Appendix 1

List of participants

NAME	SURNAME	COMPANY	COUNTRY
Arzuffi	Mirko	Amec Foster Wheeler	ITALY
Baak	Michael	Borealis Polyolefine GmbH	AUSTRIA
Ciocca	Federico	Donegani Anticorrosione	ITALY
Claesen	Chris J	Nalco Champion	BELGIUM
Comas	José	Total Refining & Chemicals	FRANCE
Corradini	Raffaele	Techint Engineering Construction	ITALY
Daly	Simon	Hempel UK Ltd	UK
De Landtsheer	Gino	Borealis	BELGIUM
de Marco	Marco	Istituto Italiano della Saldatura	ITALY
Dupoiron	François	IDEMAC	FRANCE
Farina	Carlo	CEFIT Corrosion Consultant	ITALY
Goti	Raphael	Total Refining & Chemicals	FRANCE
Gregoire	Vincent	Equinor	NORWAY
Groysman	Alec	Israeli Corrosion Forum	ISRAEL
Hairer	Florian	Linde, Engineering Division	GERMANY
Hamed	Noreldaim	SENDAN INTERNATIONAL COMPANY	SAUDI ARABIA
Hermse	Chretien	Shell Moerdijk	NETHERLANDS
Höwing	Jonas	Sandvik	SWESEN
Jayabalan	Thangavelu	INERIS	FRANCE
Kittel	Jean	IFP Energies nouvelles	FRANCE
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Kroth	Matthias	OMV Deutschland Operations GmbH & Co. KG	GERMANY
Kus	Slawomir	Honeywell	UK
Le Manchet	Sandra	Arcelor Mittal	FRANCE
Leone	Antonino	Eni	ITALY
Lobaton Fuentes	Militza	Borealis Chimie SAS	FRANCE
Low	Philip	Zerust Oil andGas	SPAIN
Maffert	Joerg	Dillinger Huttenwerke	GERMANY
Magel	Chris	PPG Protective & Marine Coatings	BELGIUM
Makhoul	Roger	Spraying Systems MENA Co	UNITED ARAB EMIRATES
Matthews	Dale	Zerust Oil andGas	SPAIN
Miyashita	Junki	MODEC, Inc	BRAZIL
Monnot	Martin	Industeel	FRANCE
Narjoz	Cyril	IGS EUROPE	FRANCE
Norling	Rikard	RISE	SWEDEN
Onodera	Yoichi	Mitsui & Co Ltd	JAPAN
Pålsson	Namurata	RISE	SWEDEN
Pojtanabuntoeng	Thunyaluk	Curtin University	AUSTRALIA
Rehberg	Thomas	KAEFER Isoliertechnik GmbH & Co. KG	GERMANY
Renaud	Lionel	Total raffinage Chimie	FRANCE
Rivero	Andres	Equinor	NORWAY
Rodriguez Jorva	Javier	CEPSA	SPAIN
Ropital	François	IFP Energies nouvelles	FRANCE
Sharma	Prafull	Corrosion RADAR	UK
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Uusitalo	Mikko	Valmet Technologies, Inc.	FINLAND
Van Dooren	Piet	Borealis	BELGIUM
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vanacore	Alessandro	Donegani Anticorrosione	ITALY
Vlad	Gogulancea	LUKOIL Neftochim Bourgas JSC	ROMANIA
Vosecký	Martin	Nalco Champion	CZECH REPUBLIC
Wassink	Casper	Eddyfi Technologies	NETHERLANDS
Watt	Clare	KAEFER Isoliertechnik GmbH & Co. KG	GERMANY
Wijnants	Geert Henk	Stork	NETHERLANDS
Wold	Kjell	Emerson	NORWAY
Yanes Guardado	Maria Jose	REPSOL	SPAIN
Yuhei	Suzuki	Nippon Steel Europe GmbH	GERMANY
Zakeri	Hadi	PetroIneos	UK
Zhang	Jian-Zhong	SABIC	UK
Zlatnik	Ivan	MITSUI & Co Deutschland	CZECH REPUBLIC

Appendix 2

EFC WP15 Activities

(Francois Ropital)

EUROPEAN FEDERATION OF CORROSION

Welcome to the EFC Working Party Meeting

"Corrosion in Refinery and Petrochemistry"
WP15

24 March 2022

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

Tribute to Stefan Winnik Memory

Stefan passed away on 12th December 2021.

Stefan gave great contributions to our corrosion activities.

Stefan was the initiator and the driving force for the EFC green book on Corrosion Under Insulation.

Stefan will always stay in our minds.

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 (ie corrosion atlas).

Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2022 Berlin-Germany, 2023 Brussels-Belgium)

In 2022 the Refinery corrosion sessions will take place on Wednesday 31 August in Berlin.

WP Meetings

One WP 15 working party meeting in Spring,

One meeting at Eurocorr in September in conjunction with the conference, this year it will be on Thursday 1 September 2022 morning in Berlin (possibility of a hybrid meeting to be checked)

Publications - Guidelines

Web site : https://efcweb.org/Scientific+Groups/WP15_+Corrosion+in+the+Refinery+and+Petrochemistry+Industry-p-38.html

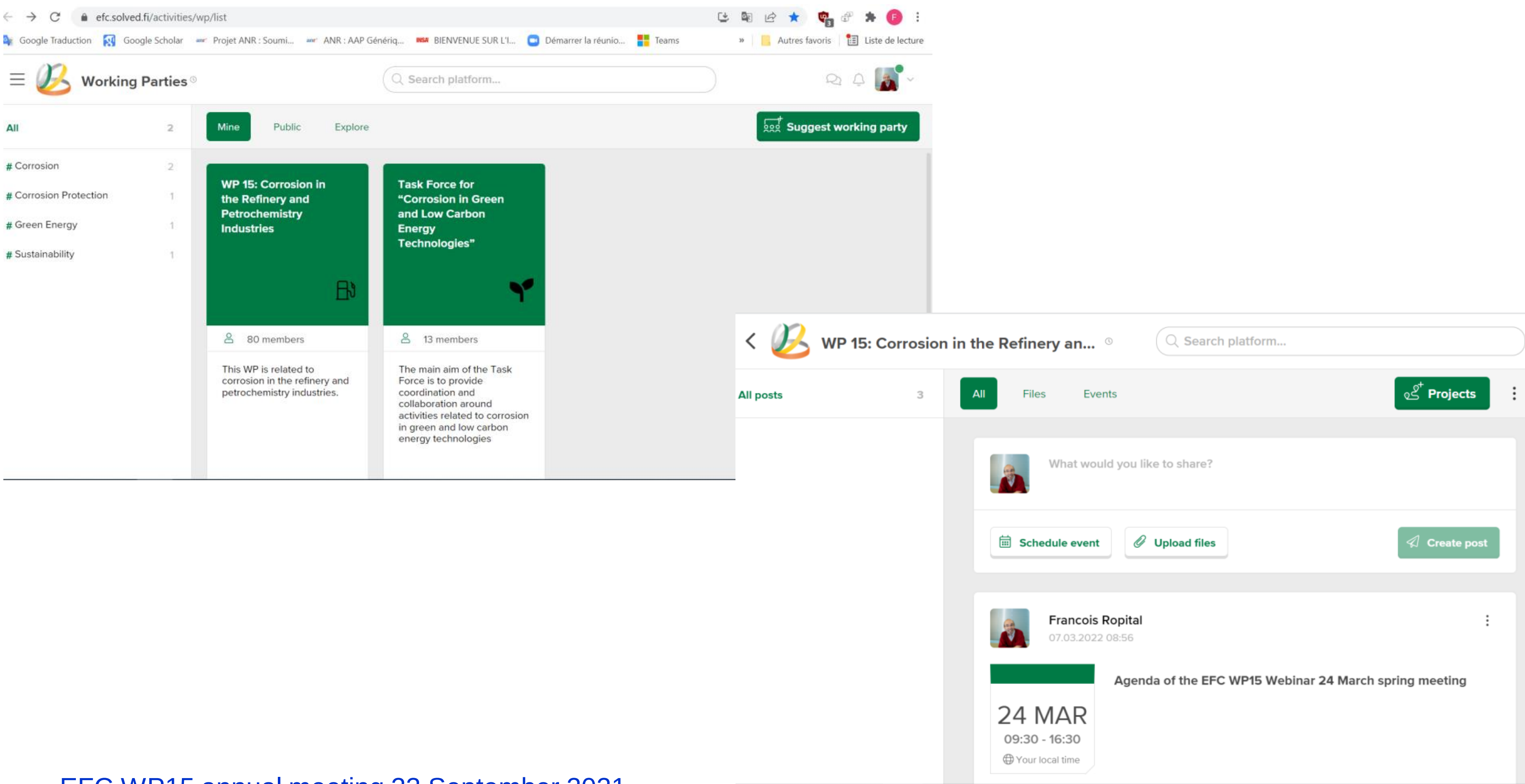
List of the WP15 spring meetings :

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

EFC Hub Platform

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

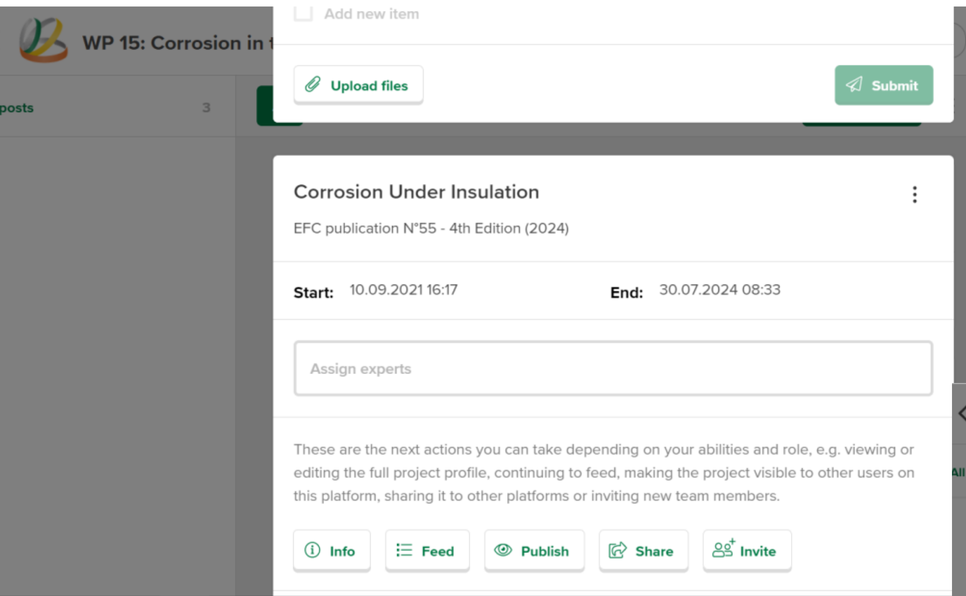
https://efc.solved.fi/activities/wp/list

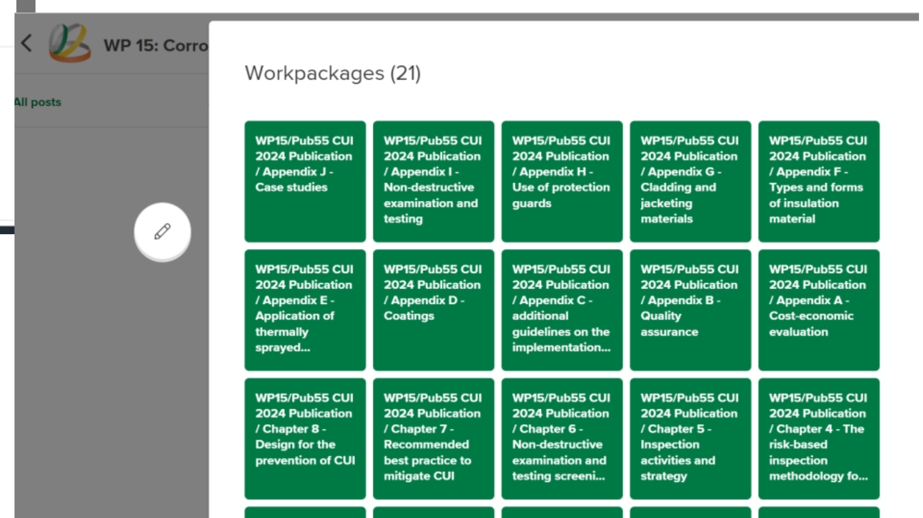


EFC Hub Platform: CUI Project

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

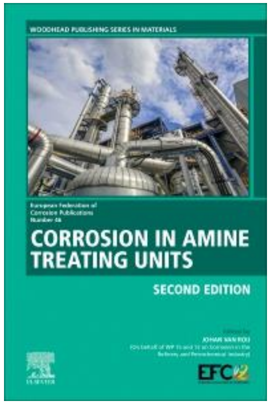
•EFC Guideline n° 46 revision on corrosion in amine units Editor: Johan van Roij
is now available

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



EFC
EUROPEAN FEDERATION OF CORROSION

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	Corrodys
4	Forms of corrosion	Valerie Bour-Beucler	Antoine Surbled
5	Biocide treatments	Valerie Bour-Beucler	Philippe Bleriot
6	Inhibitors	Philippe Bleriot	
8	Materials	Antoine Surbled	
8.1	Carbon steel		Antoine Surbled
8.2	Stainless steels		Dominique Thierry Jonas Howing
8.3	Nickel alloys		Dominique Thierry Angela Philipp
8.4	Copper alloys		Dominique Thierry
8.5	Aluminium, Titanium alloys		Antoine Surbled
8.7	Concrete		Antoine Surbled
9	Corrosion protection	Jian-Zhong Zhang	
9.1	*Material selection to avoid galvanic coupling*		*Jian-Zhong Zhang*
9.2	*Coatings*		*Jian-Zhong Zhang*
9.3	*Cathodic protection*		*Nicolas Larche Dominique Thierry*
10	Maintenance and tube cleaning	Valerie Beucler	Jian-Zhong Zhang Antoine Surbled
11	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

Appendix 3

Cefracor guideline on corrosion in cooling water exchangers

(Francois Dupoiron, Antoine Surbled)

Heat Exchangers Guide

corrosion prevention in cooling water exchangers

A CEFRACOR GUIDE

IDEMAC – François Dupoiron

Aim of the Guide

This guide was initiated five years ago by a CEFRACOR working group with members of specific commissions:

- Inhibitors and water treatments,
- Corrosion in O&G and chemical energy.

<u>Objectives:</u>

-To present synthetic information on corrosion problems occurring on cooling water heat exchangers.

-A compact guide of less than 100 pages with short chapters, accessible to operational personnel and not only to experts.

-Many points are developed in a complementary and detailed way in the appendix (150 pages).

- Sea water cooling is mentionned but not detailled

Status: The project is now 90% complete and the goal is to be proposed for publication by the end of 2022.

General structure of the Guide : HX types , water treatments and Materials

-Presentation of different types of exchangers with their advantages and disadvantages

- Assembly modes and their particularities:
- Sealing and evaluation method
- Mechanical resistance
- Economical aspects

-Materials characteristics and properties and their corrosion behaviour depending the cooling fluid (water):

- compositions and physical parameters (T°C , velocity …)
- Water treatments (specific chapter)
- Severity evaluation
- Presentation of material solutions including solid , clad , coating
    - carbon steel,,coated carbon steel,
    -common austenitic stainless steels (types 304 and 316 and variants),
    - austenitic-ferritic stainless steels (duplex),
    - copper and copper alloys,
    - nickel, nickel alloys and bases
    - titanium and titanium alloys.

Structure of the Guide :
Materials :Corrosion sensitivity/ economical aspects / Life cycle cost

For each of the materials solutions,

- Fields of use according to the conditions on the cooling fluid side,
- Effect of the different types of inhibition treatment,
- Corrosion effect of assembly modes , technics and their particularities,
- Galvanic coupling risks

- Economical aspects
- Life cycle cost
- RBI

Detailled structure of the Guide :
Damages modes

The main types of heat exchangers

2 Damage modes by exchanger family

2.2 The different forms of corrosion

2.3 Abrasion and erosion

2.4 Erosion - Corrosion

2.5 Other forms of degradation

2.6 Some reminders on the scalling mechanisms

2.5 Fouling and biofouling

2.6 Problems and recommendations specific to shell and tube exchangers

2.7 Problems and recommendations specific to plate heat exchangers

Structure of the Guide : Materials solutions

3 Material solutions

3.1 Metallic materials

3.2 Composite materials (impregnated graphite)

3.3 Non-metallic coatings for tubes and plates

3.4 Bimetallic tubes and metallic coatings for tubes and plates

3.4.1 Bimetallic tubes

3.4.1.1 manufacture

3.4.2 Inserts

3.4.3 Metal Coatings

3.5 Common dimensional characteristics of heat exchanger tubes

3.6 Specific instructions for the design of exchangers using cooling water

Strucutre of the Guide :
Assembly modes

4 Assembly methods

4.1 Tube exchangers: role of the tube/tube plate connection

4.2 Plate heat exchanger assembly

Strucutre of the Guide :
CW treatments and material selections

5 Cooling water treatment

6.Selection of materials according to cooling water conditions

6.1 Objectives and limits

6.2 Environments, metallurgy and associated services

6.3 Models

7.Life cycle analysis and life cycle costs

Aim of the Guide : Innovations

8 Innovations in heat exchange

8.1 Design and manufacture of heat exchange equipment

8.2 Low adhesion coatings / conductive coatings / self-healing coatings / improved dirt resistance

8.3 Water treatment

8.4 Cooling systems

8.5 References

Aim of the Guide :
Feedback and REX

9. Feedback :

this part contains many feedbacks with observations, failure analysis and recommendations.

This part will remain "open" to be "enriched" with new cases. .... which will not miss

Appendix A

Supplements Corrosion and scaling

1 Vulnerable areas of exchangers

1.1 Shell and tube heat exchangers (STHE) and condensers

1.2 Plate heat exchangers

2 Material behaviour to corrosion in cooling water

3.3 Corrosion behaviour of materials in seawater service

3.4 Corrosion, corrosion-erosion of copper alloys

3.5 Bibliography

Appendix A – Additional information on corrosion

Appendix A

4 Reminders on the Ryznar and Langelier indices

4.1 Limitations of the Ryznar and Langelier methods

4.2 Conclusion

Appendix B – General properties of materials

Appendix C: Heat exchange, hydrodynamics, vibrations, cavitation

Appendix C : thermomechanics of fluids

Appendix C FIV and cavitation

3 Flow-induced vibrations in shell-and-tube heat exchangers, (FIV)
3.1 Flow-induced vibrations, Principles
4.3 Vibration prevention
2.3 Anti-vibration devices
4.4 Modeling and Prediction of FIV
4 Cavitation
4.1 Definition
4.2 Origins
4.3 Forms of cavitation
4.4 Theory, mechanism and factors
4.5 Morphology

Appendix 4

A case study of corrosion in cooling water treatment

(Federico Ciocca, Alessandro Vanacore)

Donegani Anticorrosione

EFC Working Party 15 Spring "Corrosion Refinery and Petrochemistry Industry" Meeting - 24th March 2022

Corrosion in cooling water systems - A case study of corrosion in cooling water treatment

A case study of corrosion in cooling water treatment

During a field inspection it was observed that the tower water treatment was carried out incorrectly

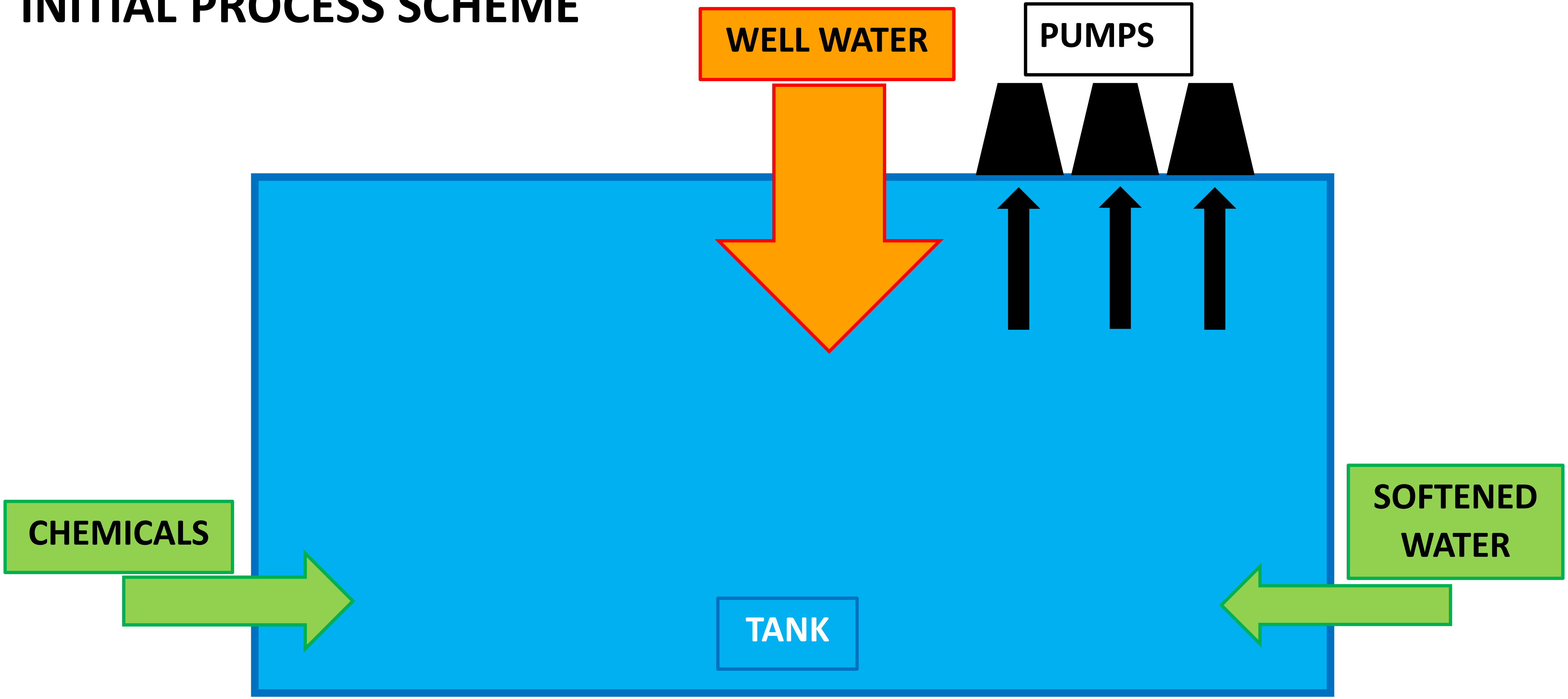
- Visual inspection of the tank → corrosion inside the tank and damages on the pumps
- Visual inspection of the line → presence of many perforated carbon steel curves
- Failure analysis → in order to establish the cause of curve perforation
- **Recommendations to mitigate the problem**

PROCESS WATER COLLECTION SYSTEM:

- **TANK:** process water storage
- **CHEMICALS:** improve water quality
- **SOFTENED WATER:** pre-treated to remove salts
- **WELL WATER:** water reinforcement
- **PUMPS:** take water for the plant circuit

A case study of corrosion in cooling water treatment

INITIAL PROCESS SCHEME



PROBLEMS:

- Well water inlet → too close to pumps
  → often greater then softened water
- Chemicals → not directed correctly
  → inlet counts carried out only on softened water
- No mixing system inside the tank

A case study of corrosion in cooling water treatment

Donegani Anticorrosione

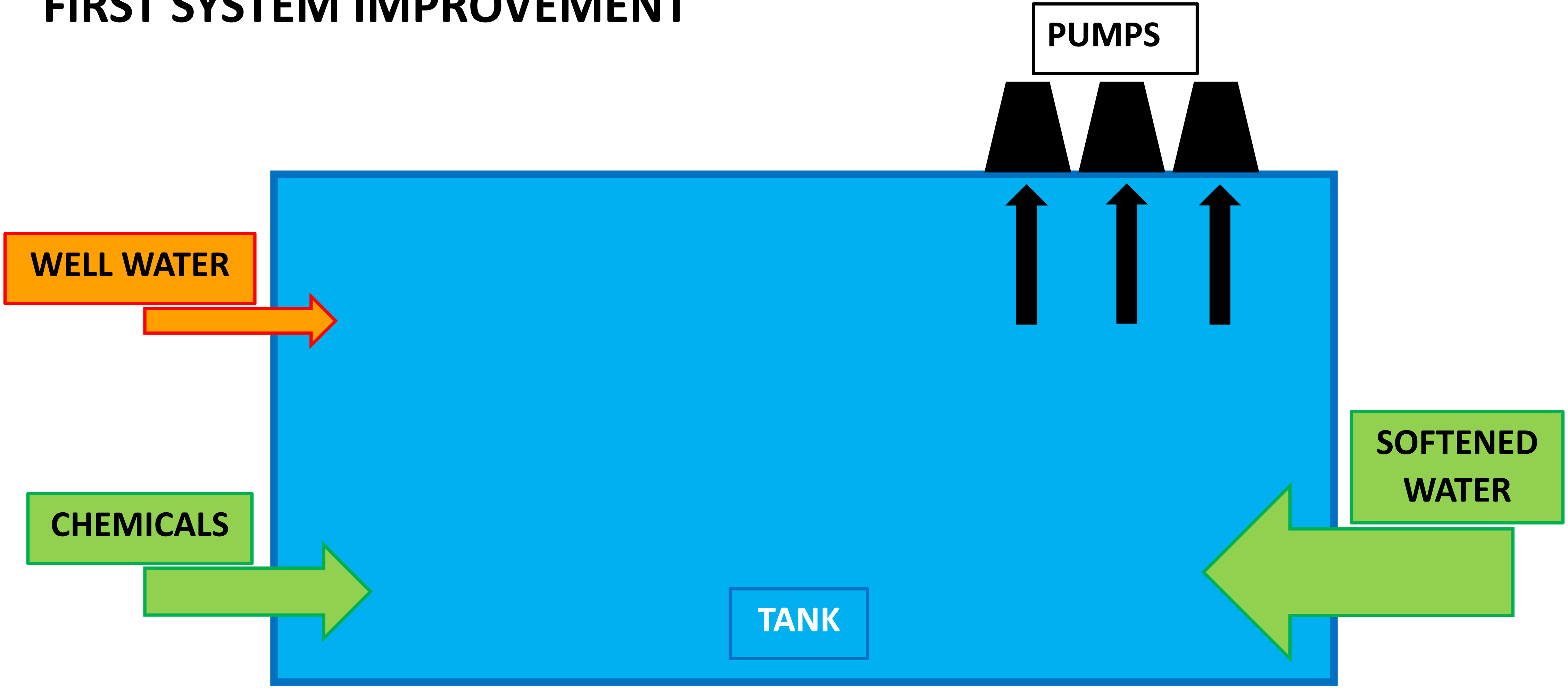
WELL WATER INJECTION

CHEMICALS INJECTION

PROBLEMS → SOLUTIONS

- Well water inlet → too close to pumps → Placed further (design change)
  → often greater then softened water → Try to reduce well water inlet
- Chemicals → not directed correctly → Repositioning of the sprinklers
  → count carried out on softened water → Increasing dosage according to inlet well water
- No mixing system inside the tank → New precaution could improve mixing in the tank

FIRST SYSTEM IMPROVEMENT

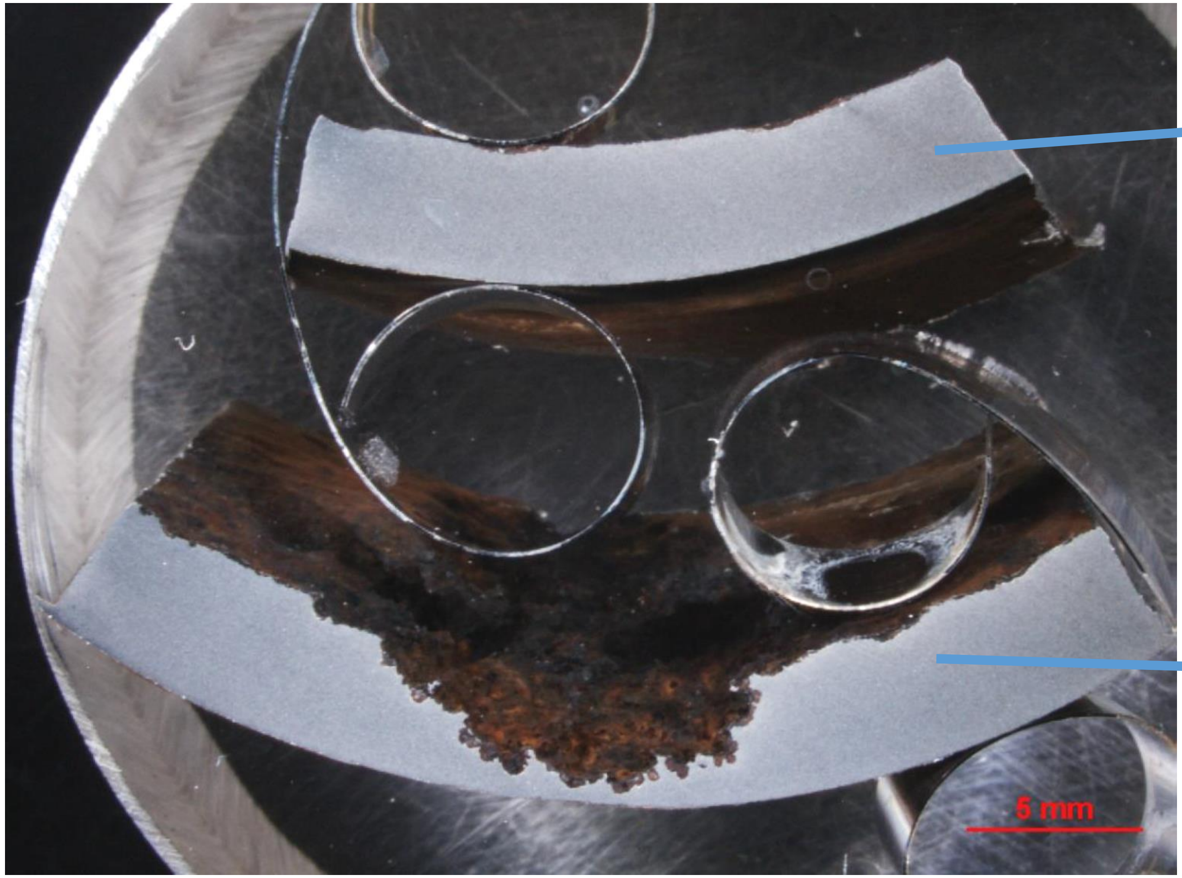


...HOWEVER... Passing corrosion on intrados curves →

A case study of corrosion in cooling water treatment

Donegani Anticorrosione

→ FAILURE ANALYSIS



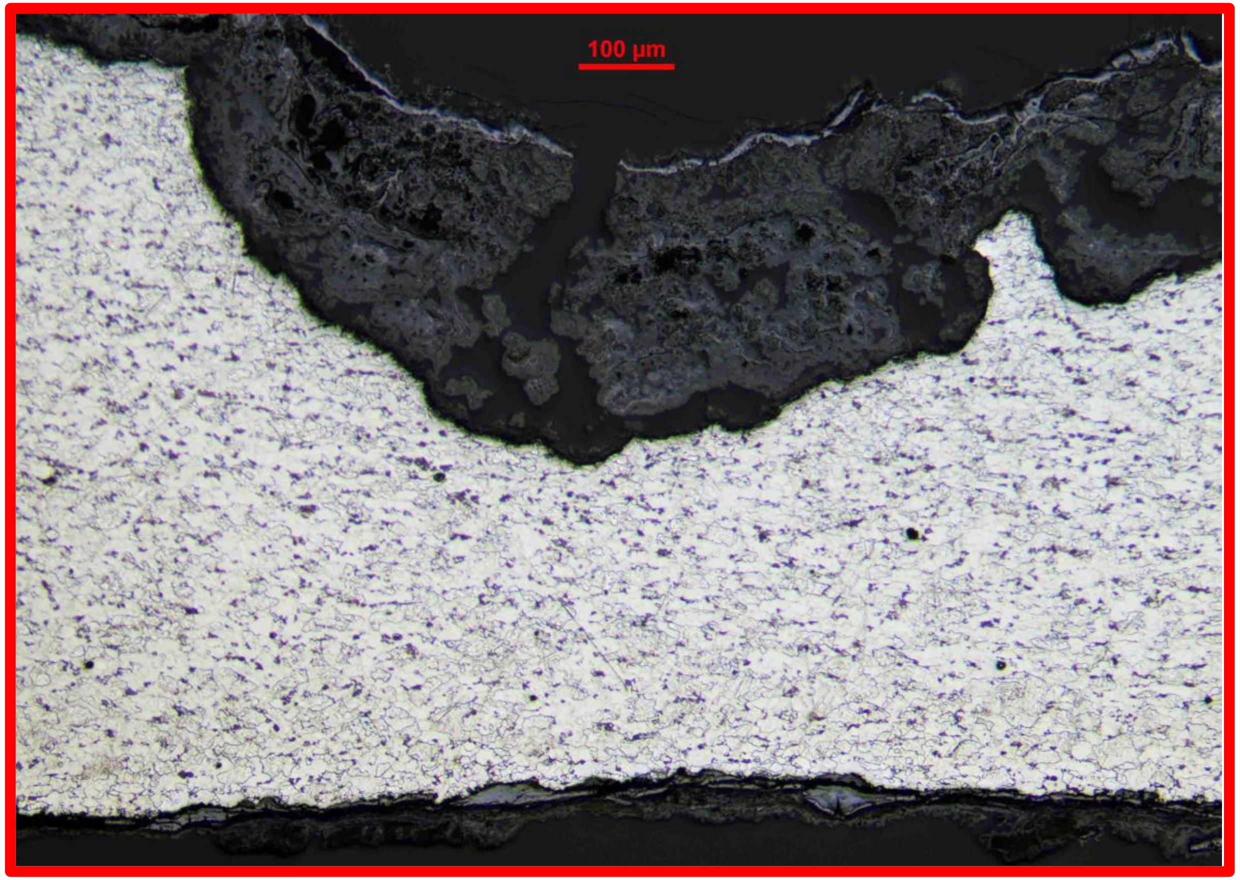
EXTRADOS: NO damages on internal / external surface

INTRADOS:

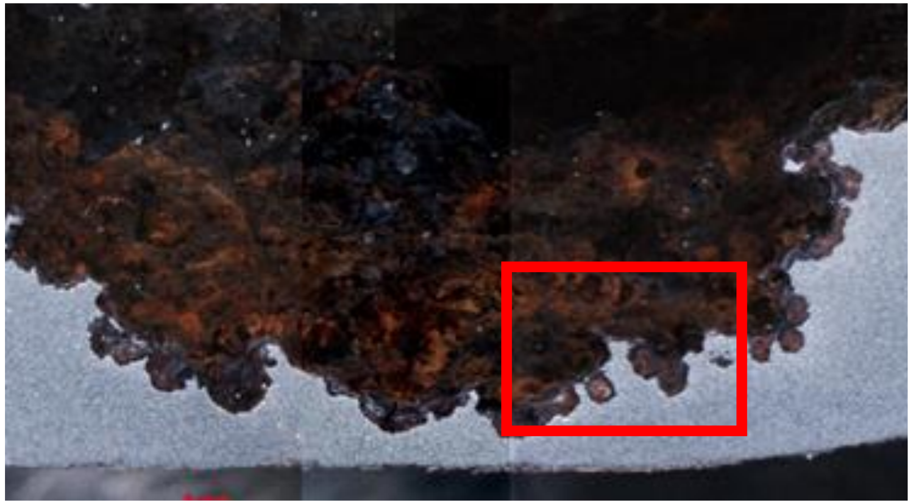
- NO damages on external surface
- Passing corrosion on internal surface

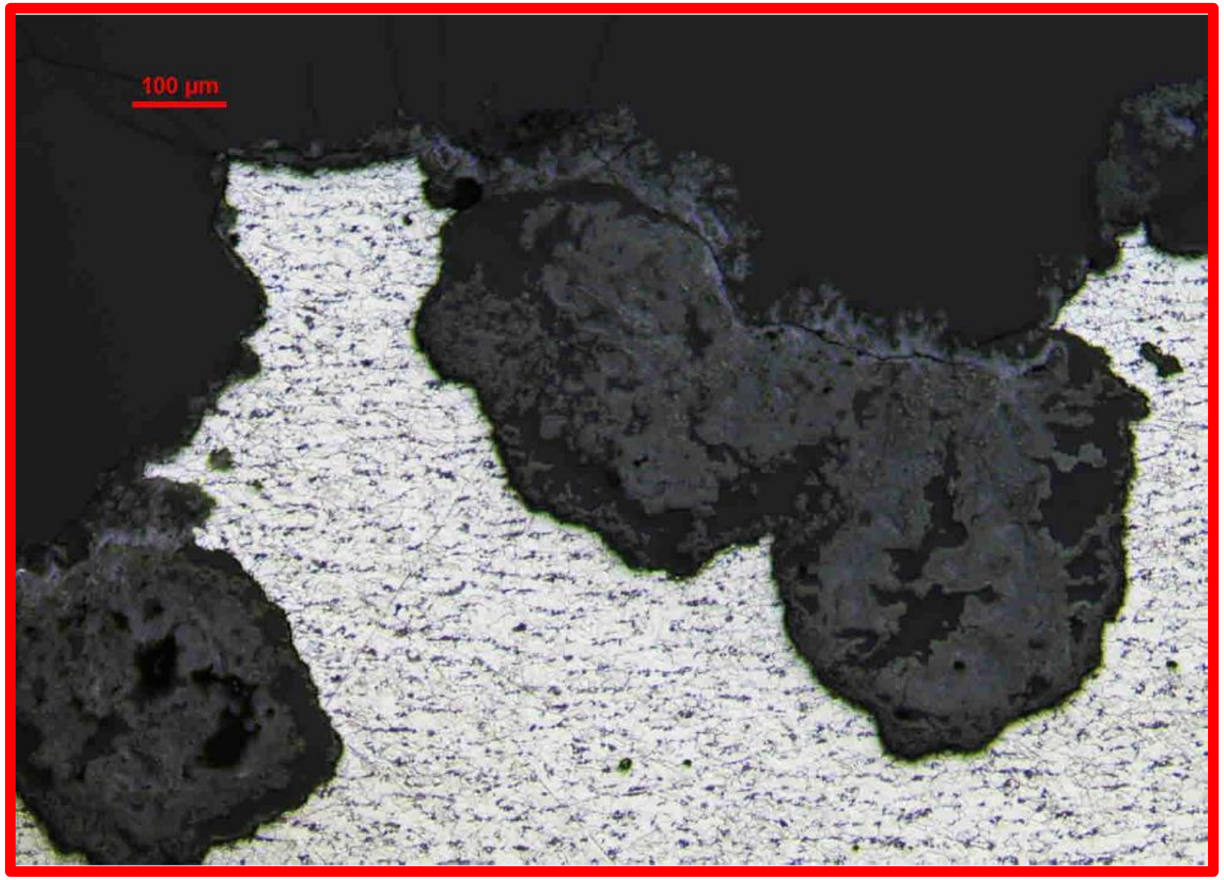
Donegani Anticorrosione

→ FAILURE ANALYSIS → Curve intrados (detail X100)

