_2**
- **In traditional refining H_2 injection inhibits NA corrosion**



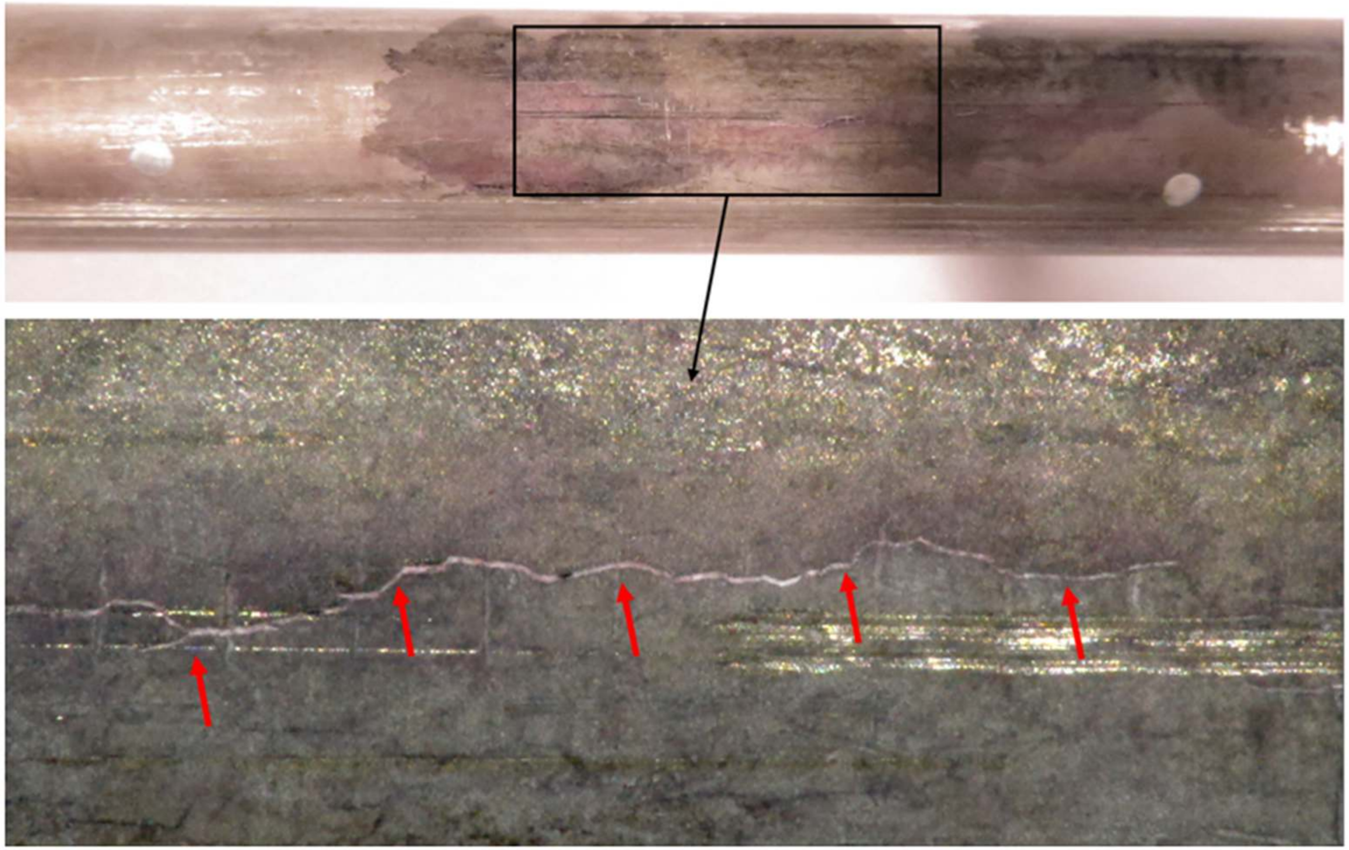
da Sutton, Kirkham, AMPP Corrosion Congress, 2022)

SCC on HX tube in Hydro-processing stripper section

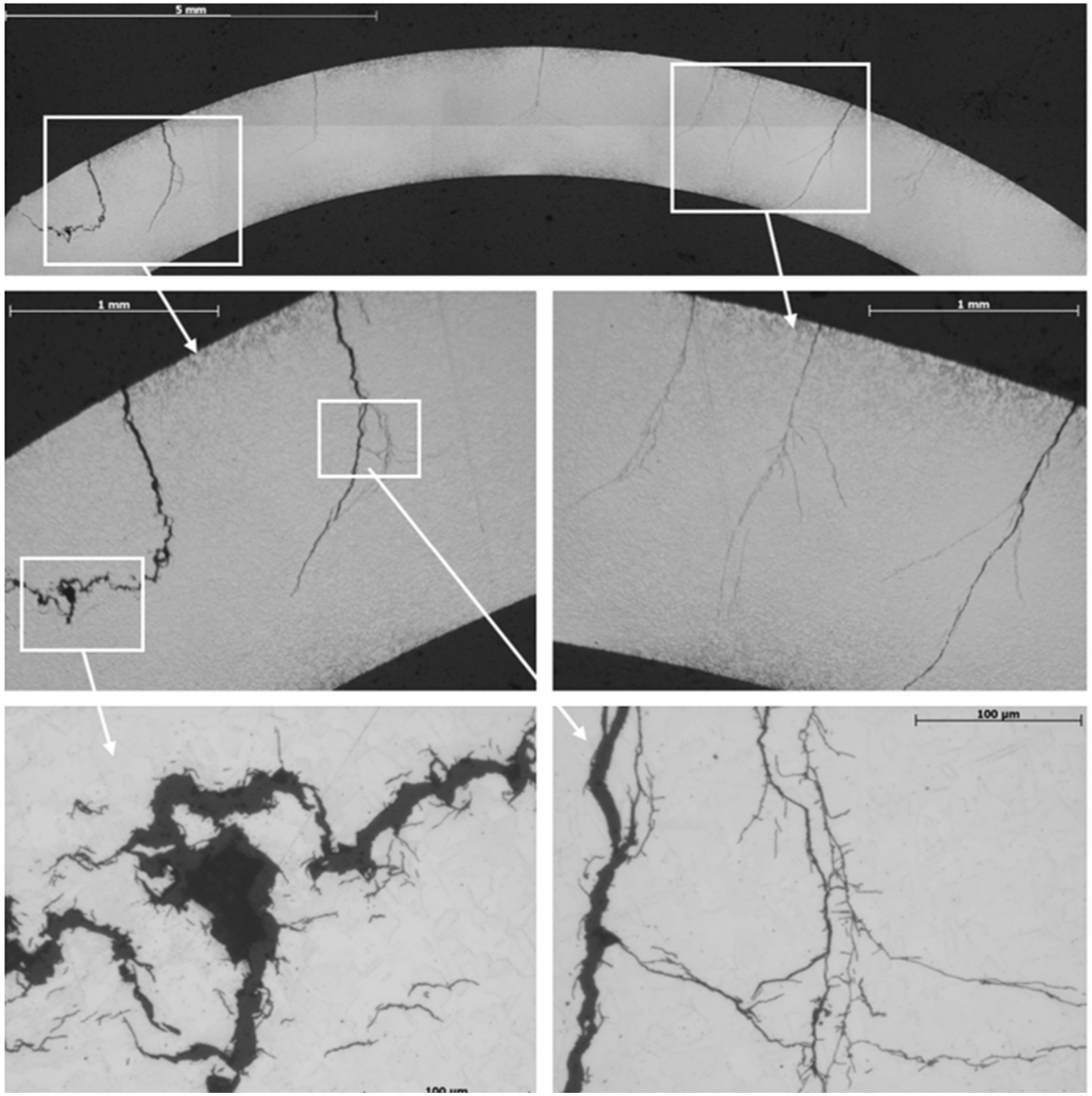
- Feed/bottom stripper heat exchanger
- **Shell side**
  - Feed to stripper from separator
  - T = 86 °C in - 138 °C out
  - P= 9 bar
- **Tube side**
  - Bottom from stripper
  - T = 201 – 167 °C
  - P= 4.75 bar
- Tube bundle material: **AISI 316 L**



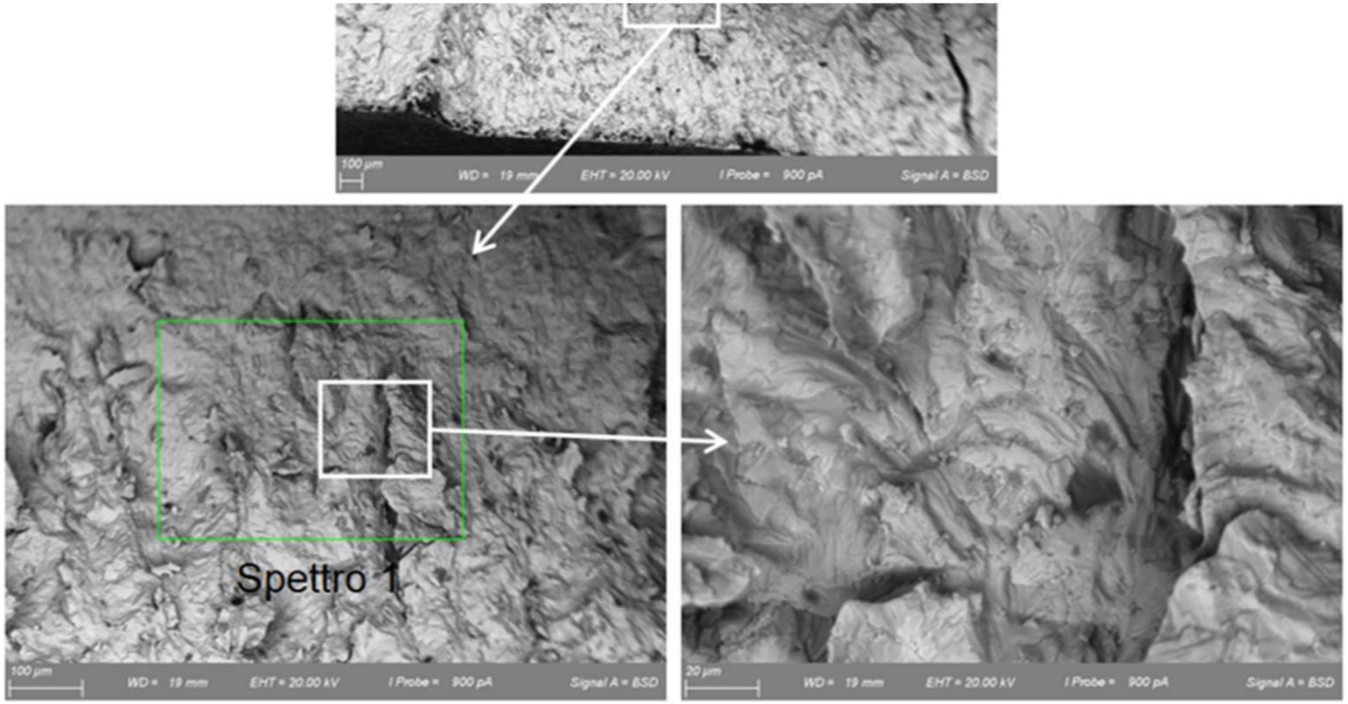
- External view of the failed tube

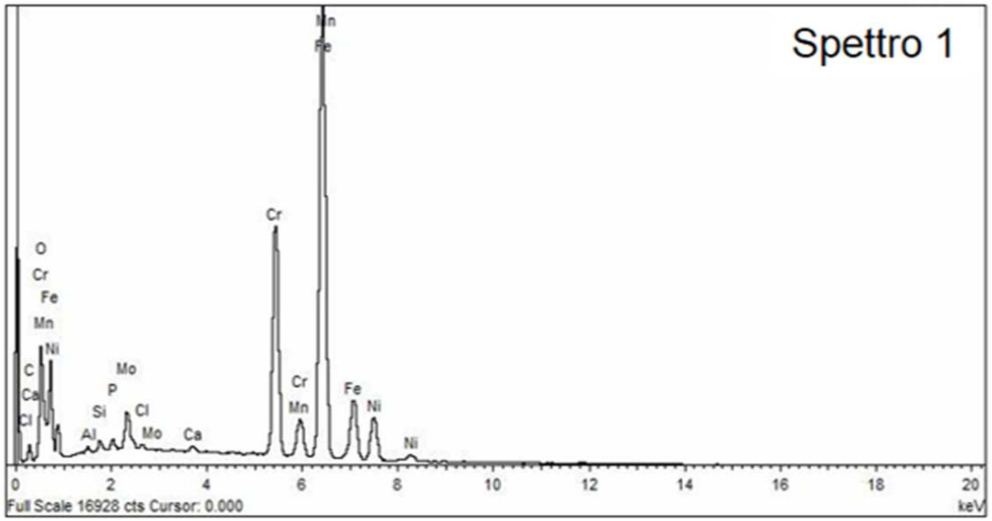


- Transversal section
- Branched transgranular cracks from outside (feed to stripper form separator)