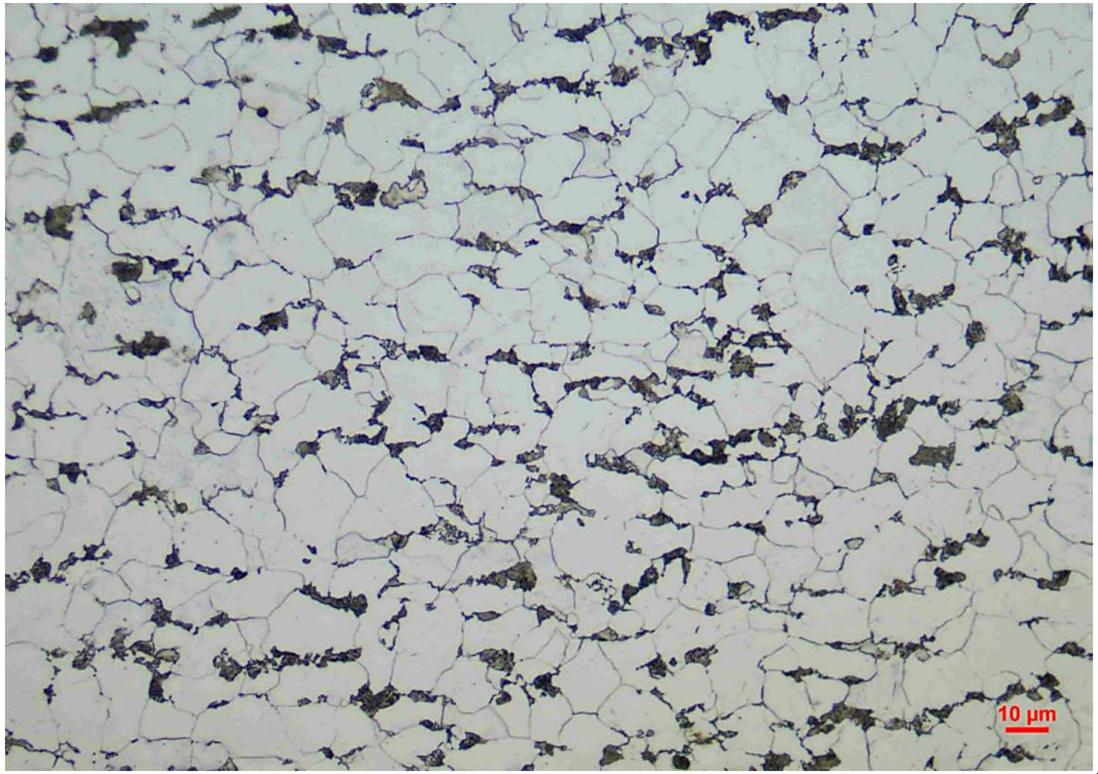


→ FAILURE ANALYSIS → Curve intrados (detail X100)





→ FAILURE ANALYSIS → Curve intrados



METHOD	HV 1
MEASURED VALUES	130 HV 138 HV 154 HV
AVERAGE HARDNESS	**141 HV**

Crystalline microstructure (X500) ✓

Hardness Test ✓

→ FAILURE ANALYSIS → CONCLUSIONS

- **Crateriform corrosion →** Incorrect water treatment
- **Microbiologically induced corrosion (MIC) →** Accelerate corrosion rate (bacteria count X10 max)
- **Why only intrados ? →** more turbolent flow

Donegani Anticorrosione

→ FAILURE ANALYSIS → Recommendations

- **Crateriform corrosion → Improvements (seen previously)**
- **MIC → Continuous biocidal treatment of tower water with hypochlorite and weekly monitoring the bacterial count (maximum recommended value < 10^3 ufc/ml)**
- **Install corrosion test samples in the circuit, to assess the aggressiveness of the water, and monthly monitoring the weight loss and visual appearance.**

IN CONCLUSION:

BAD DESIGN, AND INCORRECT TREATMENT OF TOWER WATER CAN ALSO LEAD TO FAILURES IN THE CIRCUIT

APPROPRIATE VISUAL INSPECTIONS AND THICKNESS MEASUREMENTS COULD DETECT THE PROBLEM BEFORE THE FINAL FAILURE

APPROPRIATE WATER ANALYSIS AND CORROSION TESTS IN THE CIRCUIT CAN GUARANTEE THE CONSTANT QUALITY OF THE WATER USED

EFC Working Party 15 Spring
"Corrosion Refinery and Petrochemistry Industry"
Meeting - 24th March 2022

A case study of corrosion in cooling water treatment

MANY THANKS TO ALL THE ATTENDERS

Donegani Anticorrosione

CONTACTS

Alessandro Vanacore
Capo Dipartimento Controlli non Distruttivi
3° Livello VT-PT-MT-ET-UT-PAUT-TOFD-AE-LT UNI EN ISO 9712
2° Livello RE-ME-TT UNI EN ISO 9712
Ispettore PED – ambito di Approvazioni 3.1.3 – numero identificativo 150 in collaborazione con ICEPI

Federico Ciocca
Tecnico metallografo – Failure Analysis
2° Livello RE-ME UNI EN ISO 9712

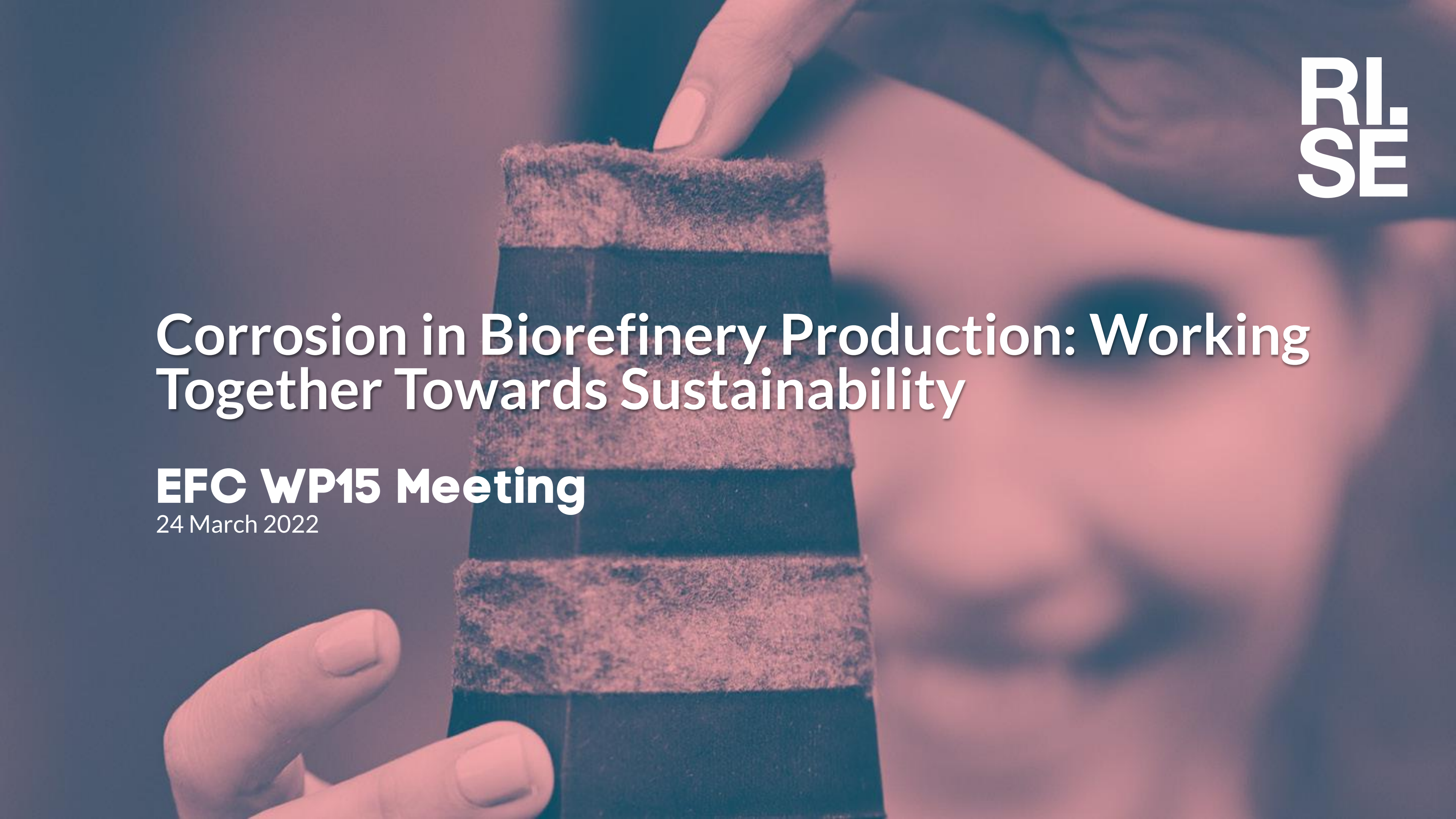
Donegani Anticorrosione s.r.l.
Via G. Fauser, 36/A
28100 – Novara (NO)
Tel. 0321/690429 - Fax 0321/696696
Mobile 0039/342 3233032

Donegani Anticorrosione

Appendix 5

Corrosion in biorefinery production: working together towards sustainability

(Namurata Pälsson)



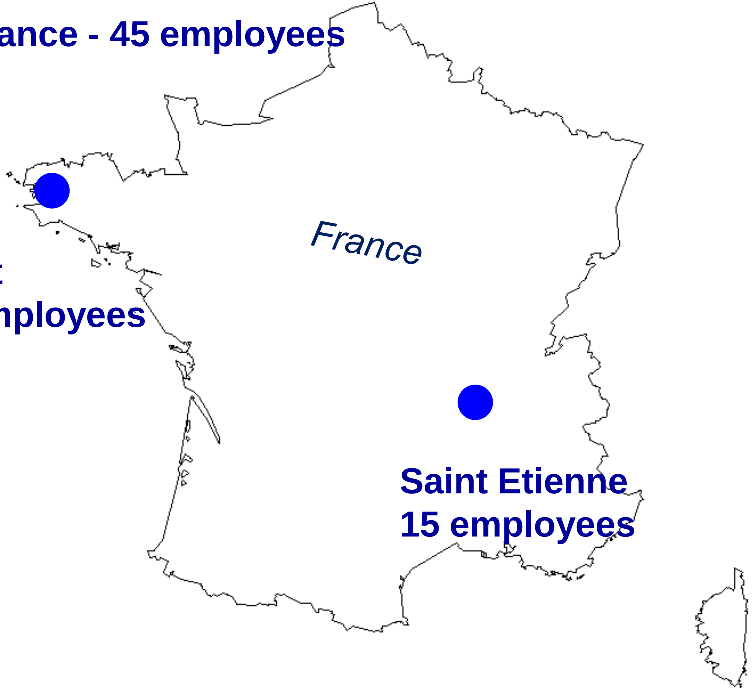
Corrosion in Biorefinery Production: Working Together Towards Sustainability

EFC WP15 Meeting

24 March 2022

Corrosion within RISE– more than 100 specialists

Institut de la Corrosion
French Corrosion Institute



RI. SE

Member programs within corrosion

(MRC – Member Research Consortium)

MRC in Sweden

- Automotive corrosion
- Surface technology
- Corrosion protection
- Corrosion in pulp & paper industry
- Corrosion of polymer materials
- Brass Alloys
- Corrosion and cathodic protection in soil
- Corrosion in Biorefinery Production

MRC in France

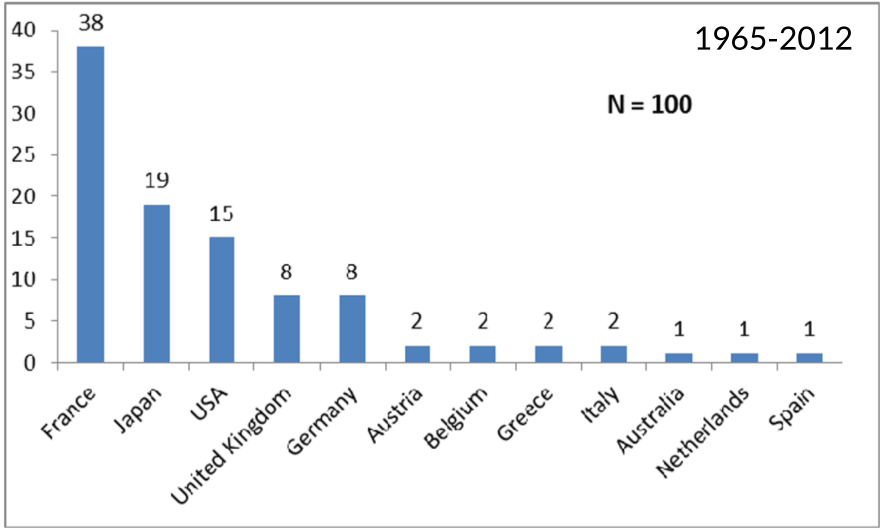
- Aerospace
- Coil coating
- Corrosion in oil & gas production
- Corrosion off-shore
- Paints and linings for steel structures
- Hydrogen

Do we really need to worry?

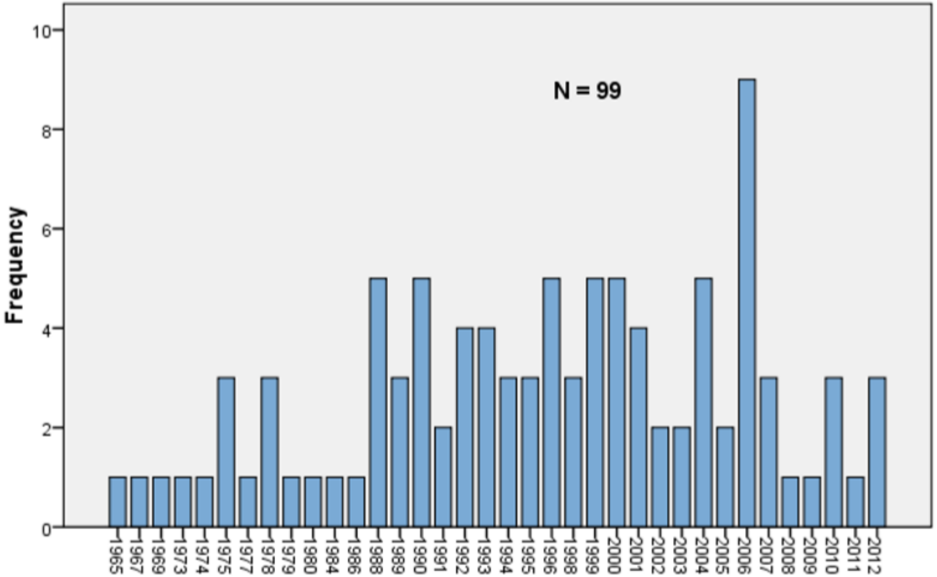
JRC SCIENTIFIC AND POLICY REPORTS

Corrosion-Related Accidents in Petroleum Refineries

Lessons learned from accidents in EU and OECD countries



Wood et al., 2013



Why we take these steps

- Possibility of corrosion in biorefinery production is not zero.
- Service conditions for biorefinery processes are highly complex.
- Knowledge related to the processes and material selection is crucial to mitigate or predict corrosion of components used in the challenging environments.
- Preventive maintenance!

Actions

- Researchers
- Scientists
- Material producers
- Biorefinery plant operators

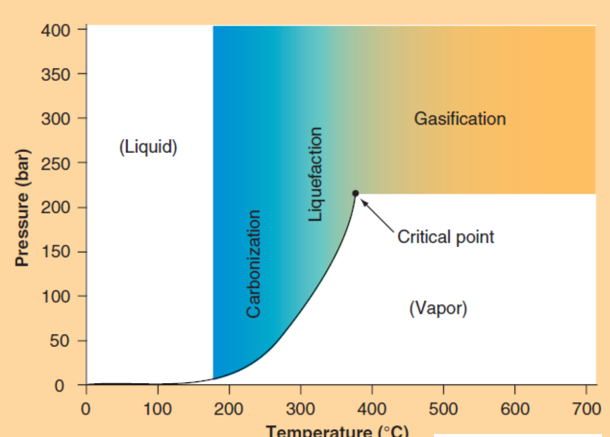
https://www.ri.se/en/what-we-do/networks/mrc-biorefinery

MRC on Corrosion in Biorefinery Production

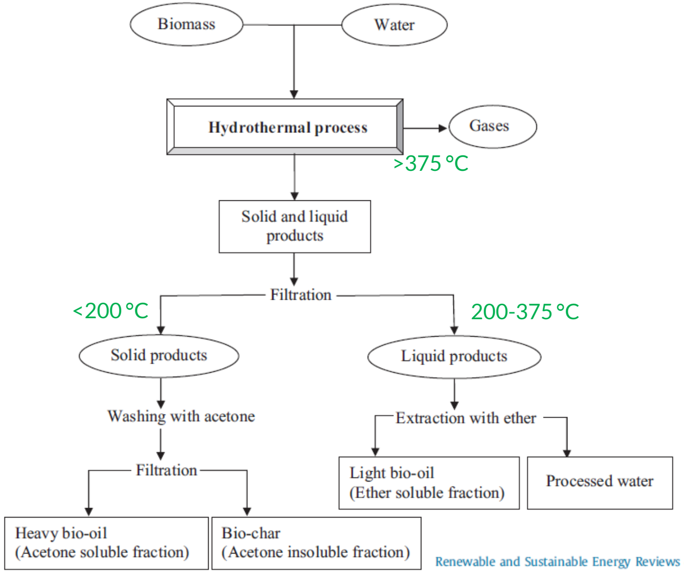
Based on scientific research, as well as strong collaboration among key players in biorefinery production, including plant operators, material producers, and experts on materials and corrosion, Member Research Consortium (MRC) Corrosion in Biorefinery Production will help its members with corrosion issues.

Actions

- 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



Biofuels (2012) 3(5), 603–623



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

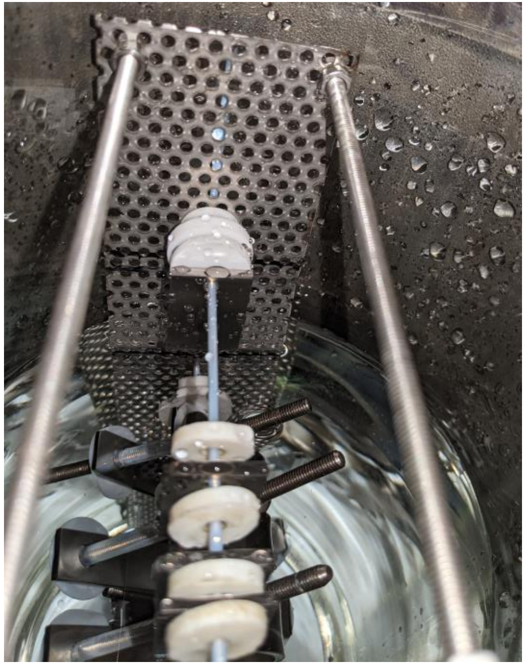
Corrosion resistant alloys

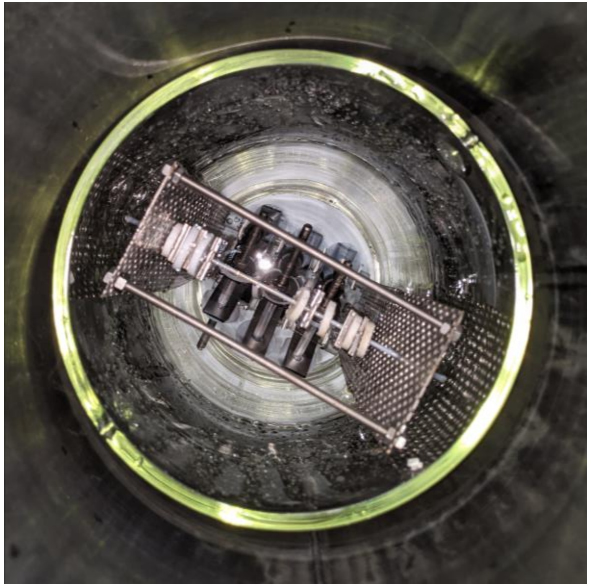
– nominal composition

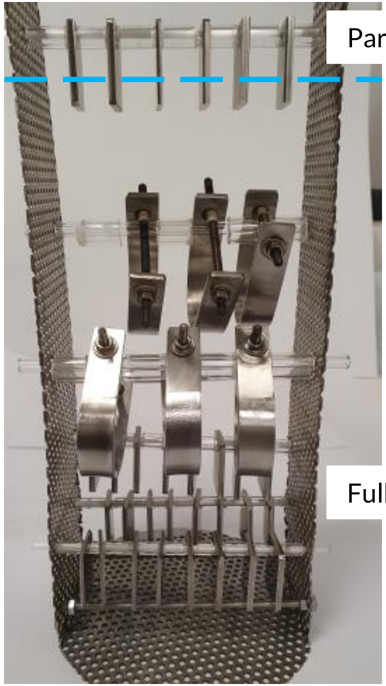
Alloys/ Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N	PREN
654 SMO	0.01		3.5			24	22	7.3	0.50	0.50	56
Sanicro® 35	≤0.030	≤0.5	0.8	≤0.030	≤0.020	27	35	6.5	0.2	0.3	53
Alloy 625	0.10	0.50	0.50	0.015	0.015	20-23	≥58	8-10	-	-	52
254 SMO	0.01					20	18	6.1	0.71	0.2	43
Sanicro® 28	≤0.020	≤0.7	≤2.0	≤0.020	≤0.010	27	31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

Pitting Resistance Equivalent Number = Cr + 3.3Mo + 16N

Testing conditions

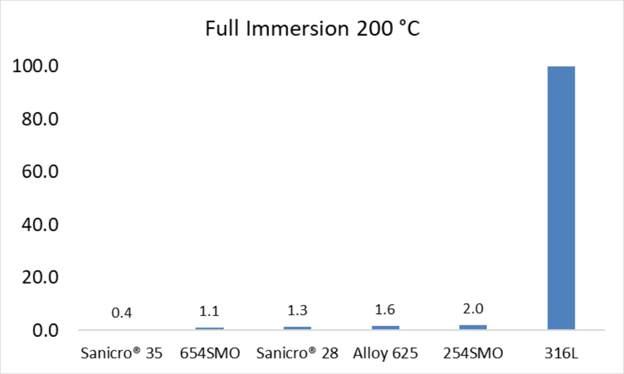


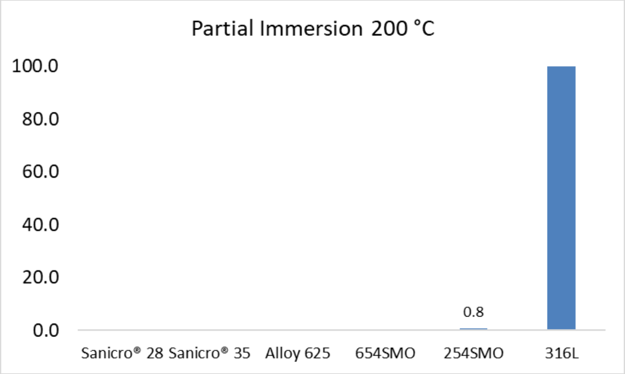


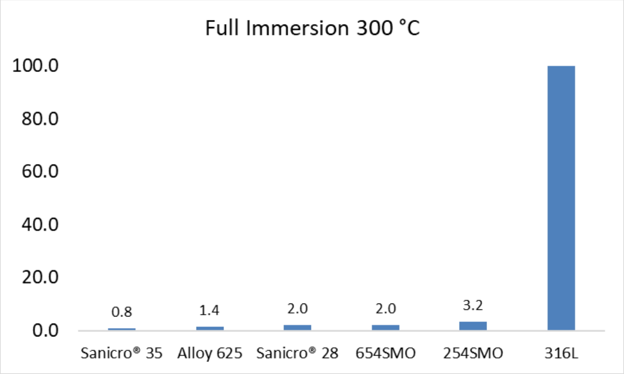


RI.
SE

Corrosion rate – relative percentage







Partial immersion for 300 °C is not available.

The test at 300 °C will be repeated.

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.

Next steps

- 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

Namurata Pålsson
namurata.palsson@ri.se
+46 70-079 65 33

Rikard Norling
rikard.norling@ri.se
+46 72-216 16 48

Christophe Mendibide
christophe.mendibide@institut-corrosion.fr
+33 78-269 50 43

Appendix 6

Corrosion with vegetable oils used for the production of biofuels

(Jean Kittel)

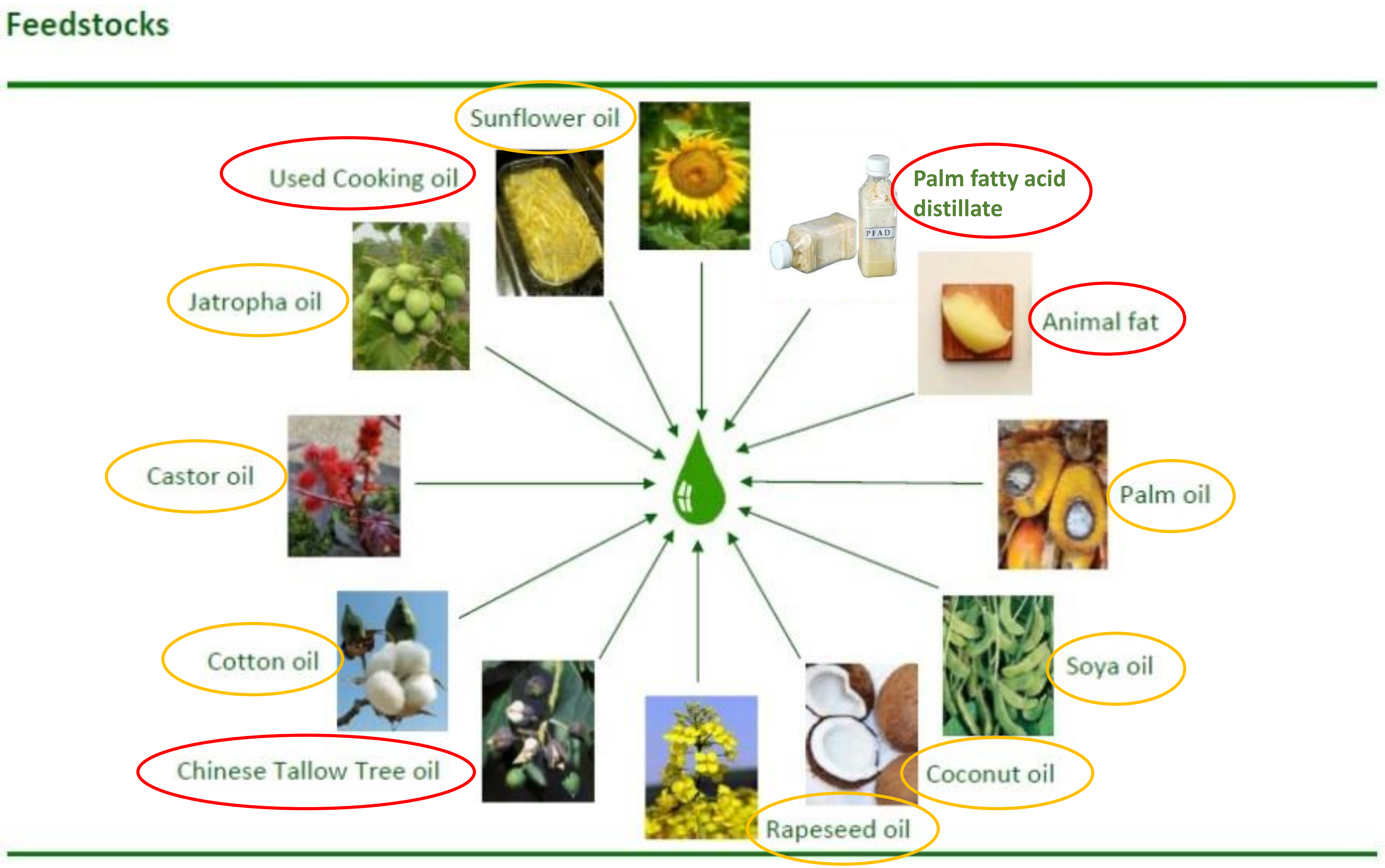
CORROSION IN VEGETABLE & WASTE OILS USED FOR THE PRODUCTION OF BIO-FUELS

Fouad Andari [a], Jean Kittel [a], Joana Fernandes [a], Benoît Ter Ovanessian[b], Marion Frégonèse[b], Nathalie Godin[b], François Ropital [a,b]

[a] IFP Energies Nouvelles, Rond-Point de l’échangeur, Solaize, France 69360
[b] University Lyon, INSA-LYON, MATEIS UMR CNRS 5510, Bât L. de Vinci, 21 Avenue Jean Capelle, F-69621 Villeurbanne cedex, France

SOME FEEDSTOCK IN BIOFUEL PRODUCTION

Renewable energies



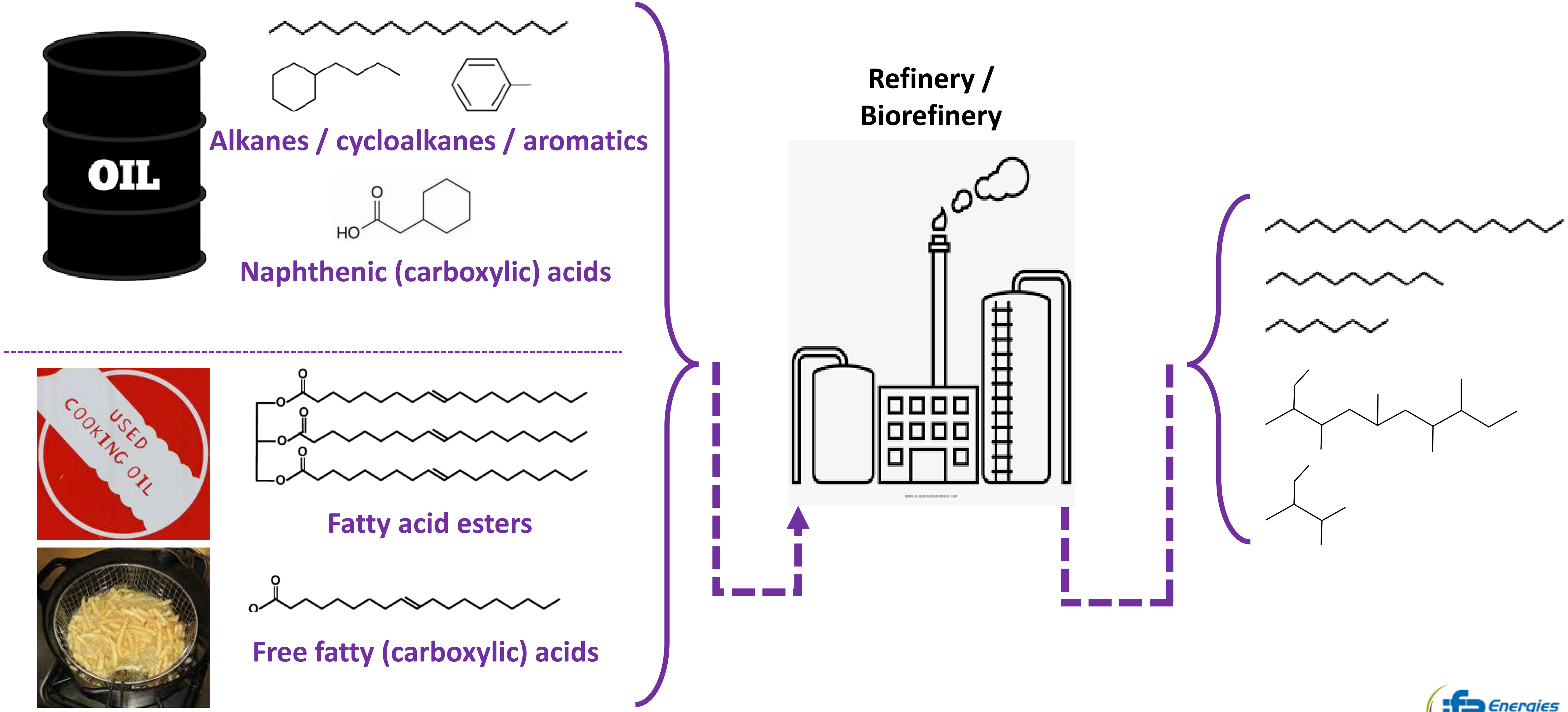
conventional

alternative

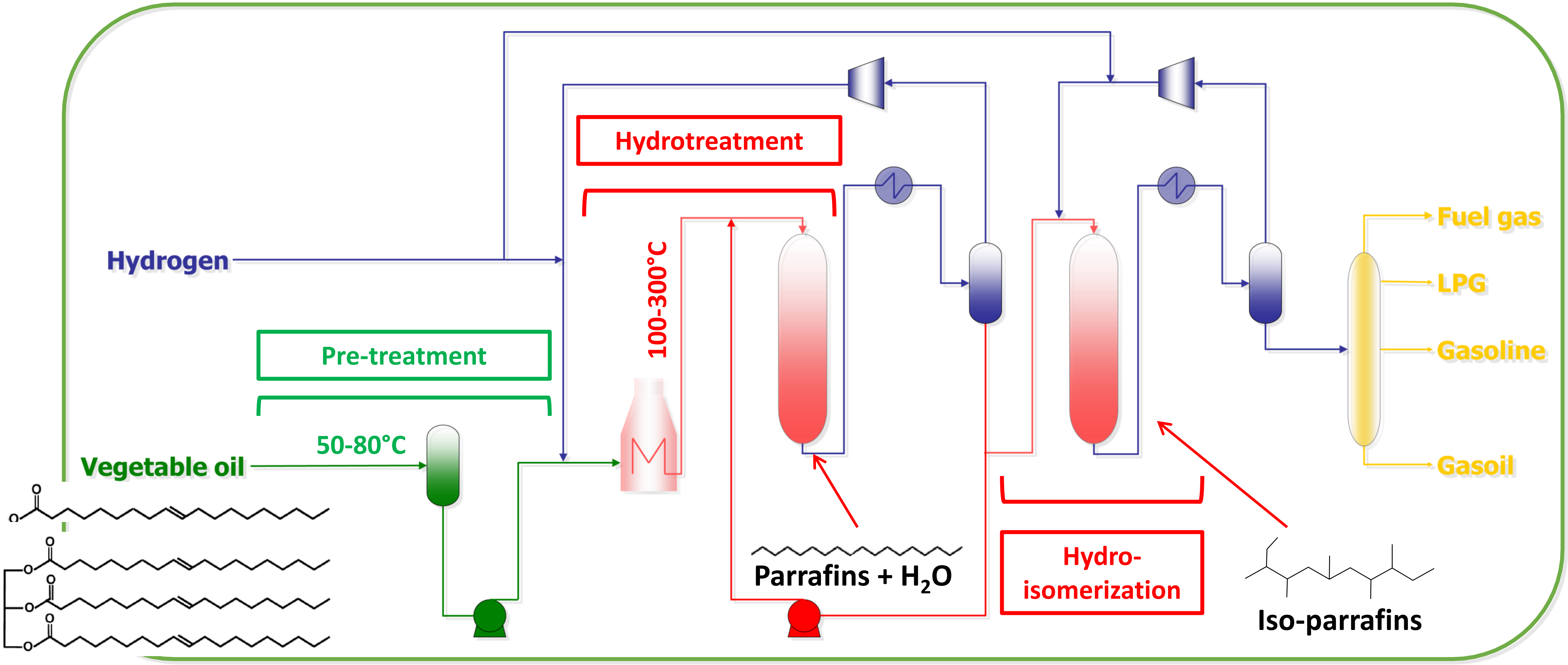
[https://www.gondwanabiodiesel.com/project-overview/]

VEGETABLE OILS VS CONVENTIONAL CRUDE OIL

Renewable energies

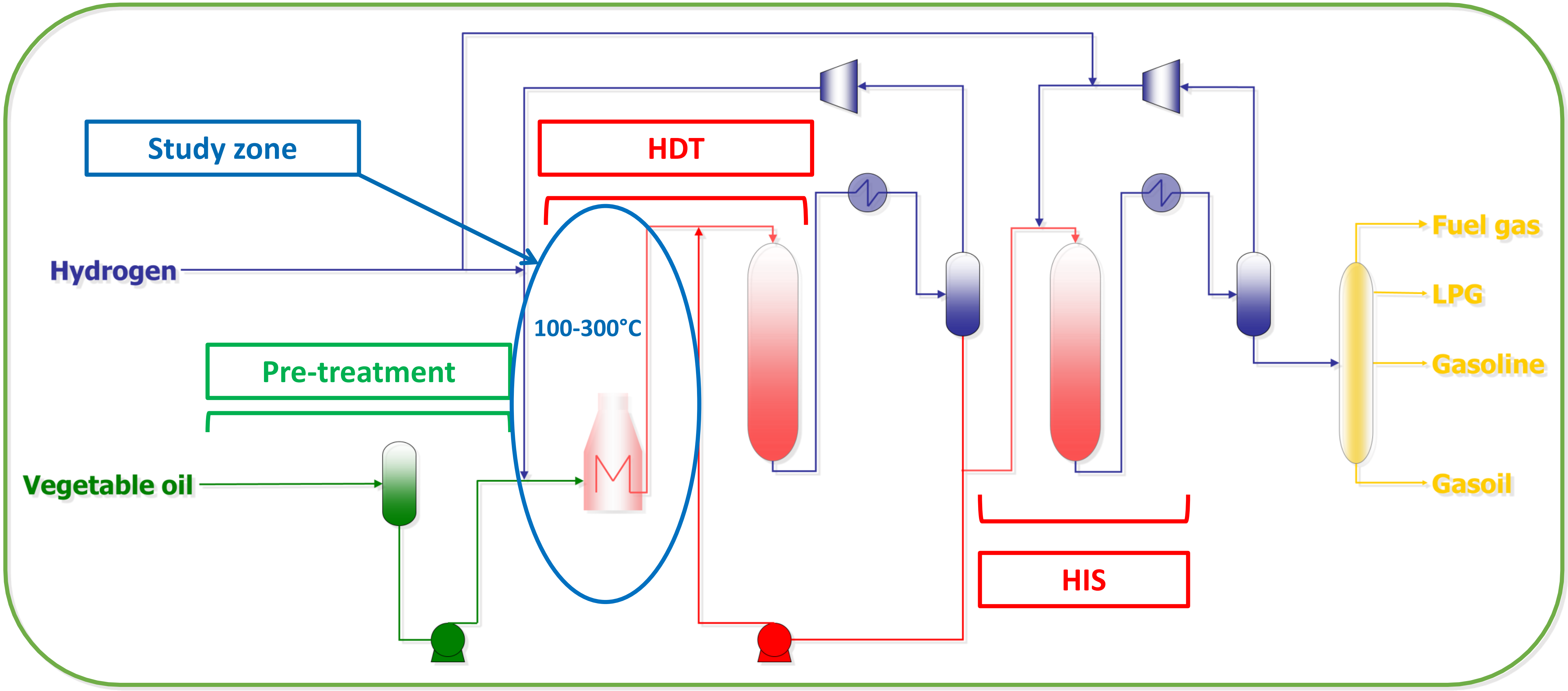


REFINING VEGETABLE OILS



STUDY ZONE

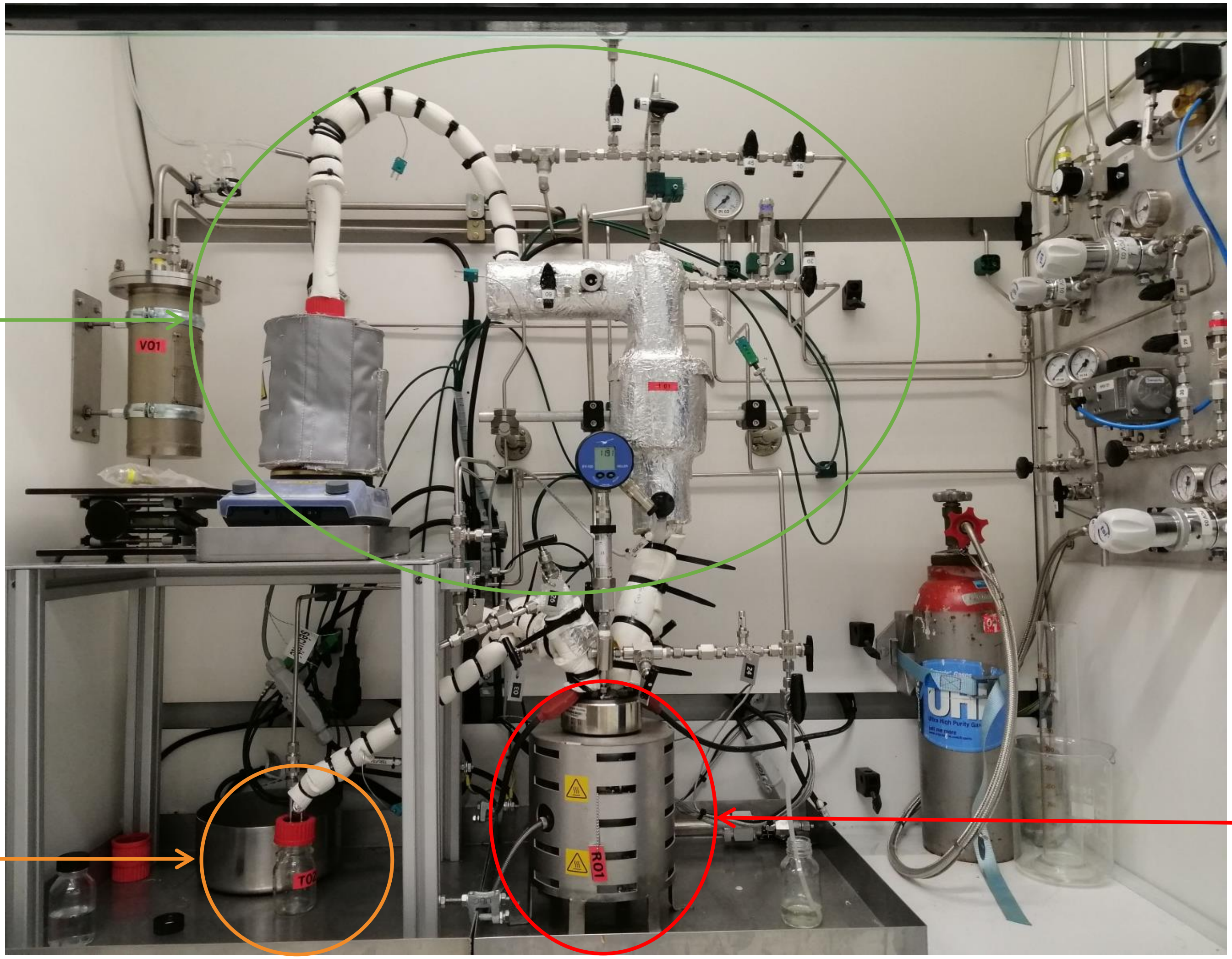
Renewable energies



EXPERIMENTAL TEST UNIT

Renewable energies

Oil conditioning and transfer



Weight-loss coupons
- 316L
- 1.25Cr/0.5Mo
- Carbon steel

Post-test analysis
- Infrared
- Simulated distillation
- Dissolved metal (ICP)

Sampling point

Autoclave
V = 600ml
T°max = 500°C
P°max = 138bar (H_2/N_2)

IFP Energies nouvelles

TEST METHODOLOGY

- Corrosion tests at 220 °C for 5 days
  - weight loss coupons (carbon steel / low alloy steel / stainless steel)
  - post test solution analysis

- Part 1
  Tests with 10 industrial feeds to detect the most influent parameters

- Part 2
  Tests with model solutions prepared with a non corrosive oil and pure oleic acid

PART 1 – TESTS IN INDUSTRIAL FEEDS
COMPOSITION OF TESTED OILS

Renewable energies

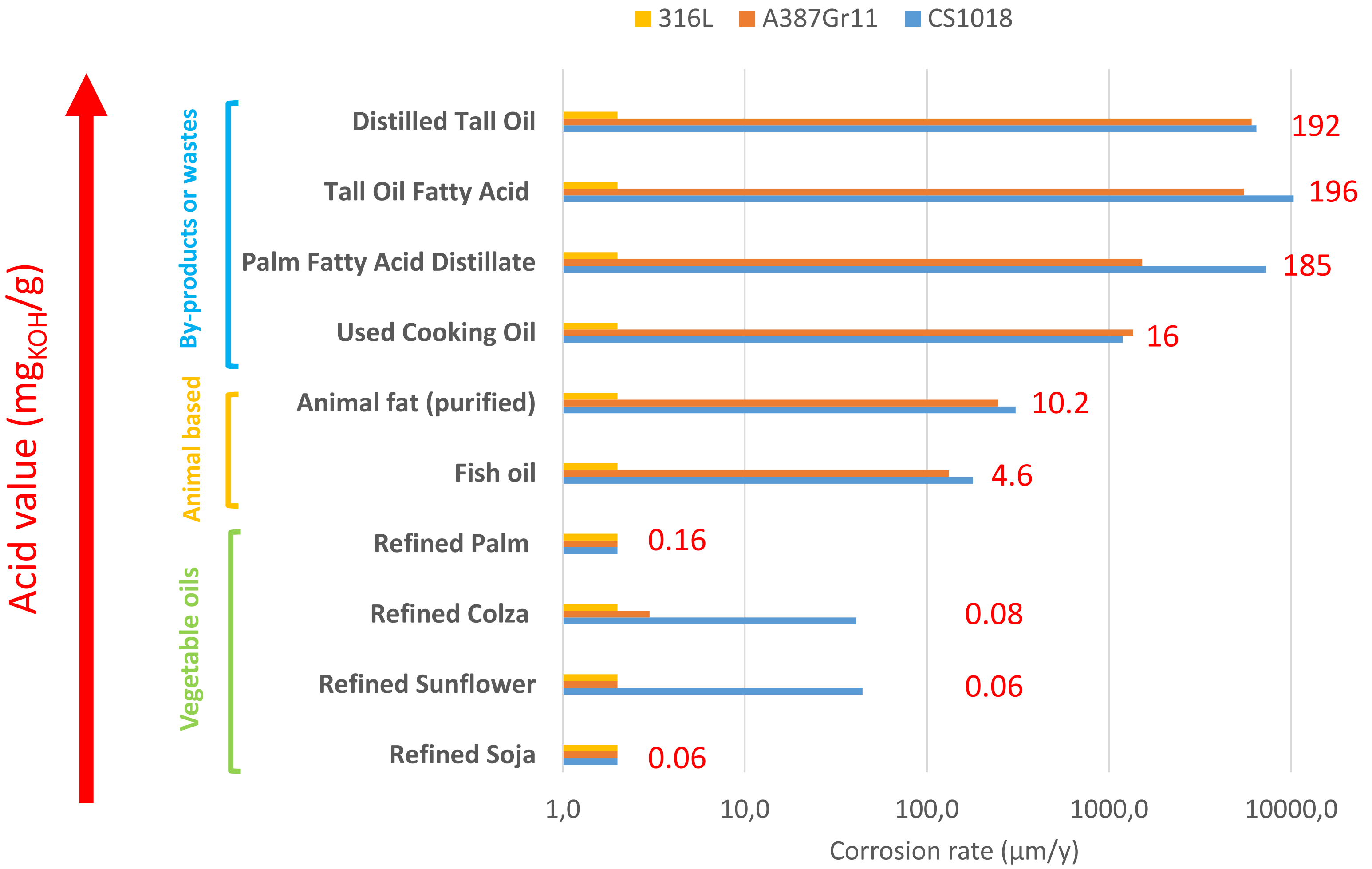
		Vegetable oils				Animal based		By-products or wastes			
		Refined Rapeseed	**Refined Sunflower**	**Refined Soja**	**Refined Palm**	**Animal fat**	**Fish oil**	**WCO**	**PFAD**	**TOFA**	**DTO**
Acid value	[mg_{KOH}/g]	0.06	0.06	0.06	0.16	10.2	4.6	16	185	196	192
Peroxide index	[meqO_2/kg]	0.6	2.1	0.7	1.1	13.4	3.4	1.2	1.2	7.2	-
Water content	[mg/kg]	150	170	150	100	709	1000	3310	1468	240	-
Iodine index	[g/100g]	115	126	132	53.5	78	136	87	61	146	-

- 10 industrial feeds
- acid values from 0 to 200 mg_{KOH}/g
- different types of fatty acid esters (C16 to C22)

IFP Energies nouvelles

PART 1 – TESTS IN INDUSTRIAL FEEDS
CORROSION RATE

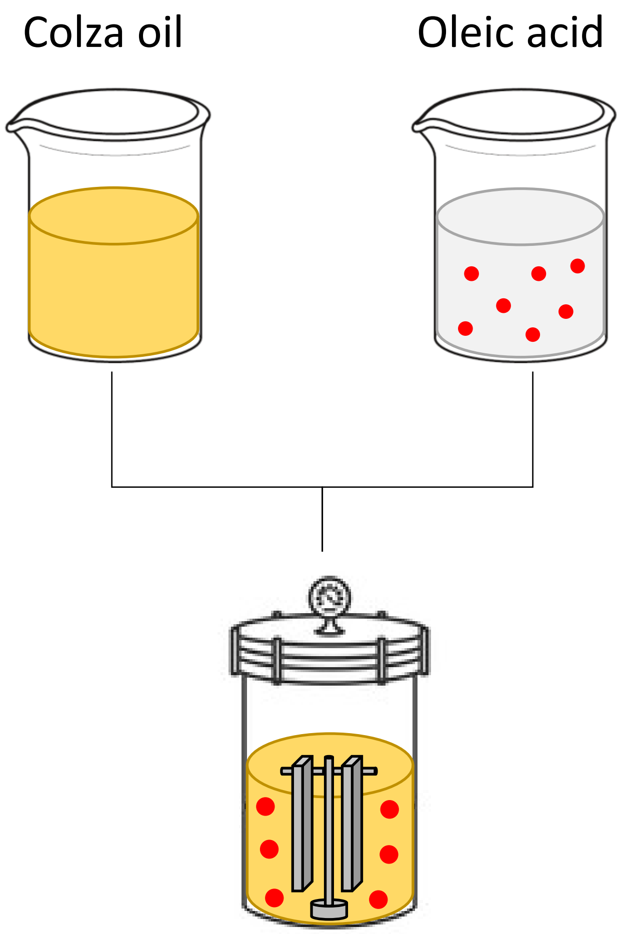
Renewable energies



- 316L is always immune
- Corrosion of CS and LAS increase with acid value
- At 220 °C, corrosion rates above 0.1 mm/y are obtained when the acid value exceeds 4 mg_{KOH}/g

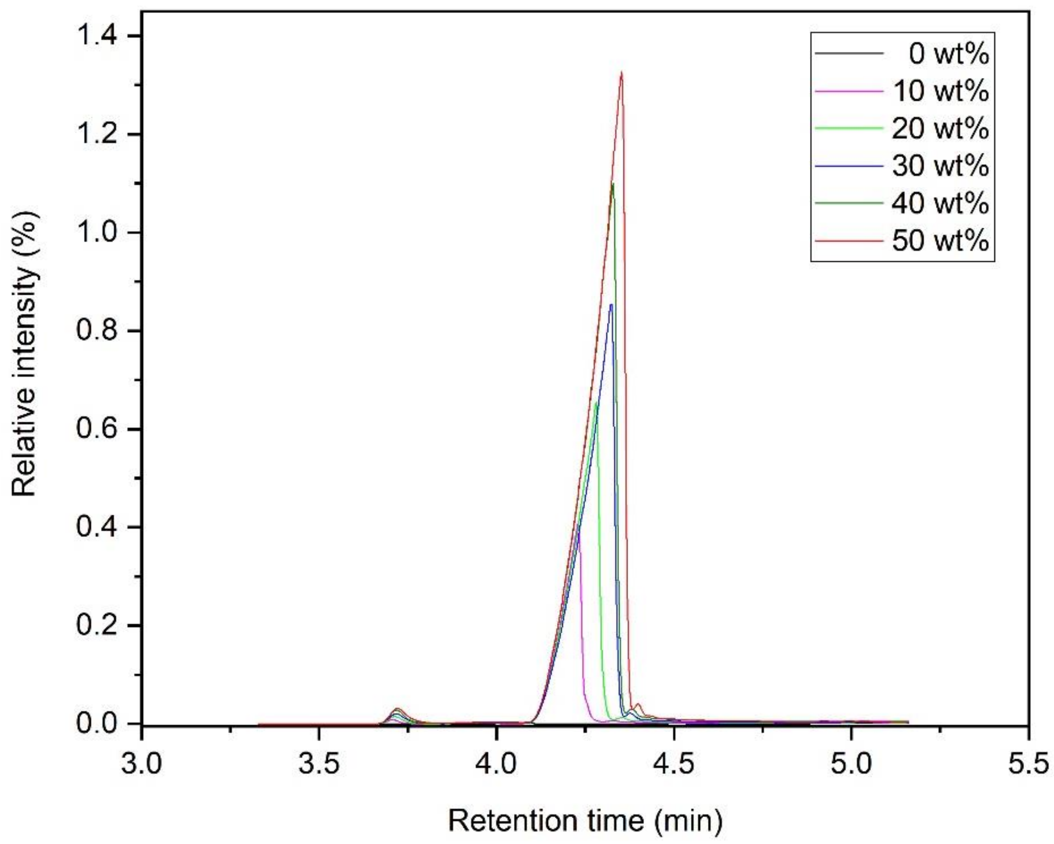
PART 2 – TESTS IN MODEL SOLUTIONS
PREPARATION OF THE SOLUTIONS

Renewable energies



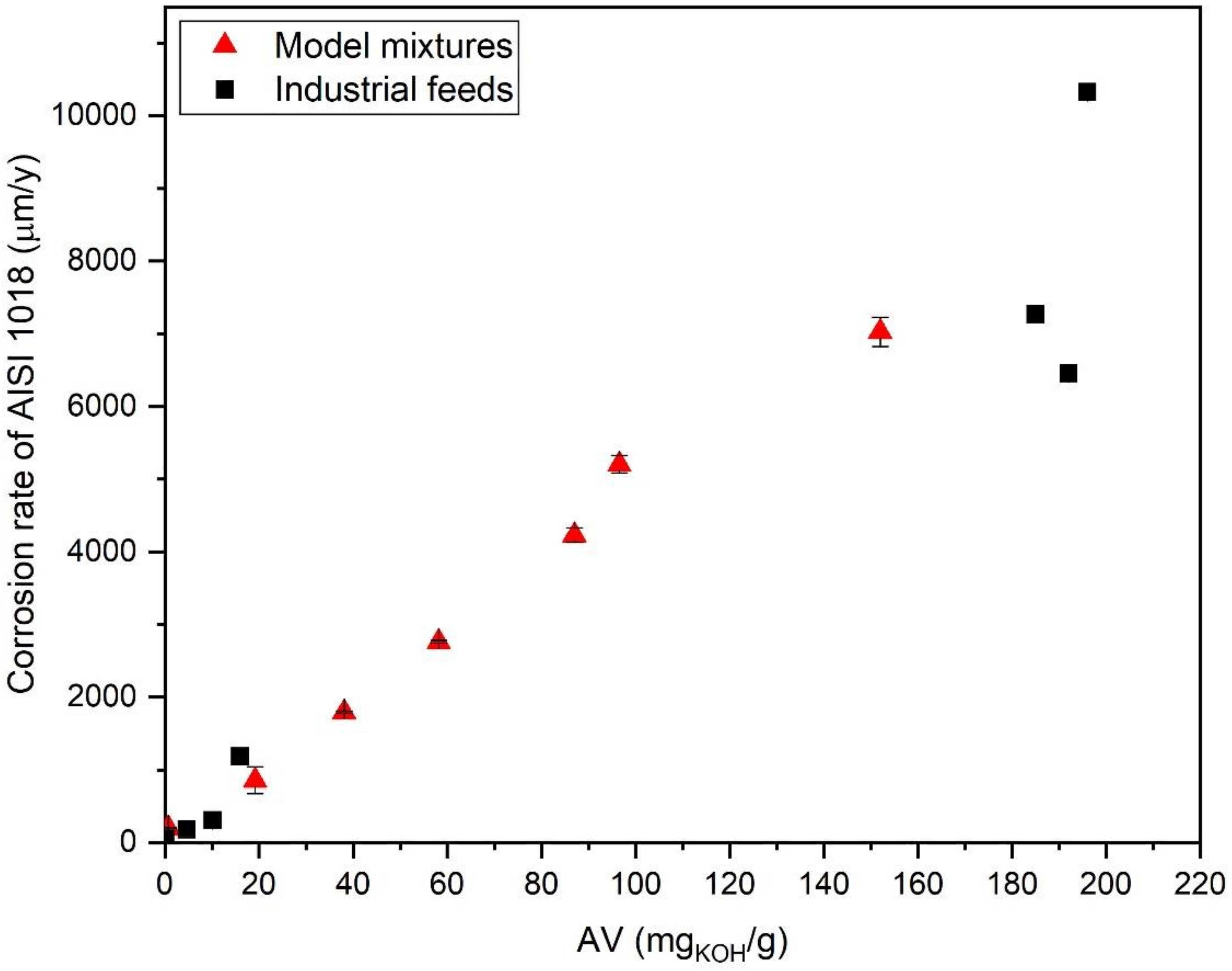
mass % of oleic acid	acid value (mgKOH/g)
0	0.8
10	19
20	38
30	58
40	77
50	97
70	152

Titration of FFA by SIM-DIS



TESTS IN MODEL SOLUTIONS
1/ CORROSION RATE VS ACID VALUES

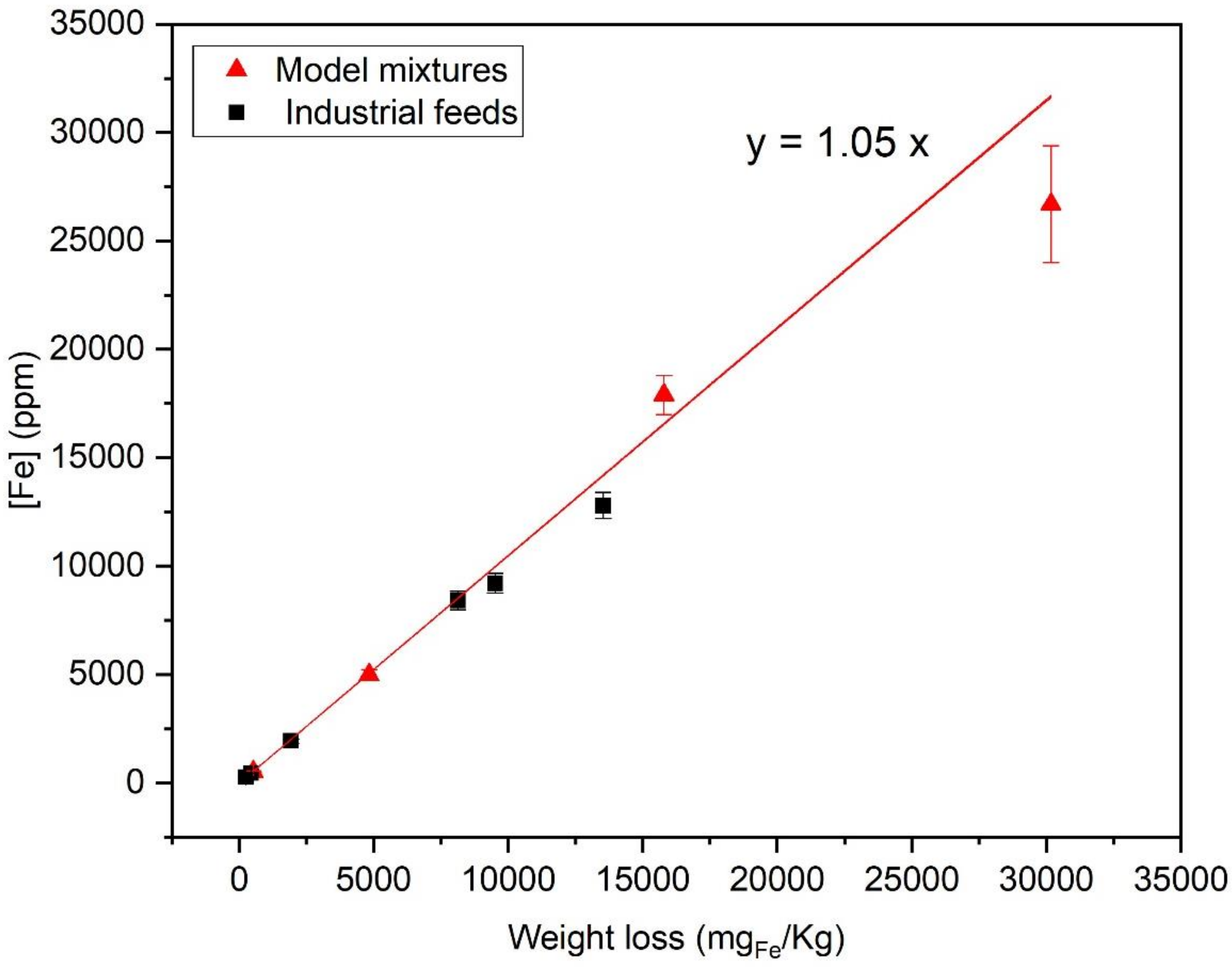
Renewable energies



- Impact of acid value is confirmed
- Linear evolution of carbon steel corrosion rate with acid value
- Same curve for model and industrial solutions

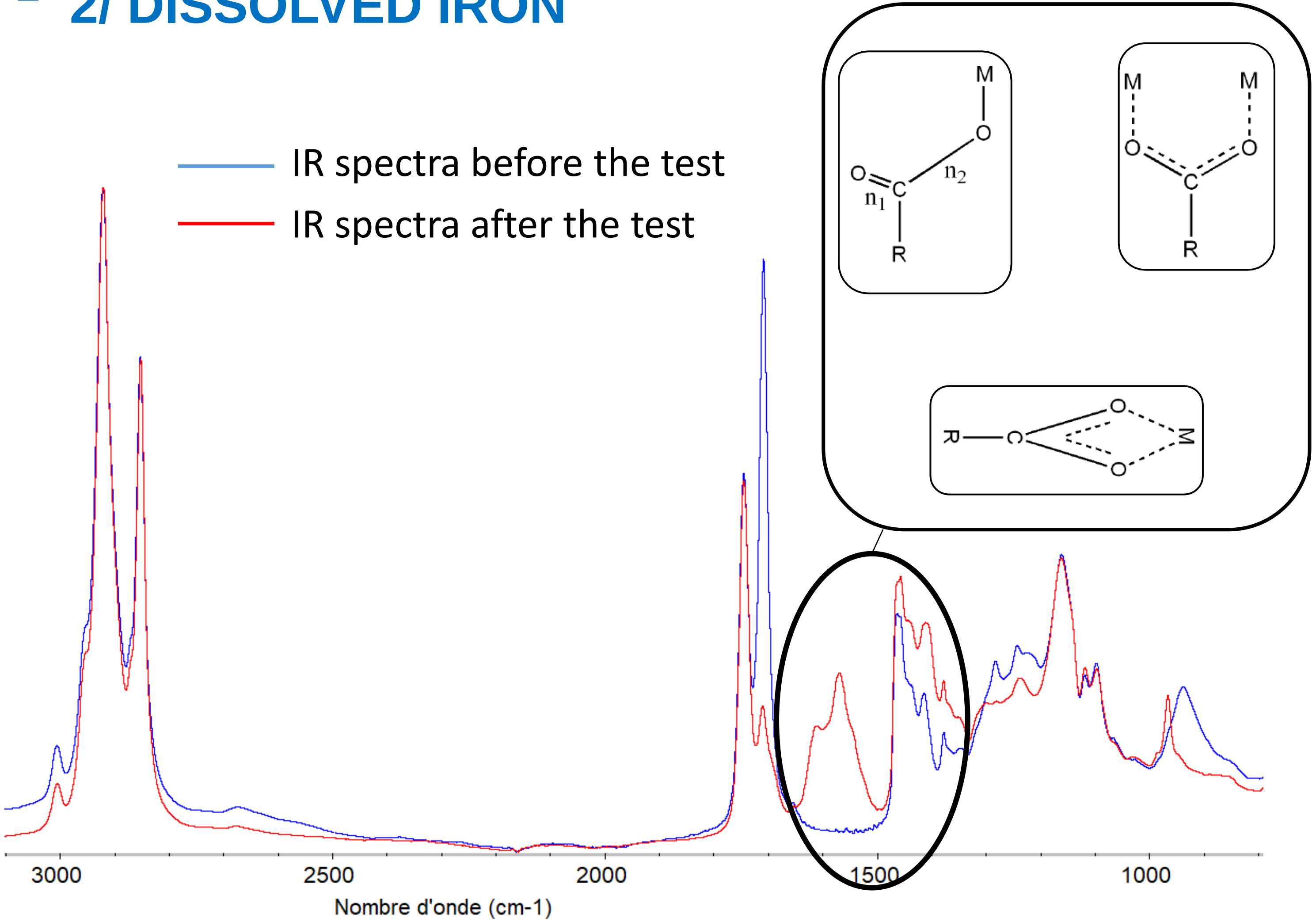
TESTS IN MODEL SOLUTIONS
2/ DISSOLVED IRON

Renewable energies



- All corroded iron stays in the solution (no precipitation)
- Huge solubility (> 30 g_{Fe}/L)

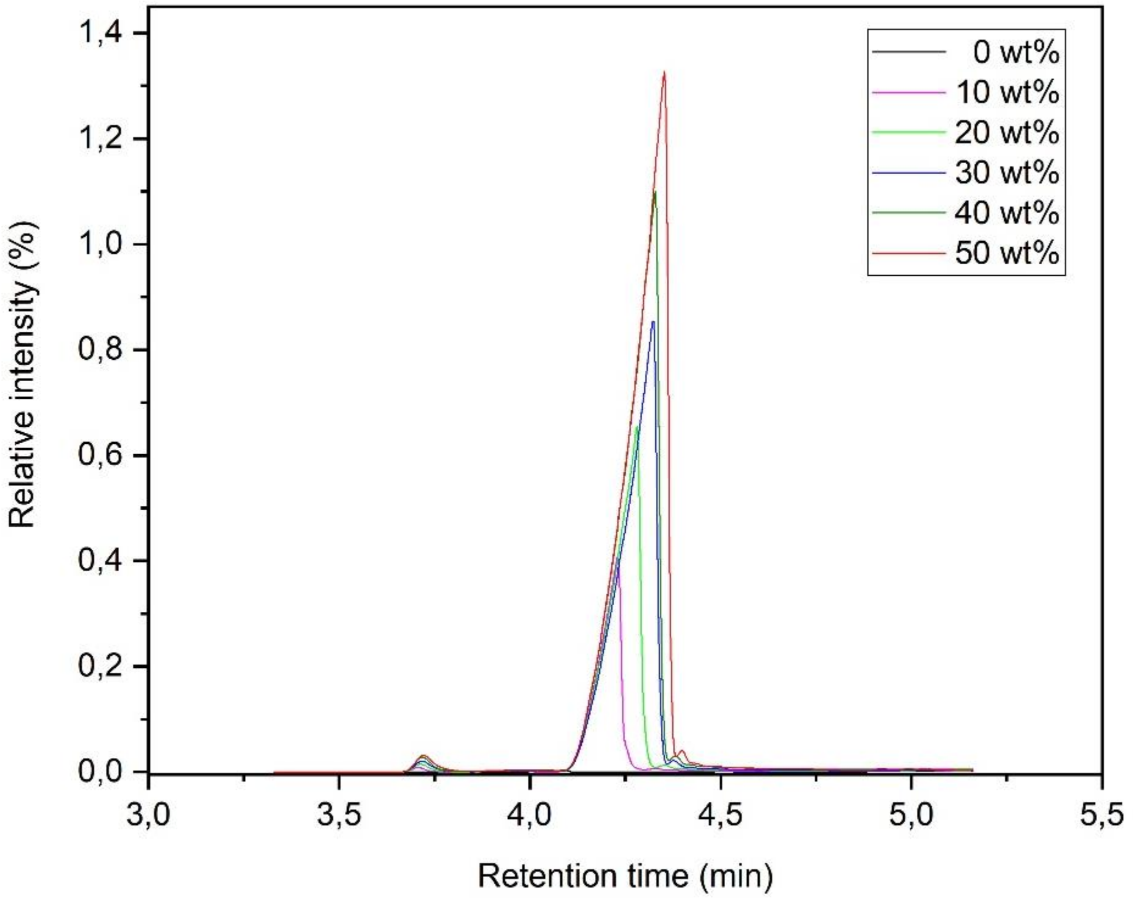
TESTS IN MODEL SOLUTIONS
2/ DISSOLVED IRON



IR spectra reveal the presence of metal complexes

TESTS IN MODEL SOLUTIONS
3/ CONSUMPTION OF FREE FATTY ACIDS

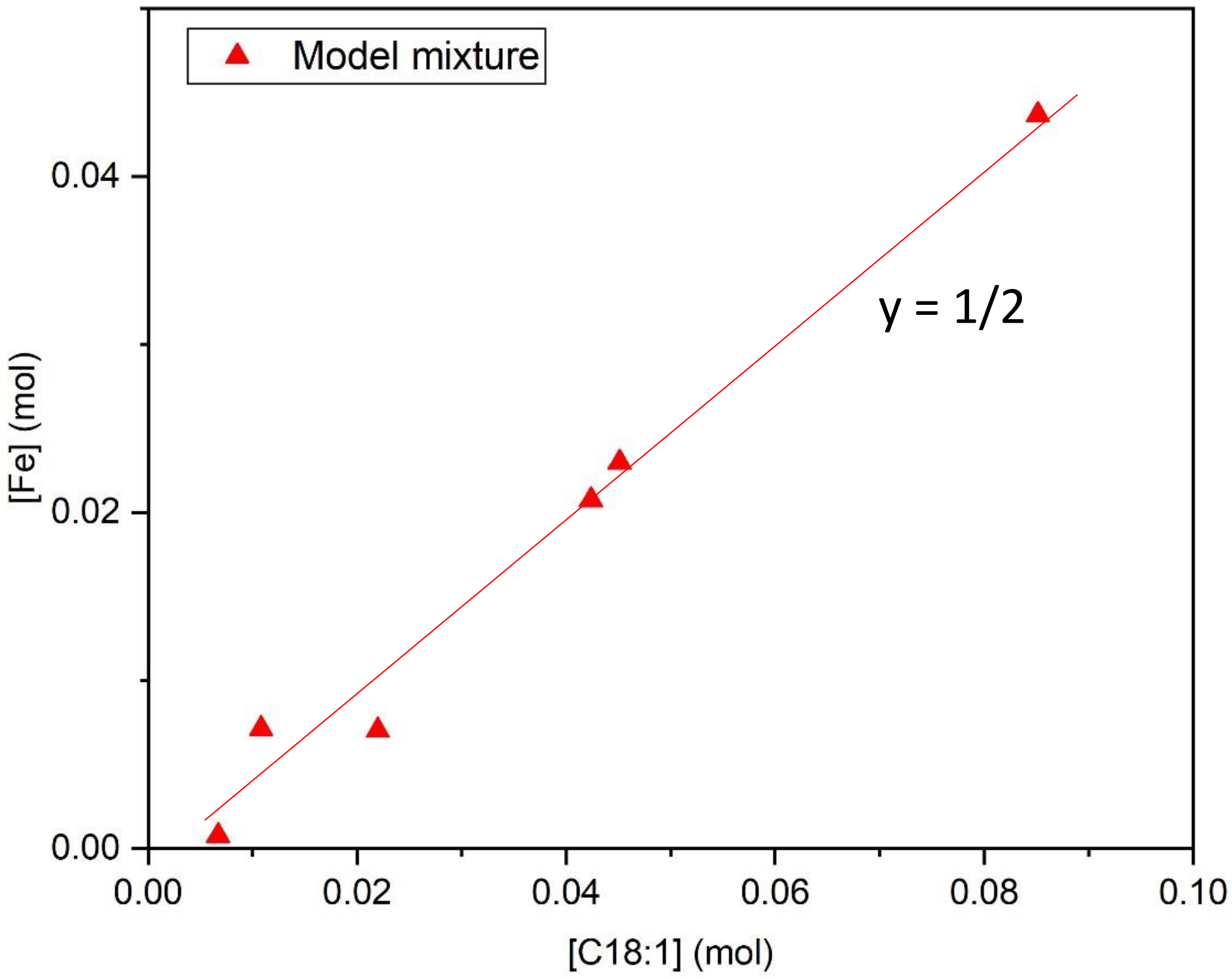
Renewable energies



- Free fatty acid content measured before / after each test with SIM-DIS analysis
- Acid consumption correlated with iron dissolution

TESTS IN MODEL SOLUTIONS
3/ CONSUMPTION OF FREE FATTY ACIDS

Renewable energies



- The amount of corroded metal is well correlated with the consumption of FFA
- 2 moles of acid react with 1 mole of Fe

CONCLUSIONS

- Carbon steel and low alloy steel show linear evolution of corrosion rates with acid value
- The linear trend is similar for industrial feeds and model solutions
- At 220 °C, the limit of 0.1 mm/y is reached when the acid value exceeds a few mg_{KOH}/g
- The amount of corroded metal is proportional (factor 1/2) to the quantity of consumed free fatty acid
- The huge solubility of iron is explained by the formation of complexes involving the carbonyl group of FFAs

Appendix 7

Corrosion overview in biorefineries

(Marco de Marco)

Overview of corrosion in Biorefinery

M. De Marco – IIS

ISTITUTO ITALIANO
DELLA SALDATURA
ente morale

“…use of vegetable oils for motor fuel may seem insignificant today, but such oils can become, over time, as important as modern-day petroleum and coal derivatives…“

Rudolf Diesel, 1912

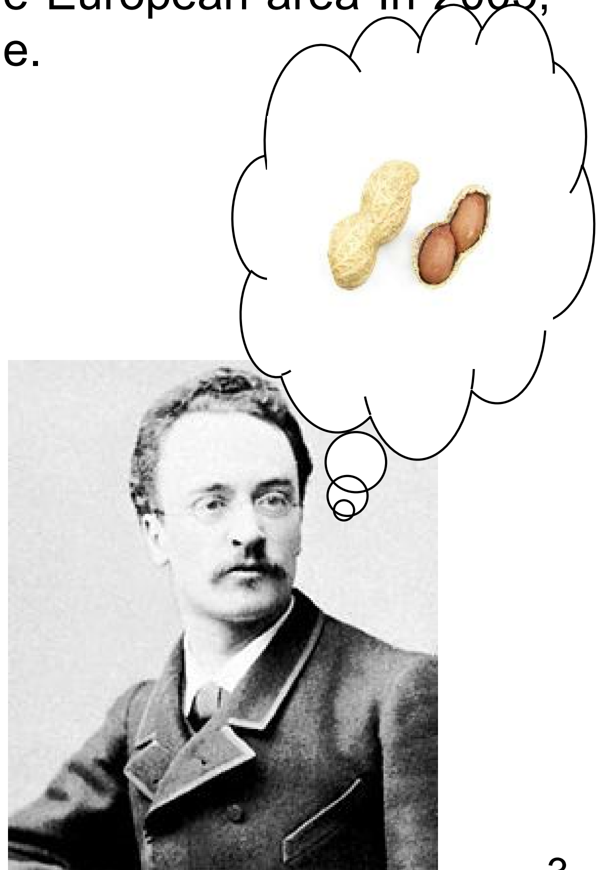
Origins

Biodiesel was originally produced by E. Duffy and J. Patrick 40 years before the invention of the diesel engine.
In 1893, **Rudolf Diesel** himself ran the first of his engines using peanut oil as a fuel.

The recent interest in biodiesel was born in 1991 with the commissioning of the **first production plant** on an industrial scale in Austria.

Since then, numerous plants have been started up especially in the European area In 2005, more than 3,500,000,000 liters of biodiesel were produced worldwide.

Jatropha Curcas and seeds



Rudolf Diesel

Feed stock - Biomass

Biomass means ***"the biodegradable fraction of products, waste and residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fishing and aquaculture, as well as the biodegradable part of waste industrial and urban".***

Biofuels are fuels that derive from biomass and are opposed to fuels of fossil origin (.. in fact, they too derive from biomass, but no longer living for a long time ...).

Examples of biomass used as a renewable base for fuels are wood, rod, corn stalk, and other agricultural waste, sugar, corn starch, soybean, rapeseed, palm oil, pongamia and jatropha, algae, oils and fats animals also waste, etc. etc.

ISTITUTO ITALIANO DELLA SALDATURA

Feed stock - Biomass

Biomasses are mainly composed of carbon, hydrogen and oxygen atoms with the presence of sulfur, nitrogen, phosphorus, other metals and chlorine.

e.g. cellulose, lignin, triglycerides, fatty acids, glycerol esters.

Soia

CH_2OCOR'

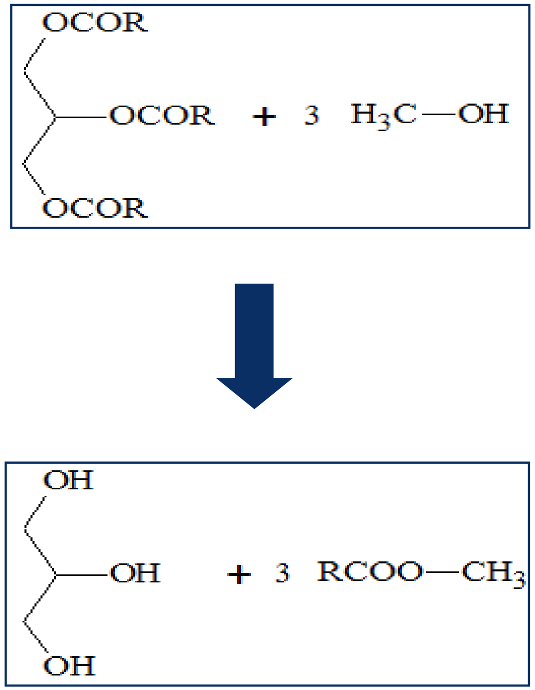
CH_2OCOR''

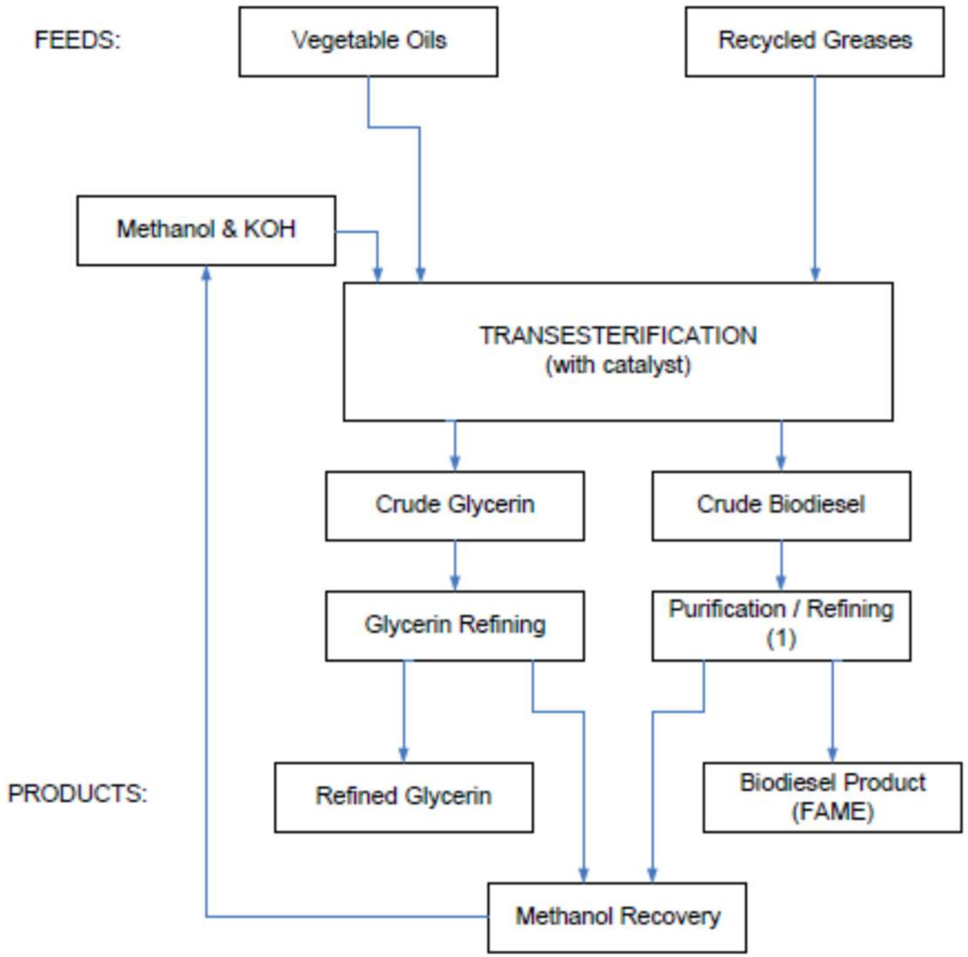
CH_2OCOR'

Vegetable oil

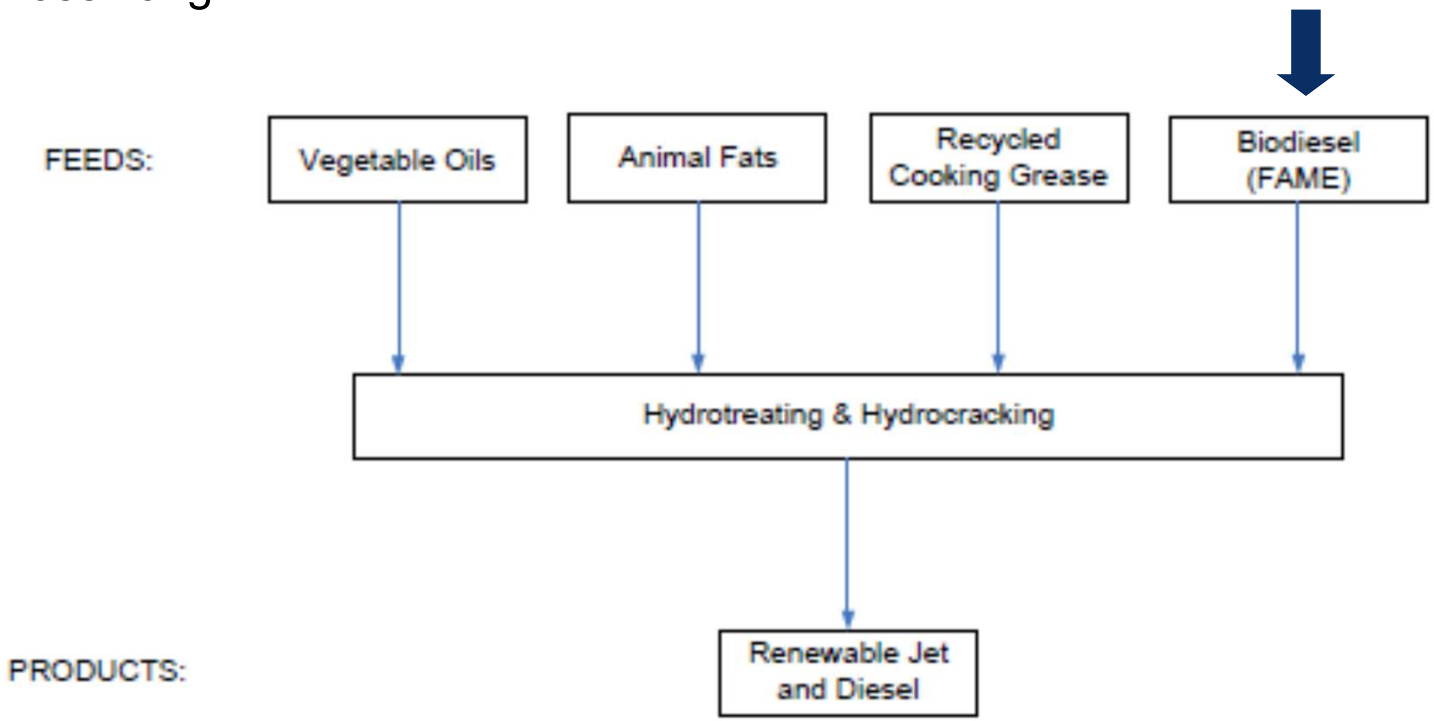
The terminology Biodiesel generally defines **mono-alkyl esters of various fatty acids** (Fatty Acid Methyl Ester - **FAME**, VME - Vegetable Methyl Ester) obtained by trans-esterification reaction of biolipids with alcohol and catalyst (e.g. soda, potash) .