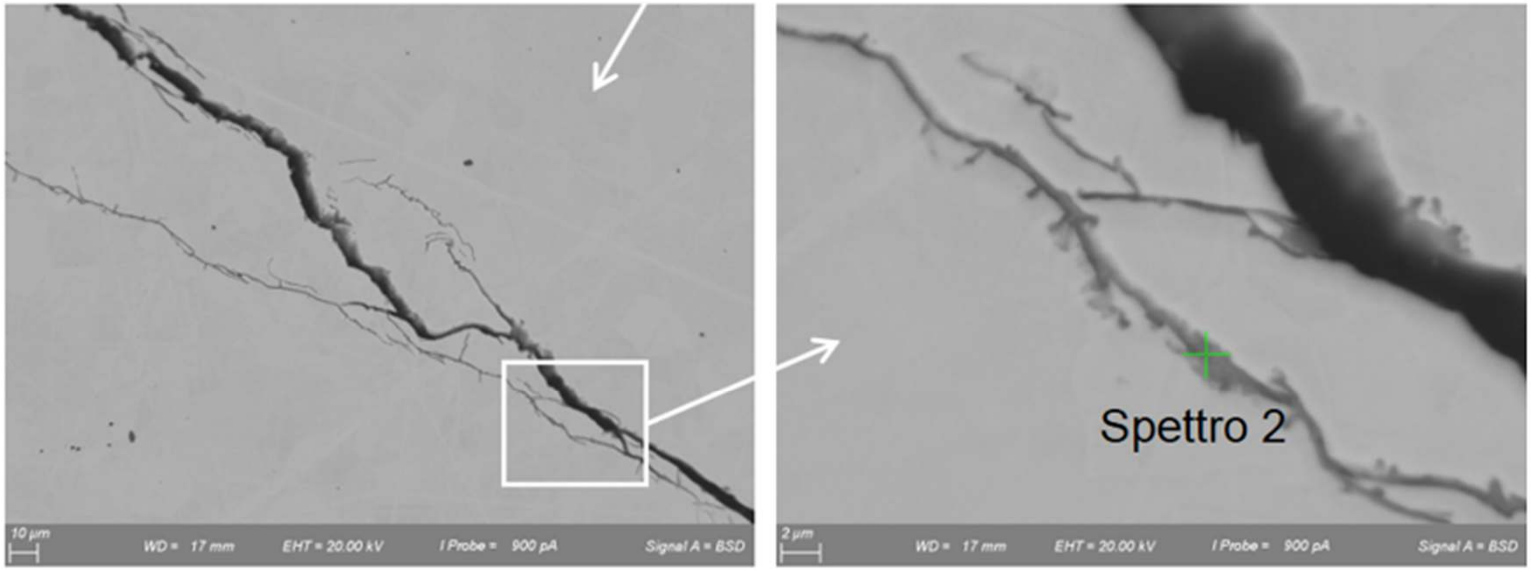


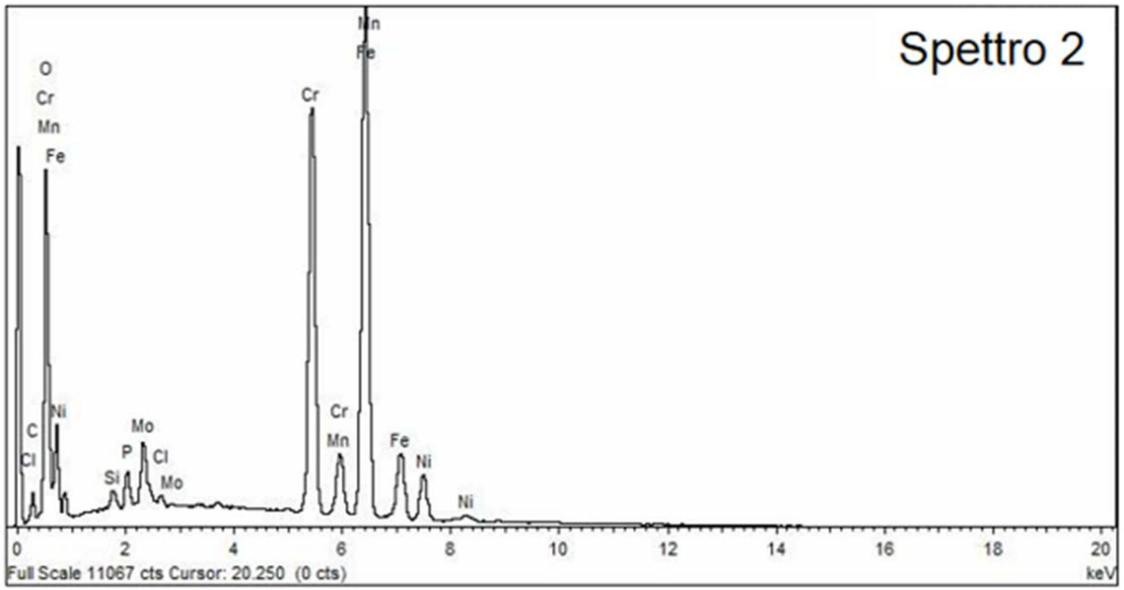
- SEM +EDS analysis



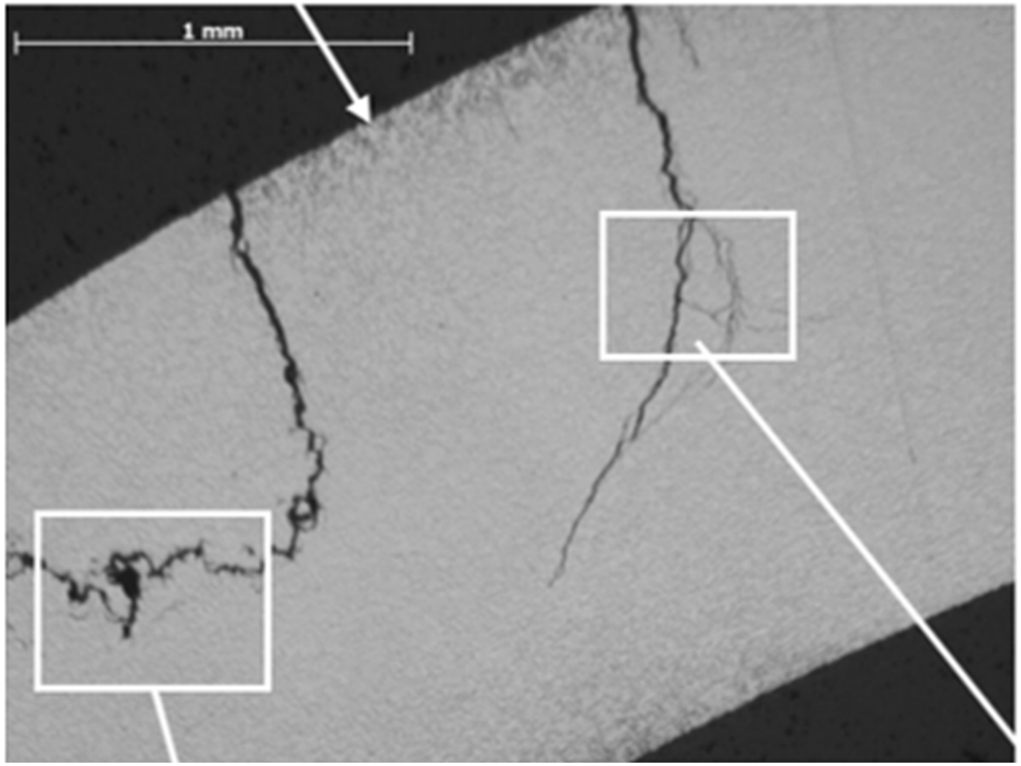


- SEM +EDS analysis inside the cracks





- Chlorides-SCC from external side
- Water +salts (Cl-) entrapped in products from separator
- Local heating and evaporation (salts concentration) on external side of tube due to heat flux form internal hot fluid
- → Materials selection!



Appendix 13

Solution to renewable processing challenges

(Alberto Ribes)

EFC WORKING PARTY 15 SPRING MEETING 2023

SOLUTIONS TO RENEWABLES PROCESSING CHALLENGES

March 30TH, 2023

ALBERTO RIBES
MARTIN VOSECKY
CHRIS CLAESEN

NALCO Water
An Ecolab Company

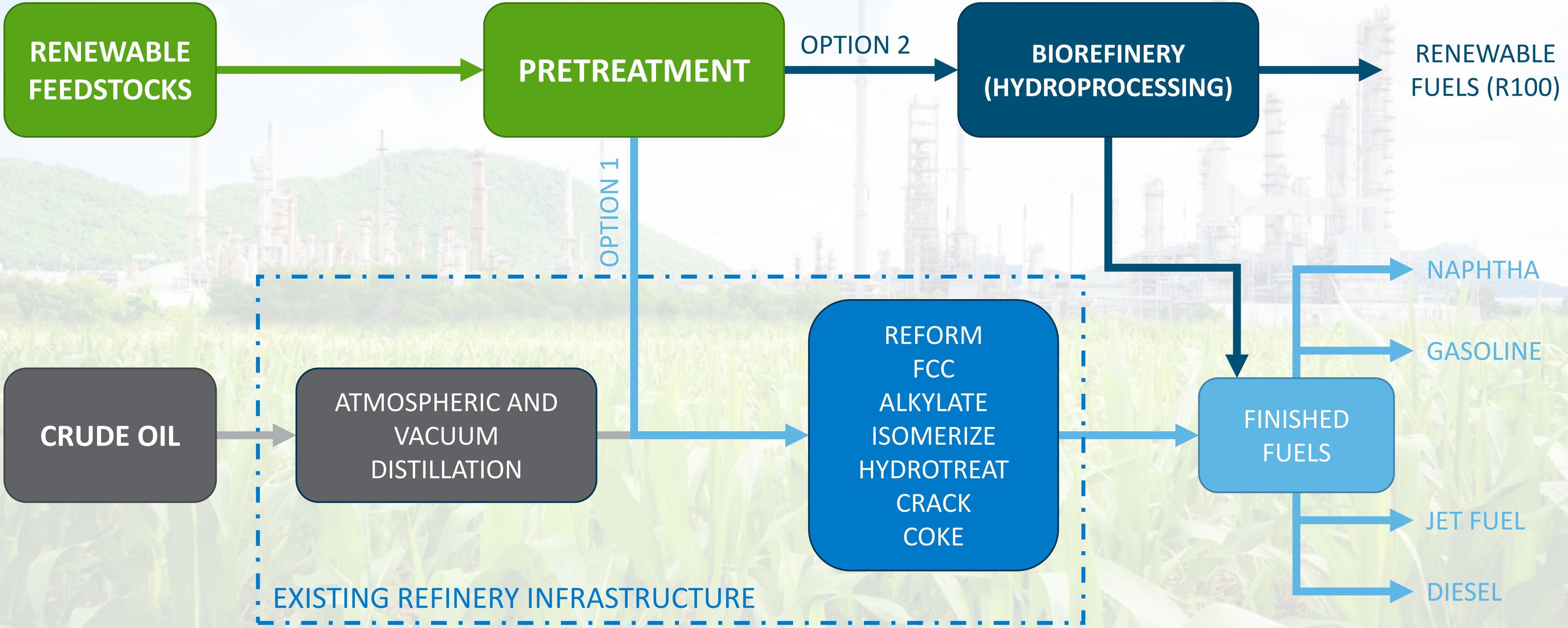
AGENDA

Solutions to renewables processing challenges

- Introduction
- Co-processing Challenges
- ACSCC
- Nalco Water Mitigation Strategy
- Q&A

INTRODUCTION

PRODUCTION PATHWAYS



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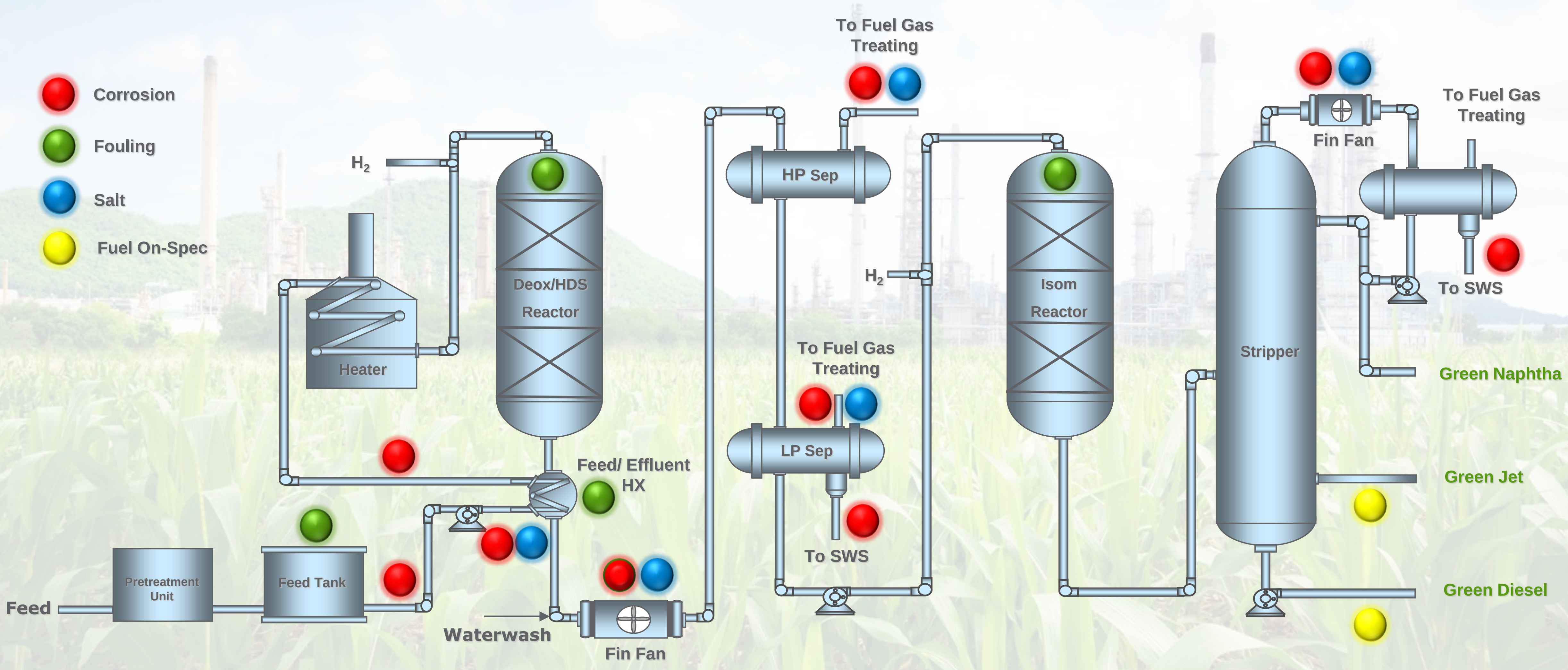
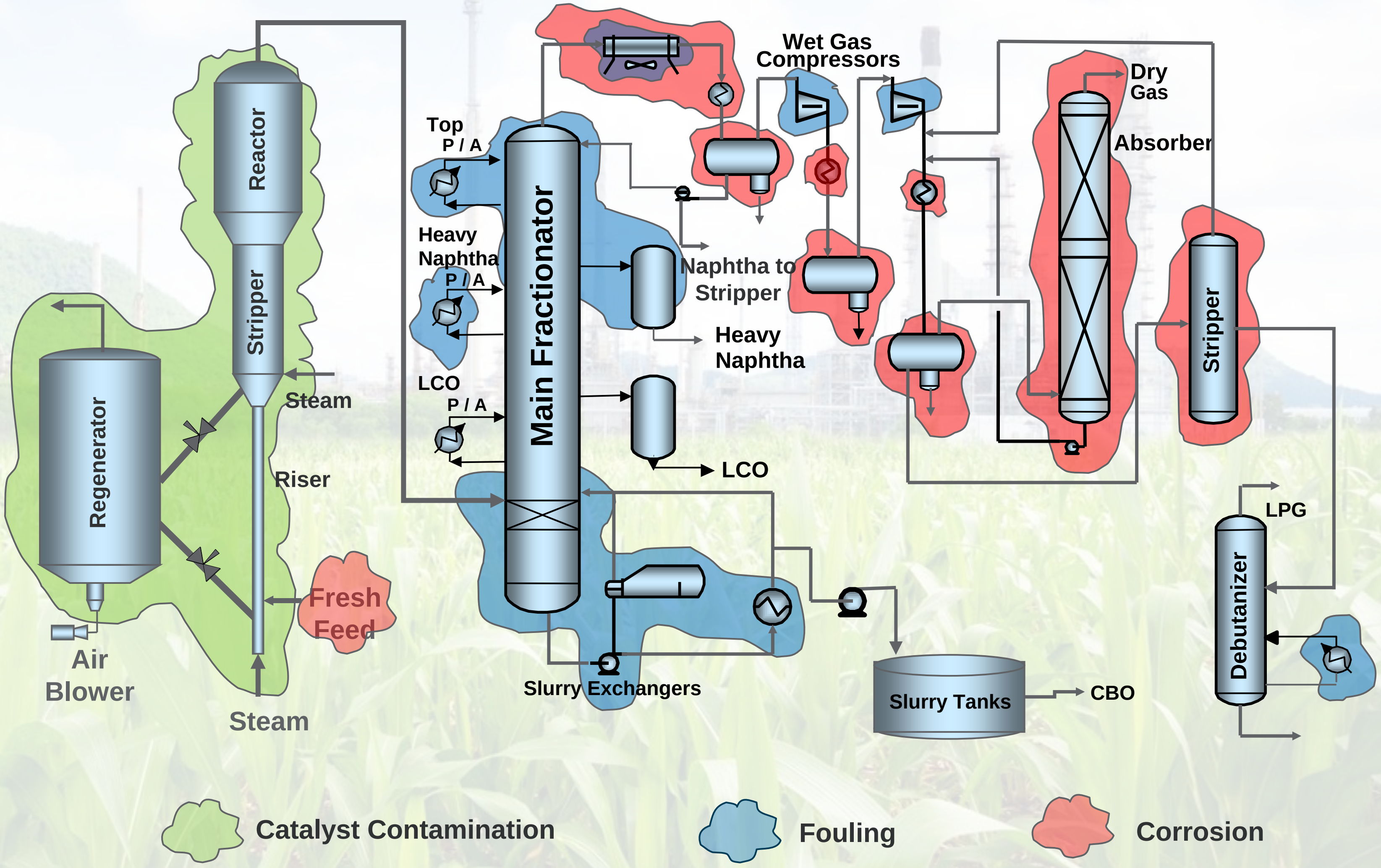
CO-PROCESSING CHALLENGES