→ First generation **Biodiesel**





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

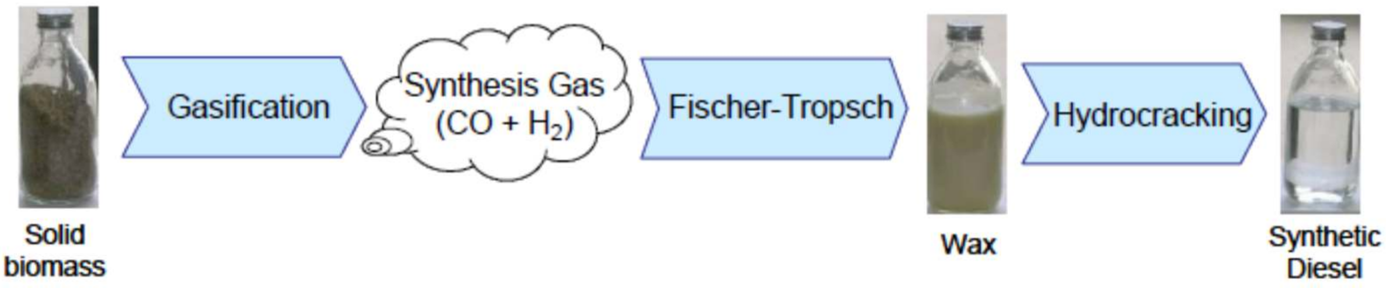


Production - Decomposing and reassembling

The molecules of biofuels are smaller than the originals from which they derive: rupture reactions (**decomposition**).
This is followed by a phase of **synthesis, purification and transformation (reconstruction)** into purer and more functional mixtures.

Biomass Feeds	Biomass Deconstruction Steps	Synthesis/Purification Steps	Biofuel/Bio-based Chemical Products
Lignocellulosic Biomass Routes			
Wood Wood Waste Corn Stalks Corn Cobs Agricultural Waste Switchgrass Energy Cane MSW (newspapers, grass clippings, etc)	Gasification to CO & H_2	Fischer-Tropsch Mixed Alcohols Methanol to Ethyl Acetate to Ethanol Fermentation	Renewable Jet Renewable Diesel Ethanol
	Strong Acid Hydrolysis	Fermentation	Ethanol Butanol Renewable Gasoline Renewable Xylene
	Weak Acid Hydrolysis	Fermentation	Butanol Isobutanol
	Enzymes (biocatalysts)	Fermentation	Ethanol
	Weak Acid Hydrolysis & Enzymes	Fermentation Fermentation-Acetic Acid-Ethyl Acetate-Hydrogenation	Ethanol
	Pyrolysis	Hydrotreating	Renewable Gasoline Renewable Jet Renewable Diesel Renewable Xylene
Plant Oil & Fat Based Routes			
Triglycerides: Plant Oils • Canola • Soy • Palm • Jatropha • Algae Animal Fats • Grease from restaurants • Slaughterhouse waste • Rendering plants	Chemical transesterification with methanol to fatty acid methyl esters (FAME) using an acid or base catalyst	N/A	Biodiesel
		Hydrogenation and hydrocracking	Renewable (drop in) jet & diesel
	High temperature hydrolysis	Hydrogenation	

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.

Corrosion Issues

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

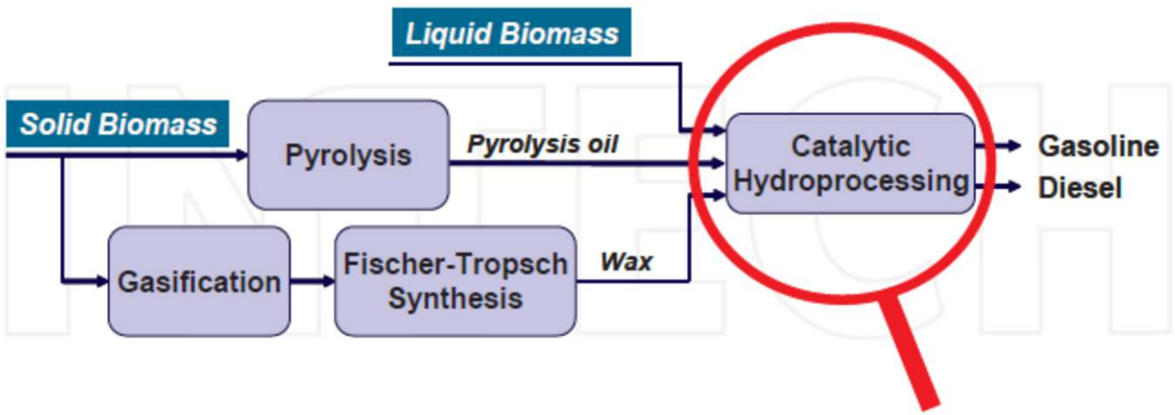
H_2O solubilizes numerous corrosive agents present

→ ***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**



The literature reports evaluations concerning the corrosion problems in the following phases of the life cycle of biofuels:

- **Raw materials:** corrosion in tanks containing vegetable oils.
- **Finished products:** corrosion in transport systems and tanks for biofuels.
- **Combustion:** corrosion in combustion products (internal combustion engines, power plants, etc.).

To the present date, there are **gaps** in the **assessments of corrosion** and **material selection issues** in the intermediate stage of production.

The variability of the processes, often covered by patents, makes the situation more complicated.

RF production– Corrosion mechanisms

The different stages of RF production are characterized by numerous potential corrosion and damage mechanisms to be considered when selecting materials and define inspection intervals (1)

→**Organic acids** in the presence of condensed water
→**High temperature organic acids (and FFA)** in the absence of condensed water (T> 100 ° C)
→**CO_2** in the aqueous phase (due to Hydrodecarboxylation reactions - HDC)
→**Chlorides** in aqueous solution (pitting and SCC)
→High temperature hydrogen attack (HTHA - API 941)
→Corrosion and alkaline SCC in soda and potash (catalysts)
→Corrosion by mineral acids (sometimes used as catalysts in the decomposition phase of biomass)

The presence of organic acids in low T anhydrous fluids can become critical even in the initial absence of water → **bio-based fuels are hygroscopic!**

*(1) Da **Impact of Organic Acid on Materials Selection for Biofuels and Bio-Based Chemical Plants -** Cathleen A. Shargay, Karly Moore and Marty West*

Corrosion Issues - Feedstock

Pyrolysis Oil	Oil Properties				Corrosion Rates (mm/yr)				
	Biomass Feed Stock	Total Acid Number (TAN)	Formic Acid Conc. (ppm)	Acetic Acid Conc. (ppm)	CS	K21590	S40900	S30403	S31603
1	Oak	86	2400	19000	0.9 / 2.4	0.2 / 0.2	0.1 / --	0.0 / --	0.0 / 0.0
2	Mixed Hardwoods	108	7756	40668	2.6 / 2.4	3.3 / 3.3	0.6 / 0.6	0.0 / 0.0	0.0 / 0.0
3	Forest Residue	66	6490	7778	2.8 / 3.1	4.0 / 4.2	0.7 / 0.0	0.0 / 0.0	0.0 / 0.0
4	Wood	14			0.5 / 0.4	1.2 / 0.1	0.8 / 0.1	0.0 / 0.0	0.0 / 0.0
5		68			2.6 / 0.2	2.4 / 2.6	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0
6	Switch-grass	58.5			0.6 / 0.6	1.4 / 1.5	0.8 / 0.8	0.0 / 0.0	0.0 / 0.0
7		0.23 (Note 1)			0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0

Treated with H_2

Medium	Corrosion Coupon Results (mm/yr)	Average Corrosion Rate (mm/yr)
B99 – Biodiesel with 1% of 3% NaCl	0.09, 0.07, 0.14	0.10
B100	0.03, 0.02, 0.01	0.02

T Amb
TAN < 0.3 mg /gr

ISTITUTO ITALIANO DELLA SALDATURA

Corrosion Issues - Feedstock

MIC cases on Soybean oil pipeline.

ISTITUTO ITALIANO DELLA SALDATURA

Processing - Organic acids in presence of condensed water

In several areas of the plants for RF production, conditions may occur in which a **condensed aqueous phase + organic acids** is present.
CO_2 and chlorides may also be present.

pH of pure water @ T=25 ° and 100 ppm acid	
Acid	**pH**
Formic	3,9
Acetic	4,2
Propionic	4,4
Butanoic	3,8
Sulfuric	3

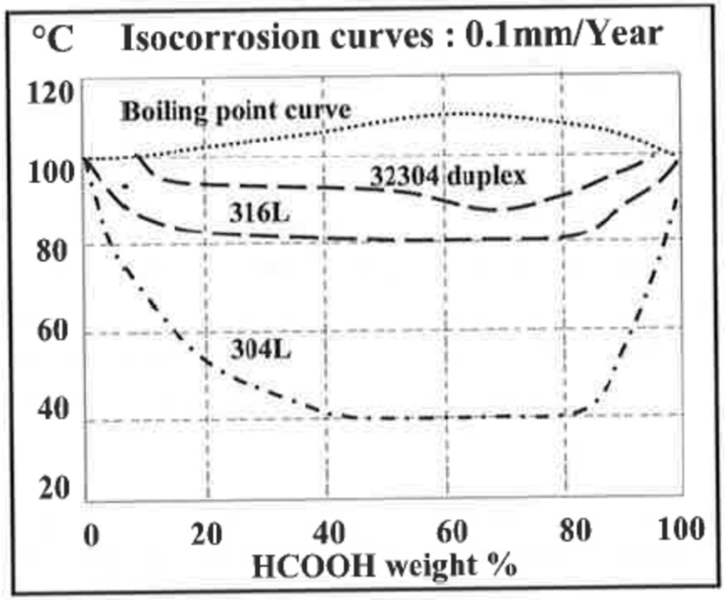
Even a few ppm of organic acids can induce corrosion on carbon steel

ISTITUTO ITALIANO DELLA SALDATURA

Organic acid and condensed water

Stainless steels perform better.
Especially with higher chromium content with molybdenum (**316, 2205**)

Formic acid



Dearated

ACID CONCENTRATION	Corrosion Rate (mm/yr)		
	S30400[A]	S31600[A]	S31600[B]
1.0	0.17	0.09	
5.0	0.77	0.04	
10.0	1.33	0.26	
20.0	1.89	0.27	
40.0	3.40	0.20	
50.0	4.20	0.50	0.46
60.0	3.40	0.46	
70.0	3.97	0.48	0.64
80.0	4.20	0.47	
90.0	3.23	0.41	0.61
100.0			0.25

Corrosion in mm/year; boiling point

	20% Formic Acid	40% Formic Acid
Type 317L	0.23	0.43
Alloy 2205 (S31803)	<0.025	--
Alloy 255 (S32550)	0.025	<0.025

Organic acid and condensed water

Acetic acid

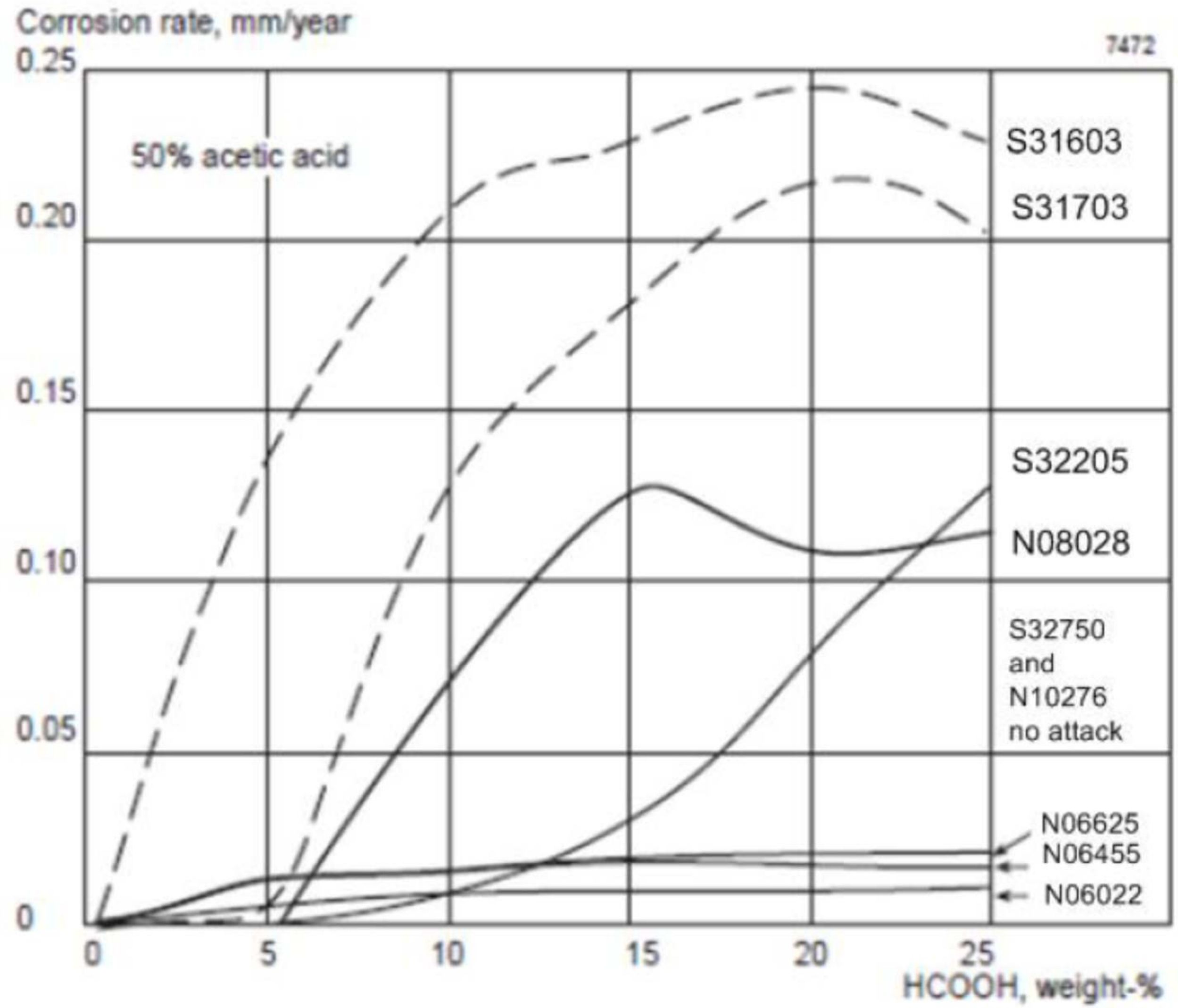
Acid Concentration (%)	Test Temperature (°C)	Test Duration	Corrosion Rate (mm/y)	
			S30200 or S30400	S31600
0 to glacial	Room	Up to 157 days	<0.003	<0.003
1	Boiling	---	<0.003	<0.003
2.2(A)	Boiling	45 days	>0.79	0.20
10	Boiling	5-7 days	1.78	0.008
20	Boiling	112 days	0.07	0.018
50	Boiling	4 days	3.30	<0.025
80-100	Boiling	80 hours	0.30	<0.003
Glacial	Boiling	21 days	0.79	0.020

ISTITUTO ITALIANO DELLA SALDATURA

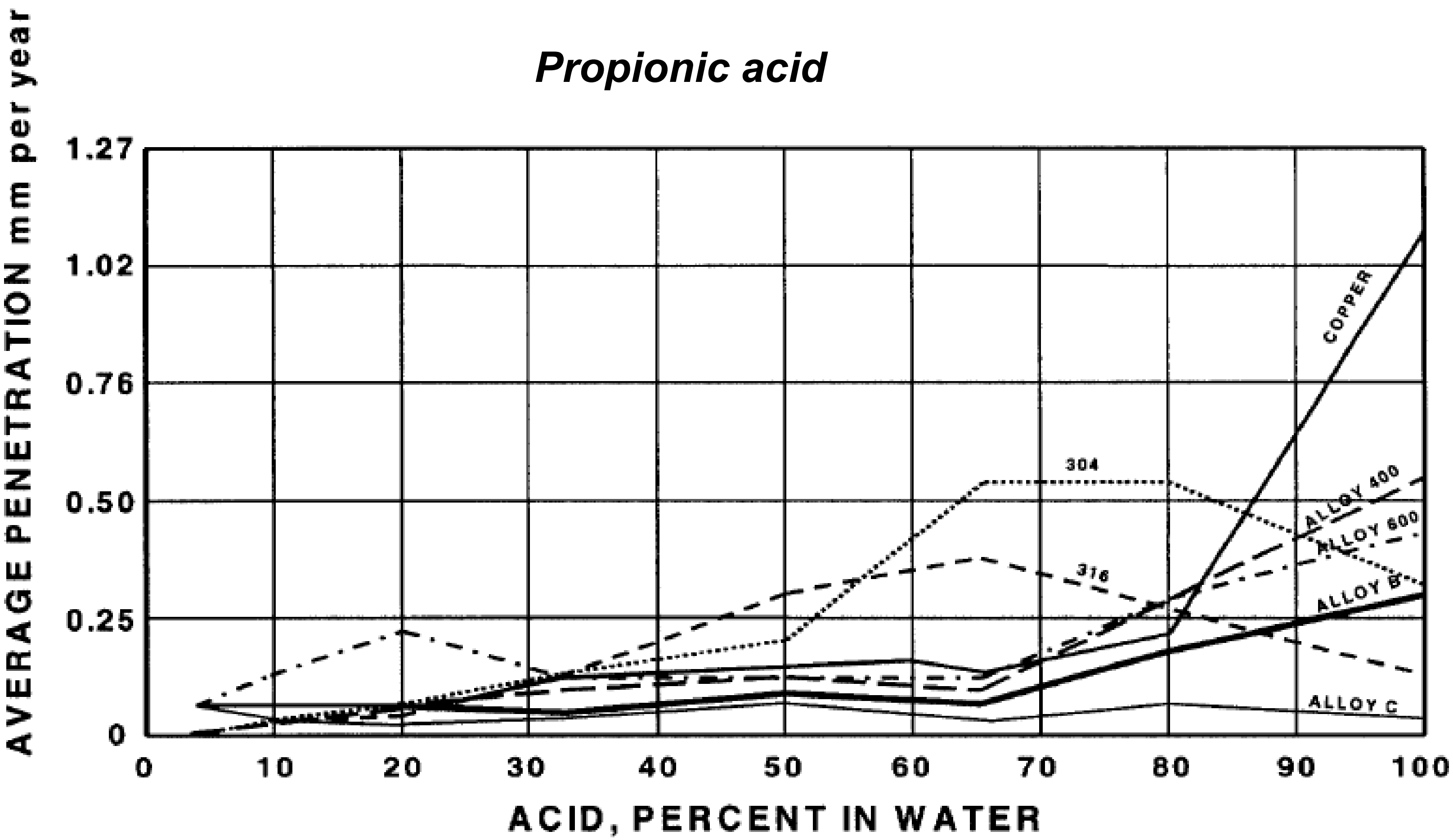
Organic acid and condensed water

Mixed acid

Corrosion rate in 50% boiling acetic acid with different formic acid content



Organic acid and condensed water



Organic acid and condensed water

Presence of CO_2

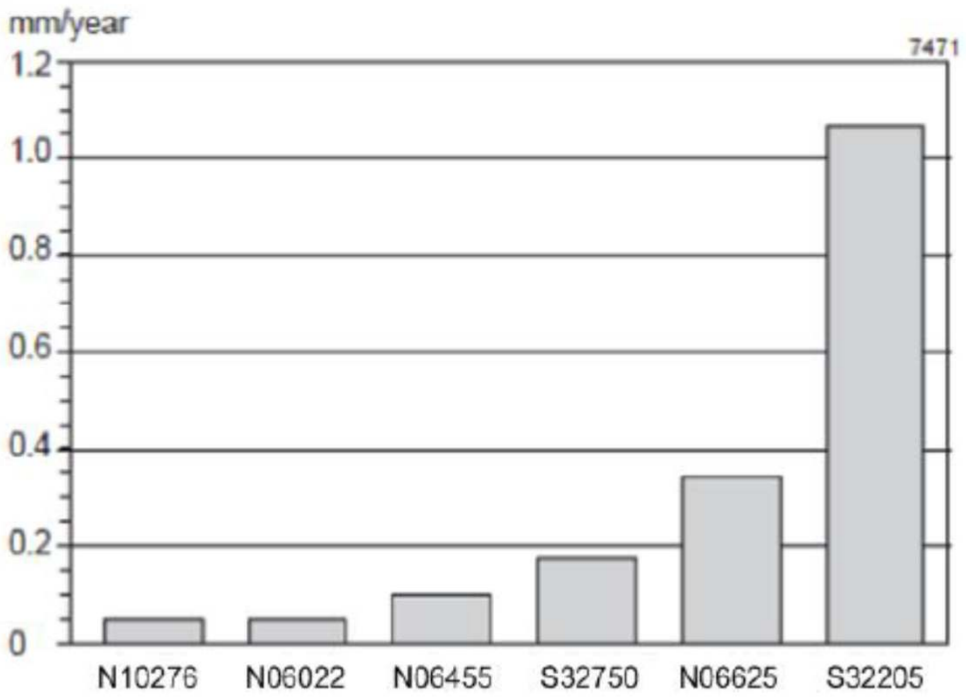
If in the aqueous phase, in addition to the organic acidity, CO_2 is present, the traditional stainless steels are show no significant increase in the risk of corrosion.

Presence of chlorides

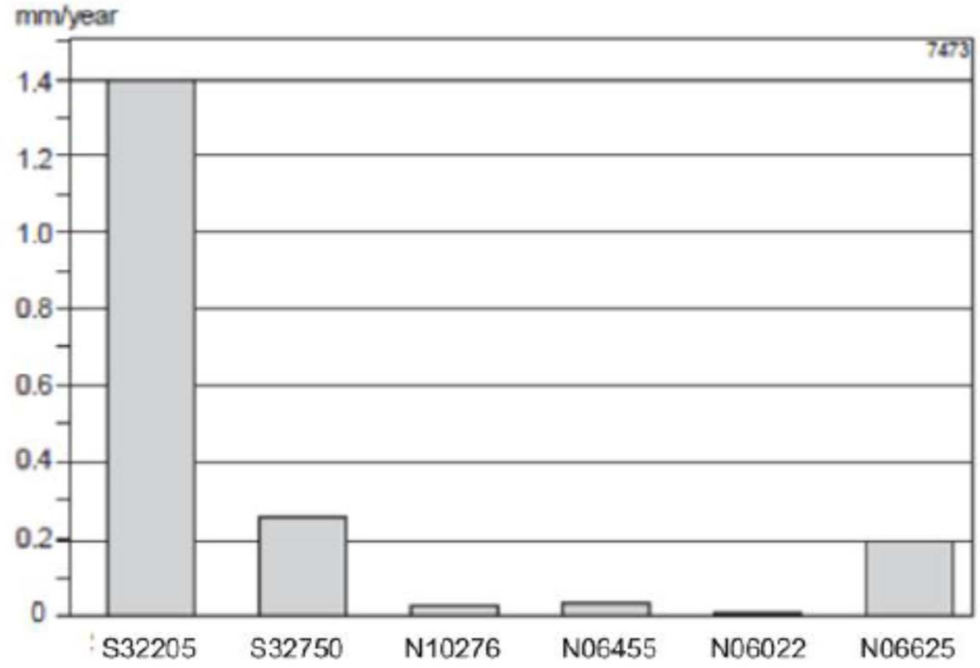
If **chlorides** (high in certain feedstock a RUCO) are present in the aqueous phase together with organic acidity, stainless steels are subject to even severe corrosion (**pitting and SCC**)

Ni-Cr-Mo alloys with high PRE (e.g. 625, C276) are more resistant

Acido formico 40% @Tb + 2000 ppm Cl^-



Acido Acetico 50% + formico 25% @Tb + 2000 ppm Cl^-



Organic acid with NO water

- Process fluids characterized by **high T conditions (T> 100 ° C)** and absence of water, are corrosive to carbon steel in the presence of various types of organic acids.
- **Similar to naphthenic acid corrosion** in traditional refineries, which however is function of the sulfur content of the stream, turbulence, flow conditions, type and content of acids, and which is typically active for T> 200 ° C.
- However, even in traditional refineries corrosion issues by organic acids in anhydrous hydrocarbon fluids for lower T (about 150 ° C) as “low temperature naphthenic acids” are reported → organic acids with a lower molecular weight.

CS corrosion rate in pure organic acid

ORGANIC ACID TYPE	T_b °C	TAN mg KOH/g	CORROSION RATE, mm/year		
			At T_b, °C	At 195°C	At 100°C
Aliphatic Acids:					
Formic acid	102	599	12	-	11
Acetic acid	114	634	21	-	20
Propionic (propanoic) acid	141	788	23	-	18
Butanoic (butyric) acid	164	629	46	-	27
tert Butylacetic acid	181	471	33	-	6
4-Pentenoic acid	183	550	61	-	6
2-Ethylbutyric acid	186	480	40	-	17
3-Pentenoic acid	190	538	34	-	8
Hexanoic acid	200	476	99	-	2
trans 2-Pentenoic acid	200	542	54	-	19
Heptanoic acid	218	430	179	-	8
Nonanoic acid	244	352	195	52	1

Organic acid with NO water

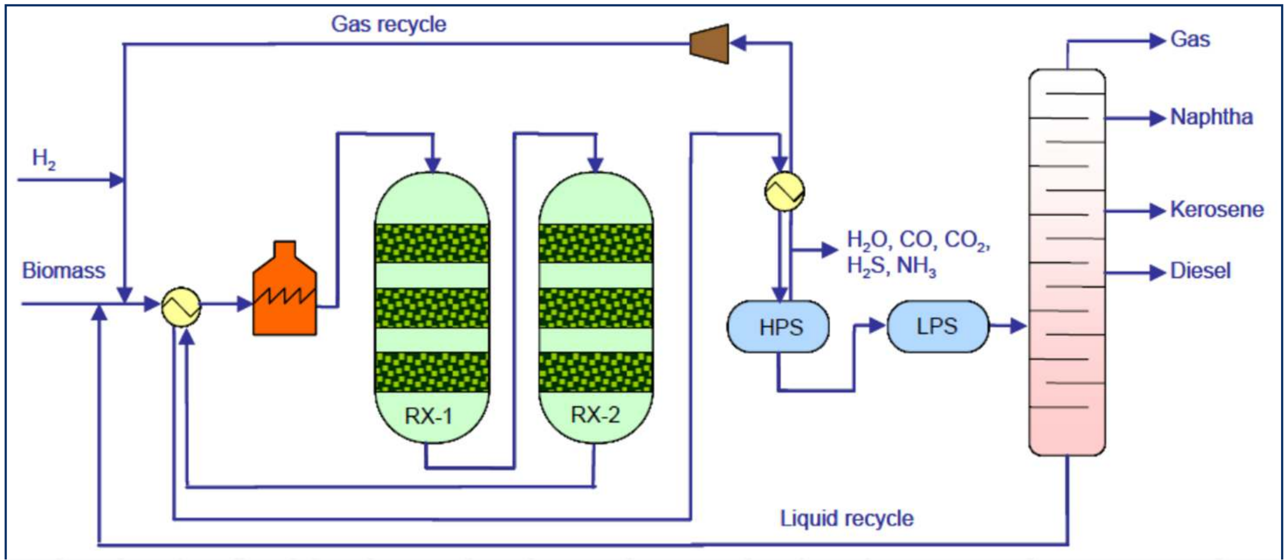
- In the presence of **organic acids with no condensed water for T> 100 ° C** (bio-fuels yet to be refined with a fair content of acids of various molecular weight), an alloy with an adequate **Mo content** must be used to limit high T corrosion:

- **317 - 825 - 625 - C276**

- In areas with high turbulence and potential high chloride content, it is advisable to choose alloys with a high Mo content (nickel alloys)

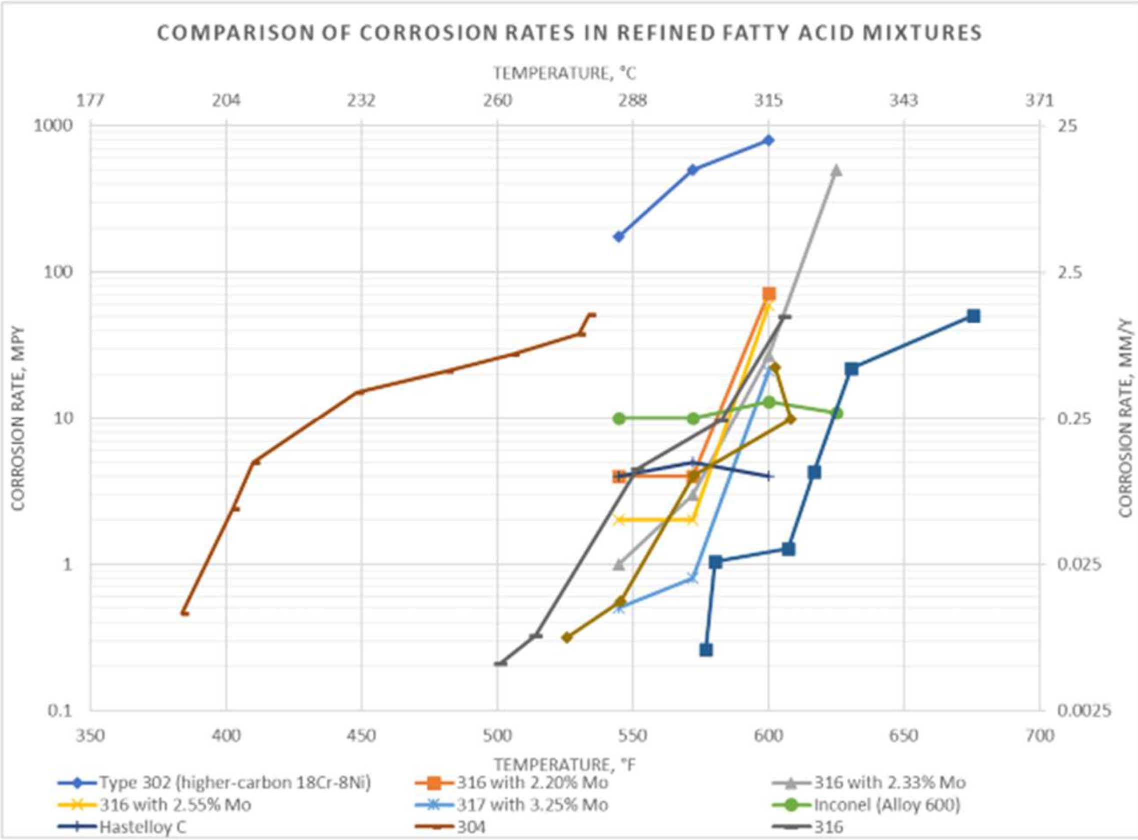
- As in fossil refinery, streams with H_2 and organic acid at high temperature are less corrosive from organic acid corrosion point of view

    - H_2 tends to destroy organic acids
    - Standard 300 stainless can fit



Free Fatty Acid topic - FFA

- Bio-oils and biomass-oil **contain greater quantity of FFA**
- Triglycerides in bio-oils can convert to FFA during storage, pretreatment and feed circuit to reactor in hydrotreatment
- Corrosion can be similar to naphthenic acid corrosion
- High T corrosion T> 250 °C
- In H_2 free high T stream, **Mo containing SS or Ni-based alloys** resist better
- Downstream H_2 FFA corrosion is mitigate, but less corrosion data than traditional refining → Mo free SS can Fit (For H_2/H_2S corrosion) -> experience needs to be gained



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

ISTITUTO ITALIANO DELLA SALDATURA

Effluent systems

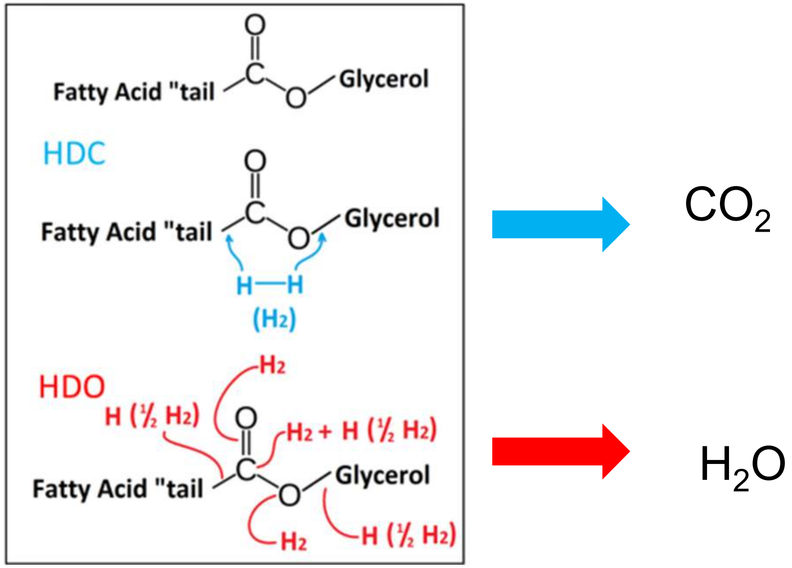
- Effluent from reactor (hydrotreating) processing **pure bio-oils** and biomass-oil contains high content
    - CO_2 from HDC reactions
    - H_2O from HDO reactions

- 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



Conclusions

- 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!**

Appendix 8

Integrated real-time corrosion prediction as a path for corrosion digital twin approach

(Slawomir Kus)

Integrated real-time corrosion prediction as a path for corrosion digital twin approach

Dr Slawomir Kus
Lead Corrosion Consultant
Honeywell Connected Plant, Bracknell, UK

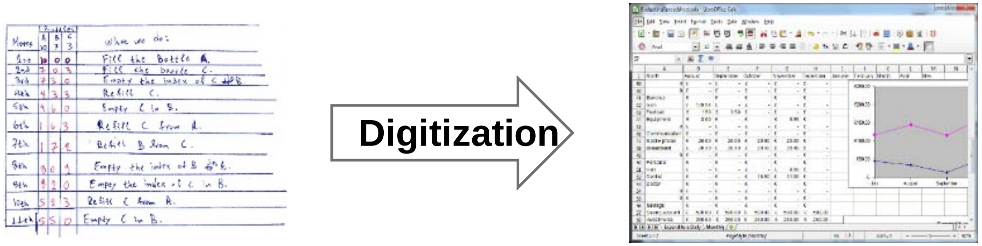
Honeywell

Agenda

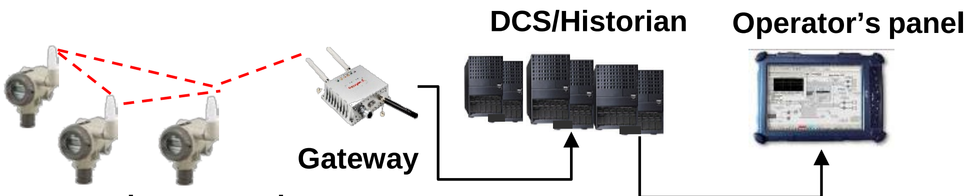
- Digital Transformation – quick recap
- Corrosion & Digital Transformation – where are we now?
- Software Sensor & Corrosion Digital Twins – integrated approach for corrosion management
- CDT/corrosion software sensor
  - Integration with other corrosion analytical/assessment tools
  - IT Security
  - Challenges
- Summary

Digital Transformation - recap

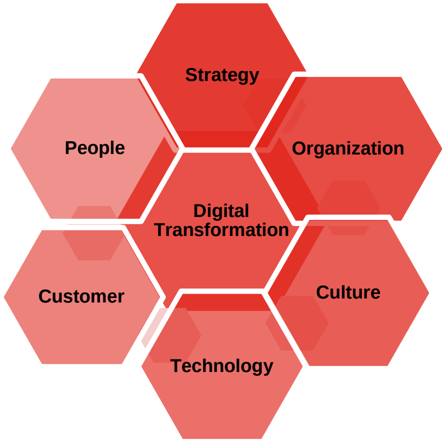
- **Digitization:** encoding of analog information into a digital format



- **Digitalization** describes how IT or digital technologies can be used to alter existing business processes

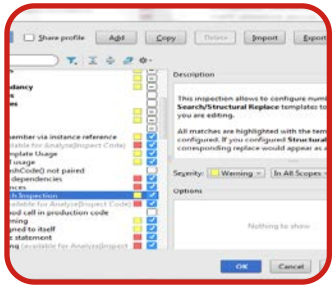


- ***Digital transformation** is the process of using digital technologies to create new / modify existing business processes, culture, and user experiences that helps to create and appropriate additional value for the company.* (1-3)

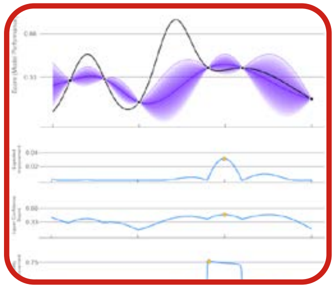


[1]Kane, at all, N. (2015). Strategy, not technology, drives digital transformation. MIT Sloan Management Review and Deloitte University Press, 14, 1–25.
[2]Liu, D. Y., at all (2011). Resource fit in digital transformation – Lessons learned from the CBC bank global e-banking project. Management Decision, 49(10), 1728–1742.
[3]Salesforce web: https://www.salesforce.com/eu/products/platform/what-is-digital-transformation/

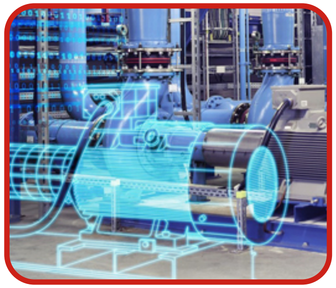
How Digital Transformation is Progressing in Corrosion World



Digitization: Data organization and basic analytics (electronic CCDs, corrosion databases etc.)

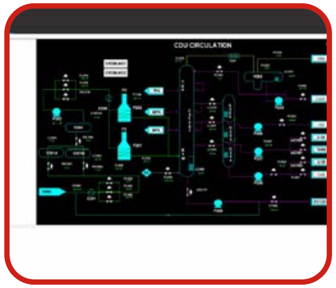


Advanced corrosion data handling: machine learning, AI, neural networks etc. for corrosion and integrity management



Corrosion Digital Twin

Advanced corrosion modelling in real time – software sensor

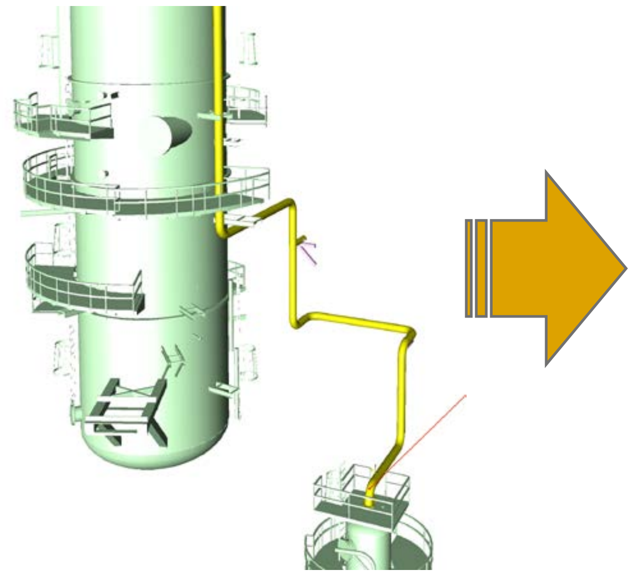


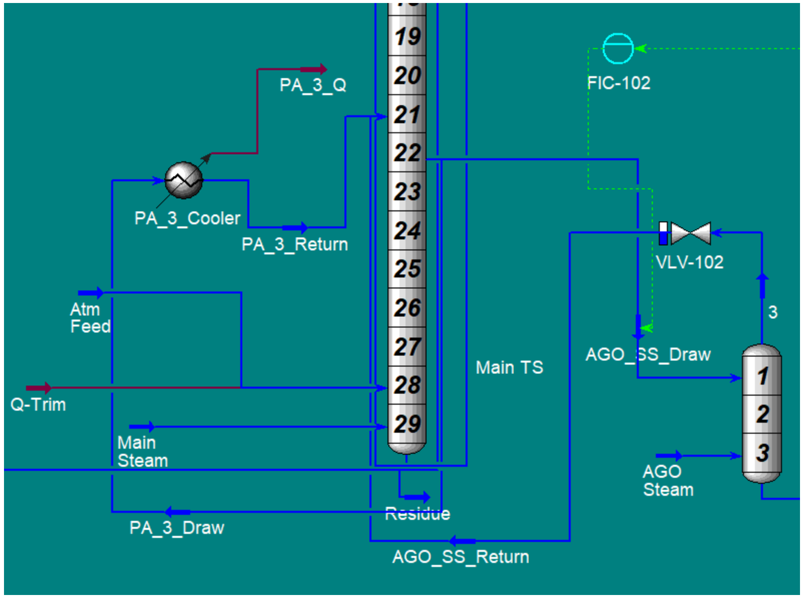
Enterprise-wide corrosion-process integration in real time for corrosion and integrity management

Status

Digital Twin (DT)

** A Digital Twin is an integrated Multiphysics, multiscale, probabilistic simulation of a complex product that uses the best available physical model, real-time sensor data, historical data etc. to mirror the life of its corresponding twin.*





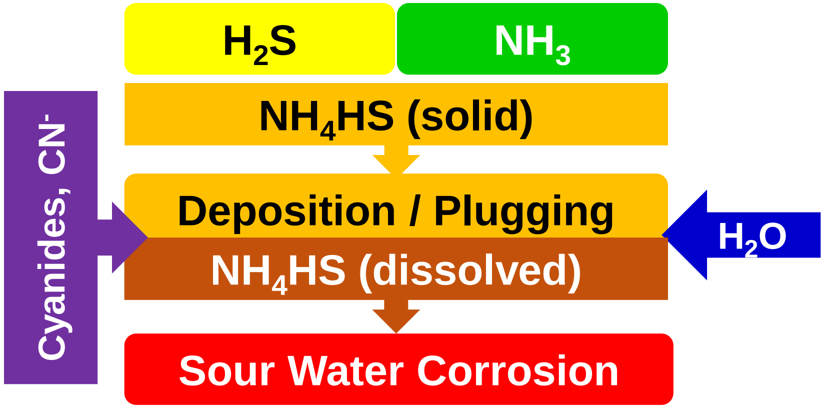
Creation of DT for <u>technological</u> process is virtually ”easy”

- large number of process controllers
- “live” and past data available in process Historian
- reliable thermodynamic/kinetic models
- usually modelling physical processes not involving complex chemical reactions

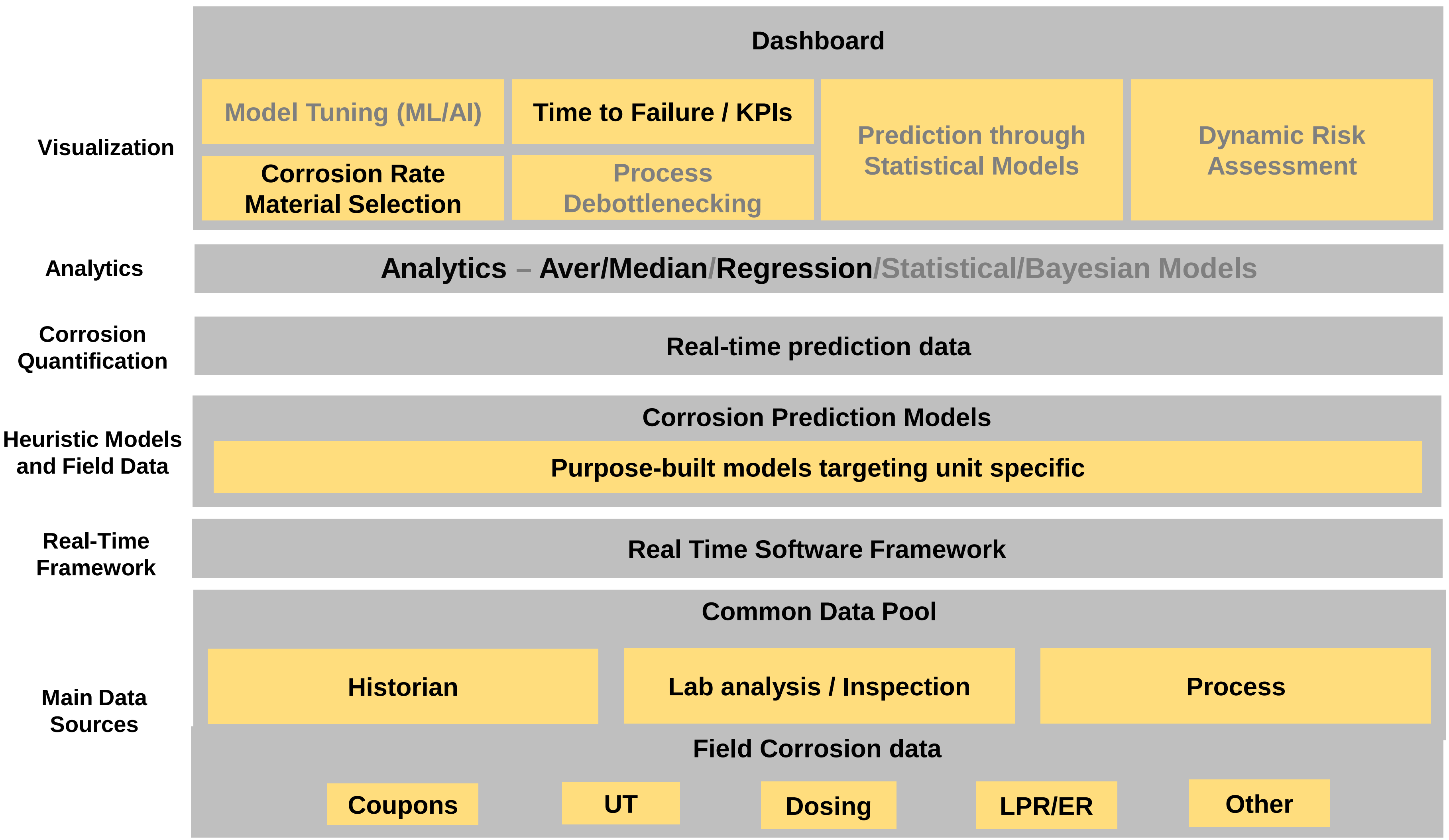
* After Glaessgen, Edward, and David Stargel, Editor, 2012. *The digital twin paradigm for future NASA and US Air Force vehicles*

Corrosion Digital Twin (CDT)

- Development of CDT is complex.
- Corrosion data flow is “lean”
  - Very few hardware corrosion monitoring points
  - Hardware locations are based on historical data and accessibility
  - Installation and expansion of hardware corrosion monitoring is a costly and time consuming effort
- Real-time, online, corrosion data streams are rarely linked with “live” process data:
  - data interpretation is complex
- “Digital Transformation” in corrosion monitoring & management **requires accurate corrosion prediction**

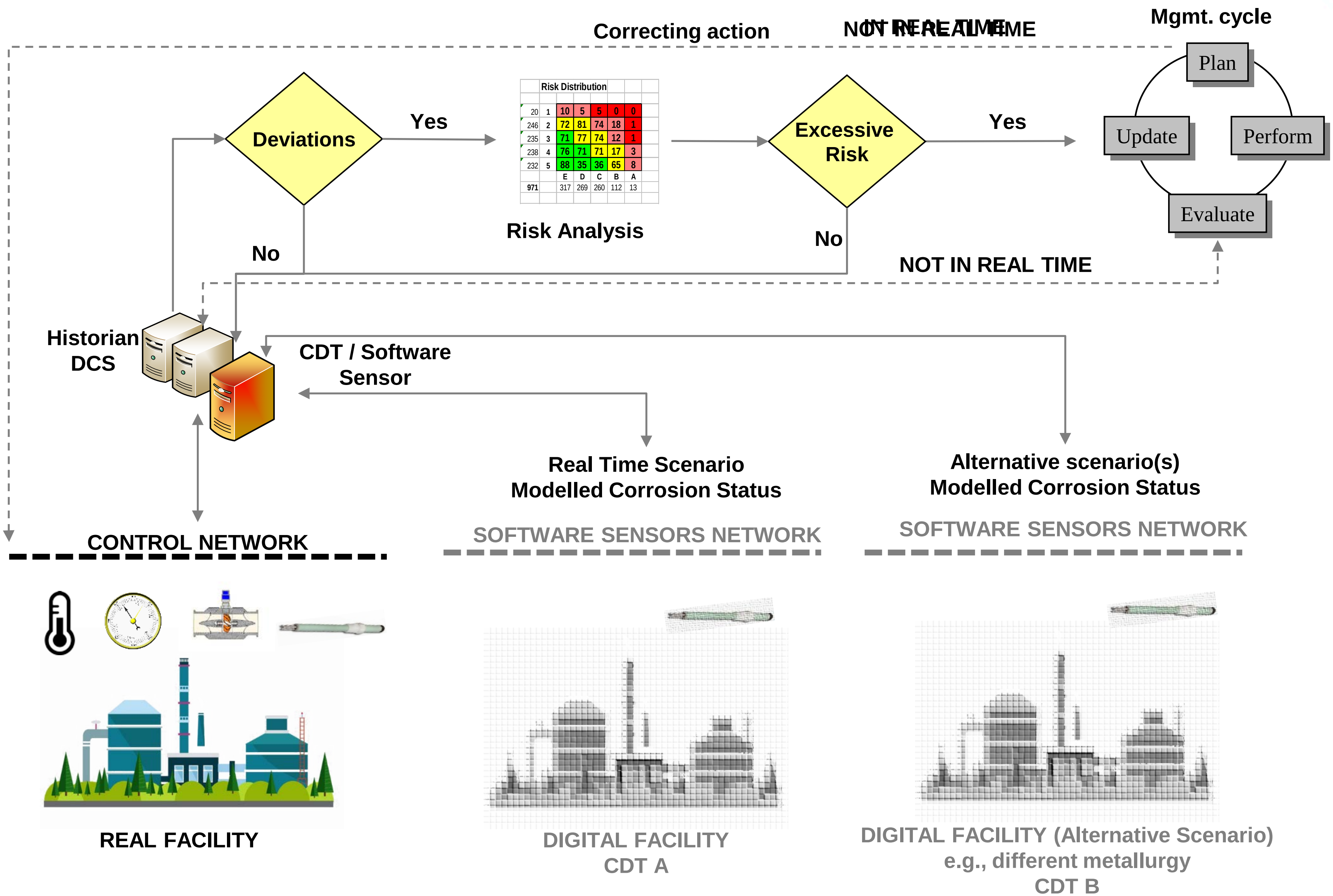


Software sensor / CDT Architecture



Integrated CDT approach

Example



Software Sensor/CDT – Challenges

Integration and real-time data exchange

- Limited solutions for real-time data exchange, slow development of corrosion/risk/integrity software

IT security

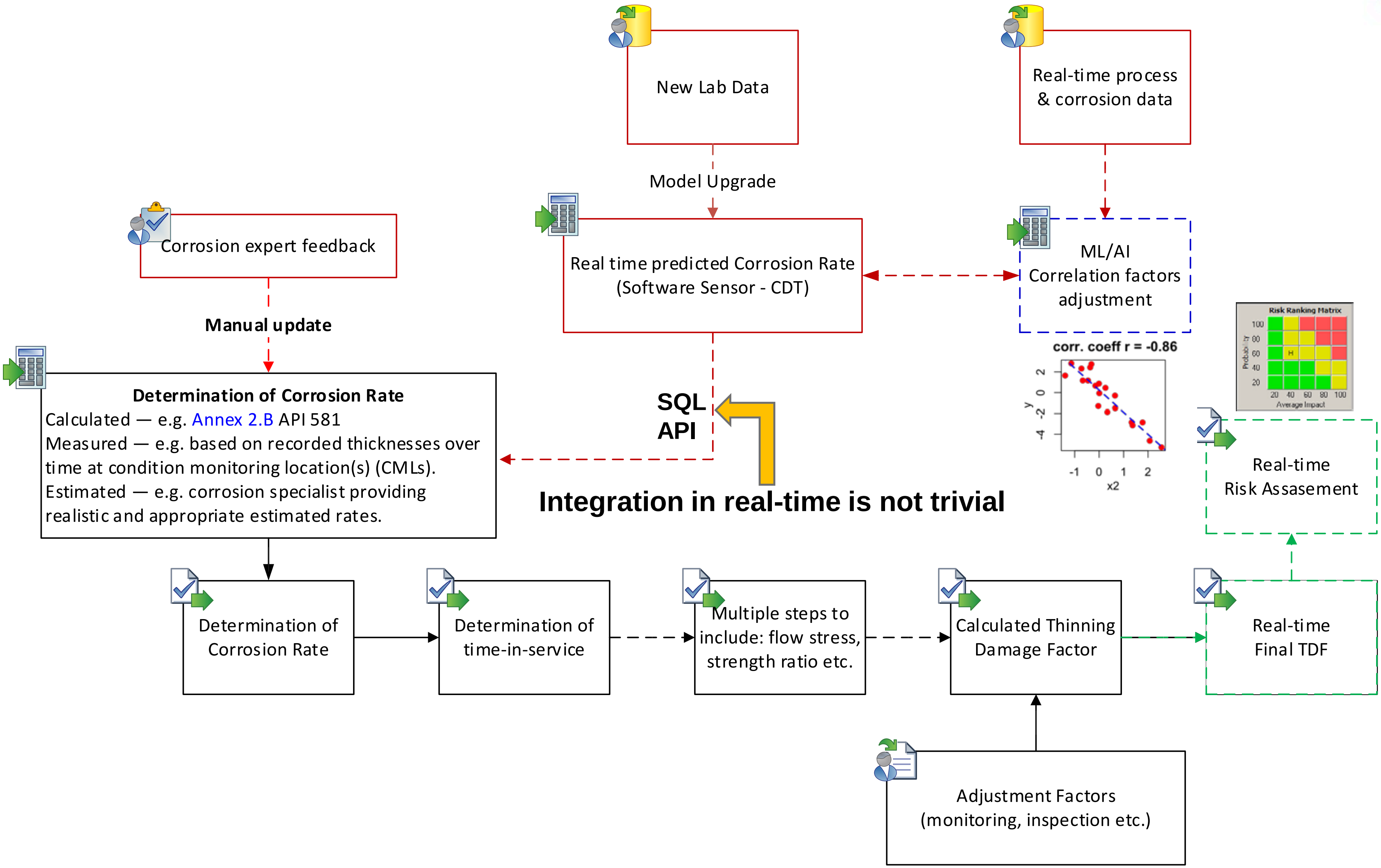
- Popular approach to keep corrosion systems (hardware and software) separated from the main operation network

Corrosion models availability

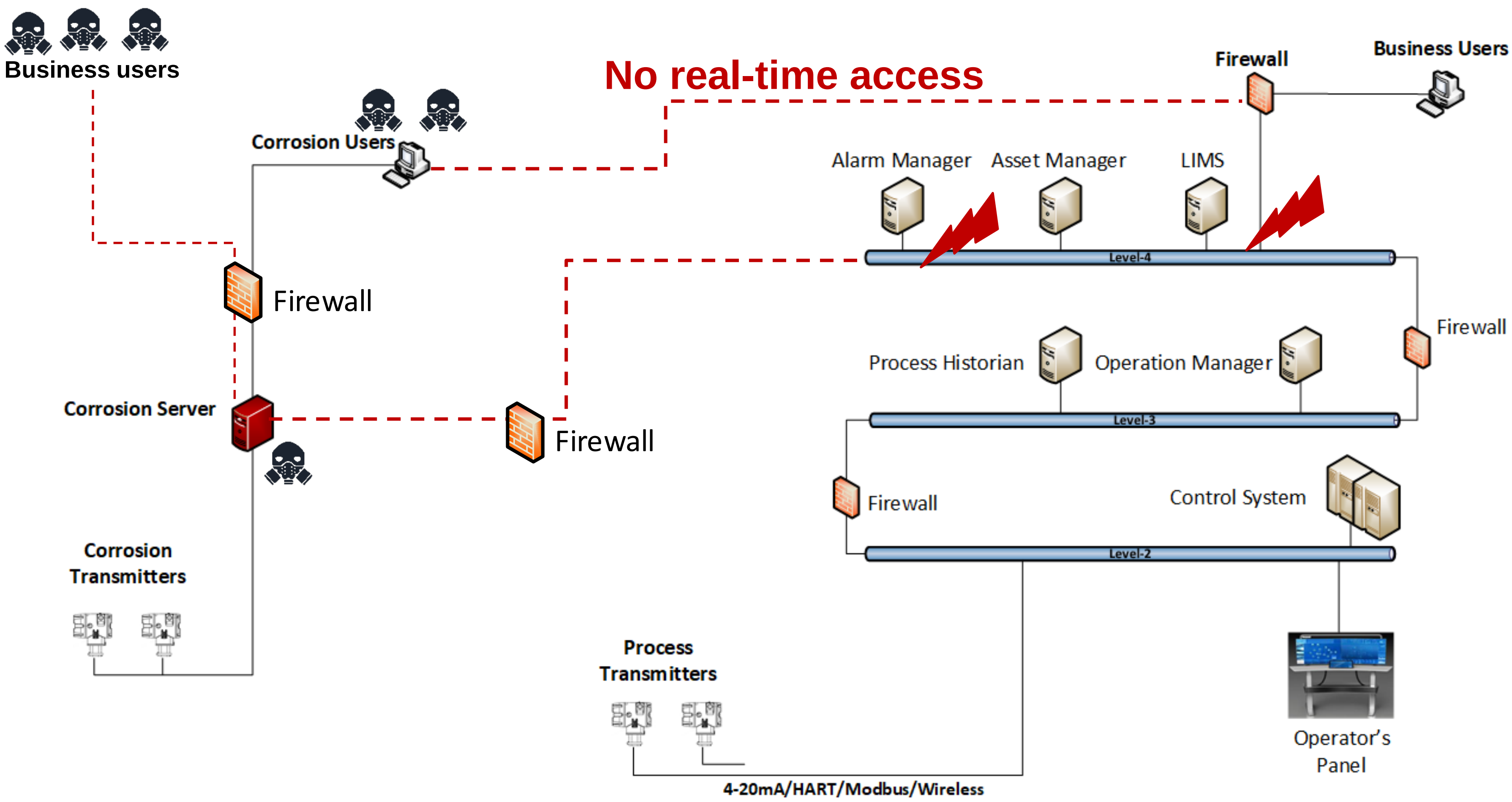
- Many corrosion damage mechanisms are not yet encapsulated into a reliable prediction models

CDT/Software sensor framework and RBI process

simplified example of work flow



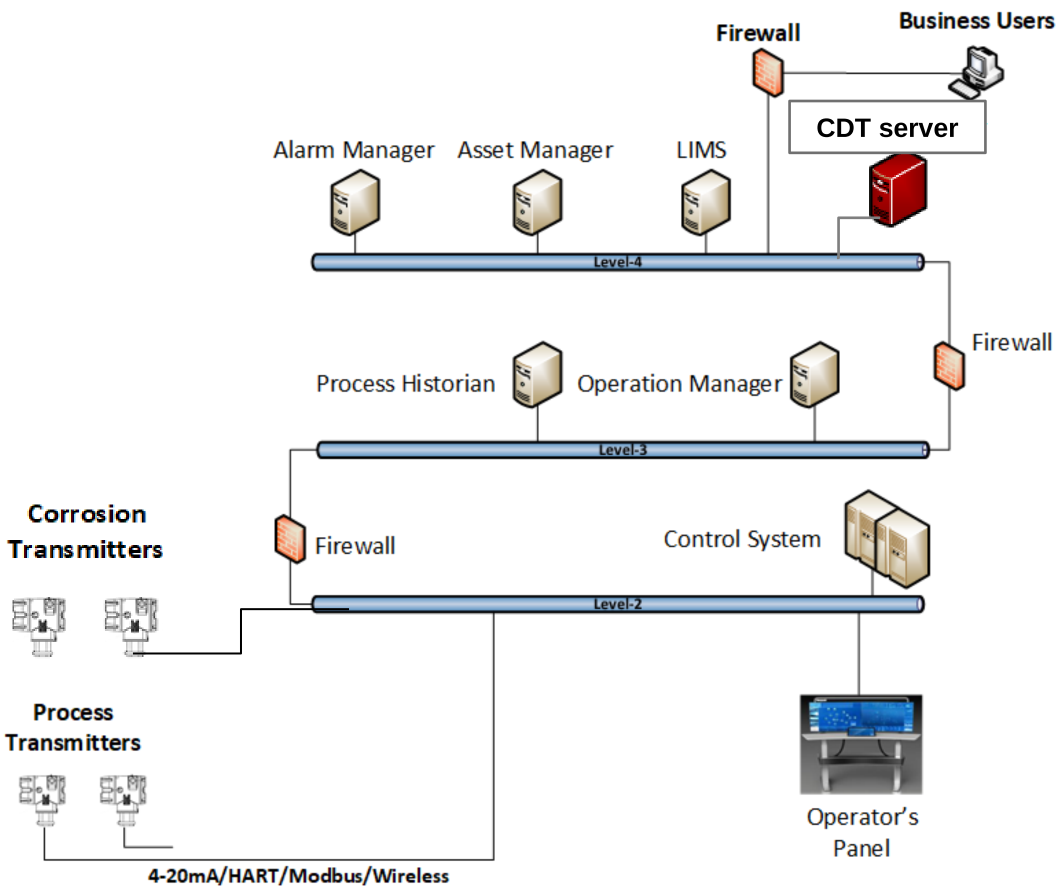
CMS IT security – traditional approach *Example*



Separate "Corrosion Server"

Typical Plant's Network System

Real time CDT/software sensor – IT security

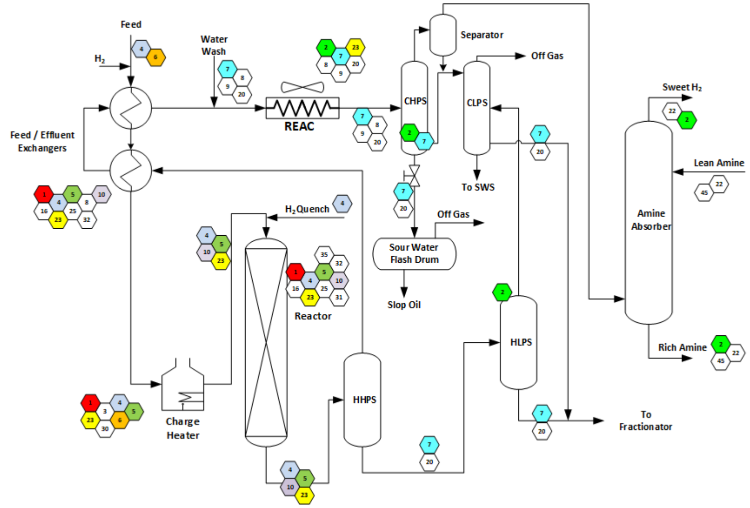


Benefits:

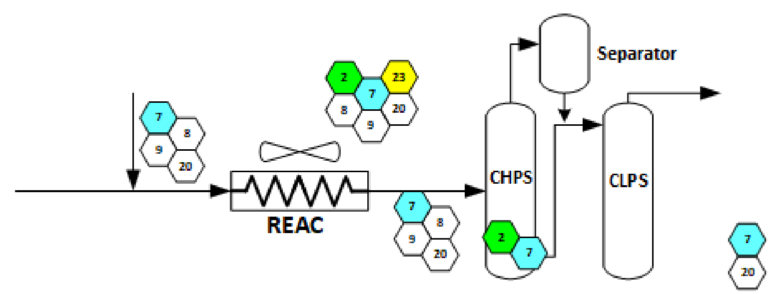
- Software sensors server is connected in **real-time** with all corrosion-process data streams
- No external interaction (bad actors) with RT server
- IT has full control on configuration and corrosion data streams

CORROSION MODELS AVAILABILITY

- API RP 571 – 2020 distinguishes of 67 various damage mechanisms present in the refining industry.
- There are <10 of well-developed and established corrosion models.



- Need to focus on "active" DMs
  - NH4HS corrosion (7)
- Progress in application of ML and AI will enhance/expand existing models capabilities and build new
  - Erosion-corrosion (20)
- New models development (lab researches)
  - NH4Cl corrosion (8)
  - HCl corrosion (9)



Summary

- Digital Twin is a key element of plant digital transformation
- Corrosion “Software Sensor” framework aka Corrosion Digital Twin (CDT) allows for real time integration of process and corrosion data.
- CDT allows for duplication of number of corrosion processes and predict their current and future status
- CDT enables enterprise-wide access for corrosion information while operating within safe and secure IT oversight.
- Development on real-time integration of CDT and risk assessment tools is required.

Appendix 9

Emerson automation solutions: digital connected services enhance value of corrosion monitoring data

(Kjell Wold)

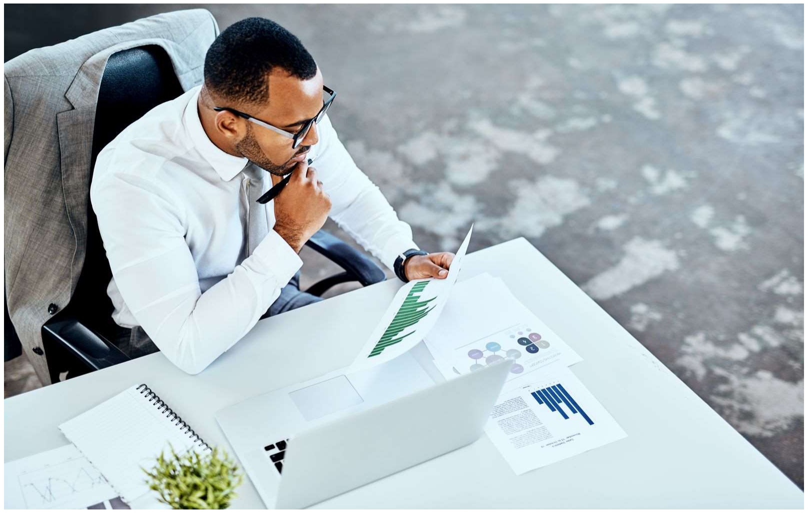
“Digital Connected Services Enhance Value of Corrosion Monitoring Data “

Presenter: Kjell Wold, Emerson Corrosion and Erosion

EMERSON

Corrosion Measurement Numbers Depend on Many Parameters

Why isn't my monitoring system providing the info I need for my corrosion management?



Suitable (combination of) corrosion technologies for the application?

System performance and uptime?

Access to and understanding monitoring data?

Data converted to actionable information?

Your Corrosion and Erosion Challenges Require a Complete Sensing Portfolio

MONITOR RISK

MONITOR IMPACT

Coupons

- Any process
- Verification
- Corrosion mechanism analysis
- MIC verification

🚫 Periodic data only

Intrusive

Inline Probes
(ER / Electrochemical)

- Quick response time
- Detect process changes
- Chemical treatment verification

Emerson Gold Standard

Non-intrusive

Sand Acoustic Monitor (SAM)

- Quick response time
- Enables production optimization and sand seperator efficiency monitoring

Emerson Gold Standard

Highest sensitivity, quickest response

Non- intrusive

Ultrasonic Thickness (UT)

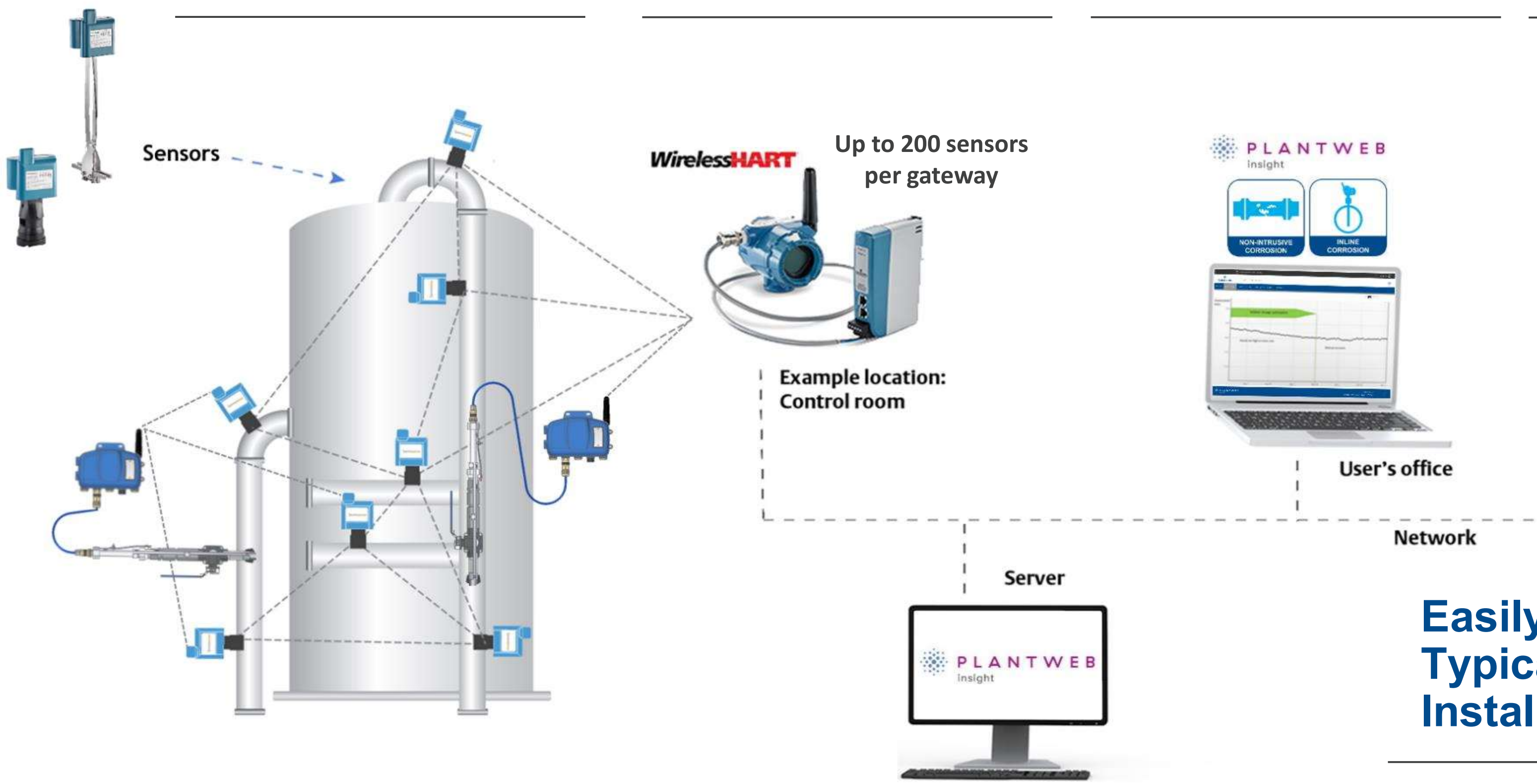
- Flexible, highly distributable, single point wall thickness integrity measurements

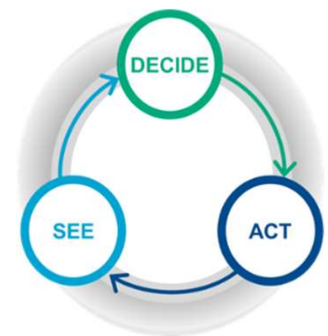
Emerson Gold Standard

Actual metal thickness and loss

Continuous, Real Time Corrosion Risk and Asset Health Data Directly to Desk

Data | **Connectivity** | **Analytics** | **Action**





Easily Installed Online - Typical Size System Installed in 1- 4 Days

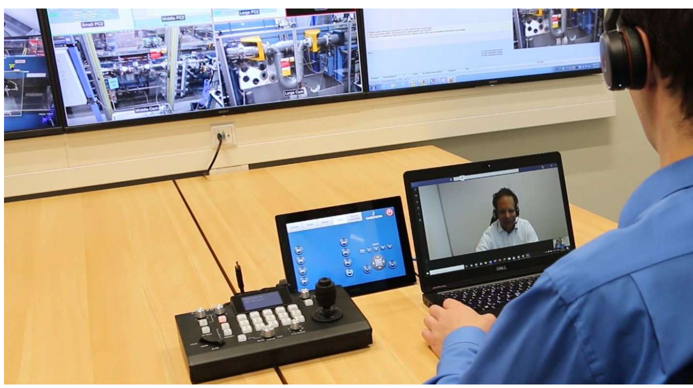
Corrosion and Erosion Remote Digital Services – Site Visits not Required

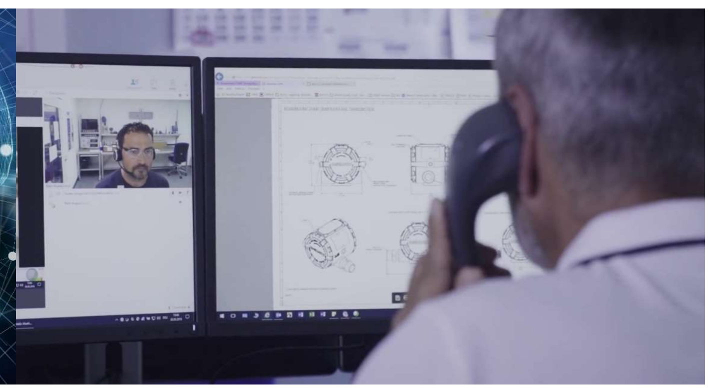
Remote Health Check

- VPN Remote Acess
- Screen Sharing Sessions
- Off-line Data Base Back-up Analyses
- Value
  - Cost effective confirmation on system performance
  - Custom built system improvement increases uptime

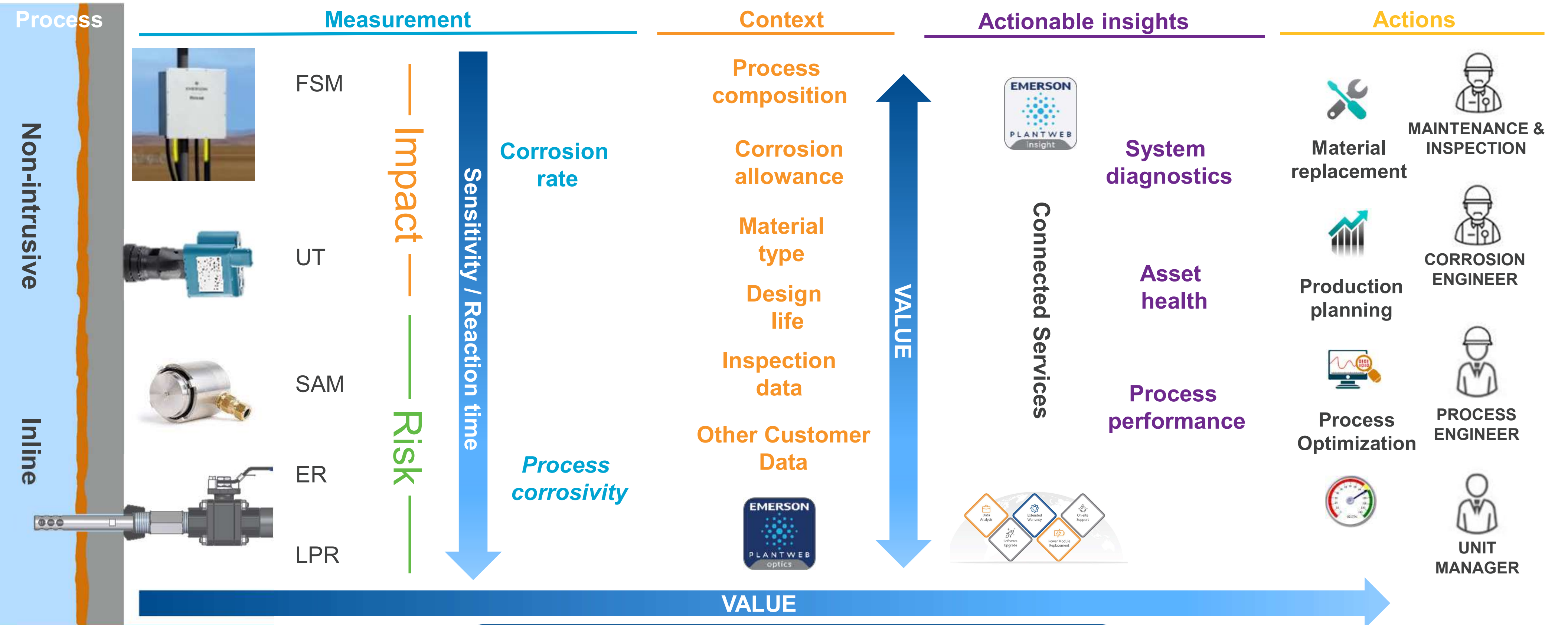
Data Base Services

- Merging or splitting of data bases
- Migration of historic data from Permasense Data Manager to Plantweb Insight Corrosion Application
- Value
  - Cost efficient database management
  - Focus on priority information