POTENTIAL PROBLEM LOCATIONS IN HVO/CO-PROC UNITS



CO-PROCESSING BIOFEEDSTOCKS IN FCCU

- **Corrosion**
  - Carbonic Acid
  - ACSCC
  - TAN
  - HCN
- **Fouling**
  - Injection quill plugging
  - Heater Exchanger fouling
  - Fractionator Salting
  - SWS
- **Foaming**
  - SWS
  - Amine Unit

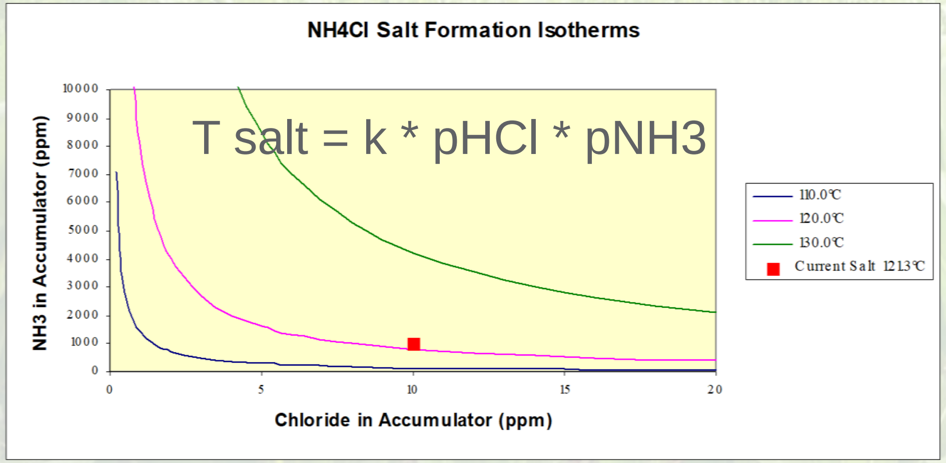


FEEDSTOCK CHALLENGES

STORAGE TANKS AND FEEDING LINES

- Bio-feedstocks, hygroscopic by nature, can be corrosive to carbon steel due to free acids and high-water content
- Biological activity can cause corrosion and fouling
- Potential for high oxygen content and absence of H_2S to passivate carbon steel
- Others: Pumpability issues depending on biofeedstock

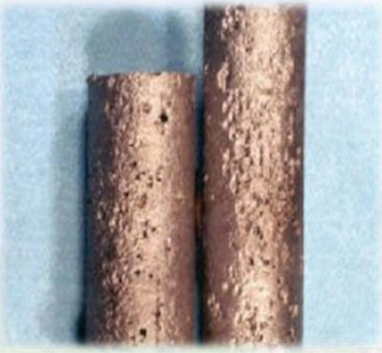
AMMONIUM CHLORIDE SALT RISK

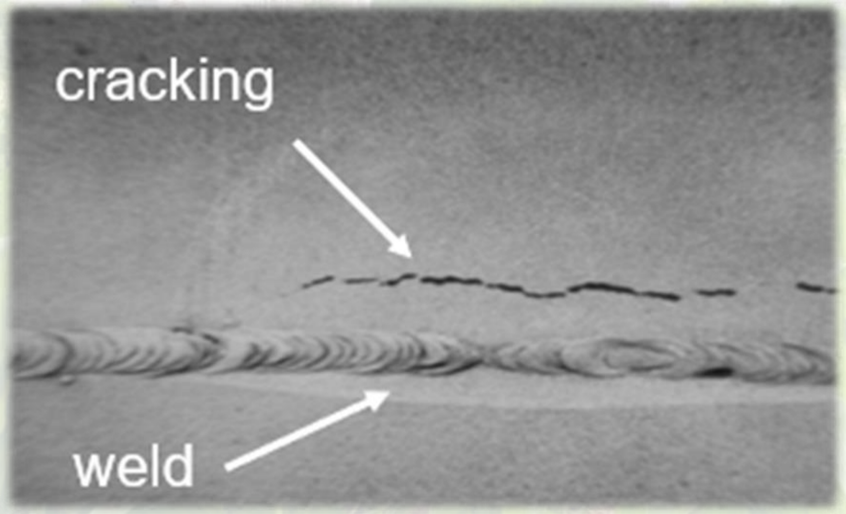


REACTOR EFFLUENT COOLERS

- Chloride content in 2nd Generation Feedstocks, (UCO, pyrolysis oil) can vary
- NH_3 content will be influenced by co-processing. Generally, there will be less N in bio feedstocks
- The presence of H_2O leads to a concentrated salt solution
- Aggressive localized attack results
- [N] and [Cl] monitoring is needed in feed and sour waters.
  - NH_4Cl formation potential and water dewpoint needs to be simulated and monitored.
- Water-wash location and quantity may need to be adjusted
- **Salt Dispersant application**

AQUEOUS CORROSION AND ALKALINE CARBONATE SCC





SEPARATORS & STRIPPER OVERHEADS

- Decarbonisation reactions can lead to high CO_2 content
- Low pH corrosion due to CO_2
- With co-processing and high pH, risk for carbonate stress corrosion cracking increases
- Depending on feedstock and water wash operation potential chloride presence leads to NH_4Cl formation

ALKALINE CARBONATE STRESS CORROSION CRACKING

ALKALINE CARBONATE STRESS CORROSION CRACKING

OBJECTIVES

Purpose was to determine the performance of filming corrosion inhibitors in mitigating Alkaline Carbonate Stress Corrosion Cracking (ACSCC).

A reproducible testing to evaluate the relative performance of selected inhibitors for controlling ACSCC under simulated process conditions.

The test work should demonstrate whether these inhibitors can be utilized as part of risk mitigation strategy against ACSCC in affected refinery process units.

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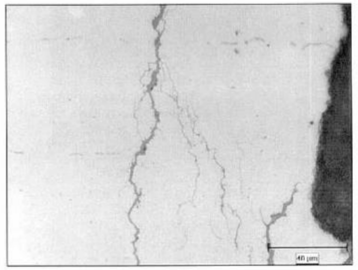
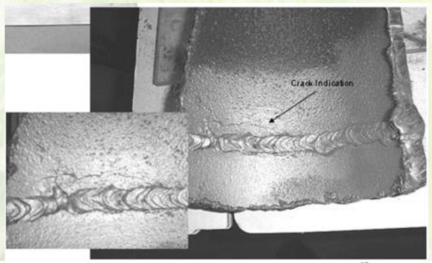


Photomicrograph illustrating the cracks visible on the inside surface. Note the branching propagation (unetched—magnification 500X).



Photographs of as-received 4 in (100 mm) diameter ASTM A 53[16] Grade B pipe from the reflux line on the main fractionator (top left); cracks on inner surface after abrasive blasting and application of dye penetrant (bottom right); and closeup of crack (bottom center). Installed in 1952 (52 years of service).

ACSCC presents itself under the combined set of conditions:

- **MATERIAL:** Carbon Steel
- **STRESS:** Non-stress relived areas with high levels of residual stress
- **ENVIRONMENT:** Presence of an aqueous alkaline carbonate containing environment

Source: NACE Publication 34108, pp. 20 & 23, NACE International, 2008.

ALKALINE CARBONATE STRESS CORROSION CRACKING

- The sour water conditions have been the subject of several papers & industry guideline documents (API 581 & NACE 34108).
- API 581 sets out the following sets of sour water conditions needed for ACSCC to occur:

pH of Water	Susceptibility to Cracking As a Function of CO_3 Concentration in Water [1]		
	PWHT, Possible Cold Working	No PWHT, Possible Cold Working	
	CO_3 All Concentrations	$CO_3 < 100$ ppm	$CO_3 \geq 100$ ppm
<7.5	None	None	None
≥7.5 to 8.0	None	Low	Medium
≥8.0 to 9.0	None	Low	High
≥9.0	None	High	High

NOTE 1 Traditional alkalinity titration methods (P,M alkalinity) are not effective for measurement of CO_3 in sour water.

Source: API Recommended Practice 581, pp. 2-68, Third edition 2016, Addendum 1 2019, API, 2019.

- Feed quality may also impact: The lower the sulphur and the higher the nitrogen in feed the higher the susceptibility to ACSCC.

NALCO WATER MITIGATION STRATEGY

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AQUEOUS CORROSION MITIGATION

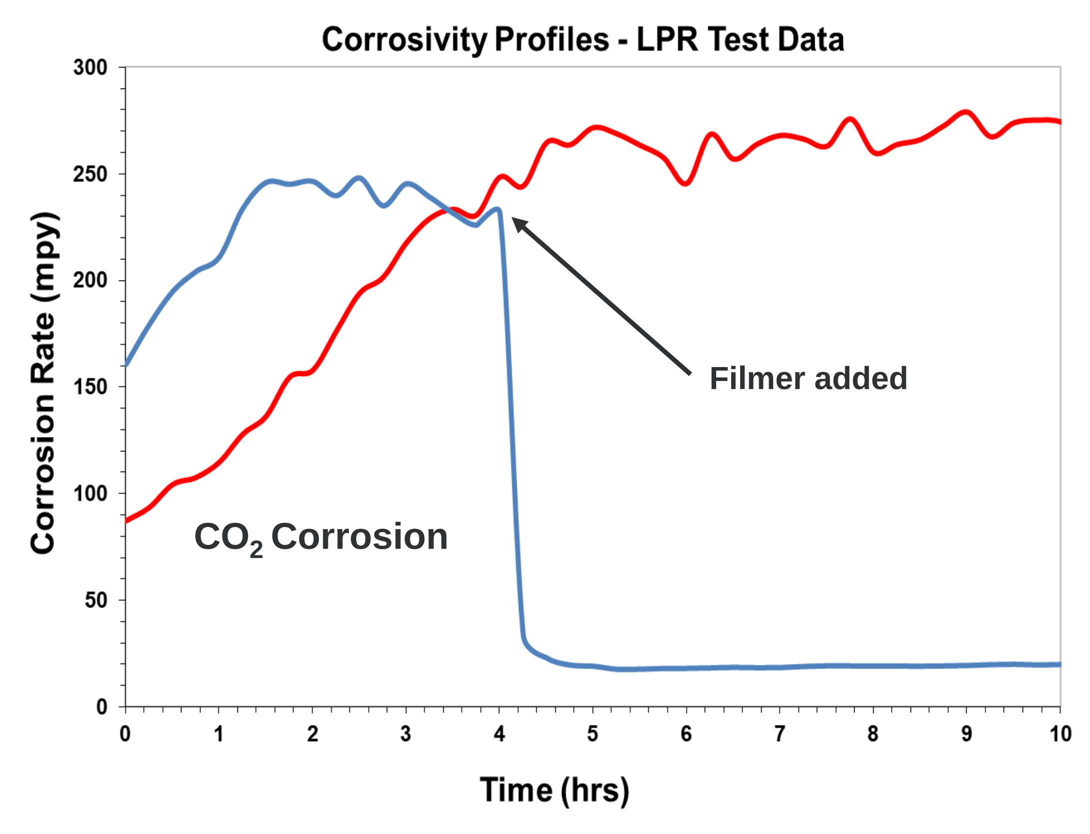
Aqueous corrosion risks:

- Water and CO_2 generation
- Chloride content
- Lower H_2S compared to traditional refining conditions

NALCO Water mitigating strategy:

- **Process condition simulation**
- **Corrosion Monitoring**
- **Chemical Solutions:**
  - **Corrosion Inhibitor (Filmer)**
  - **Corrosion Inhibitor (Neutraliser)**

PATHFINDER®



FEED SIDE HIGH TEMPERATURE CORROSION

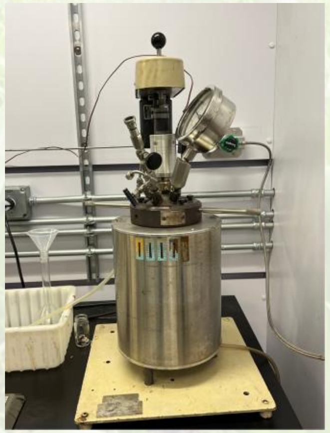
High temperature corrosion risks:

- Type of feedstock
- TAN content
- Temperature
- Metallurgy
- Operating conditions

NALCO Water mitigating strategy:

- **Conducting Risk Assessment**
- **Design: solution and monitoring**
- **Implementation and Follow-up**
- **Retro-feedback and value communication**

Properties	Crude Tall Oil	RDB Soybean Oil	Tallow	Palm Oil
TAN (mg KOH/g)	> 130	< 0.1	16	7
Sulfur (ppm)	2100	< 6	93	< 10
Nickel (Ni) (ppm)	20	1	0.126	< 0.5
Vanadium (ppm)	70	0.1	<0.018	<10
ASTM Solids (Lbs / 1000 bbls)	1	< 1	< 1	140
Bromine number (Cg Br/g)	70	58	36	21

ALKALINE CARBONATE STRESS CORROSION CRACKING

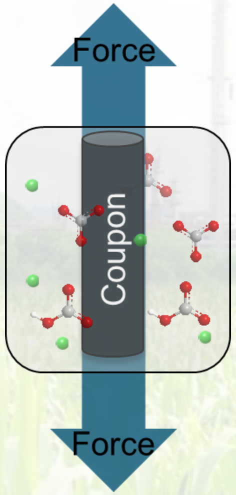
Areas of risks:

- Elevated CO_2 levels in overhead
- Alkaline pH

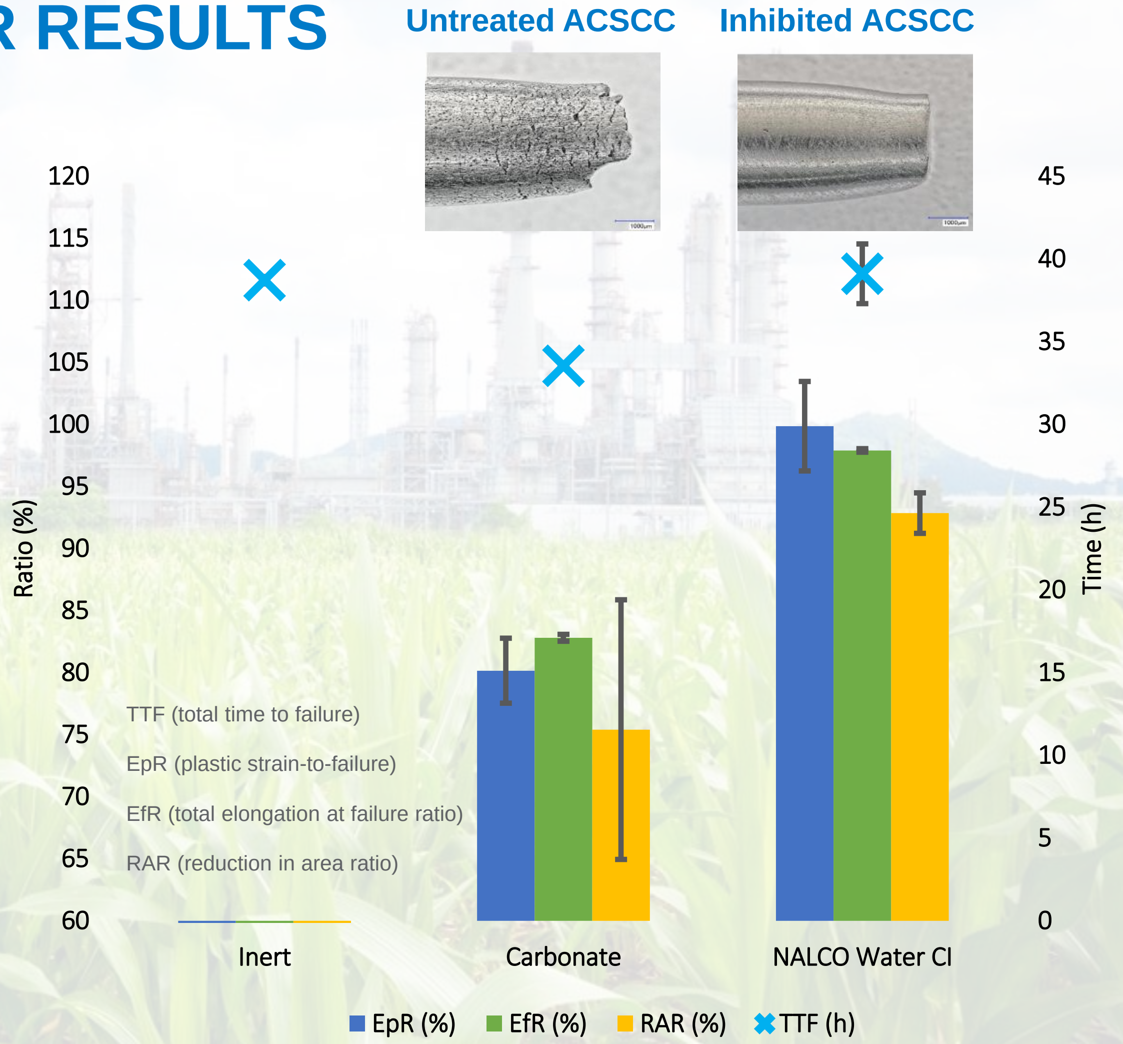
NALCO Water mitigating strategy:

- **Corrosion Inhibitor for ACSCC**

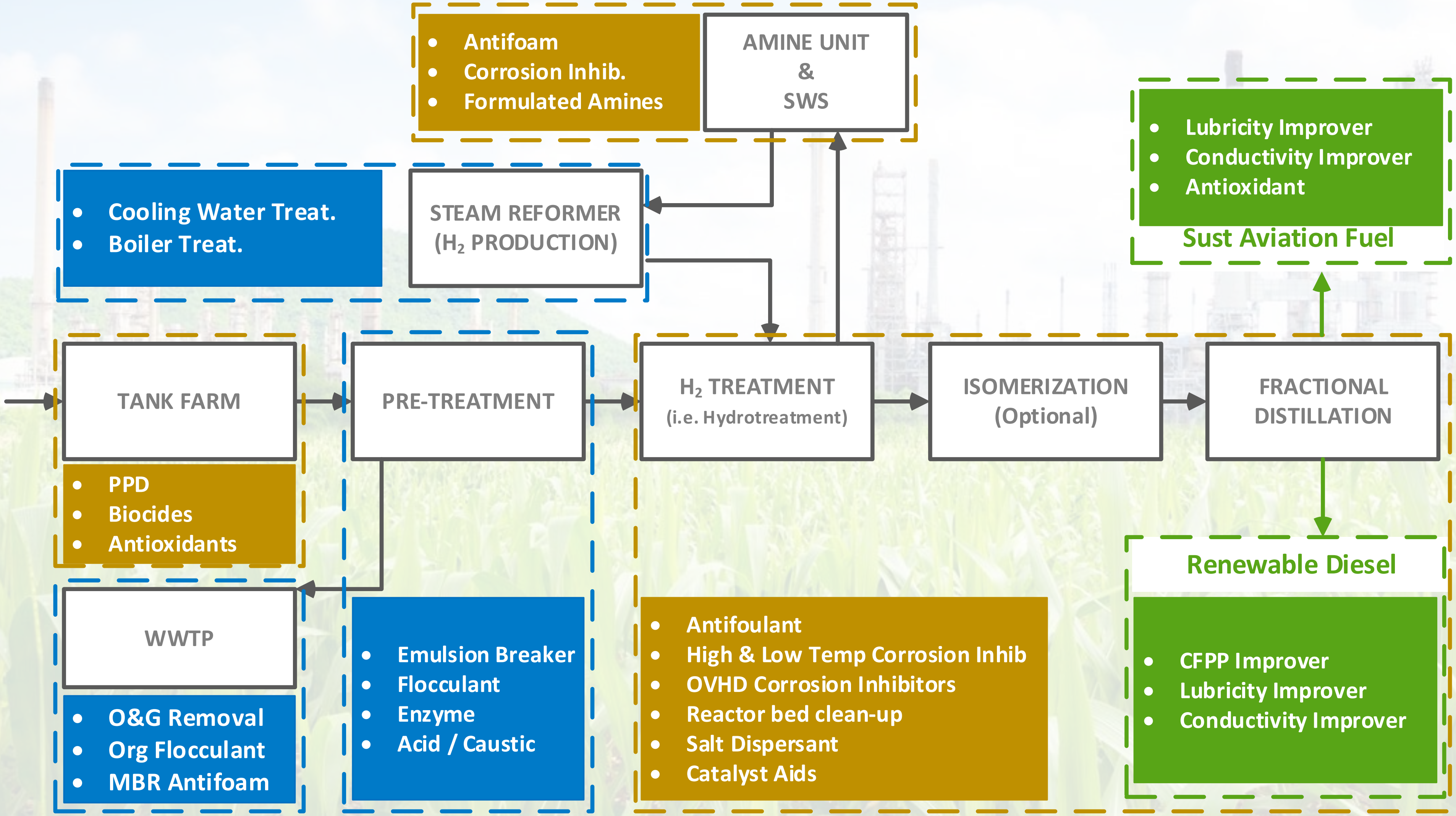
  New patent-filed technology that outperforms existing offering



SSR RESULTS



HOLISTIC SOLUTION BIOFEEDSTOCK



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QUESTIONS & ANSWERS

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Appendix 14

Bio oils / vegetable oils hydroprocessing, possible impacts on corrosion

(Joan de la Paz)

Bio-Oils/Vegetable oils Hydroprocessing, possible impacts on corrosion

Baker Hughes

Summary

- Hydrotreating of vegetable/bio-oils, either alone or in blend with gasoil generates oxygenated by products after the reactor, mainly CO_2 at > 1 wt% levels.
- Water is produced by deoxygenation at high percentages by weight due to deoxygenation
- Carbon monoxide and acetic acid are produced too but at much lower levels (CO_2:CO is 6:1 to 3:1 wt% ratio), acetic acid is likely less than 100 ppm
- Removal of carboxylic acidity at normal hydrotreating conditions is practically very high > 90-95%
- Vegetable oils triglycerides thermal cracking produce higher content of free fatty acids and TAN upstream the hydrotreater. The reaction is above 310°C
- Carboxylic acids content and TAN decrease starting at 220-250°C but reaction is slow. Decarboxylation is accelerated by magnesium

Summary

- Reported data from literature show no napthenic corrosion during processing of pure vegetable oils (TAN >10, no sulphur) with austenitic steels metallurgy suited for napthenic acids (AISI 316 or better 317L) even with high content of free fatty acids
- There is much less know how on naphtenic corrosion of blends of gasoil (sulphur, TAN) with high TAN/high free fatty acids. UOP anyway suggests that this metallurgy is safe also for co-processing gasoil with bio-oils at hydrotreaters
- Most vegetable oils have free fatty acids in the range of C16-C18. These are from literature low in corrosion rates at napthenic attack temperatures
- Napthenic iron carboxylates decompose starting from 220-250°C to give ketones. These ketones can generate partially protective as they generate magnetite
- Solubility of free fatty acids, their dimer structure vs temperature and solubility of iron carboxylates have a role on the different corrosivity of nap acids

Renewable Diesel Overview – Biomass to Bio-Oils

Feedstocks
Crops
Agriculture byproducts
Algal biomass
Forestry byproducts
Municipal waste

→

Fast Pyrolysis
Non-Catalytic
Catalytic

↑

Fuel gas
Hydrogen
Methane
Carbon monoxide

↓

Bio-Char
Charcoal
Soil improver
Activated carbon
Gunpowder

→

Bio-Oil

Alcohols
Aldehydes/Ketones
Carboxylic Acids/Esters
Furans/Pyrans
Mono-saccharides
Anhydrosugars
Water (15-20%)

↓

WWTP

Heating Oil

Further Processing
Hydrotreating
Fractionation
Isom/Reforming
Hydrocracking

↓

Renewable fuels
Diesel
Aviation*
Gasoline*
Petrochemicals Feed

Baker Hughes

Hydrotreating of fatty acids, reactions

Reactions:

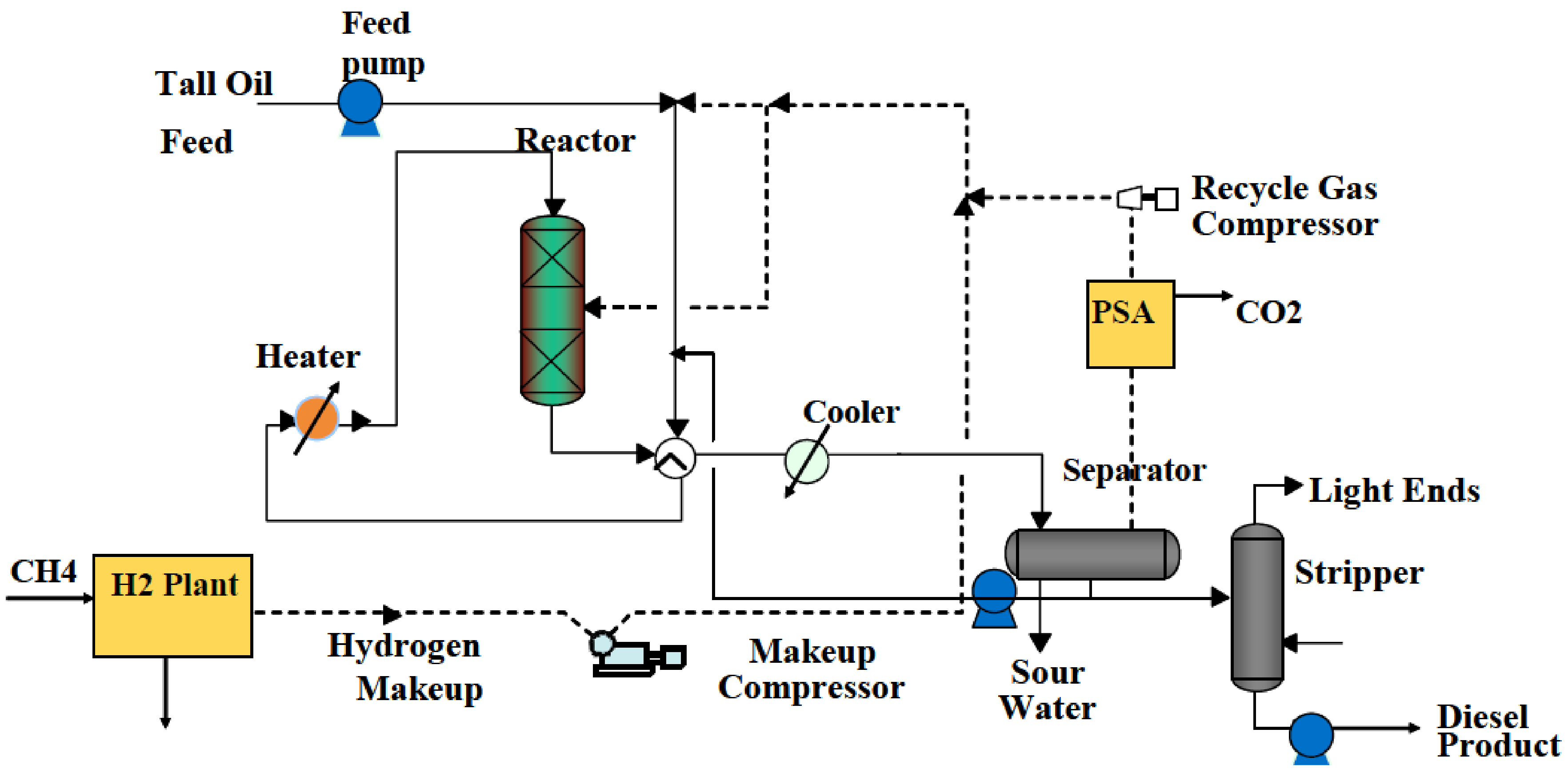
- Hydrogenation of fatty acids as first step
- Deoxygenation as rate limiting step
- Hydrodeoxygenation and hydrodecarboxylation are fast starting from 340C
- Hydrodecarboxylation is favored at higher temperatures
- Hydrogen pressure increase favors hydrodeoxygenation over hydrodecarboxylation

Baker Hughes

Typical biodiesel hydrotreating unit

- Hydrotreating plant scheme

One possible flow scheme for a standalone unit is shown in Figure 14.