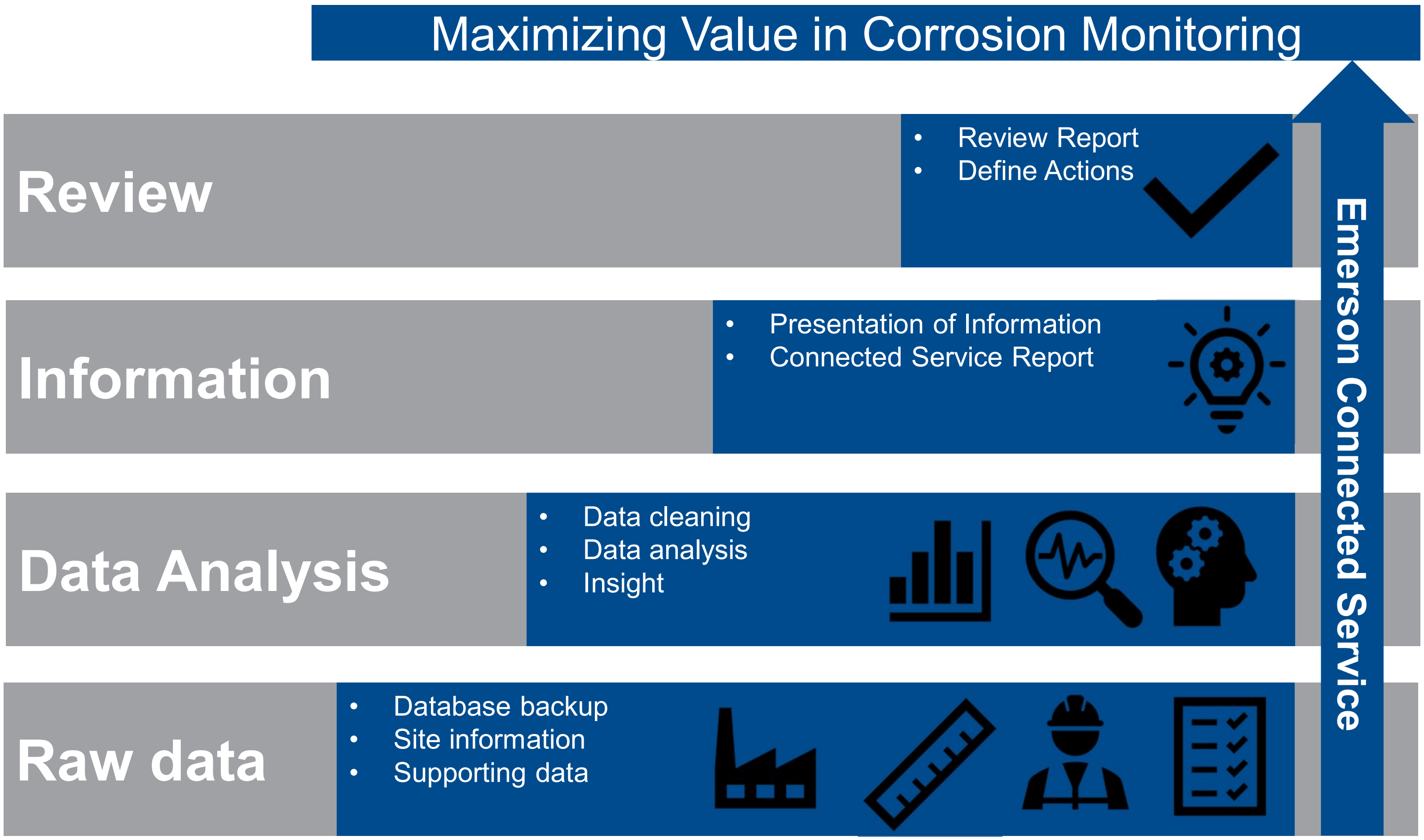


Connected Services Turns Data into Actionable Information



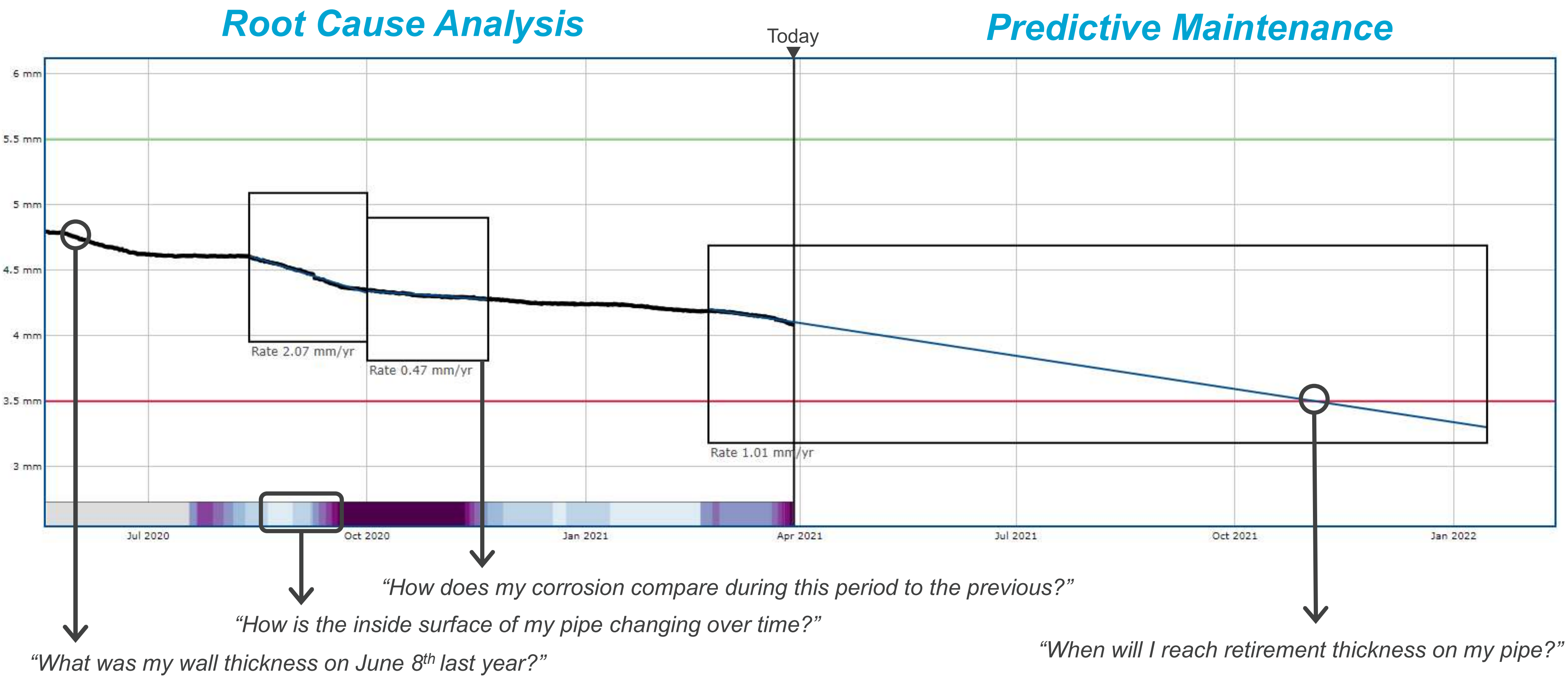
Unlock True Value of Corrosion Monitoring System

Remote Data Enhancement - Data Analysis Delivering Information

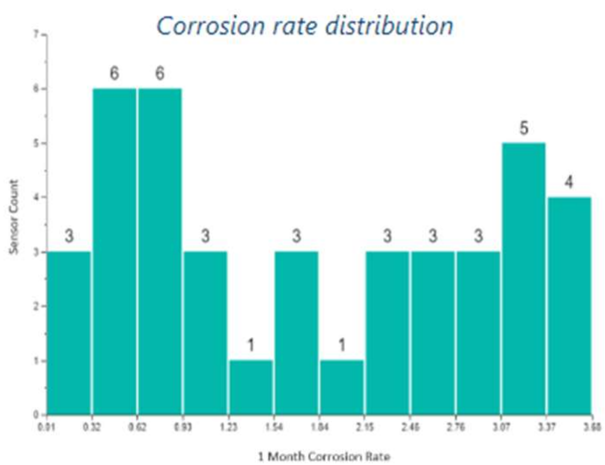


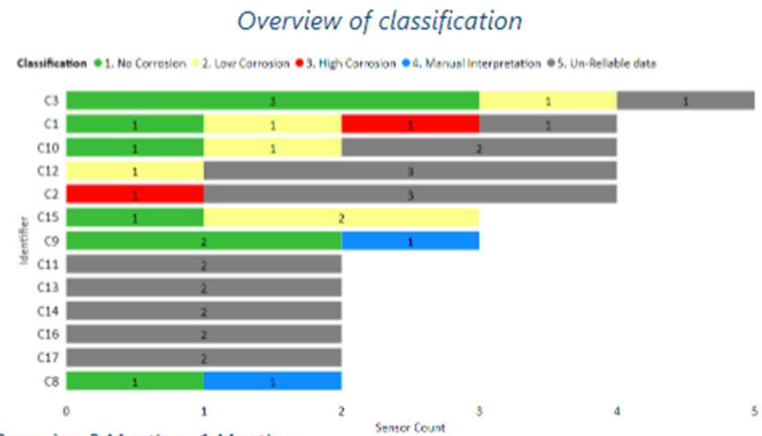
EMERSON

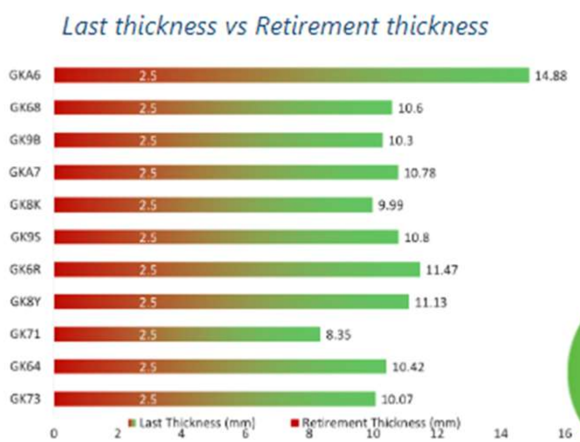
Thickness Monitoring Data for Root Cause Analysis of Corrosion Events and Turnaround Scope and Timing Improvement

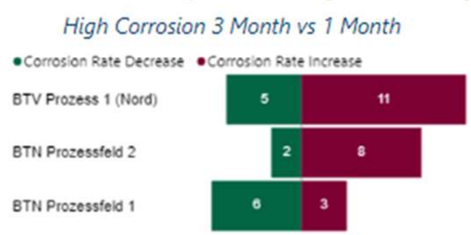


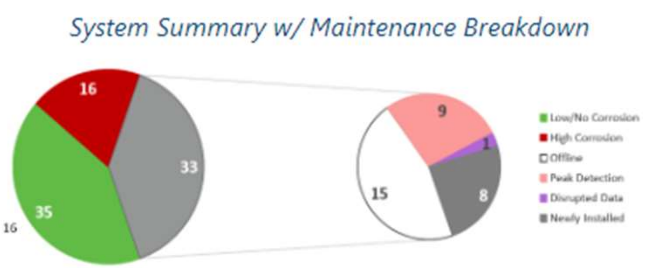
Dashboard to Gives Accessible Overview of Corrosion Activity





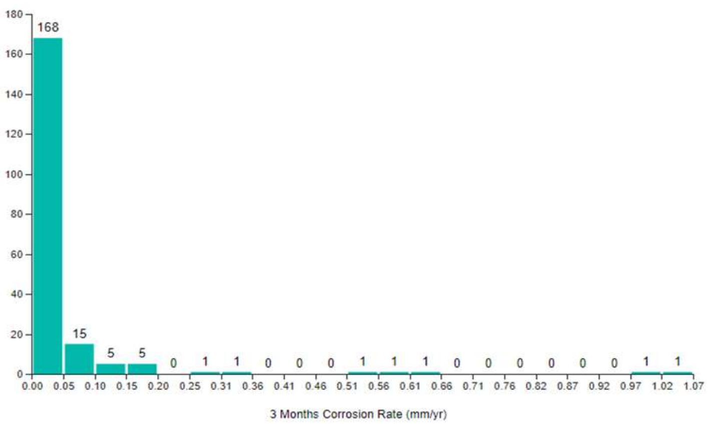


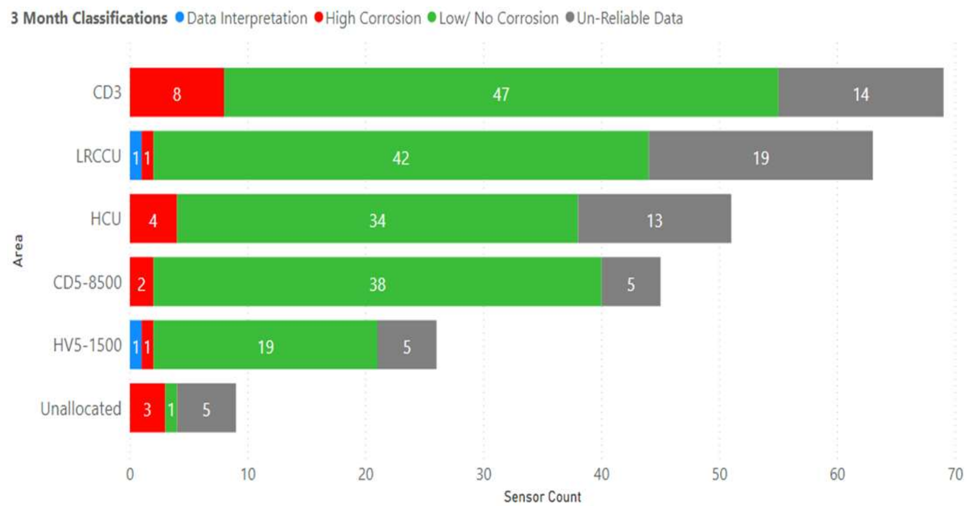




Sample Corrosion dashboard

Histogram of Corrosion Rate Distribution





Corrosion Rate Variation (1 Months vs 3 Month)

Out of 69 sensors in CD3

Out of 45 sensors in CD5-8500

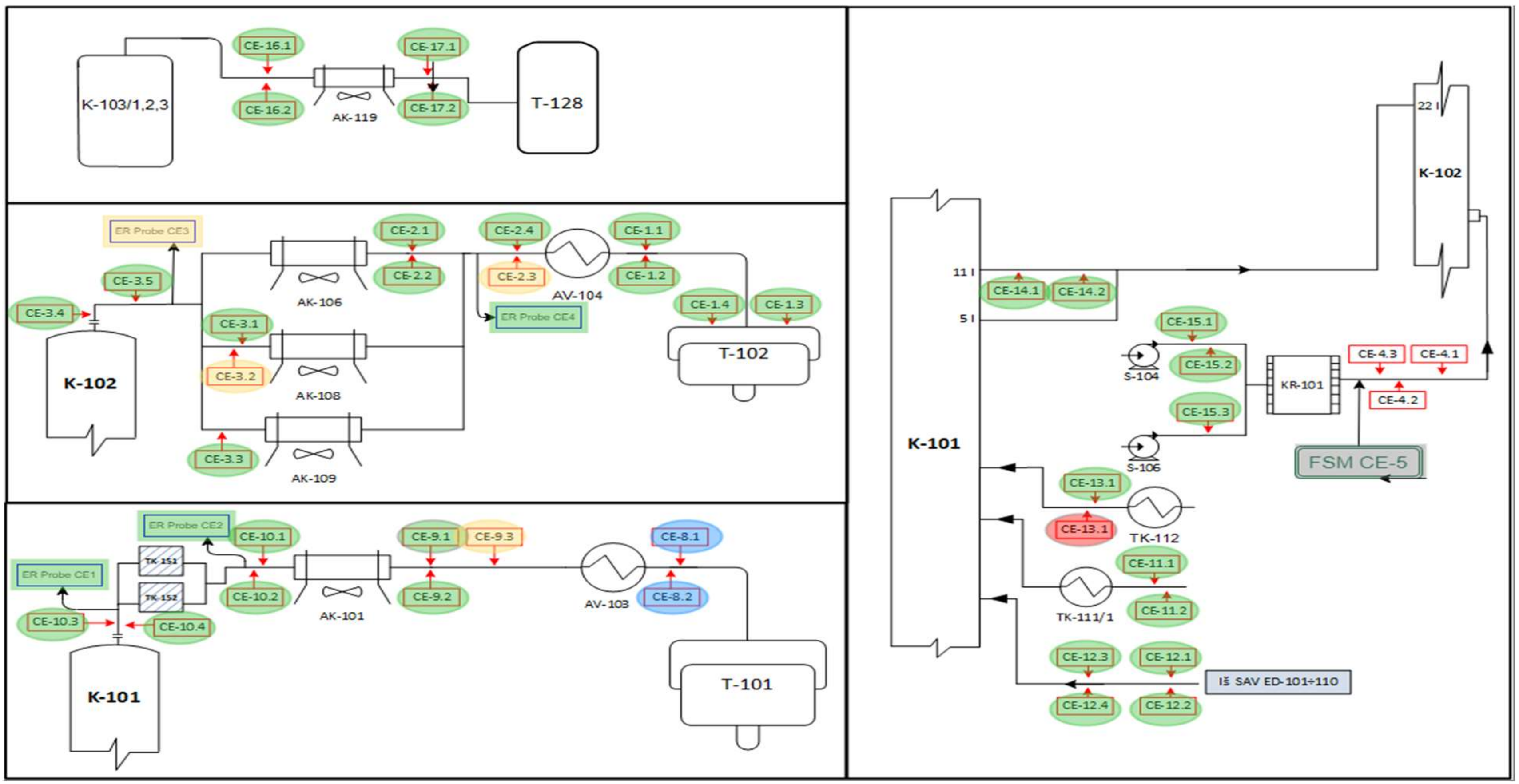
Out of 51 sensors in HCU

Out of 63 sensors in LRCCU

If the difference between 1 Month corrosion rate and 3 Months corrosion rate is (above/equal) ≥ 0.05mm/yr then the sensor will be classified as Corrosion Rate Increase. If corrosion rate difference is (below/equal) ≤ -0.05mm/yr, then the sensor will be classified as Corrosion Rate Decrease.

EMERSON

System Summary – This Quarter



EMERSON

Summary

- Wireless standardization and digital data has made on-line communication affordable and allows remote handling of housekeeping information as well as corrosion data
- Remote Digital services contribute to proactive maintenance and trouble shooting with a minimized need for site visits
- Data analysis and reporting by external experts ensure correct data interpretation and that information is converted to actionable information

Appendix 10

Lowering the top temperature in FCC fractionator: corrosion issues

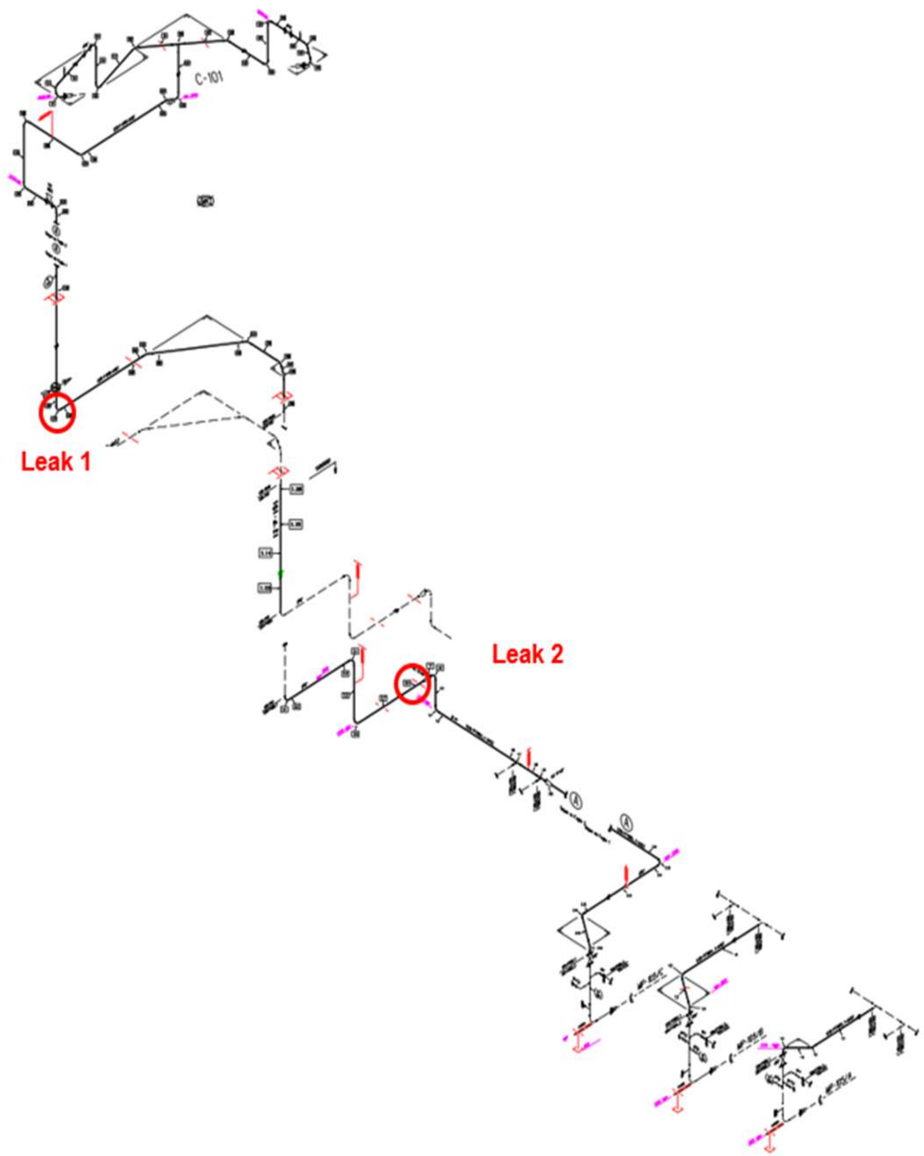
(Marco de Marco)

Lowering the Top Temperature in FCC Fractionation Tower : Corrosion Issues

M. De Marco – IIS

ISTITUTO ITALIANO DELLA SALDATURA
ente morale

- FCC Unit Fractionation Tower
- Top Pump Around (TPA) line from column to pumps
- N° 2 leaks in 2021
- 30 yr old plant (1982)
- Revamping of the TPA circuit in 2015.
- New line installed in 2015
- No temperature probe in TPA after 2015
- Data only on T overhead
  - Lower than before revamping

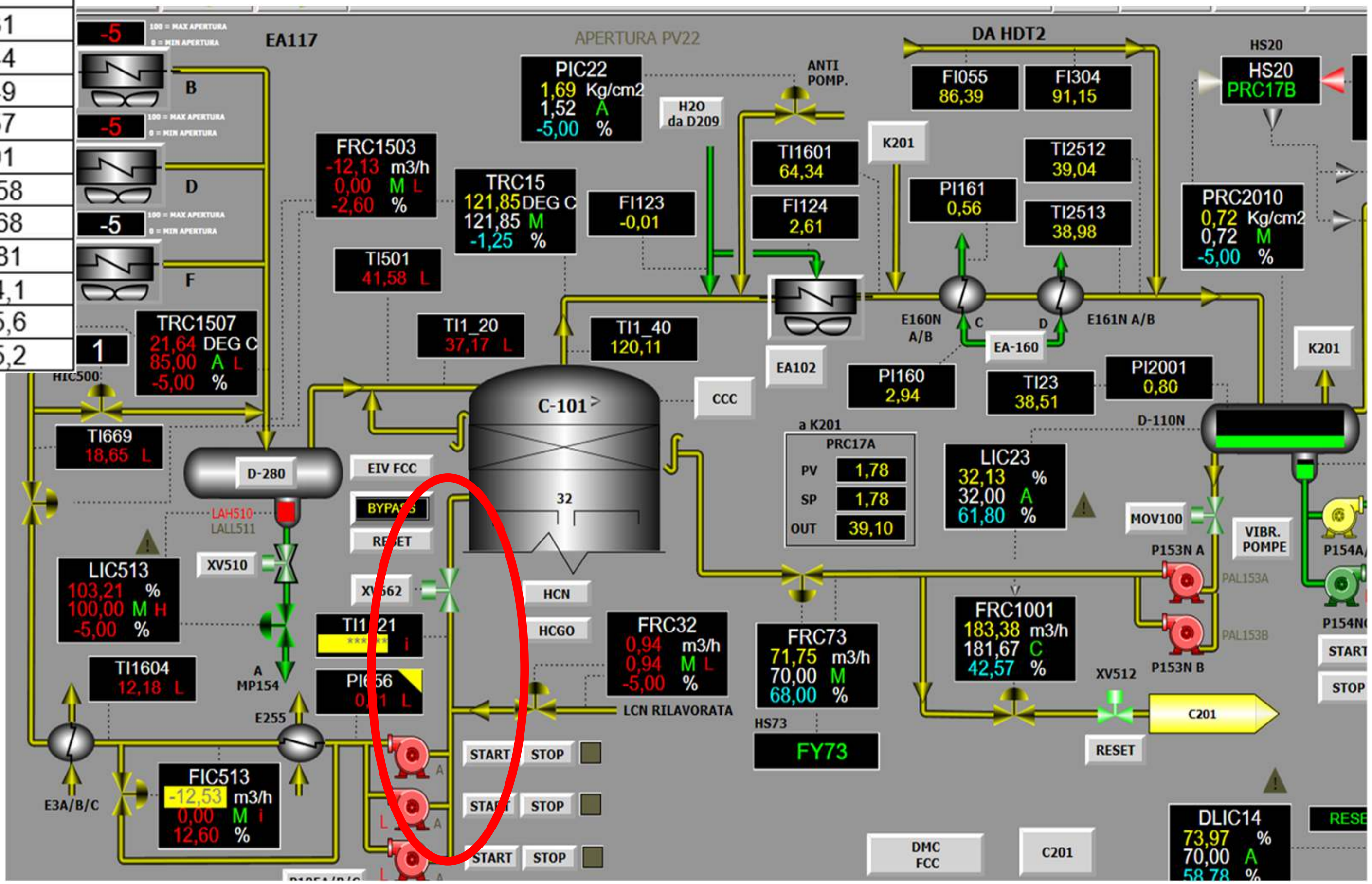


Ts:	*not measured*
Ps:	*0.6 barg*
Fluid:	*Top Pump Around*
Diam.:	*12”*
Thickness:	*8,38 mm*
CA:	*3,00 mm*
Material:	*ASTM A106 Gr. B.*

Introduction

- Overhead T controlled to optimize naphta cut in TPA

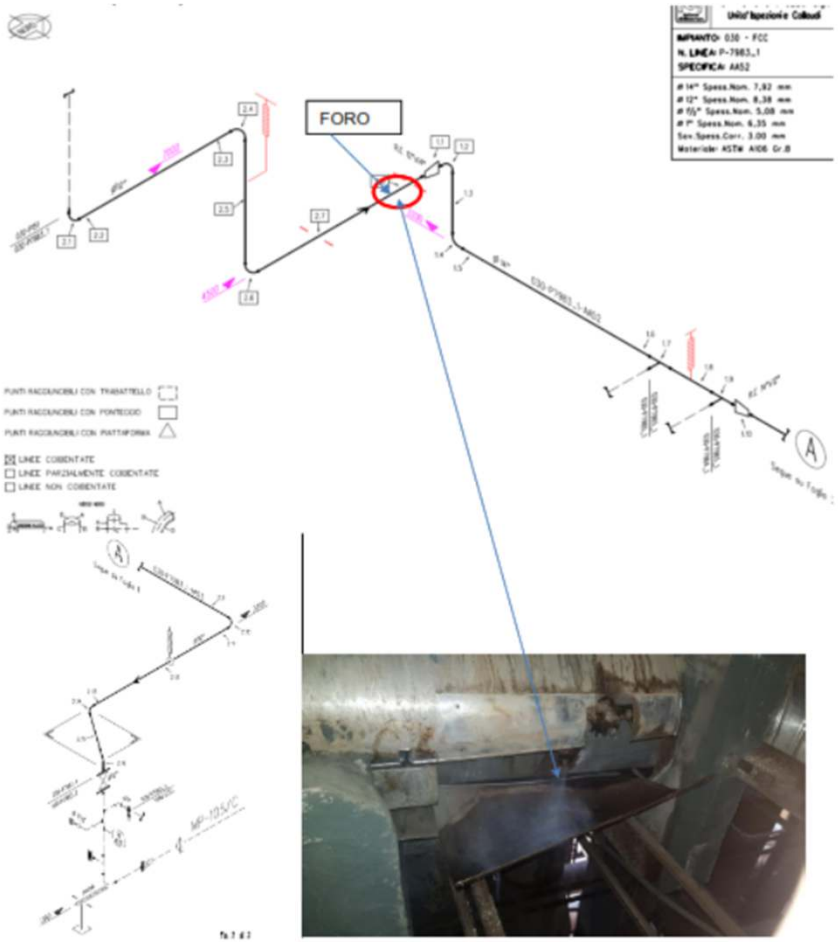
PARAMETER		VALUE
DENSITY A 15 °C(DEN00)	kg/m3	736
T.V.R.(TVR00)	HPA	625
COLOUR SAYBOLT(COS01)	*	15
C4 TOTALS(NC400)	VOL%	
I.B.P.(H0100)	C°	31
5% REC.(H0200)	C°	44
10% REC.(H0300)	C°	49
20% REC.(H0400)	C°	57
50% REC.(H0700)	C°	91
90% REC.(H1100)	C°	158
95% REC.(H1200)	C°	168
F.B.P.(H1300)	C°	181
EVAP. A 70 °C(H1400)	VOL%	34,1
EVAP. A 100 °C(H1500)	VOL%	55,6
EVAP. A 150 °C(H1600)	VOL%	85,2



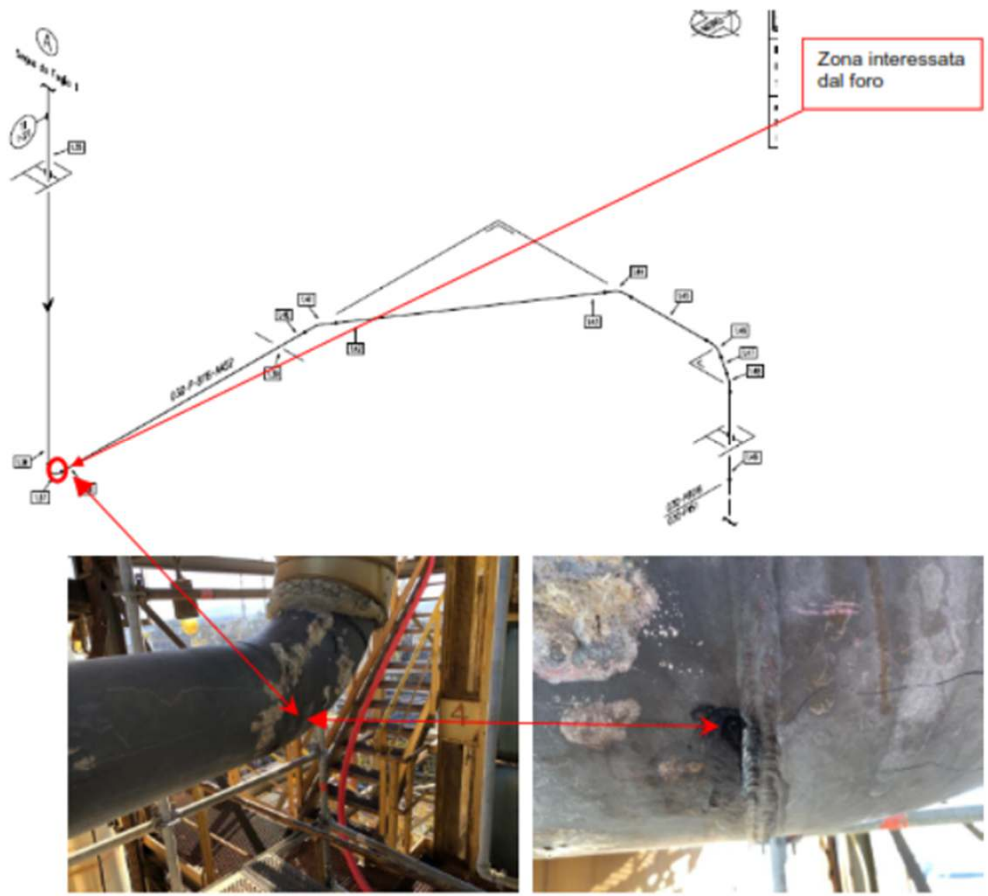
LEAKS

- N°2 leak event for **internal corrosion**
- **Diffused internal metal loss** in the line revealed by NDT

Horizontal lay-out

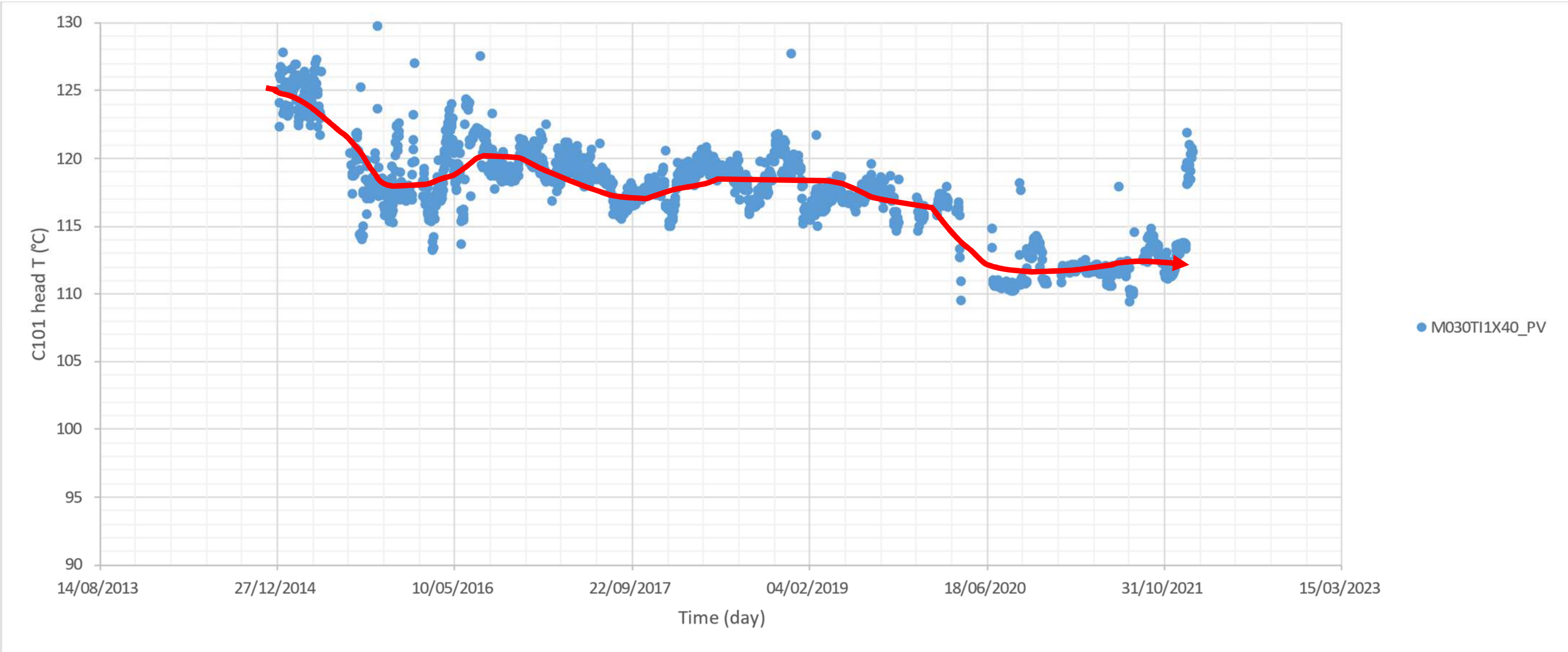


Vertical to Horiz. Bend



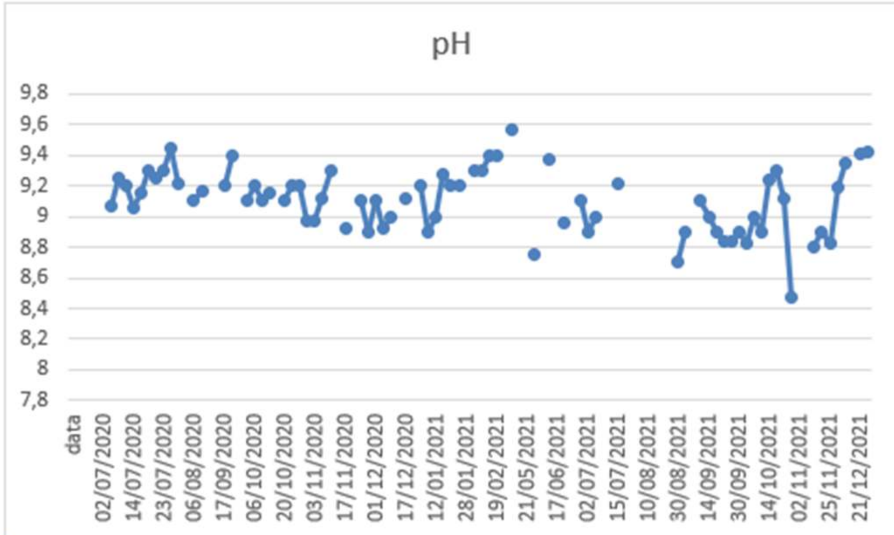
Overhead T trend

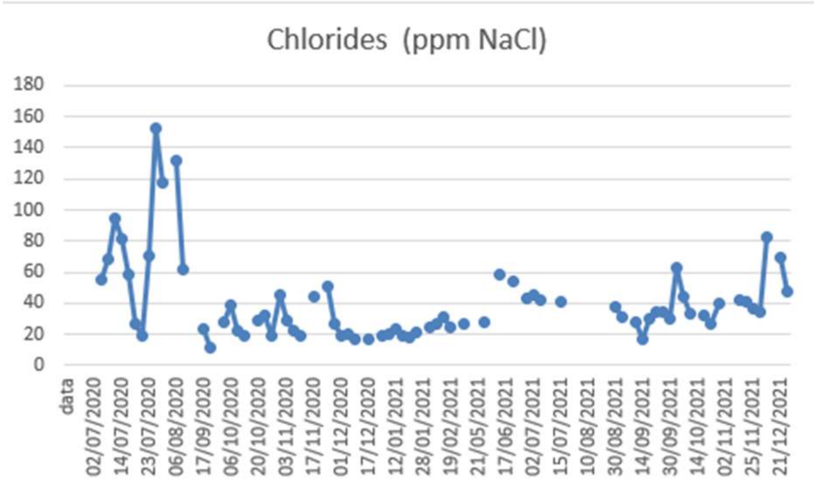
- **Overhead temperature** was progressively reduced over time