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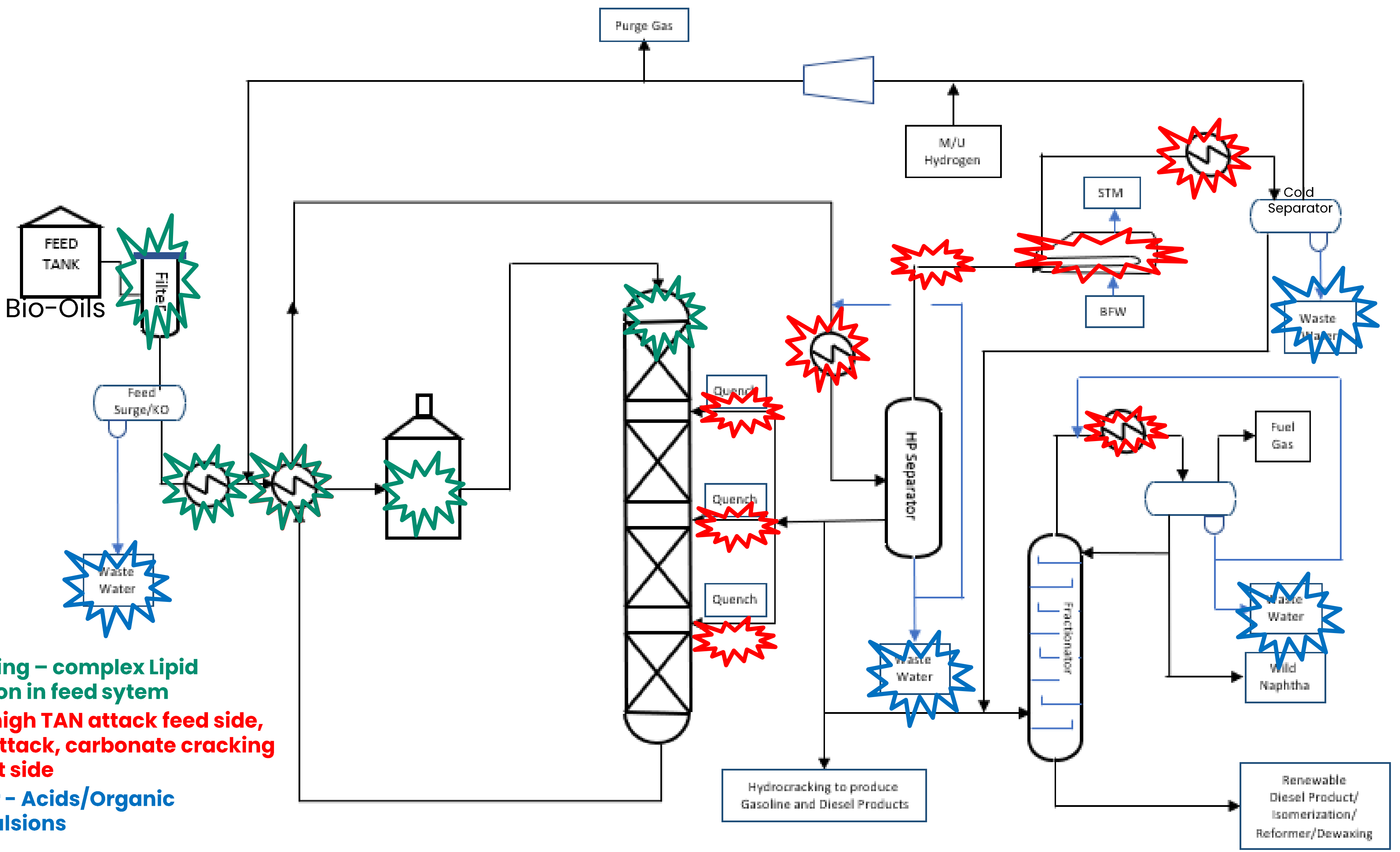
Concern Areas in Renewable Diesel Plant



Organic Fouling – complex Lipid Polymerization in feed sytem

Corrosion – high TAN attack feed side, low pH CO_2 attack, carbonate cracking on Rx effluent side

Waste Water - Acids/Organic Loading, Emulsions

Renewable Diesel Chemical Impacts

1. **Pretreatment, Filtration, Centrifuge Aids**
   a. Acidification
   b. Waste reduction
      i. Solid waste from centrifuge, cyclone
      ii. Filter waste

2. **Oil-Water-Solids Separation**
   a. Pretreatment in tankage for emulsion
   b. Primary demulsifiers
   c. Reverse demulsifiers

3. **Fouling Control**
   a. Organics dispersants
   b. Antioxidants/Antipolymerants

4. **Foam Control**
   a. Antifoams

4. **Corrosion Control**
   a. Inhibitors, neutralizers for aqueous acidic corrosion due to CO_2 and light carboxylic acids
   b. Inhibitors for high temperature corrosion due to fatty acids
   c. Water Wash Design
   d. Carbonate SCC risk analysis

5. **Water Treatment**
   a. Flocculants, Coagulants
   b. Macro-nutrients management (N, P)
   c. pH Adjustment
   d. Antifoams

6. **Finished Fuel Quality**
   a. Conductivity
   b. Lubricity
   c. Dehazer

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Potential Corrosion Damage Mechanisms

Naphthenic Acid Corrosion

- TAN
  - Traditional feedstocks ranges up to ~4 mg KOH/g sample
  - Renewable feeds typically >20 mg KOH/g sample due to presence of free fatty acids
- Unknowns
  - Same risk as traditional Nap acids?
  - Benefit of hydrogen addition?
- Mitigation
  - Design w/corrosion resistant alloy
  - High temperature corrosion Inhibitors an option

Aqueous Acidic Corrosion

- High CO_2 leads to low pH in water streams
- Mitigation
  - Neutralizer to adjust pH
  - Corrosion inhibitor (filming amines) to protect surfaces

Impact of chloride in feed

- Chloride can be present as HCl in H_2 feed
- Metal chlorides may also be in some feedstocks
  - Metal chlorides hydrolyze to form HCl
  - High acidity increase hydrolysis of metal chlorides
- HCl Increases aqueous acidic corrosion risk and poses risk of neutralizer salt deposition, undersalt corrosion
- Aqueous chloride raise risk of chloride stress corrosion cracking if austenitic stainless steel in use
- Assessment and Mitigation
  - Ionic Model to assess risk
  - Neutralizer selection (TOPGUARD Ionic Model)
  - Water wash (TOPGUARD Spray Model)
  - Metallurgy selection

Carbonate Stress Corrosion Cracking:

- High CO_2 leads to increase in CO_3^{-2} in water streams
- Assessment and Mitigation
  - Ionic Model to assess risk
  - Post weld heat treating
  - Addition of low CO_3^{-2} wash water (dilution)

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Appendix 15

Update on RISE member program: MRC corrosion in biorefinery production

(Rikard Norling)

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Update on RISE member program: MRC Corrosion in Biorefinery Production

EFC WP15 Meeting

Rikard Norling

30 March 2023

Corrosion within RISE– more than 100 specialists

RISE – Dept. Corrosion

Sweden - 58 employees

Stockholm
43 employees

Borås
15 employees

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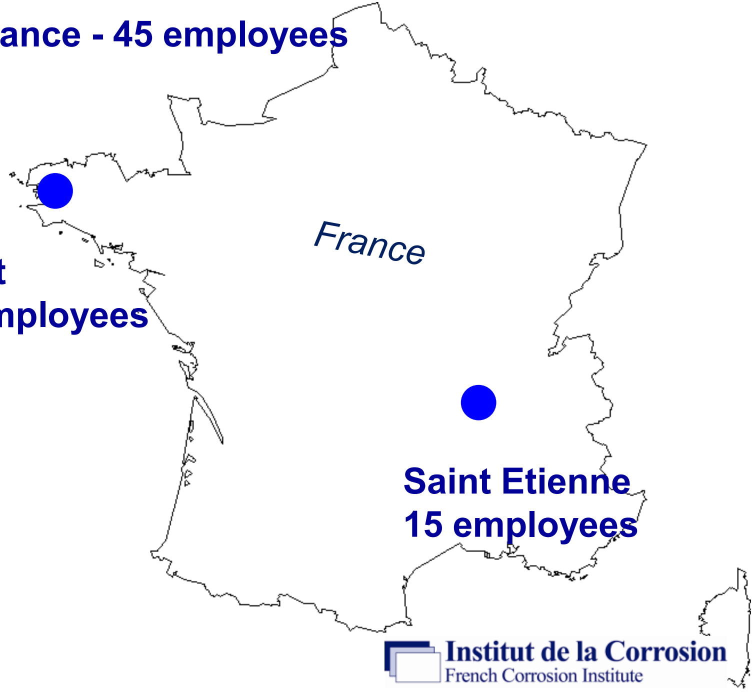
France - 45 employees



Brest
29 employees

Saint Etienne
15 employees

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Member programs within corrosion

(MRC – Member Research Consortium)

- Automotive corrosion
- Surface technology
- Corrosion protection
- Corrosion in pulp & paper industry
- Corrosion of polymer materials
- Brass Alloys

MRC in Sweden

- Corrosion and cathodic protection in soil
- **Corrosion in Biorefinery Production**

MRC in France

- Aerospace
- Coil coating
- Corrosion in oil & gas production
- Corrosion off-shore
- Paints and linings for steel structures
- Hydrogen

Our member programs are not closed consortia, they remain open to new members.

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Actions

- Researchers
- Scientists
- Material producers
- Biorefinery plant operators

https://www.ri.se/en/what-we-do/networks/mrc-biorefinery

MRC on Corrosion in Biorefinery Production

Based on scientific research, as well as strong collaboration among key players in biorefinery production, including plant operators, material producers, and experts on materials and corrosion, Member Research Consortium (MRC) Corrosion in Biorefinery Production will help its members with corrosion issues.

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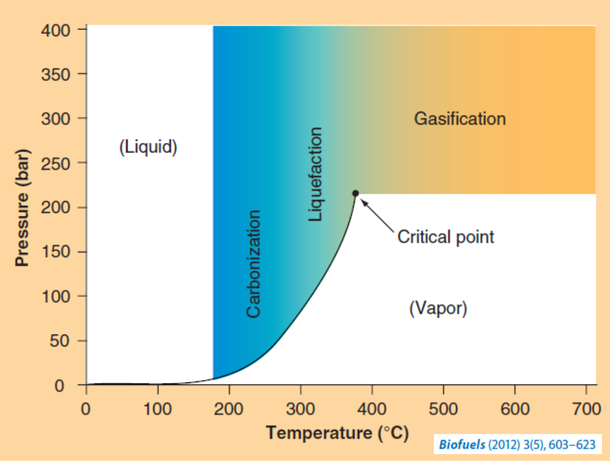
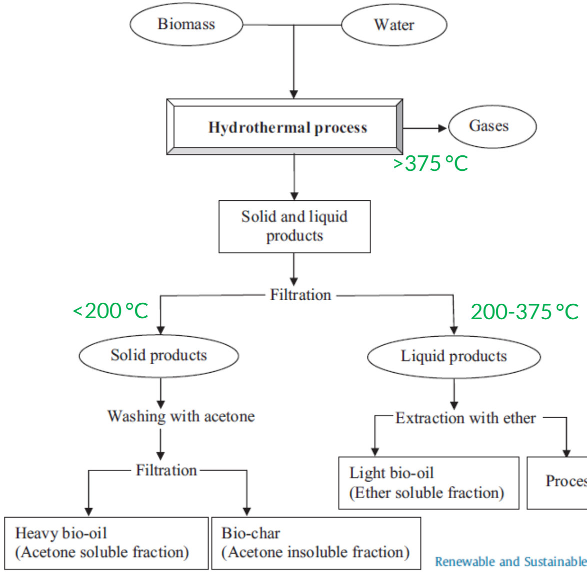
Completed work

- Experimental tests based on a literature study
- Temperature
  - Hydrothermal carbonization: 200 °C, 15 bar
  - Hydrothermal liquefaction: 300 °C, 90 bar
- Additive
  - HCl pH 3
- Exposure time
  - 500 h





Renewable and Sustainable Energy Reviews 40 (2014) 673–687

Corrosion resistant alloys

– nominal composition

Alloys/ Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N	PREN
654 SMO	0.01		3.5			24	22	7.3	0.50	0.50	56
Sanicro® 35	≤0.030	≤0.5	0.8	≤0.030	≤0.020	27	35	6.5	0.2	0.3	53
Alloy 625	0.10	0.50	0.50	0.015	0.015	20-23	≥58	8-10	-	-	52
254 SMO	0.01					20	18	6.1	0.71	0.2	43
Sanicro® 28	≤0.020	≤0.7	≤2.0	≤0.020	≤0.010	27	31	3.5	1.0	≤0.1	40
316L	0.02					17.2	10.1	2.1	-		24

<u>P</u>itting <u>R</u>esistance <u>E</u>quivalent <u>N</u>umber = Cr + 3.3Mo + 16N

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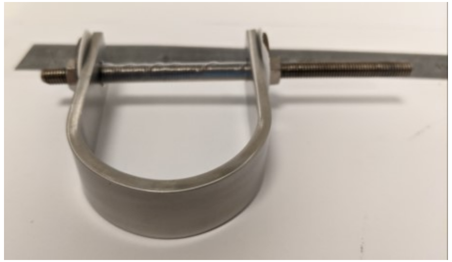
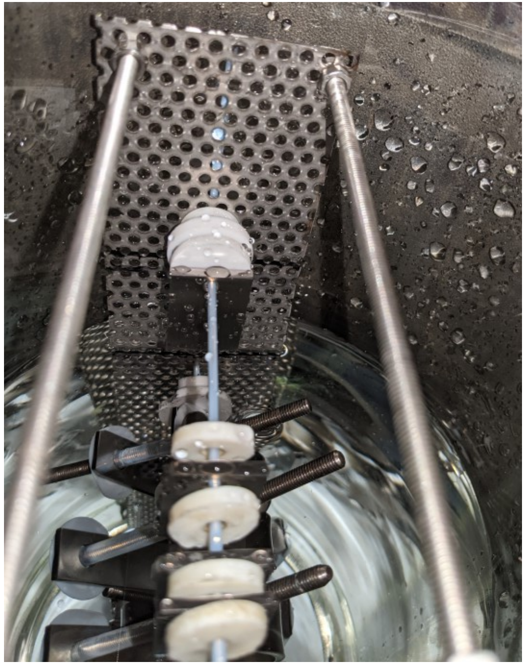
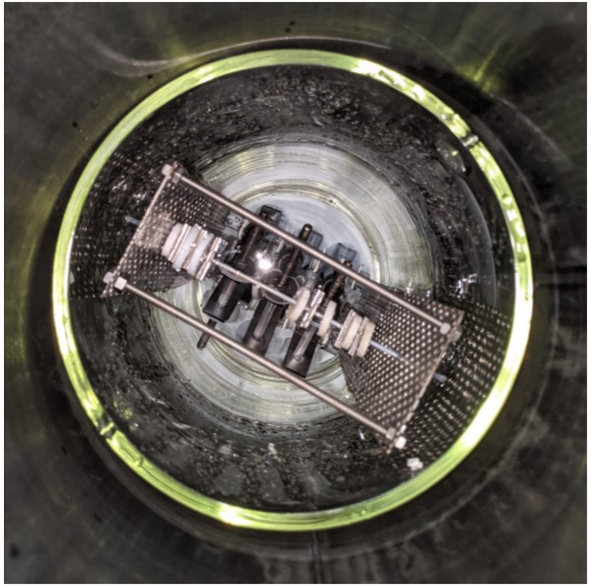
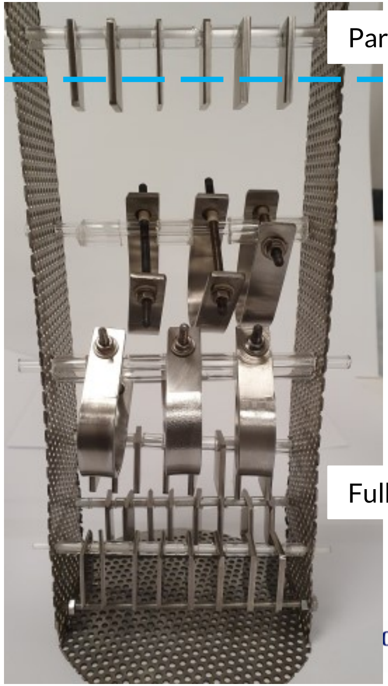
Testing conditions