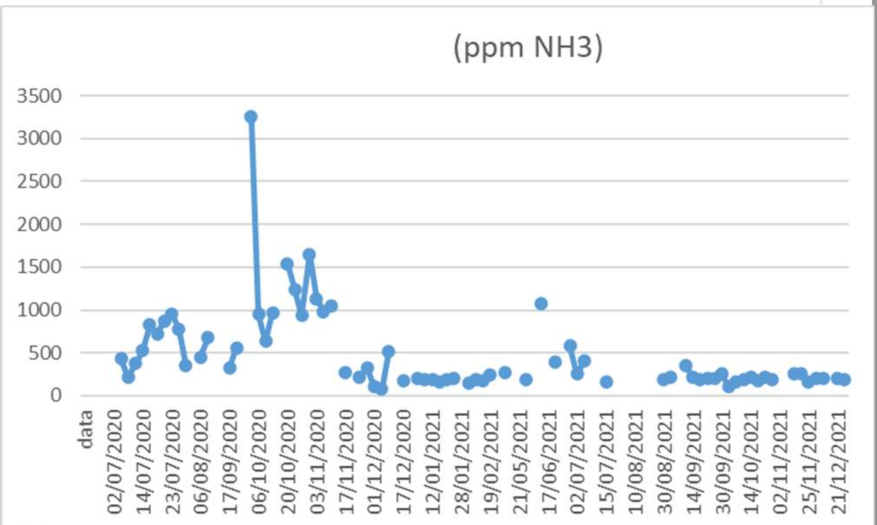


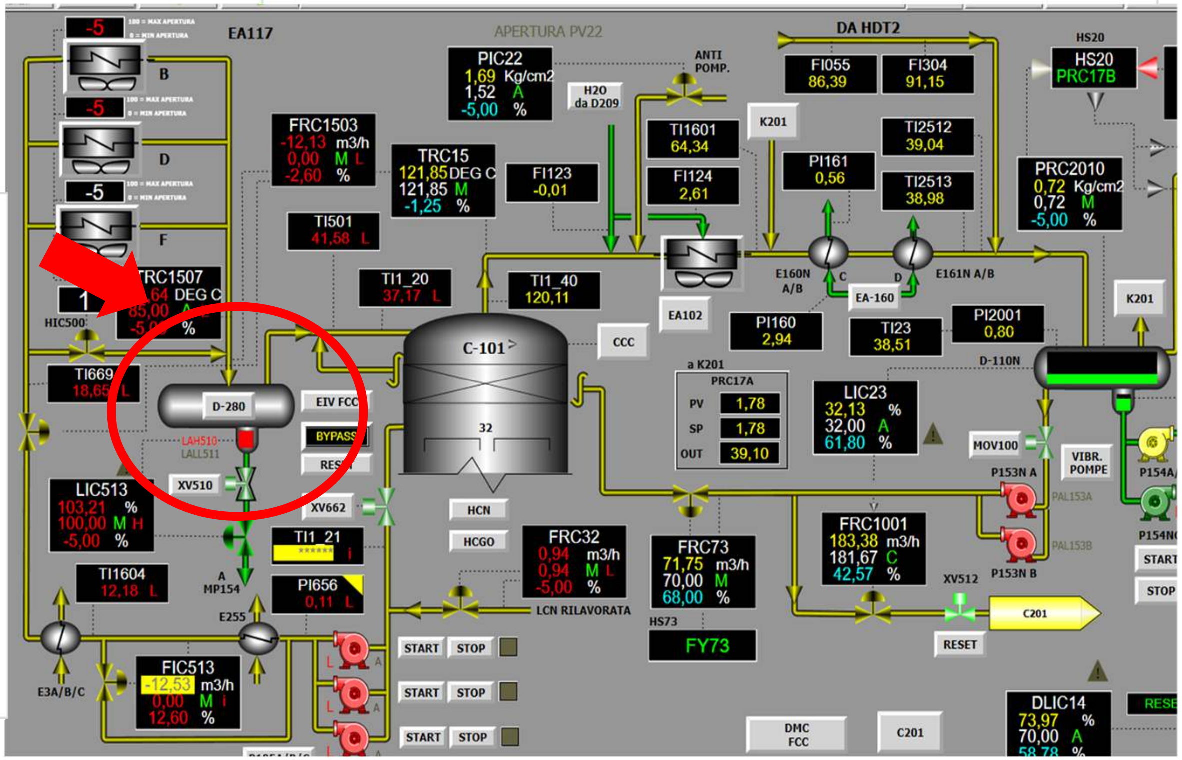
Overhead T trend

- Process KPI data
- Downstream accumulator – low T









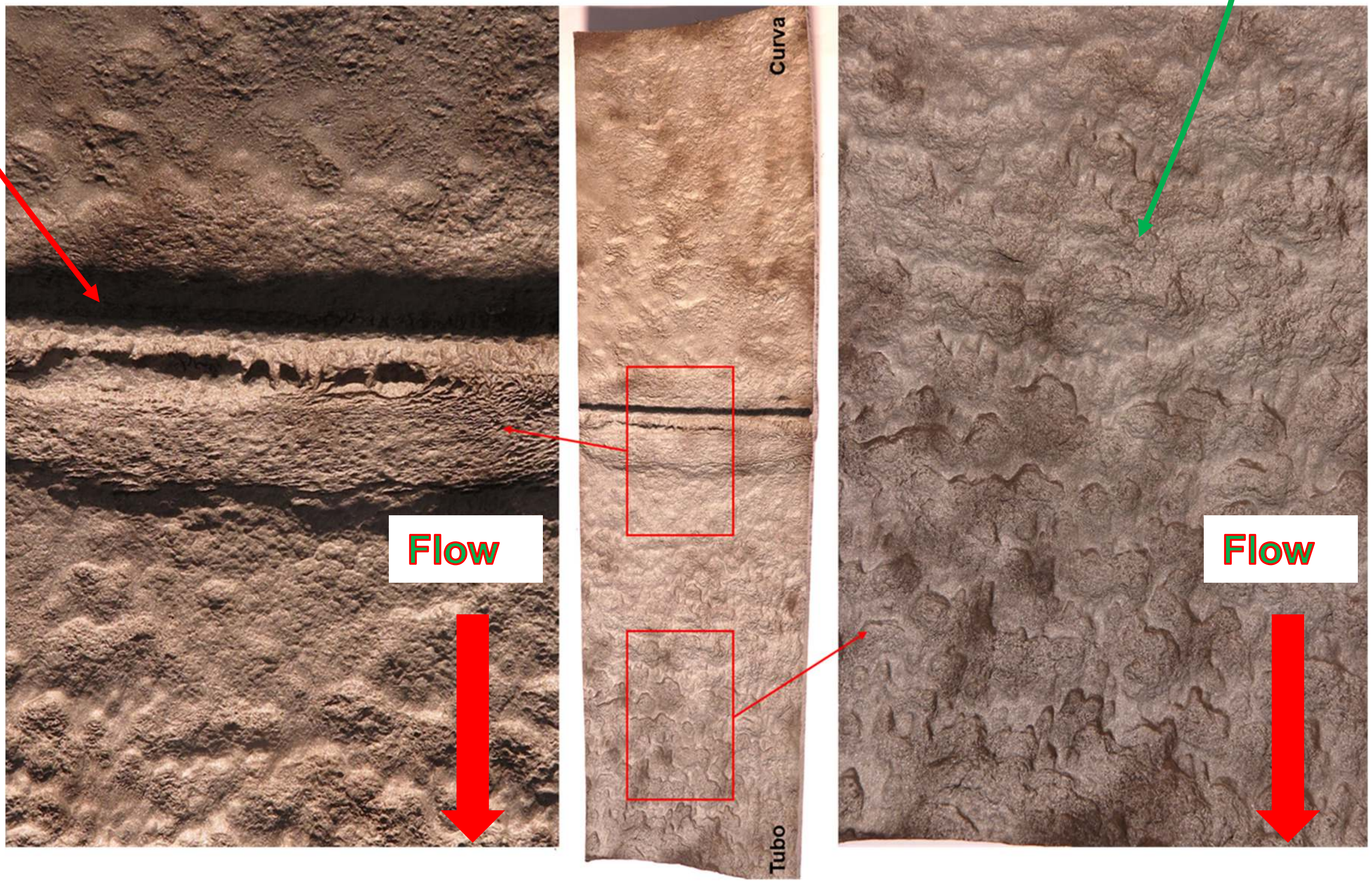
DAMAGE – LEAK 1

- Internal corrosion
- Bend and horizontal portion of tube downstream of bend
- Weld area (HAZ) with high corrosion rates
- **Black** and **brown** deposits

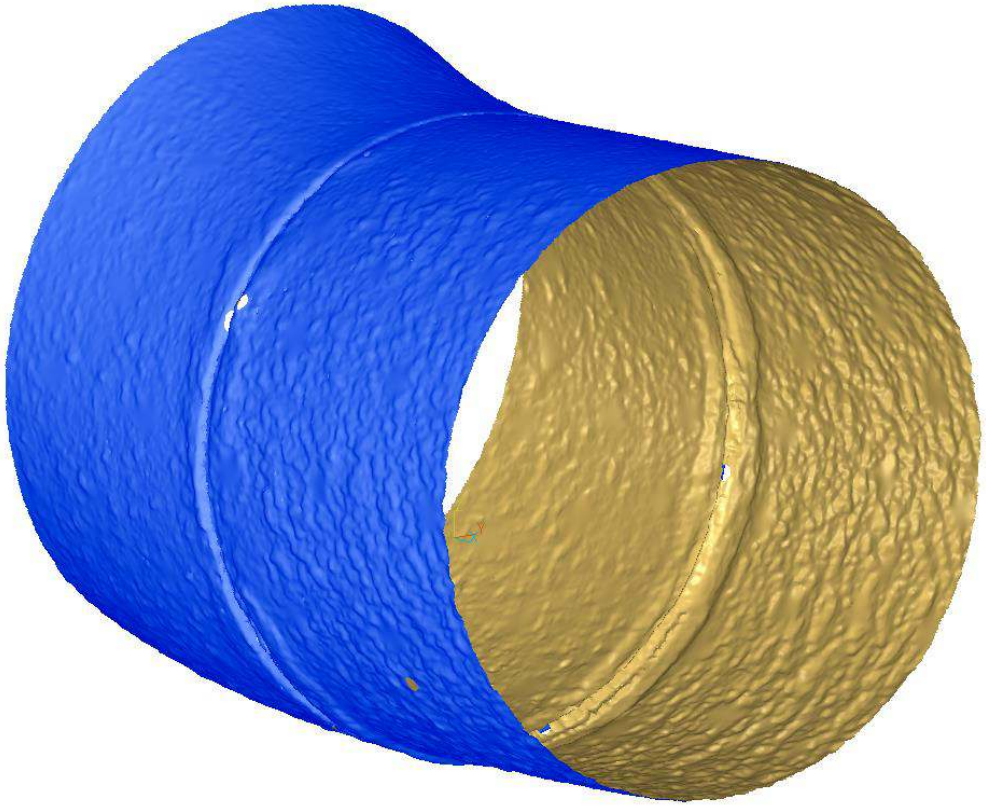
DAMAGE – LEAK 1

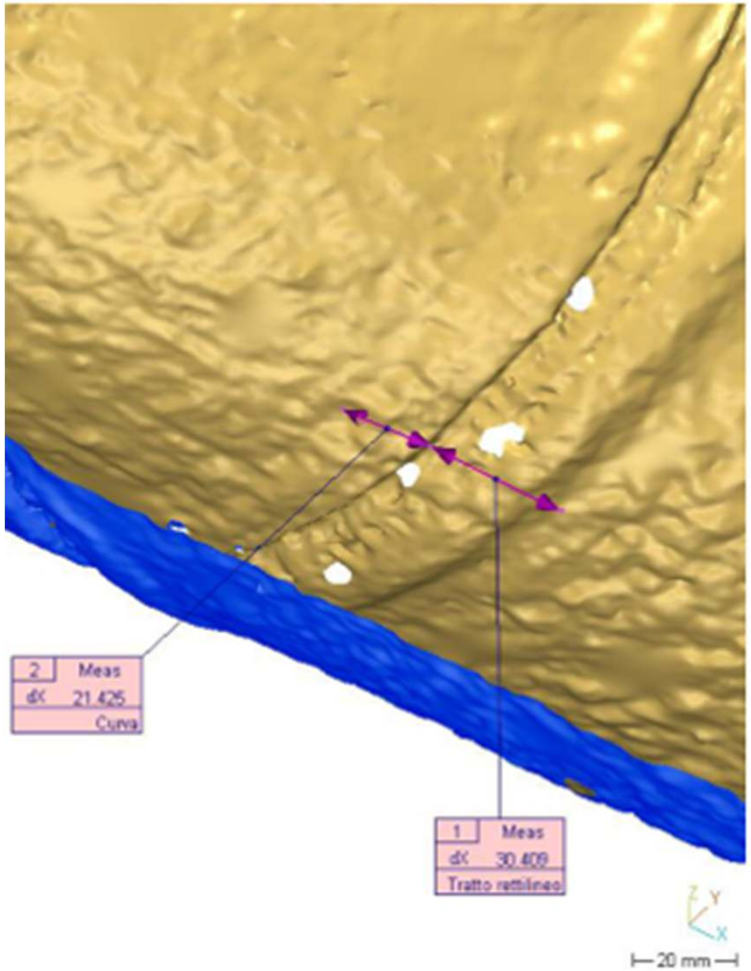
- Acid type attack morphology especially in weld zone
- In tube base material attack with flow assisted morphology

After sandblasting



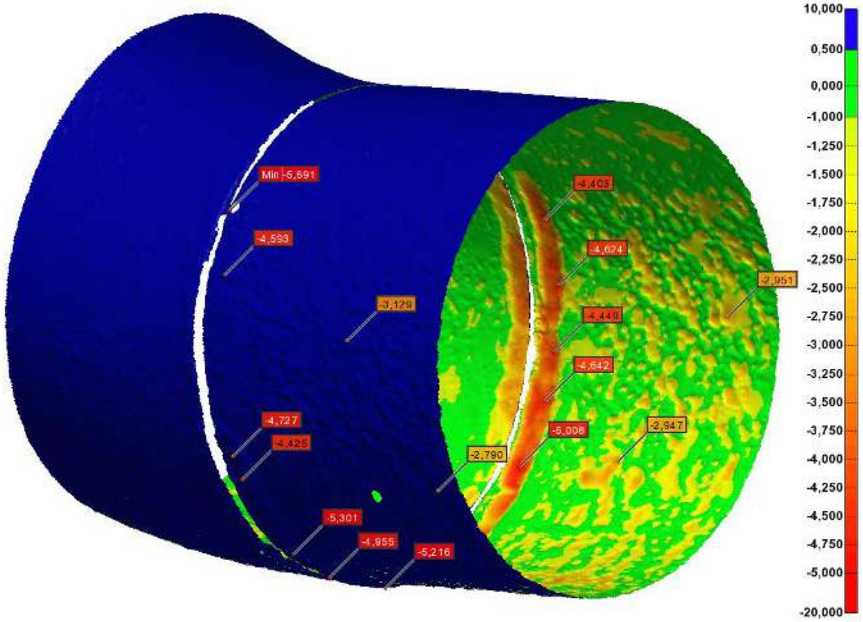
Corrosion mapping

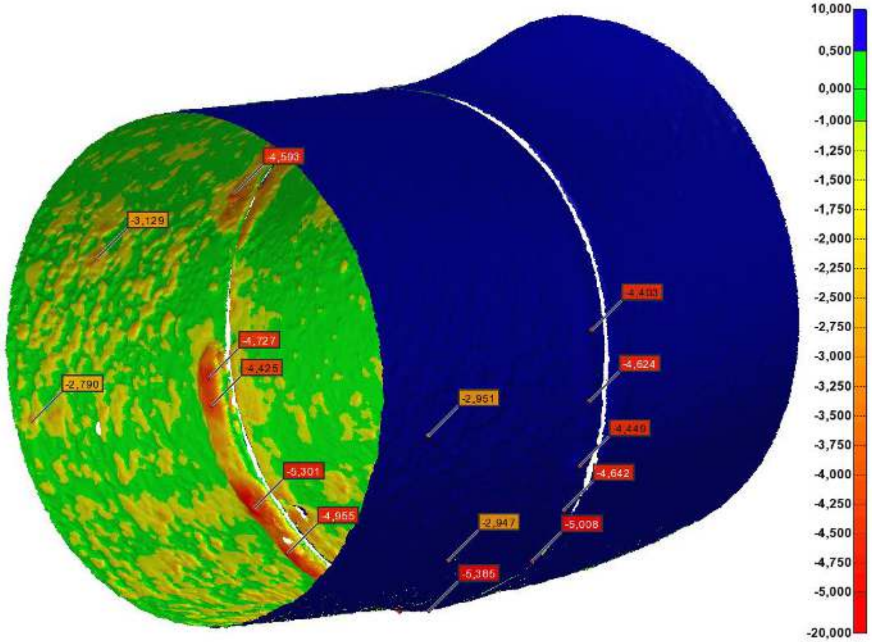


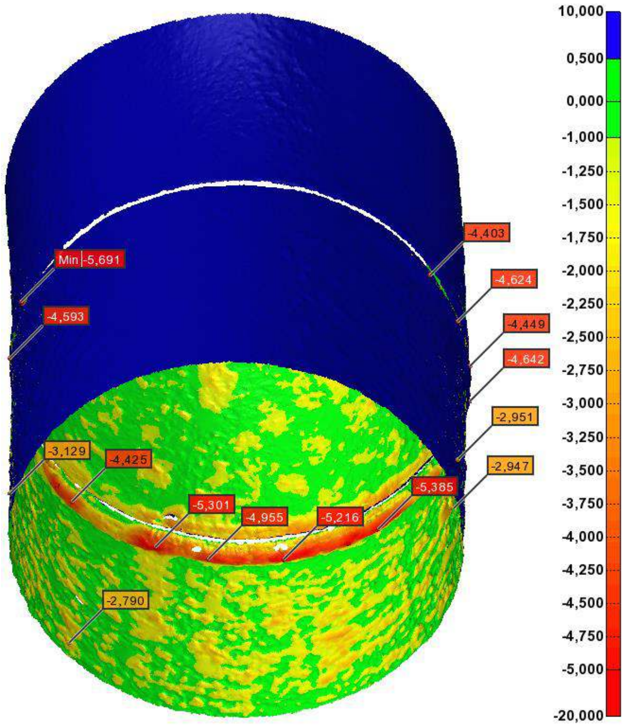


ISTITUTO ITALIANO DELLA SALDATURA

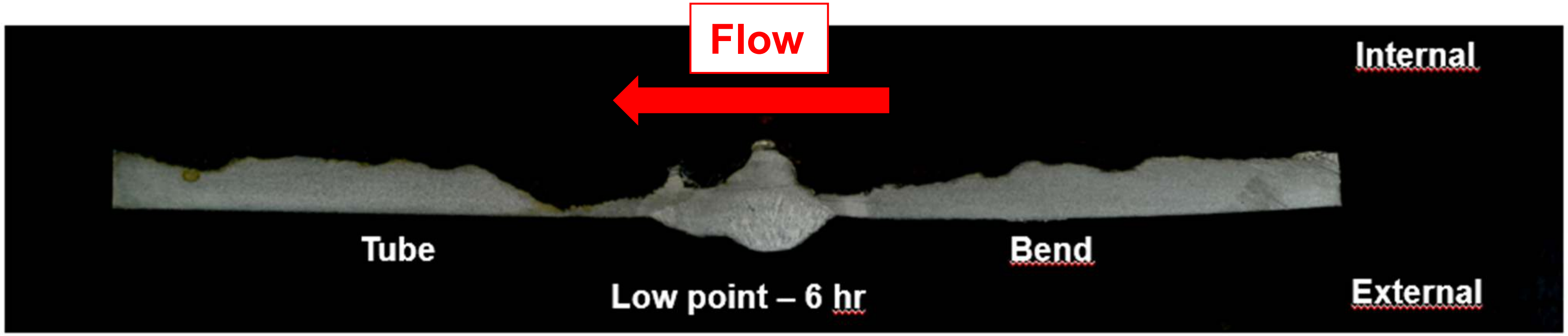
Corrosion mapping

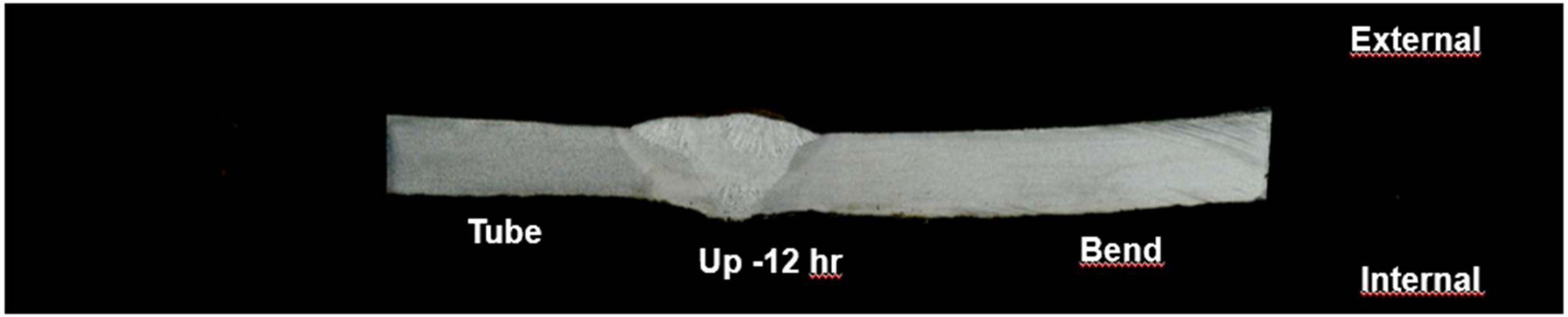






Corrosion morphology

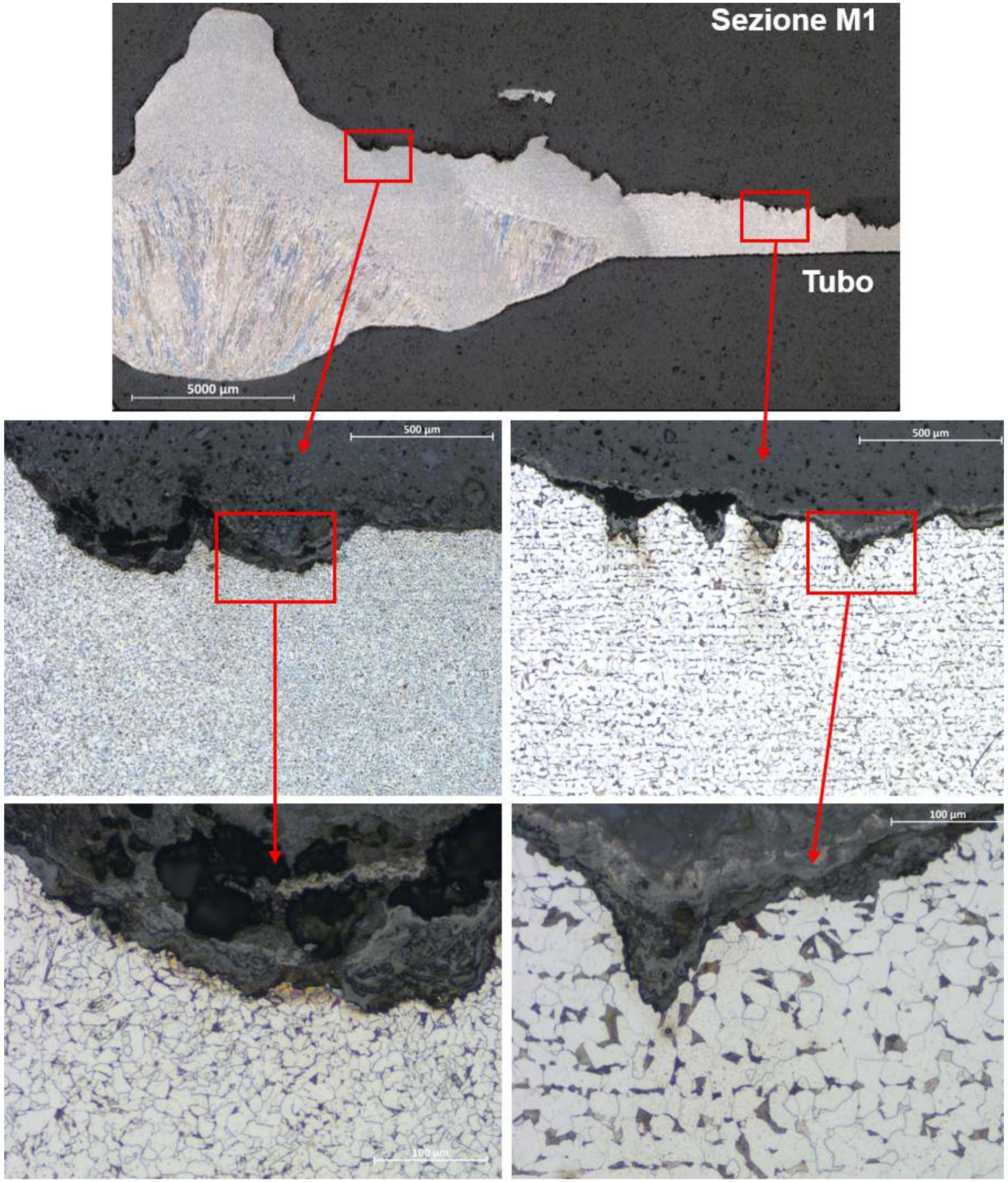




ISTITUTO ITALIANO DELLA SALDATURA

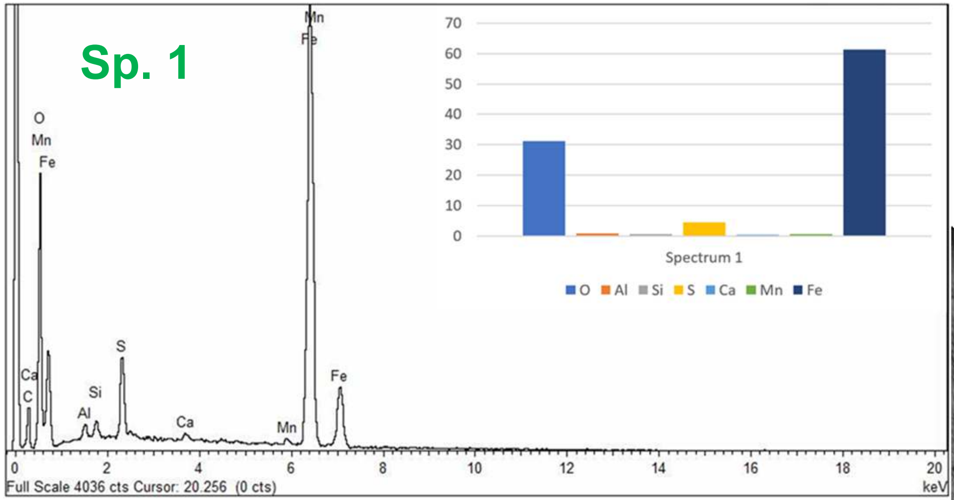
Corrosion morphology

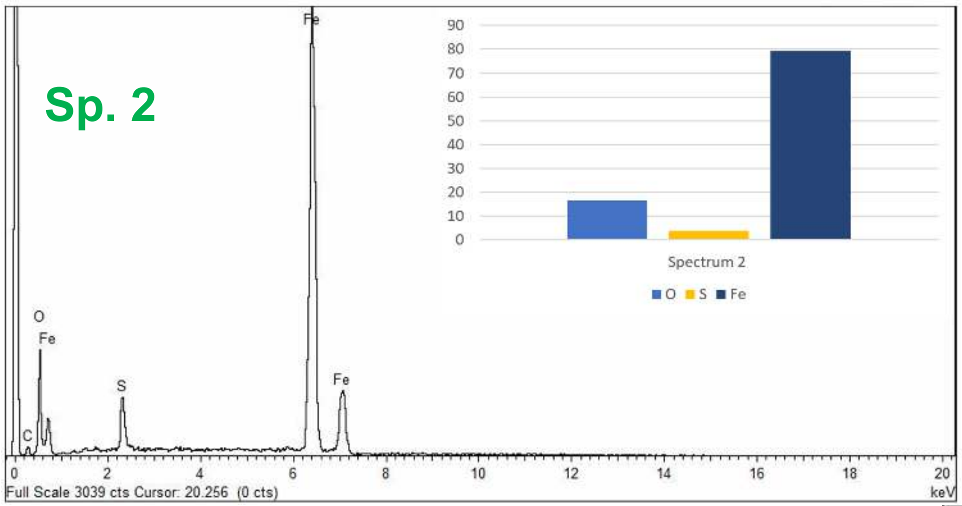
Micrographic examination

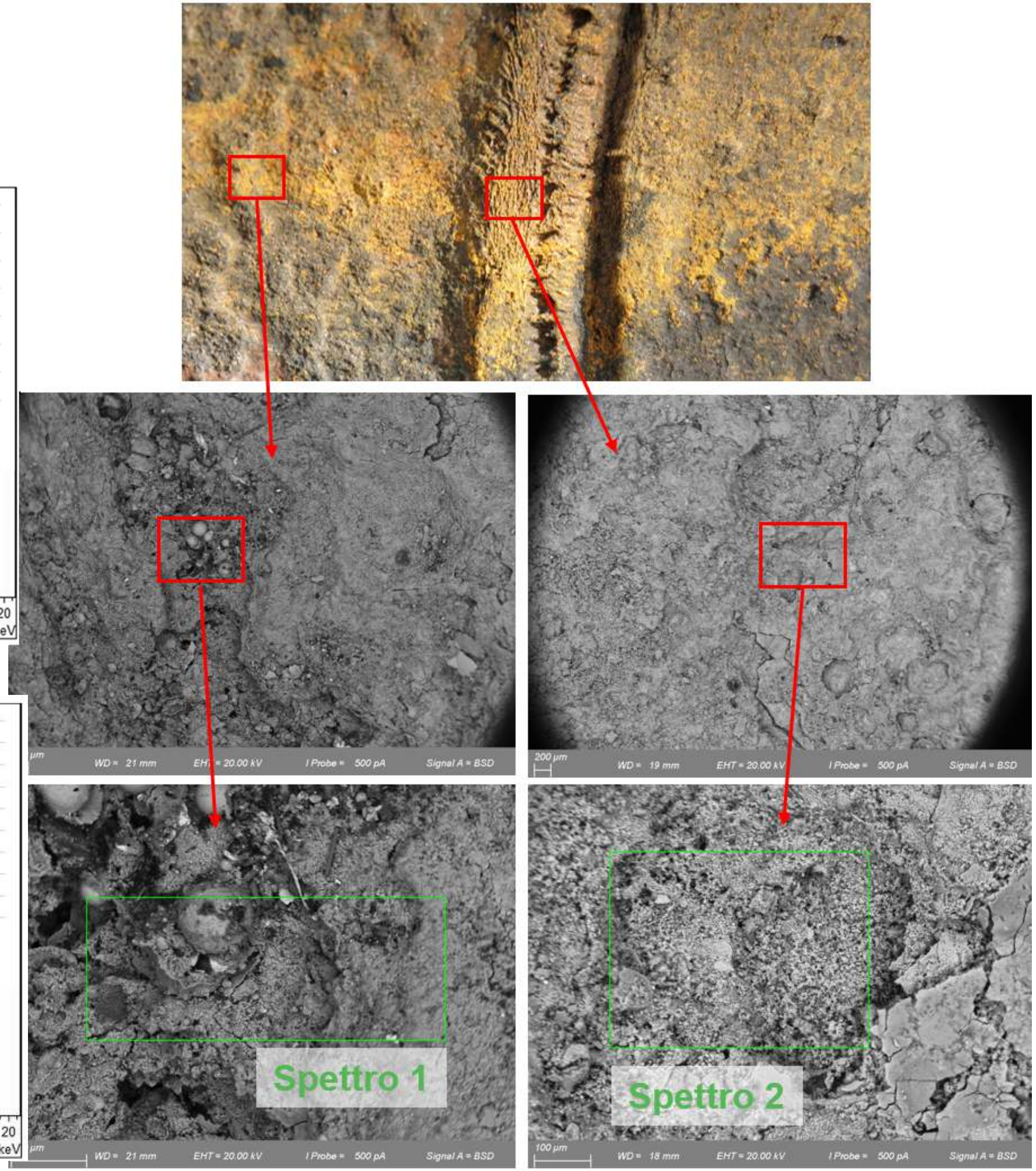


ISTITUTO ITALIANO DELLA SALDATURA

SEM + EDS Examination

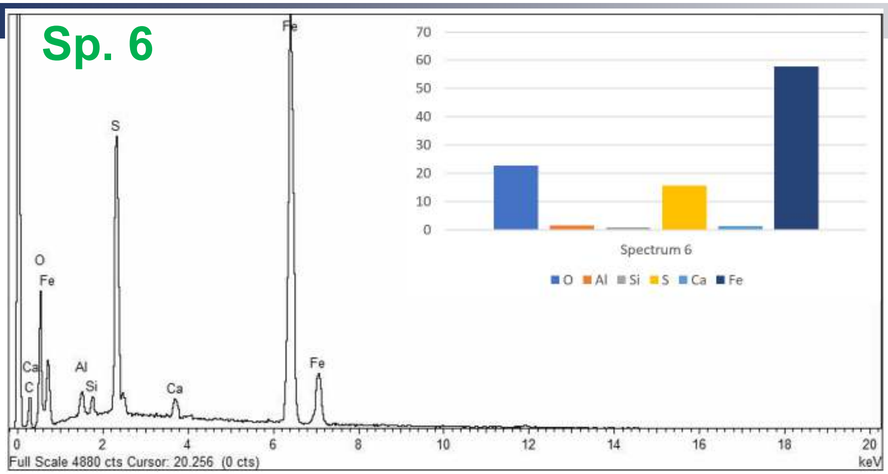


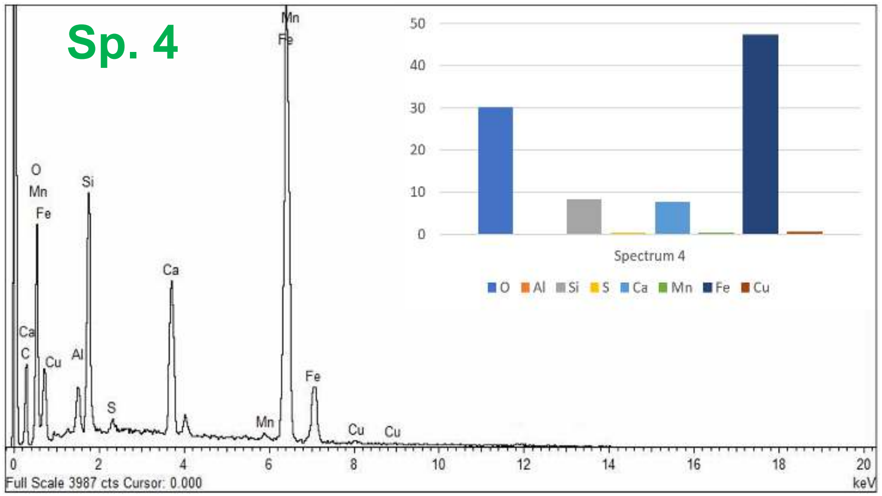


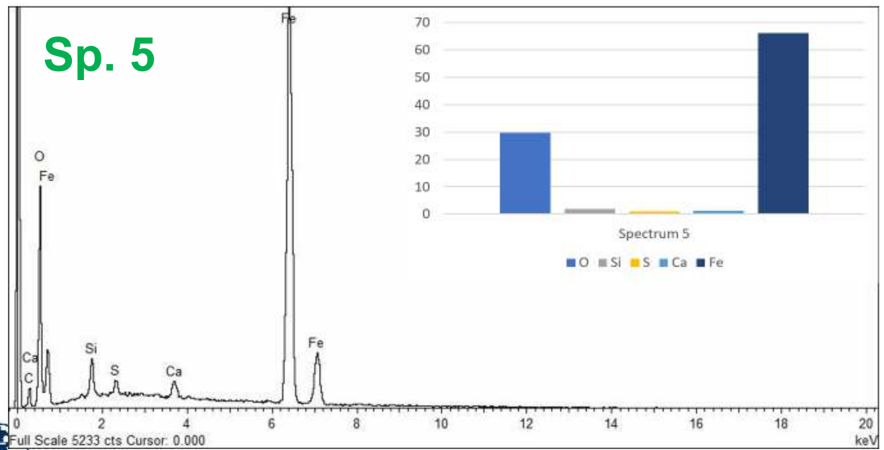


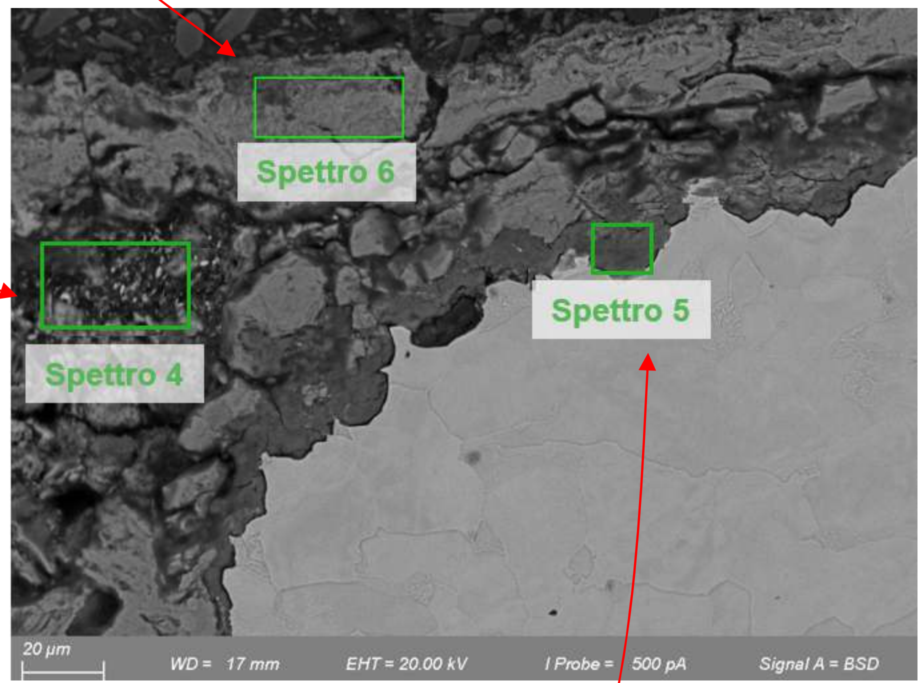
ISTITUTO ITALIANO DELLA SALDATURA

SEM + EDS Examination





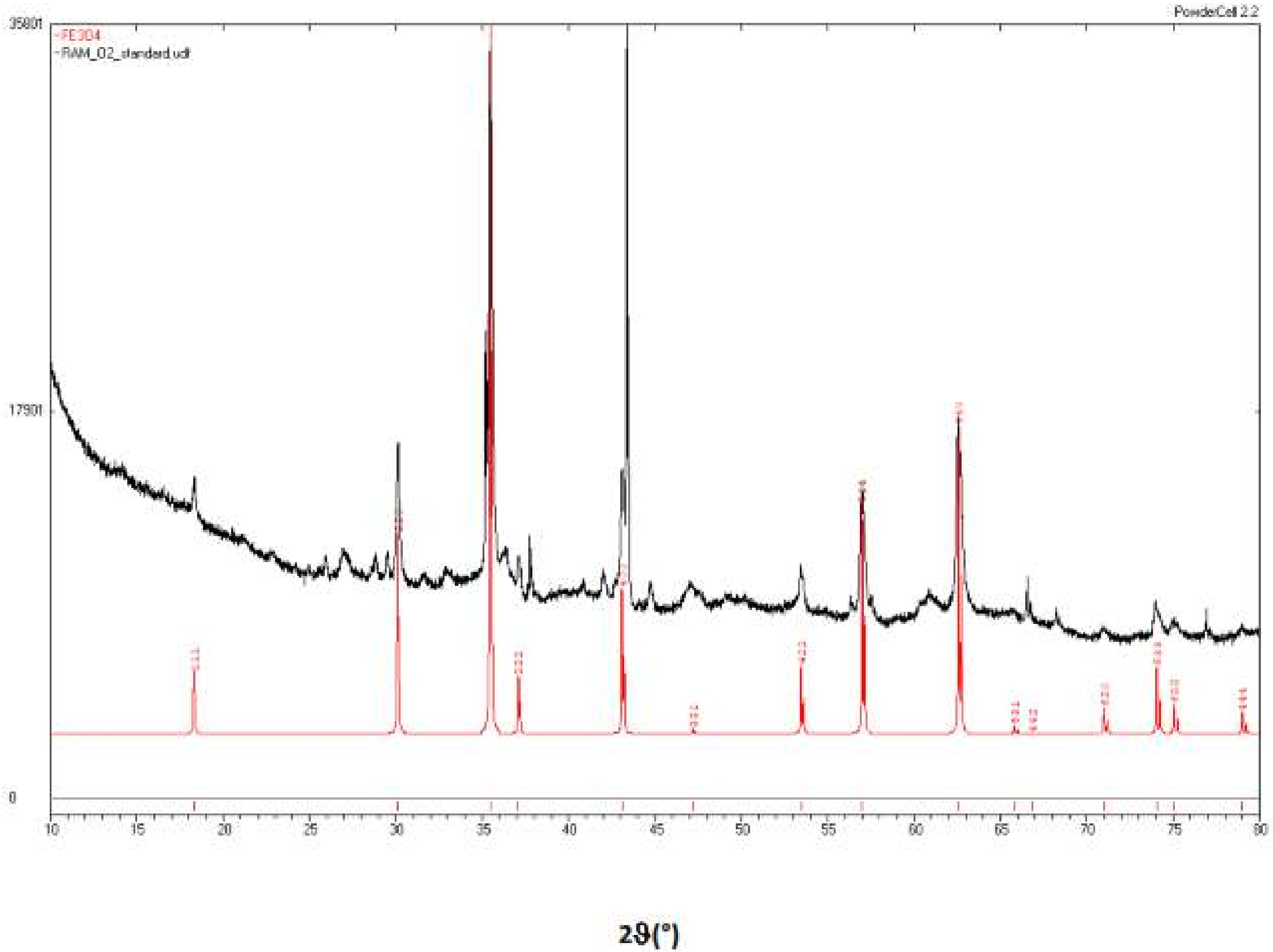




ISTITUTO ITALIANO DELLA SALDATURA

XRD

- Permits to characterize the crystalline part of deposits
- $Fe_3O_4 \rightarrow$ no oxygen in the environment (as expected)