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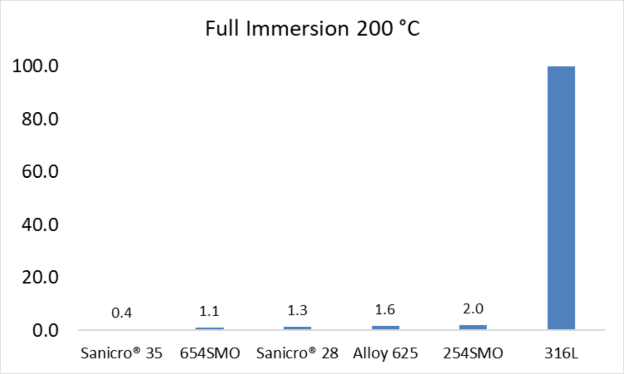
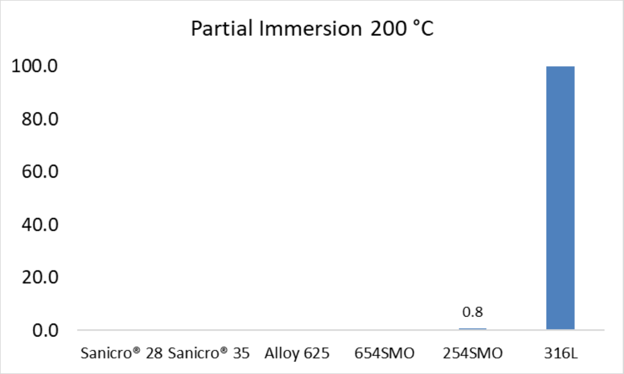
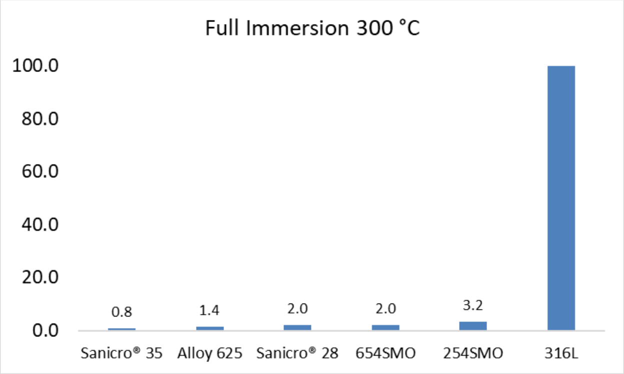
Corrosion rate – relative percentage







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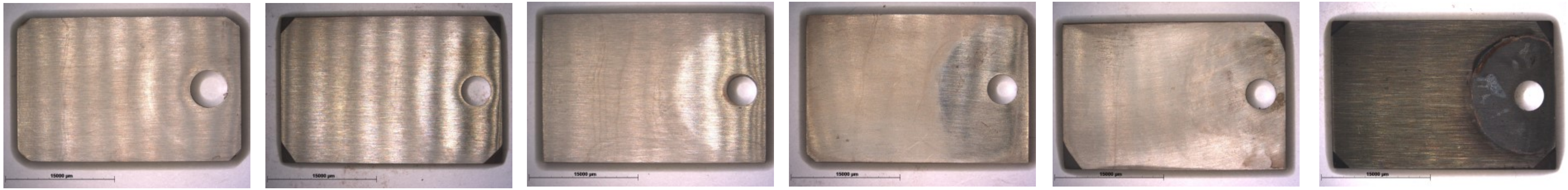
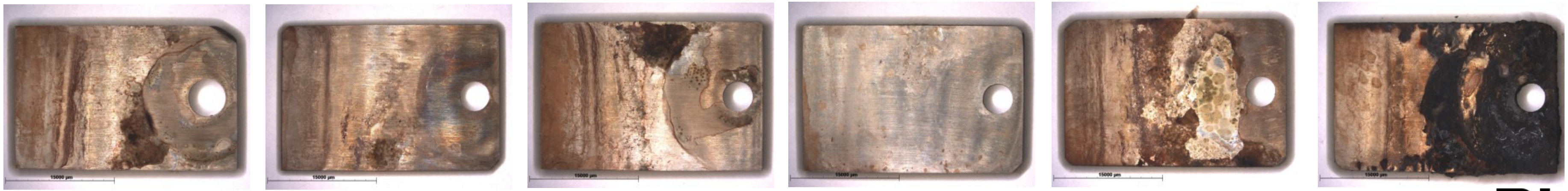
Sanicro® 35	654SMO	Sanicro® 28	625	254SMO	316L

Before testing

Full immersion



Partial immersion



200 °C
Before cleaning

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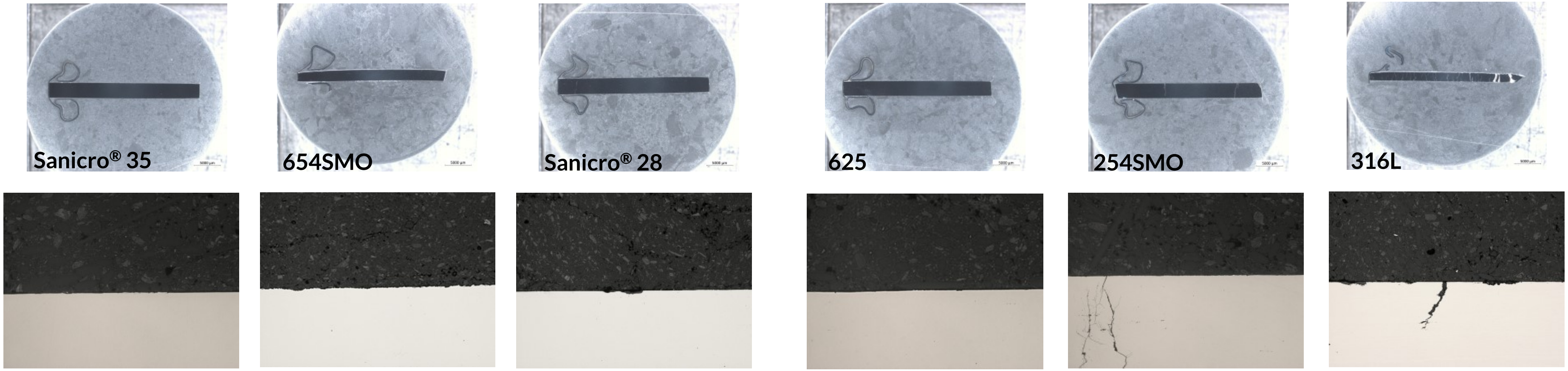
Macrograph of cross-section after testing at 200 °C – partial immersion



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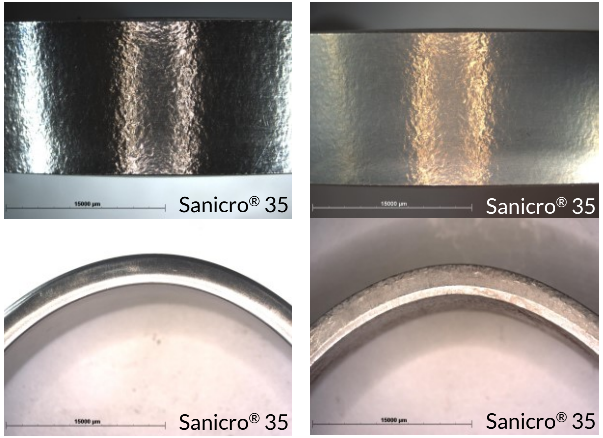
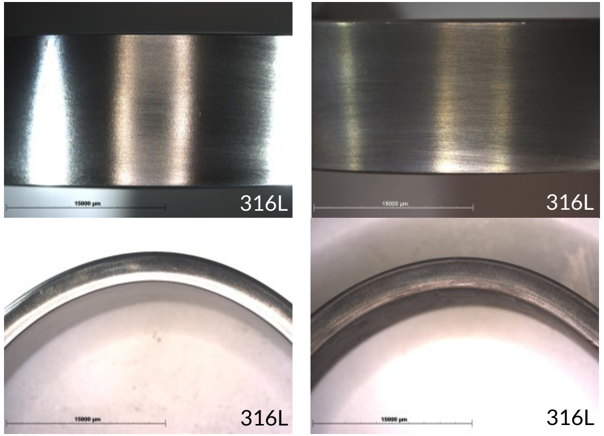
200 °C
Rinsing with DI water

Before testing | Full immersion

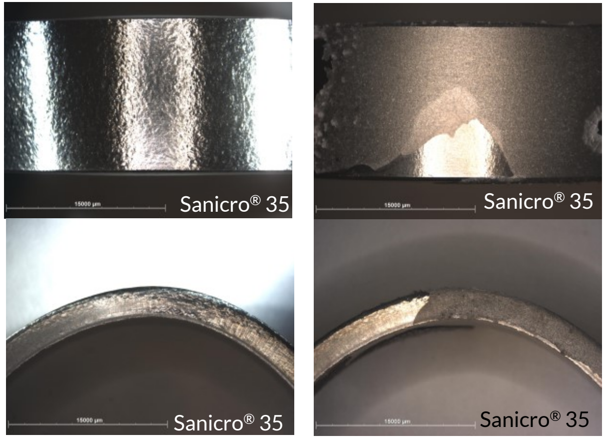


Before testing | Full immersion

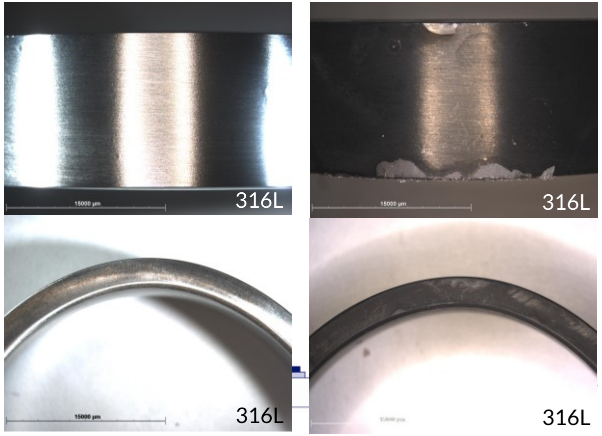


300 °C
Before cleaning

Before testing | Full immersion



Before testing | Full immersion



Summary of the results

- ***Effect of chemical compositions***
  - Corrosion of Sanicro® 28, Sanicro® 35 654SMO, Alloy 625 and 254SMO were in the same range and significant lower than that of 316L.
- ***Effect of exposure conditions***
  - Samples exposed to two-phase environment exhibited significantly higher corrosion rate than those exposed fully in the liquid phase.
- ***Effect of testing temperature***
  - Testing temperature of 300 °C exhibited much more aggressive results than testing at 200 °C.
- ***Effect of applied stress***
  - U-bends did not show crack after exposure.
  - Partial immersion of U-bends is of interest for future work.

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Next steps – addressed in an ongoing project

- Effect of chloride on corrosion of different alloys with and without acid at high temperature and pressure
  - Literature study
    - Knowledge gap
    - Effect of organic and inorganic salts
  - Experimental work
    - Different sources of chloride based on different processes

Ongoing project

- **Effect of chloride on corrosion behaviors of different alloys in simulated biorefinery process** *(January 2022-December 2024)*
  - WP1: Effect of NH4Cl on corrosion of different alloys *(January 2022-December 2023)*
  - WP2: Effect of additional chloride on corrosion of different alloys in high temperature and pressure of HCl *(June 2022-March 2024)*
  - WP3: *Tentative* - Development of a test method to study effect of deposit NH4Cl on corrosion of metal *(January 2024-)*
  - WP4: *Tentative* - Effect of weldment on corrosion of metals used in simulated biorefinery production process *(January 2024-)*

Background & Objectives

Identification of NH_4Cl formation

NH_4Cl deposit

$$NH_3\ (g) + HCl\ (g) \rightarrow NH_4Cl\ (s)$$

Service temperature drop to crystallization temperature

$$NH_4Cl\ (s) + H_2O \rightarrow NH_4Cl\ (aq)$$

RH >20% and temperature above the dew point

NH_4Cl concentrated solution

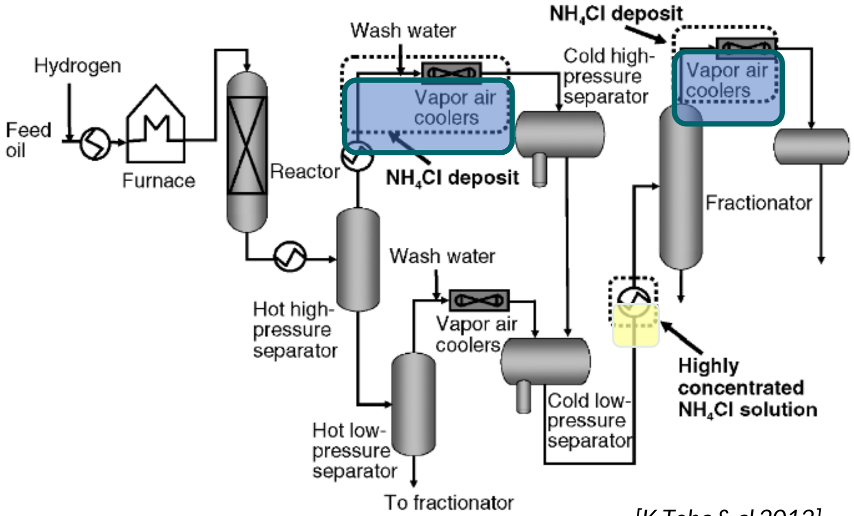
Evaporation of water from aqueous solution (NH_3 & HCl)

Downstream of FCC rector: lower temperature leads to condensation and formation of NH_4Cl dissolved in water

[www.digitalrefining.com/article/1002648]

Objectives

To study corrosion behavior of different alloys in saturated NH_4Cl solution at different temperature



[K.Toba & al 2012]

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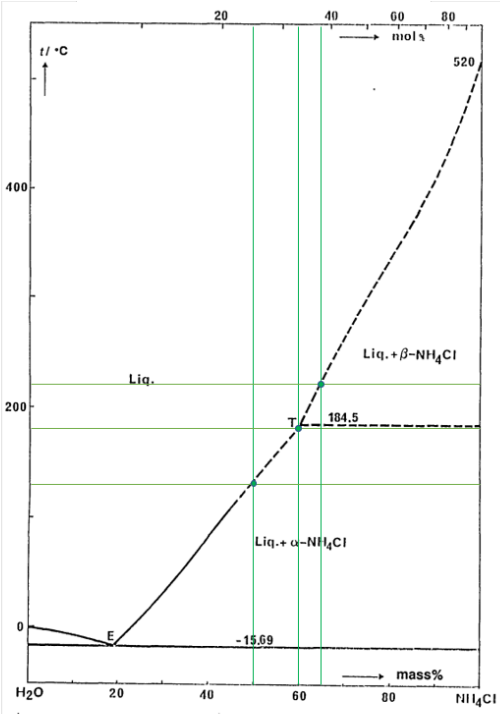
Test method

Simulated conditions and hypothesis

NH_4Cl solubility vs. Temperature



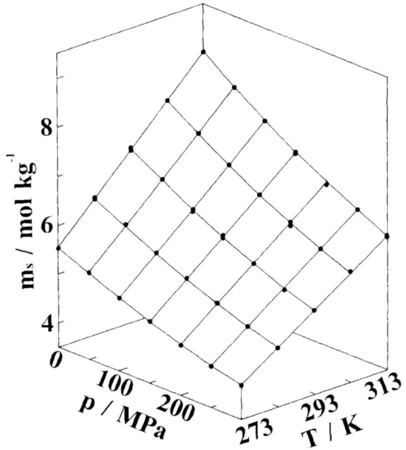
[R. Cohen-Abab & al – Solubility data series Vol, 47]

At constant P, increase of T >> increase of solubility

NH_4Cl solubility vs. Pressure

p/MPa	T/K				
	273.4	283.2	293.2	303.2	313.2
0.10	5.50	6.28 6.24	7.02 7.06 7.08	7.79	8.49
	5.57*	6.27*	7.01*	7.78*	8.58*
50	5.28	6.00	6.63	7.34	8.04
100	5.00	5.68	6.24 6.29	6.94	7.63
150	4.78	5.41	5.98 5.99 6.02	6.60 6.62	7.25 7.27
200	4.52	5.16	5.68	6.27 6.22	6.80
250	4.32	4.91	5.36	6.00	6.54
300	4.13	4.65	5.21	5.78	6.26 6.26

[S. Sawamura & al 1999]



At constant T, increase of P >> decrease of solubility

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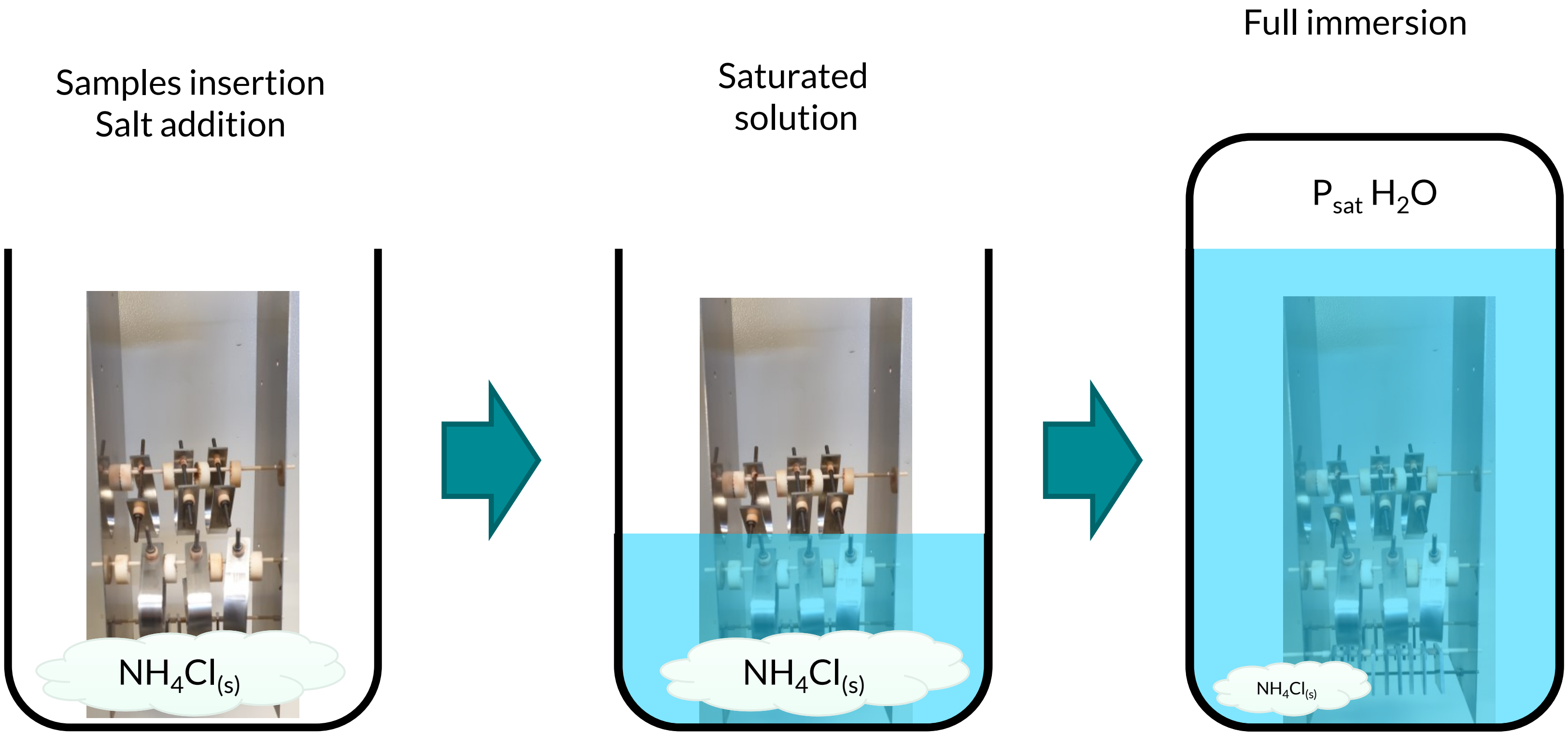
Test method

Our developed protocol



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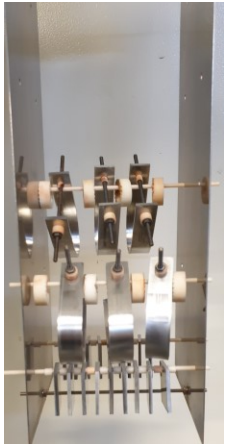
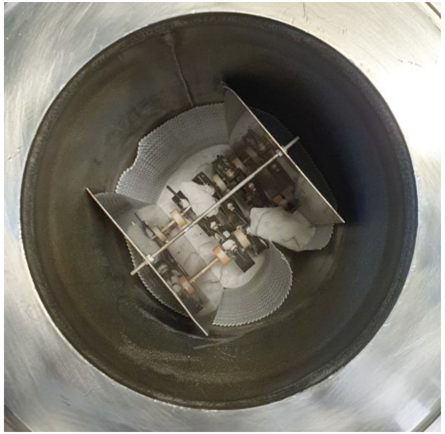
Test method

Our developed protocol

1000 h testing
Temperature monitoring
Pressure daily monitoring





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Ongoing project

- **Effect of chloride on corrosion behaviors of different alloys in simulated biorefinery process** *(January 2022-December 2024)*
  - WP1: Effect of NH_4Cl on corrosion of different alloys *(January 2022-December 2023)*
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  - WP4: *Tentative* - Effect of weldment on corrosion of metals used in simulated biorefinery production process *(January 2024-)*

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Thanks for listening!

Please feel free to contact us to learn more!

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Appendix 16

CO_2 specification

(Ludovic Gaillot)

TotalEnergies

CO2 Specification for Carbon Capture & Storage (CCS)

WP15 – 30/03/2023

Ludovic GALLIOT

TotalEnergies CO2 capture projects

TotalEnergies

- Northern Lights: Norway
- Aramis: Netherlands
- Bifrost: Denmark
- Northern Endurance Partnership : UK

Northern Lights

ARAMIS

bifrost

Northern Endurance Partnership

- *Other under investigation*

Aramis CO2 specification

- Public specification available on the website:

  https://www.aramis-ccs.com/news/co2-specifications-for-aramis-transport-infrastructure

- Corrosives species highlighted in red

ARAMIS

Specification for CO2 supplied to Aramis via:

Class	Component	Constraint	unit	Ships	Pipeline infrastructure
	CO_2	larger than	mol%	balance	95
	H_2O	less than	ppmmol	30	70[1]
inerts	N_2	less than	mol%	-	2.4
	O_2	less than	ppmmol	10	40
	H_2	less than	ppmmol	500	7500
	Ar	less than	mol%	-	0.4
	CH_4	less than	mol%	-	1
	CO	less than	ppmmol	1200	750
	$O_2+N_2+H_2+Ar+CH_4+CO$	sum less than	ppmmol	2000	40000
	NO_x	sum less than	ppmmol	1.5	2.5[4]
sulphur	SO_x	sum less than	ppmmol	10	-
	H_2S	less than	ppmmol	5	5
	CarbonylSulphide	less than	ppmmol	-	-[1]
	DimethylSulphide	less than	ppmmol	-	-[1]
	H_2S + COS + SO_x + DMS	sum less than	ppmmol	-	20
Volatile organic components	Amine	less than	ppmmol	10	1
	Formaldehyde	less than	ppmmol	20	-
	Acetaldehyde	less than	ppmmol	20	- [1]
	Aldehydes	sum less than	ppmmol	-	10
	carbolylic acids & amides	sum less than	ppmmol	-	1
	phosphorus-containing compounds	sum less than	ppmmol	-	1
	NH_3	less than	ppmmol	10	3
	Ethylene (C_2H_4)	sum less than	ppmmol	-	-[1]
	H-Cyanide (HCN)	less than	ppmmol	-	2
	Total volatile organic compounds (excl. MeOH, EtOH, aldehydes)	sum less than	ppmmol	10	10
	Methanol	less than	ppmmol	40	620
	Ethanol	less than	ppmmol	20	20
Heavies	glycols (TEG)	sum less than		-	Follow dew-point specification
	C_{2+} (aliphatic hydrocarbons)	sum less than	ppmmol	-	1200
	Aromatic Hydrocarbons	sum less than	ppmmol	-	0.1
Metals	Hg	less than	ppbmol	30	-
	Cadmium + Thalium	sum less than	ppbmol	30	-
Dew-point	Dew point (any liquid phase)	sum less than	°C (@ 20 bar)	-	-10[2]
Solids	Full removal cut-off diameter	Less than	micron	1[3]	1[3]

Notes to the table

(1) There are some specific limits when transporting via OCAP infrastructure that can be obtained from OCAP B.V. (www.ocap.nl)
(2) Measured or predicted using CPA equation of state.
(3) This is the entry solids / dust specification for the envisaged Aramis stores. In order to achieve this Aramis will request Aramis emitters to install dust removal facilities with a cut-off diameter of 10 micron as a minimum. Furthermore, Aramis is planning to locate filters with cut-off diameter of 1 micron at optimal locations at the envisaged compressor and terminal stations.
(4) Specification more stringent than Porthos CO2 specification v 3.1 at 5 ppmm The limit is set based on testing similar to those described in section A.4 in ISO TR 27921 at seabed conditions.

A number of impurities are included in the overview without a specific limit to their content. Emitters agree to inform Aramis in case these components are expected in the CO_2 product at levels above 1 ppmmol. Aramis will then conduct a risk assessment study to understand the maximum amount that can be tolerated.

If the aforementioned CO2 stream, includes components that are not included in the Aramis CO2 specification and that can adversely affect Aramis, its personnel or the Aramis Transport System (e.g. as a result of liquid formation, corrosion or toxicity (HSE)), then Aramis shall in relation to each such component in consultation with customer, but at Aramis' sole discretion establish an upper concentration limit. The aggregate of these components and related concentration limits, as established from time to time shall constitute the CO2 specification.

The risk assessment for impurities in a CO2 collection hub system and in particular the interaction of impurities from different sources is an ongoing field of research. A good summary of today's understanding is the 2020 issue of ISO TR 27921. Evolving insights may result in a re-visit of the risks associated with a particular impurity or combination of impurities. Aramis plans to actively manage these risks and hereby reserves the right to adjust the specification, if the existing level will adversely affect Aramis, people working on the project, or the envisaged Aramis Transport System.

Focus on corrosives species

- H_2O: if too high amount in CO_2, risk of water dew point :
  - acidic droplet in equilibrium with >99%w CO_2
- O_2:
  - Will enhance corrosion if aqueous phase already formed
  - Will promote oxidation reaction between impurities
- H_2S:
  - Sour service evaluation depending on concentration and pressure at different location
  - Could be oxidized in elemental sulfur, then SO_2/SO_3
- SO_x: coming from combustion fumes, will be mainly made of SO_2
  - SO_2: could lead to elemental sulfur / SO_3 depending on reducing/oxidizing environment
  - SO_3: will trap H_2O to generate H_2SO_4
- NO_x: coming from combustion fumes, will be mainly made of NO_2
  - NO_2:
    - strong oxidizer will convert H_2S and SO_2 to SO_3, and so sulfuric acid.
    - Could also generate HNO_3 in contact with water
  - NO: could be oxidized to regenerate NO_2

Corrosion risk assessment

- Strong acid risk will be impacted by P&T
  - Acid generation kinetic
  - Solubility of acid generated within the CO_2 matrix ➔ acid drop out

- NO_2 will trigger very fast oxidation reaction and generate sulfuric & nitric acid

  ➔ **focus on NO_2 reduction in the CO_2 specification, to avoid reactions and so strong acid generation**

CO2 capture forecast – *open talk*

- Do you have plan/ forecast for CO_2 capture in your plant?
  - Which technology to use for CO_2 capture and treatment (purification)?
  - Do you plan a transport in pipeline (gas/ dense) or ship (liquid cryogenic phase)?

- How corrosion risk is managed along your CO_2 capture & transport process ?

- Is the low NO_x specification a critical parameter regarding your process/stream composition?

Merci

Thank you

Avertissement - Propriété intellectuelle

Définition TotalEnergies / Compagnie
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Avertissement
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Propriété intellectuelle

Appendix 17

Corrosion management

(Alec Groysman)

How to Manage Corrosion Situation in Oil Refining and Petrochemical Industry?

Alec Groysman

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EFC Working Party 15 Spring "Corrosion Refinery and Petrochemistry Industry" Meeting

30th March 2023

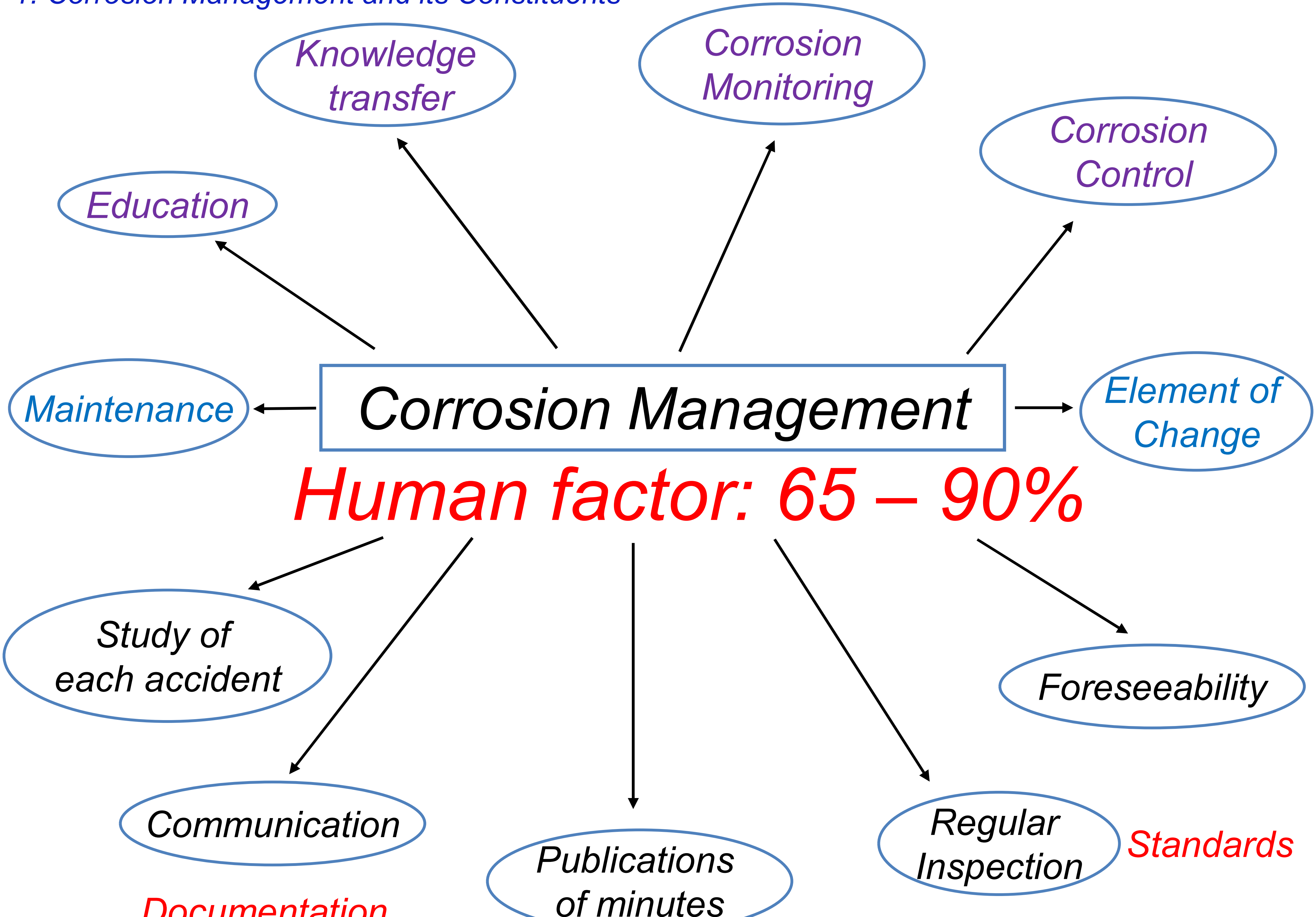
Lille France

Outlines:

1. Corrosion Management and its Constituents.

2. How to organize Corrosion Management at oil refinery?

3. Insufficient Corrosion Management at oil refinery …



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Corrosion Management - planning actions of:

- selection,
- design,
- corrosion mitigation,
- prevention,
- monitoring,
- inspection,
- prediction.

Design stage

Corrosion/Materials engineer should sign projects!

2. How to organize Corrosion Management at oil refinery?

1990 - 2019 – 2022 – four refineries in Israel and in Kazakhstan

- Audit at each Unit during shutdown.

- Analysis and conclusion about corrosion situation:

  Real estimation of corrosion rates.

  Was a material selection correct?

  Were corrosion control methods chosen correct?

  Fouling and its composition. Cleaning measures.

  Determination of causes of corrosion and mitigation measures.

  How to monitor corrosion situation?

- *Creation of corrosion maps and passports.*

- *Courses and Training on the Audit Results.*
    - *Technological processes!*

- *Creation of suitable corrosion committees:*
    - *Corrosion committee.*
    - *Cathodic protection committee.*
    - *Coating committee.*

Must participate in committees:

Corrosion and Materials Engineers

Chemical engineers (processing)

Mechanical engineers

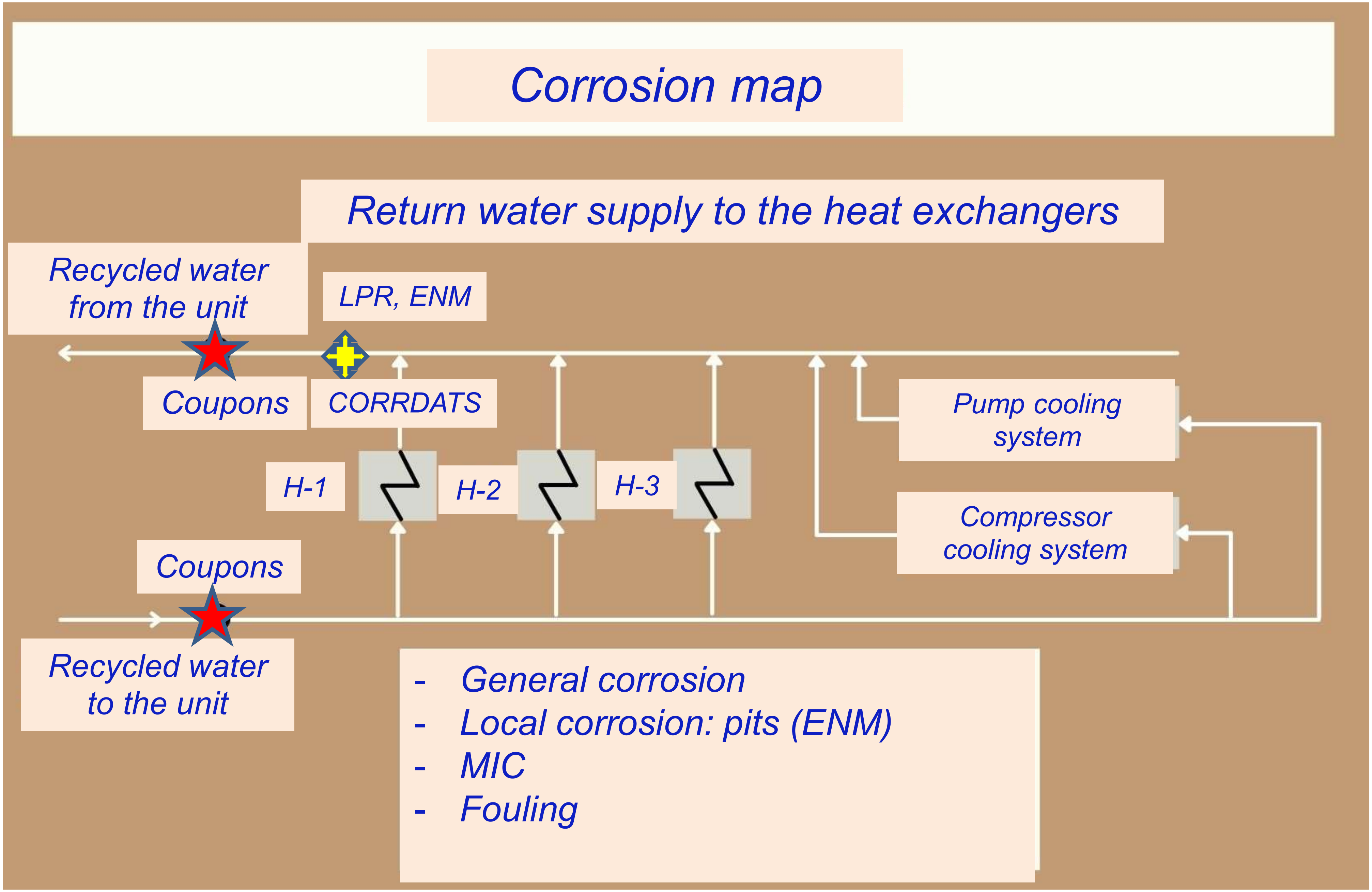
Inspectors

Departments of maintenance, processes, operation, equipment and ecology (environment),

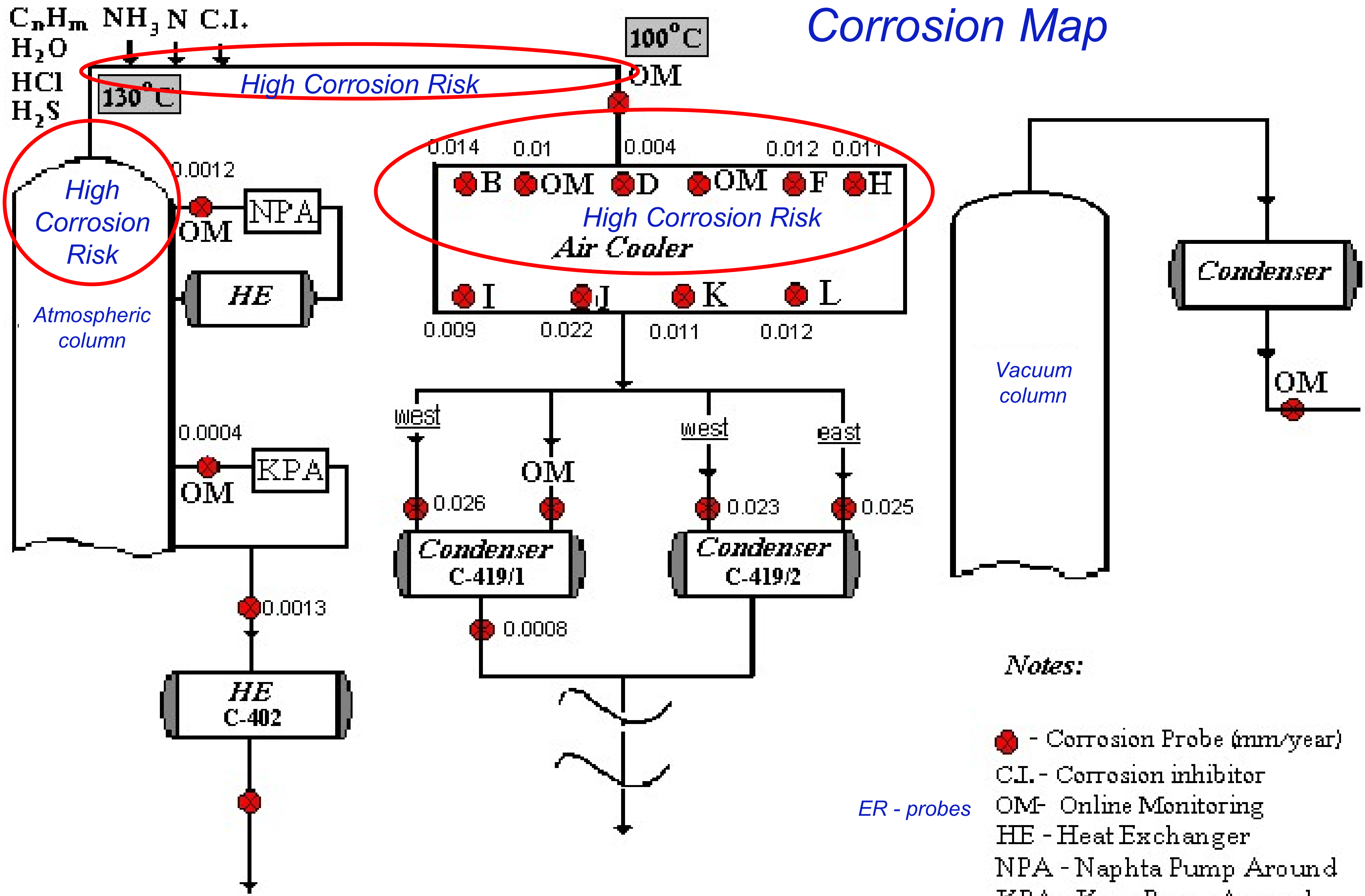
Economists

Managers

Cooling Water System



Corrosion Map



Notes:

- Corrosion Probe (mm/year)

C.I. - Corrosion inhibitor

OM- Online Monitoring

HE - Heat Exchanger

NPA - Naphta Pump Around

KPA - Kero Pump Around

ER - probes

Overhead Distillation Column

1992 - 2022

Dr. Alec Groysman

WP 15

3. Insufficient Corrosion Management

WP 15

Standards, codes, specifications, rules, and knowledge are not effectively used.

Specialists are often not familiar with existing literature, experience, and achievements of others.

WP 15 !

Audit and survey are not always carried out on a regular basis.

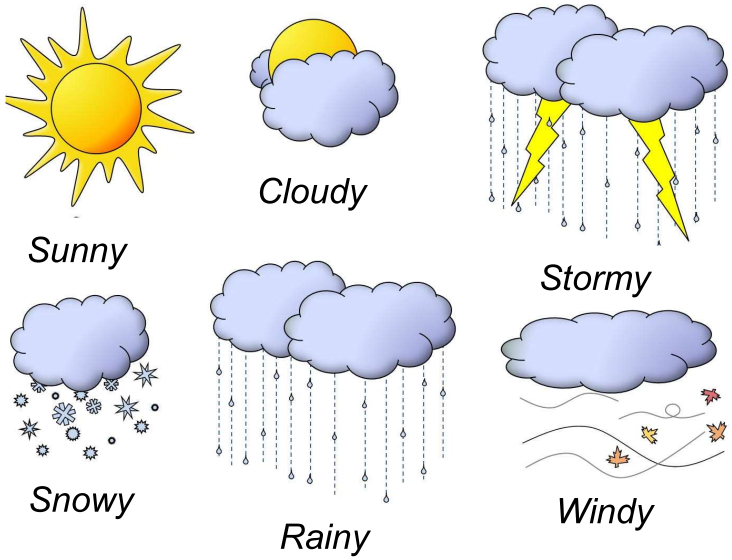
About 30% of corrosion accidents are not registered.

The Human Factor plays a Vital Role!

WP 15

WP 15

Creation of corrosion predictive models is similar to weather models



Weather - constantly changing state of the atmosphere.

Corrosion - constantly changing state of a metal – environment system.

Specialists continue creation of predictive models of general and localized corrosion but … without success.
This is like prediction of duration of human`s life. Anybody can predict?

Like burse (exchange) or history.

The Past cannot be the basics for the prediction of the Future! .

Degree of uncertainty will remain.

Honeywell Predict® Corrosion Suite - 2018

Unlike conventional corrosion management methods, we employ unique prediction models that encapsulate deep expertise and extensive process data to correlate corrosion rates to specific process units, damage mechanisms, and operating conditions.

Thermodynamic modelling software for one. Software, such as that developed by OLI Systems*, including its Mixed Solvent Electrolyte (MSE) model and Aqueous (AQ) model, allows users to better predict where corrosion might occur, but not the actual corrosion rate.*

Is anybody familiar with Prediction Models that work?

60 participants WP15!

700 refineries and 150 crude oil types!

The Naked King

Ageing and new processes …

Conclusion

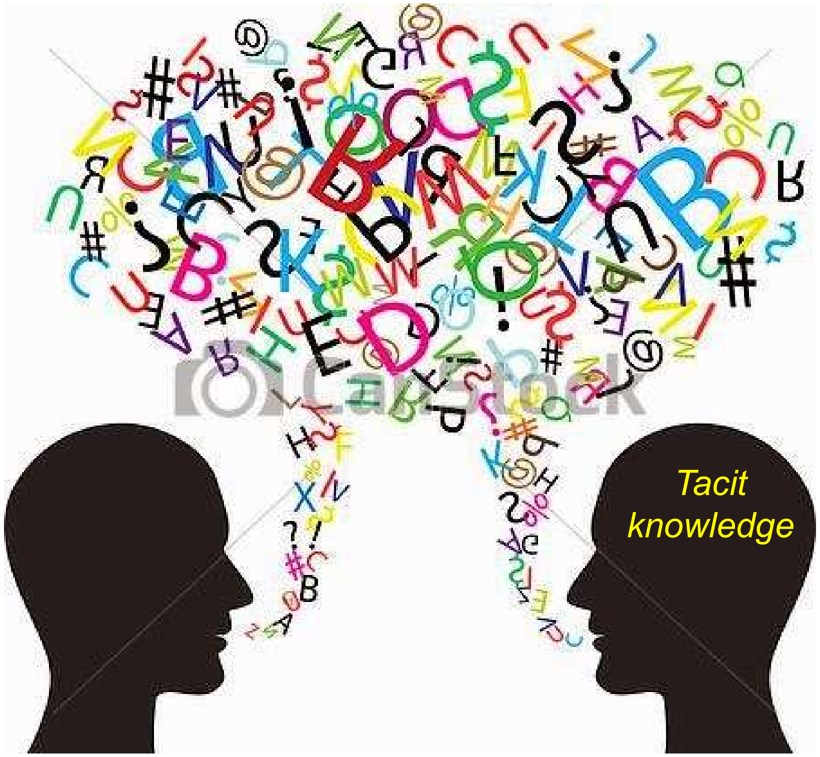
We need to change Corrosion Management Culture!

Legislation in the field of corrosion management (Proposal)

Forcing managers to establish penalties and incentives.

To establish penalties for the lack of anti-corrosive preventive actions and corrosion monitoring.

Education and Knowledge Transfer



75% of all corrosion failures happen because of insufficient information, communication, interaction, and knowledge.

To organize teaching of educators!

Dr. Alec Groysman