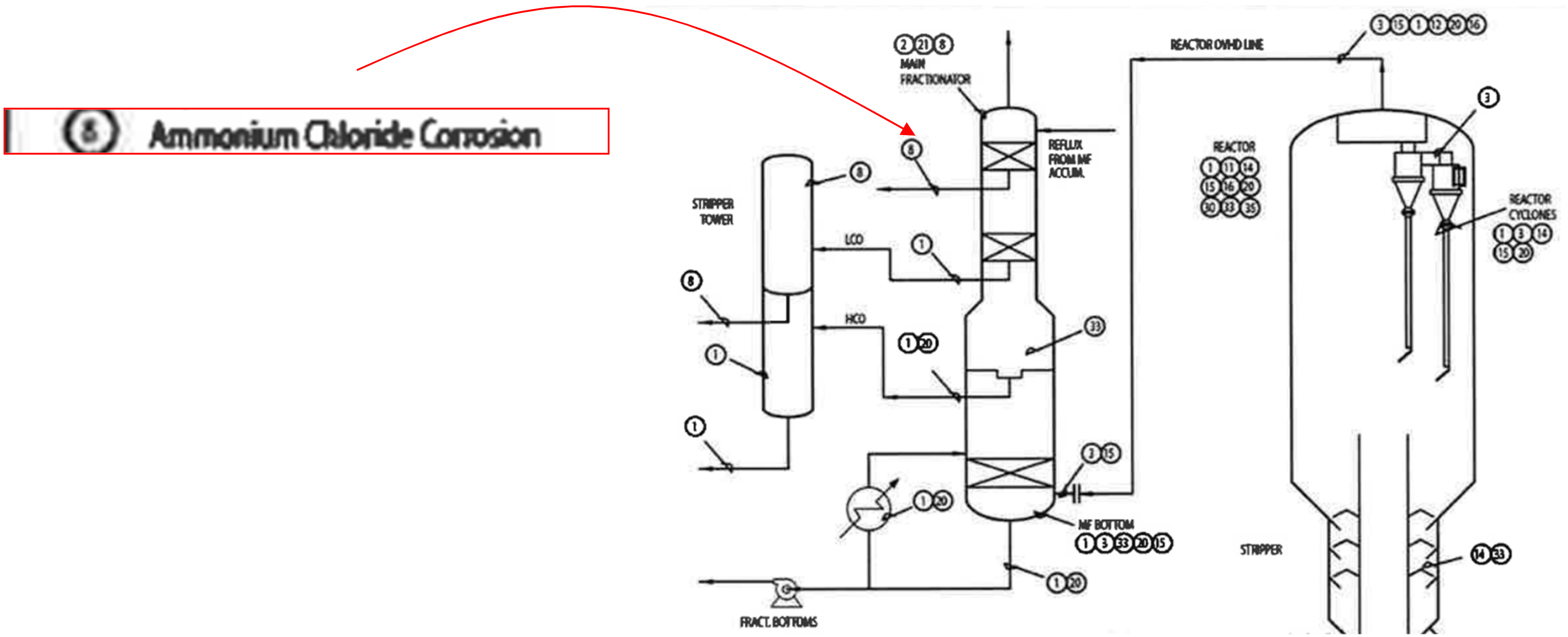
Water Extract

- No acidic
- Low chlorides

Parameter	Risultato
Aspect	solid
Color	Brown
Odor	No odor
State	Powder solid
pH (upH)	8,23
Chlorides (mg/kg)	130
Fluorides (mg/kg)	217
Phosphates (mg/kg)	< 100
Sulfates (mg/kg)	638
Nitrates (mg/kg)	< 100
Nitrites (mg/kg)	< 100
Soluble Ammonium (mg/kg)	314
Calcium (mg/kg)	525
Magnesium (mg/kg)	38,5
Potassium (mg/kg)	430
Sodium (mg/kg)	89,9

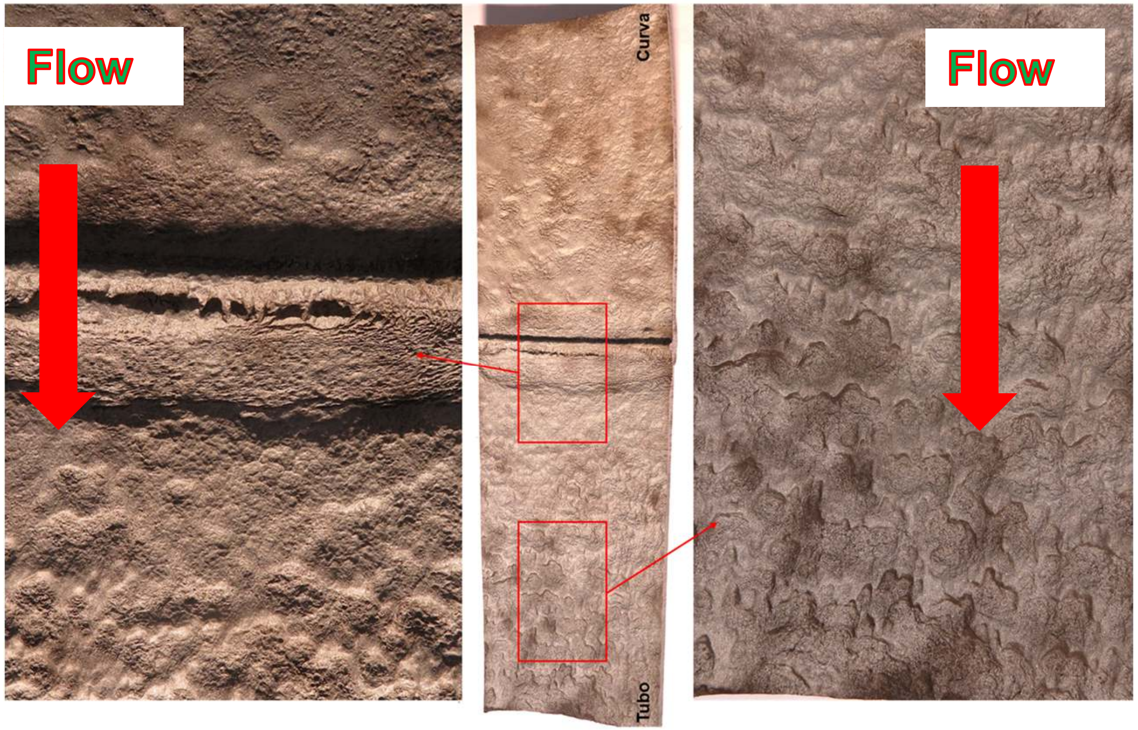
Discussion

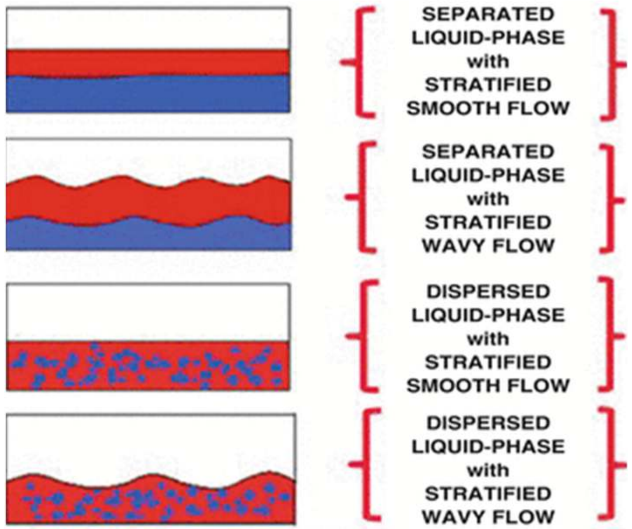
- Corrosion due to condensed water phase.
- High quantity of water withdrawn in TPA
- Overhead temperature progressively low in last months → increases water cut in TPA streams
- Typically, in FCC Unit TPA corrosion associated to NH_4Cl corrosion → under-deposits acid corrosion in case of low water cut → high water cut washes salts



Discussion

- Morphology more associated to **acidic water phase (stratified flow)** and flow assisted corrosion.
  - *Weld metal not affected (More noble?)*
  - *HAZ most affected (electrochemical or flow effects?)*
- Deposits not acidic , no detectable chlorides in deposits

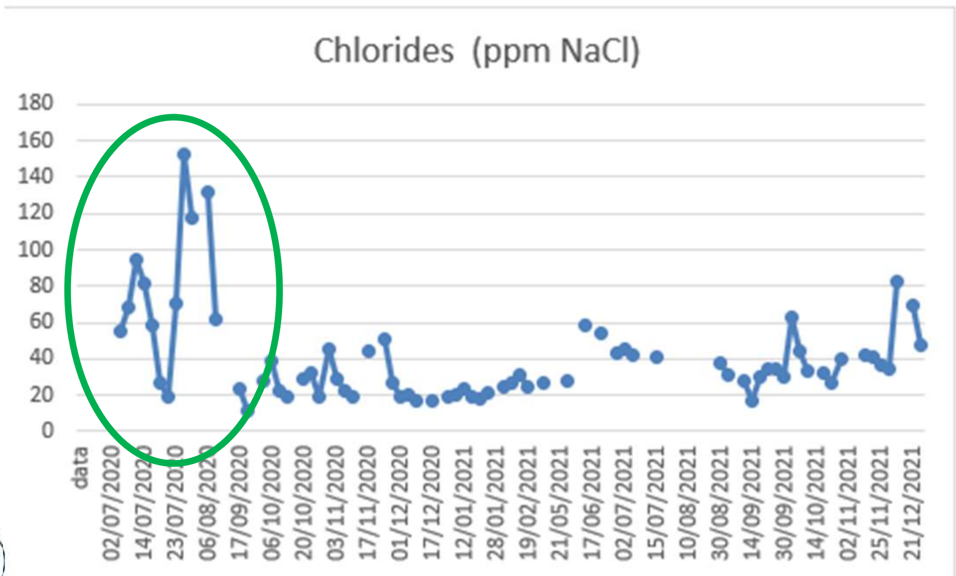


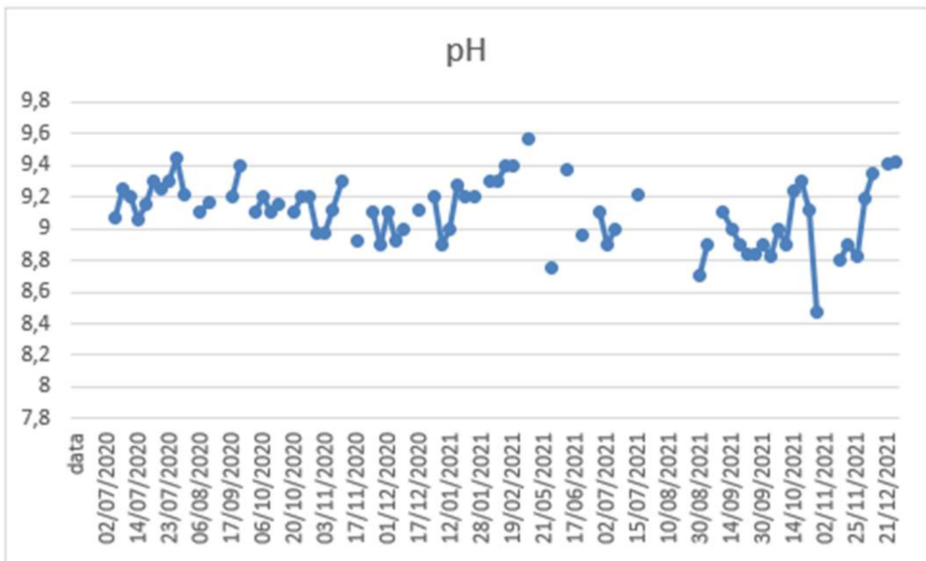


Discussion

- Water analyzed in **downstream accumulator** (low T and total condensate)
  - Spikes in chlorides in 2020 (until sept. 2020).
  - pH between 8,5 and 9,6 (slightly alkaline) – buffering effects of NH_3 at low T
  - Unknown pH in first water condensate (line of interest) at T> 100 °C (ammonia in vapor / chlorides in condensed phase) - No simulation carried out
  - No data 2015 – 2020 (?)

- Periodic ingress of (organic/inorganic) chlorides in the UNIT?
- Other acids in feed to fractionator (e.g. SOX, organic acids)???



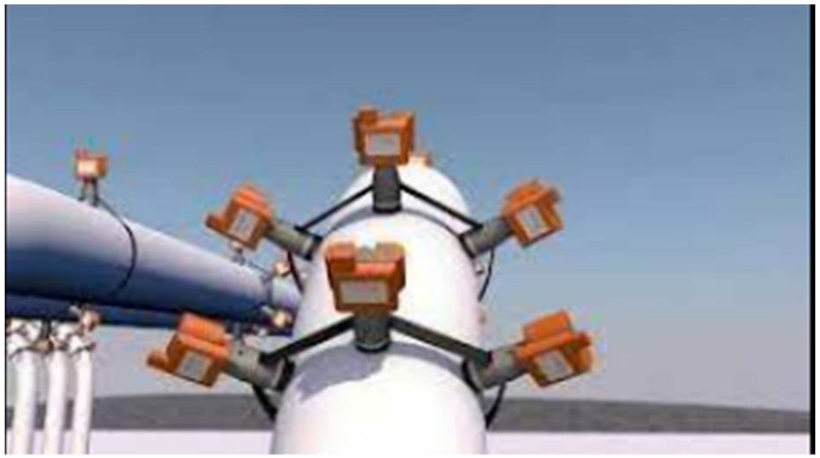


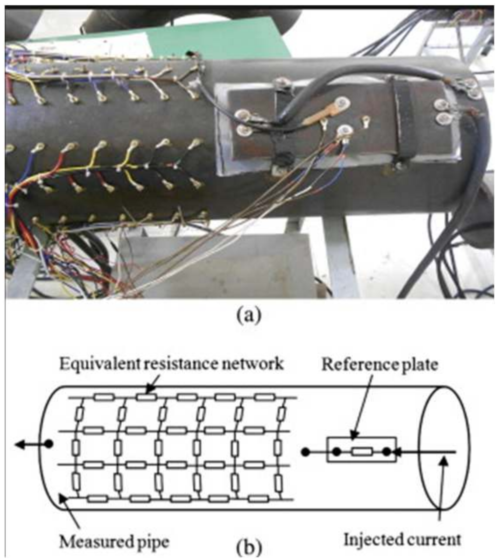
ISTITUTO ITALIANO DELLA SALDATURA

Discussion – Corrosion management

- **Until Now →**
- Washing waters in overhead circuit with corrosion inhibitors (filming/neutralizing amine).
- In TPA only dispersant

- **Opportunity →**
- Use Neutralizer in TPA? (risk of fouling?; accumulator boot water is already Alkaline in nature → how control injection?)
- Process simulation (dew point, salting point?)
- Application of UT Probe or FSM systems for real-time thickness monitoring and associate them to process variables
- Water withdrawal in column (dedicated water draw tray)





Appendix 11

A Hybrid Approach to Volatile Corrosion Inhibitors (VCIs) and Soluble Corrosion Inhibitors (SCI) for addressing CUI/Scab Repair and Flange Corrosion

(Dale Matthews)

Rig-Tech Solutions
Plan/Protect/Preserve

Zerust ZIF Tape

EFC WP15 "Corrosion in refinery and petrochemistry"

A Hybrid Approach to Volatile Corrosion Inhibitors (VCIs) and Soluble Corrosion Inhibitors (SCI) for addressing CUI/Scab Repair and Flange Corrosion.

Agenda

1. What are VCI's and how do they work.
2. CUI Prevention, Scab repairs using ZIF Tape (Zerust Inhibitor Fusion Tape)
3. ISO 19277

What are VCI’s?

And how do they work?

How do VCIs work?

1 - The molecules will form a molecular film on any metal they encounter. This film prevents oxygen from reaching the base metal and therefore the corrosive reaction.
2 - The VCI and SCI will neutralize the PH of particularly acidic environments, raising the pH to a level of 8/9 which results in a dramatic reduction in corrosion rates)
3 - The VCI and SCI will search out and neutralize any contaminants found in the area in which they are introduced. Such as acidic and ionic species, sulphides and chlorides.

ZIF Tape – CUI/Scab Repairs/Flanges

What is ZIF Tape…

1. ZIF tape is a self fusing, corrosion inhibiting tape based on silicone elastomers with proprietary Zerust corrosion Inhibitor chemistry impregnated into the matrix.
2. ZIF is cold applied and requires only an ST2 surface prep – Wire Brush and Wipe
3. Strong mechanical properties/robust due to silicone nature. 10 years +
4. Only bonds to itself, resulting in a very easy removal and easy inspection process.
5. No residues following removal.
6. Translucent allowing visual inspections.
7. UV stable.
8. Minimizes entire work parties and entire processes resulting in large cost savings. – Explain Inspections/Maximo processes…
9. Wide temperature range -40deg.C to +220deg.C
10. Tested to ISO – 19277

Areas…

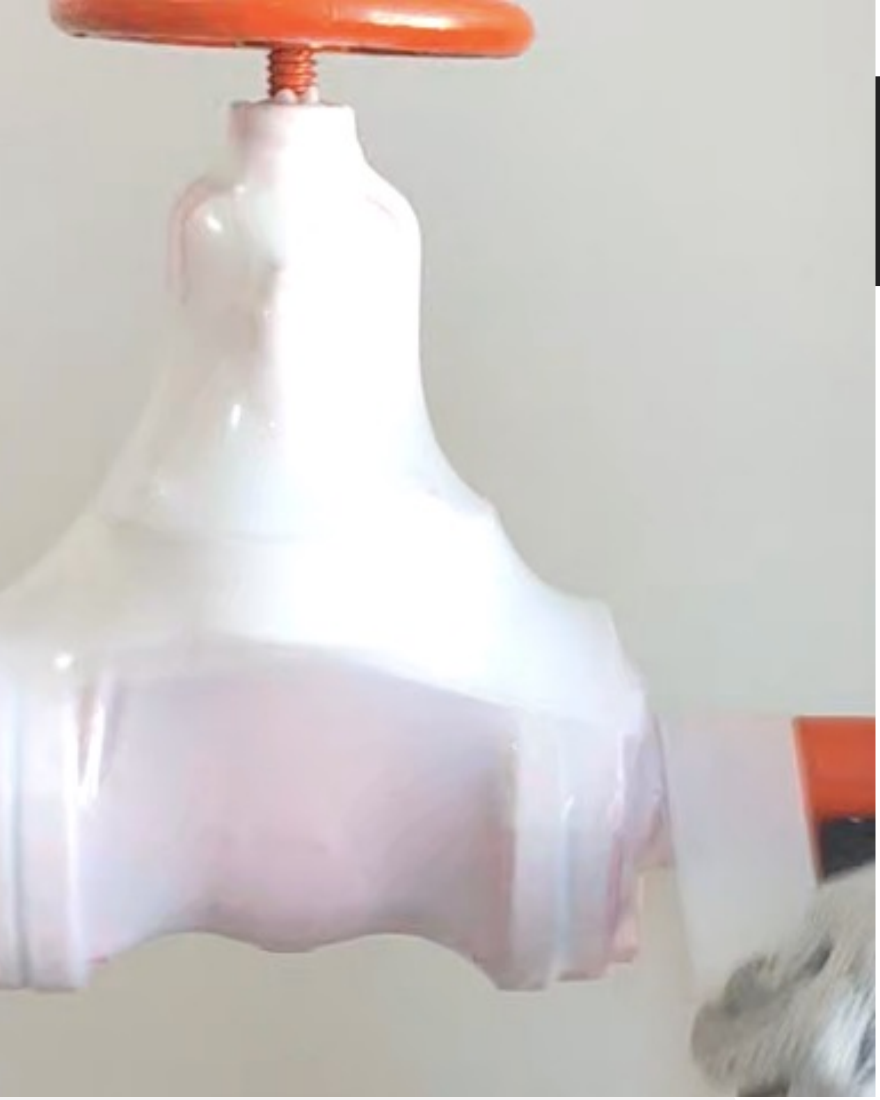
1. Valves/Flanges
2. CUI
3. Scab repairs
4. Coating defects

Winner of the French Oil & Gas Council Innovation Award for Zerust's® ZIF Tape

Valves


Anchor Wraps of 2” ZIF Tape


Overwrap of 12” ZIF Tape



Edges Tied in with 2” ZIF Tape

Sticker indicating application date applied

Flanges...

CUI IS A MAJOR ISSUE ON INDUSTRIAL PIPING AMOUNTING TO APPROXIMATELY 10% OF PLANT'S MAINTENANCE COSTS – DEVELOPMENT OF PREVENTIVE ACTIONS HAVE BEEN NEGLECTED

Corrosion Under Insulation (CUI)

Description & Challenge

- CUI is a severe form of localized, **external corrosion that mostly occurs on carbon,** low alloy steel and stainless-steel which are insulated
- CUI is most prevalent in the chemical/petrochemical, refining, offshore, and marine/maritime industries**. If left undetected**, CUI can result in **catastrophic leaks or explosions**, **equipment failure**, **prolonged downtime** due to repair or replacement, and **safety and environmental concerns**
- CUI accounting for an estimated **10% of a plant's overall maintenance costs** and **40%- 60% of its pipeline maintenance costs**
- **More than 90% of maintenance work** related to corrosion detection based on risk-based assessment shows no corrosion and, therefore, **could be avoided**



*The **global cost of corrosion** is estimated to be US$2.5 trillion, which is equivalent to **3.4% of the global Gross Domestic Product (2013)***

Customer Potentials

Reduction of "unnecessary" maintenance costs

Revenue lost due to **unplanned down time** (opportunity costs)

Mitigation of accident potential: Direct accident costs & reputation costs

CUI+ SCAB Repairs …

12 month live refinery lines Antwerp 90 -120c

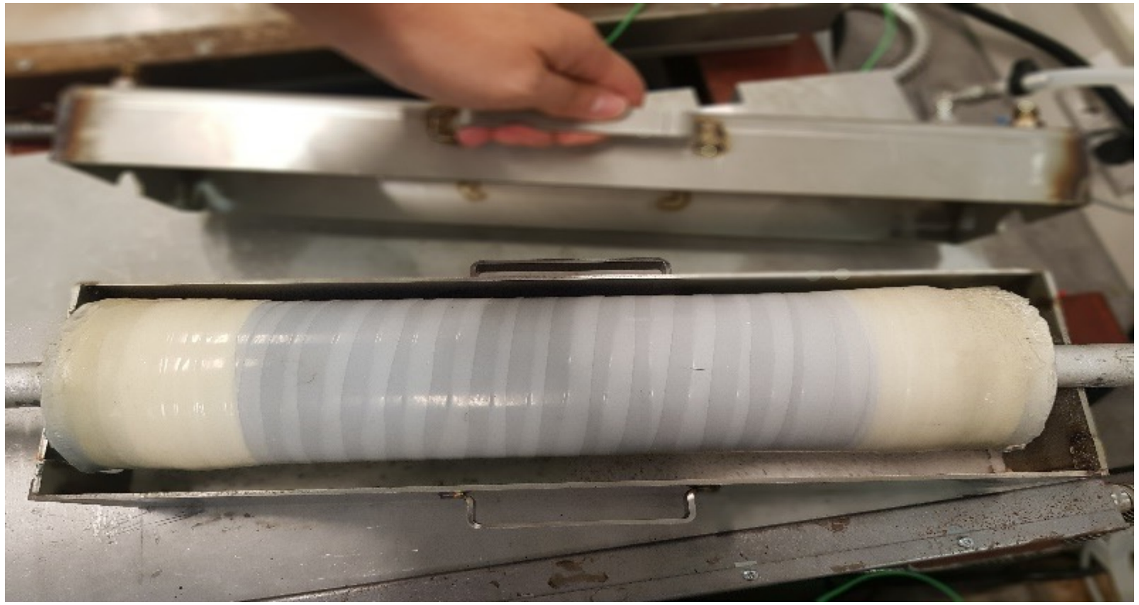
CUI+ SCAB Repairs …

6 Months Jetty Side Antwerp

TESTED to ISO 19277 MULTI-PHASE CUI CYCLIC CORROSION TEST CUI-3 …

The Tape was evaluated at a third-party (Element Testing NL) lab per the test cycle in ISO 19277 MULTI-PHASE CUI CYCLIC CORROSION TEST CUI-3. A brief outline of the test procedure can be found below:

Multi-phase CUI cyclic corrosion test CUI-3 A multi phase corrosion under insulation corrosion test according to modified ISO 19277 was conducted for 6 weeks..



- Test “coupon” is a bare steel cylinder
- Cylinder is internally heated by circulating oil at 175° C
- Cylinder wrapped with Tape and placed into test chamber
- Test chamber held for four hours at 175°C
- Test chamber filled with 5% NaCl solution and held at 175° C for four hours
- Test chamber drained and held at 175° C for four hours
- Test chamber filled with DI water and held for 4 hours at 175°C
- Cycle repeats for five days
- Test chamber opened, drained, cleaned and allowed to stand at ambient for two days
- Entire seven-day cycle repeated six times for a total test time of 1008 hours 15 cycles in total for a 6 week period.
- At the end of the test, the sample is evaluated for any defects in the Tape, in which apart from some discoloring, no defects were found.

Ease of Removal

No residue, glues or adhesives to remove

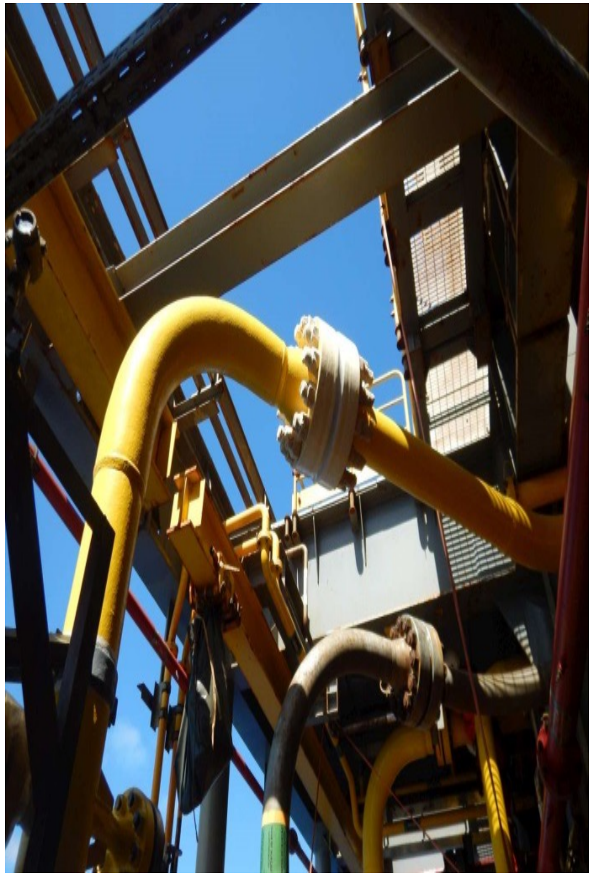
Inspection Cycles/RBI – ZIF – Part of the remedial tool kit.

Inspection – A Useful Tool

By minimizing the blasting element, entire work order/processes can be eliminated, such as: reducing hot work down to cold work permits, eliminating blasting on live lines (BOLL), reducing hazards and costs, eliminating heavy equipment such as blasting equipment, hoses, gauntlets, air purification tests, compressors, generators and so on.

Thereby, also eradicating coating equipment. Inspectors can use the Tape to a great effect during integrity inspections works and complete repairs following an NDT inspection.

This could drastically reduce workflows: reporting and entire work party management flows and saving multiple crews visiting the same jobsite to perform remedial works.



Zerust® Inhibitor Fusion (ZIF) Tape Conclusion

- Easy to Implement
- Substantial overall commercial savings vs. conventional coating systems.
- Non-Intrusive
- Continued In-Service Operational activities
- 5-10+ years of protection
- Ease to Inspect due to translucent nature of the ZIF Tape and ease of removal and/or reinstallation is required.
- Provides a 2 layer barrier: By means of a physical barrier of a robust Silicone based material and by means of a corrosion inhibitor that will form a molecular layer of protection and neutralize any contaminants.

THANK YOU!

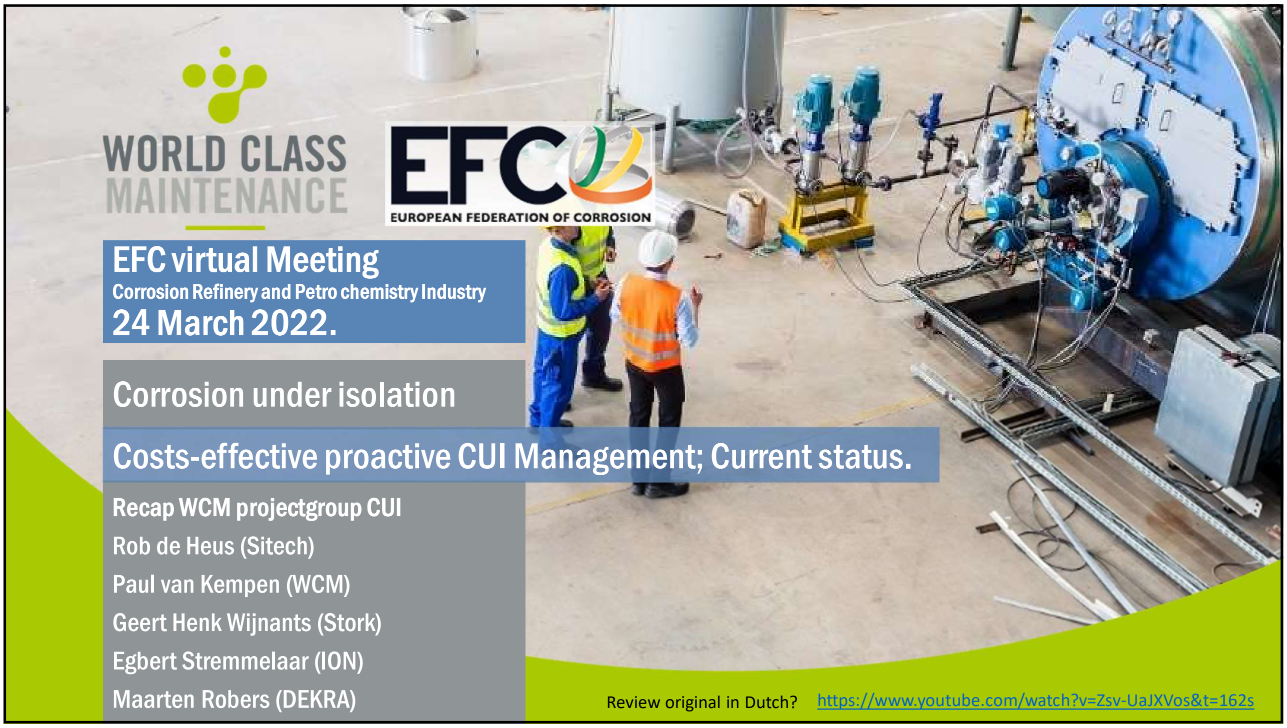
Any questions?

dale@rig-techsolutions.com

Appendix 12

VCM best practice for Risk Based CUI management

(Geert Henk Wijnants)

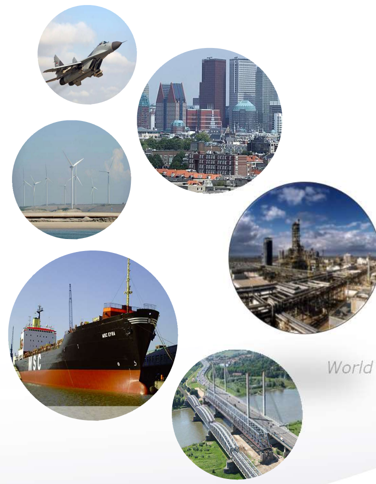

WORLD CLASS
MAINTENANCE
EFC
EUROPEAN FEDERATION OF CORROSION
EFC virtual Meeting
Corrosion Refinery and Petro chemistry Industry
24 March 2022.
Corrosion under isolation
Costs-effective proactive CUI Management; Current status.
Recap WCM projectgroup CUI
Rob de Heus (Sitech)
Paul van Kempen (WCM)
Geert Henk Wijnants (Stork)
Egbert Stremmelaar (ION)
Maarten Robers (DEKRA)
Review original in Dutch? https://www.youtube.com/watch?v=Zsv-UaJXVos&t=162s


WORLD CLASS
MAINTENANCE
Corrosion
under
Insulation
Network for Smart Maintenance
CUI Project, information sessie, Sept. 9th 2020
Geert Henk Wijnants
Principal consultant. Secretary of WG BP CUI Management

Our goal: make our partners maintenance world champions

- Maintenance
- Asset Management
- Life Cycle Management

- Competiveneness
- Safety
- Sustainability



World Class Assets

WORLD CLASS MAINTENANCE

CUI 22-06-2020

We believe in

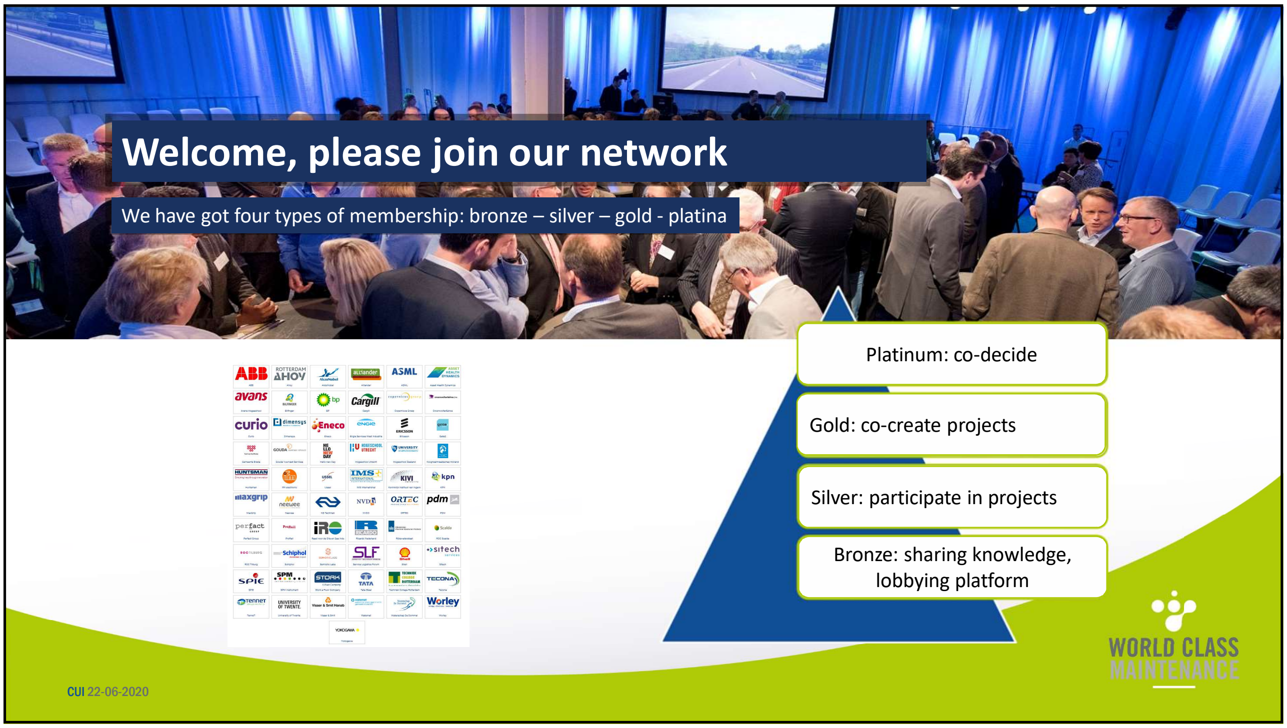
WORLD CLASS MAINTENANCE

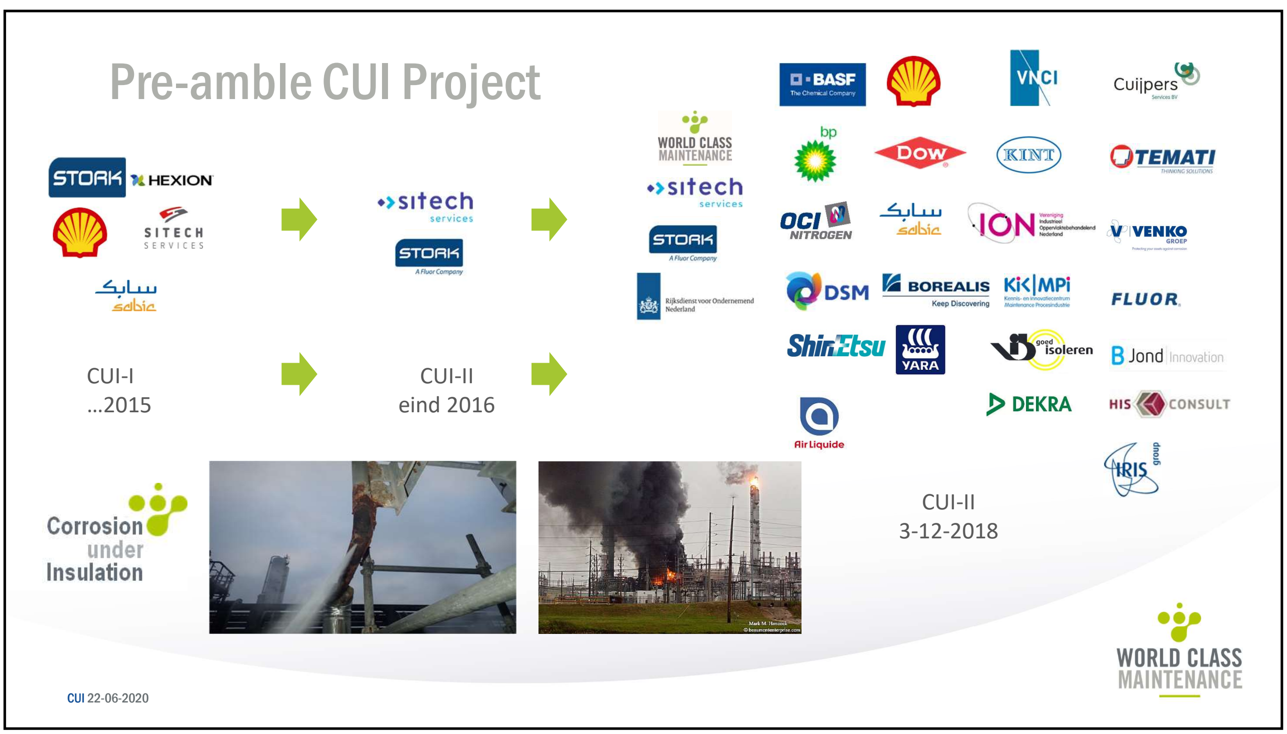
- Open Innovation
- Cross-sectoral cooperation
- Cooperation of companies, knowledge & education institutes and government

Fieldlabs & projects | Knowledgde and info | Lobby & politics | Network

FME POWERED BY DUTCH TECHNOLOGY

CUI 22-06-2020


Welcome, please join our network
We have got four types of membership: bronze – silver – gold - platina
Platinum: co-decide
Gold: co-create projects
Silver: participate in projects
Bronze: sharing knowledge, lobbying platform
WORLD CLASS MAINTENANCE
CUI 22-06-2020


Pre-amble CUI Project
CUI-I
...2015
CUI-II
eind 2016
CUI-II
3-12-2018
Corrosion under Insulation
WORLD CLASS MAINTENANCE
CUI 22-06-2020

Objectives CUI project

Corrosion under Insulation

"The 'Prevention and Detection of Corrosion under Insulation' project aims to establish industry practices with which COI can be established and controlled more accurately and predictably. These practices include: NDT (non destructive testing), Coating and Risk Based CUI practices. "

"The results of the working groups transcend the legal bases from the Pressure Equipment (Commodities Act) Decree 2016 and also the practical rules for pressure equipment."

"...based on this, a new plant manager could be explained, in a manner of speaking, how we currently approach CUI as 'BV Netherlands'. "

CUI 22-06-2020

WORLD CLASS MAINTENANCE

Participating Industry

Steering group
Rob de Heus, Sitech
Geert Henk Wijnants / Ferry Visser, Stork
Maarten Robers, Dekra
Age Balt, Dow
Pieter Raes, KI<Mpi
Arie van Stappen, BP
Bert Goffings, Sabic
Danny Schepkens, Borealisgroup
Casper Wassink, KINT
Jacko Aerts, DSM
Johan Sentjens, Temati
Egbert Stremmelaar, Vereniging ION
Marc Schoonacker, BASF
Patric de Konink, OCI Nitrogen
Peter Bareman, VNCI
Ruben van de Wijer, Shell
Jo van Montfort, Bjond
Jan Heerings, HISconsult
Paul van Kempen, WCM

Workgroup NDT
Maarten Robers, Dekra (chairman)
Jan Heerings, HISconsult (technical secretary)
Rob van den Boogaart, Air Liquide
Gerd De Smedt, BASF
Rino van Voren, Dow
Marcel Warnier, Sitech
Cees Smits, Shinetsu
Casper Wassink, KINT

Workgroup Coatings
Egbert Stremmelaar, ION (chairman)
Jo van Montfort, Bjond (technical secretary)
Marco Arentshorst, Cuijpers
Rene Spier, Fluor
Erik Scheper, Venko
Olaf Smale, Venko
Jo Neefs, Iris
Peter Janssen tijdelijk namens Bert Wolfs, Sitech
Johan Sentjens, Temati

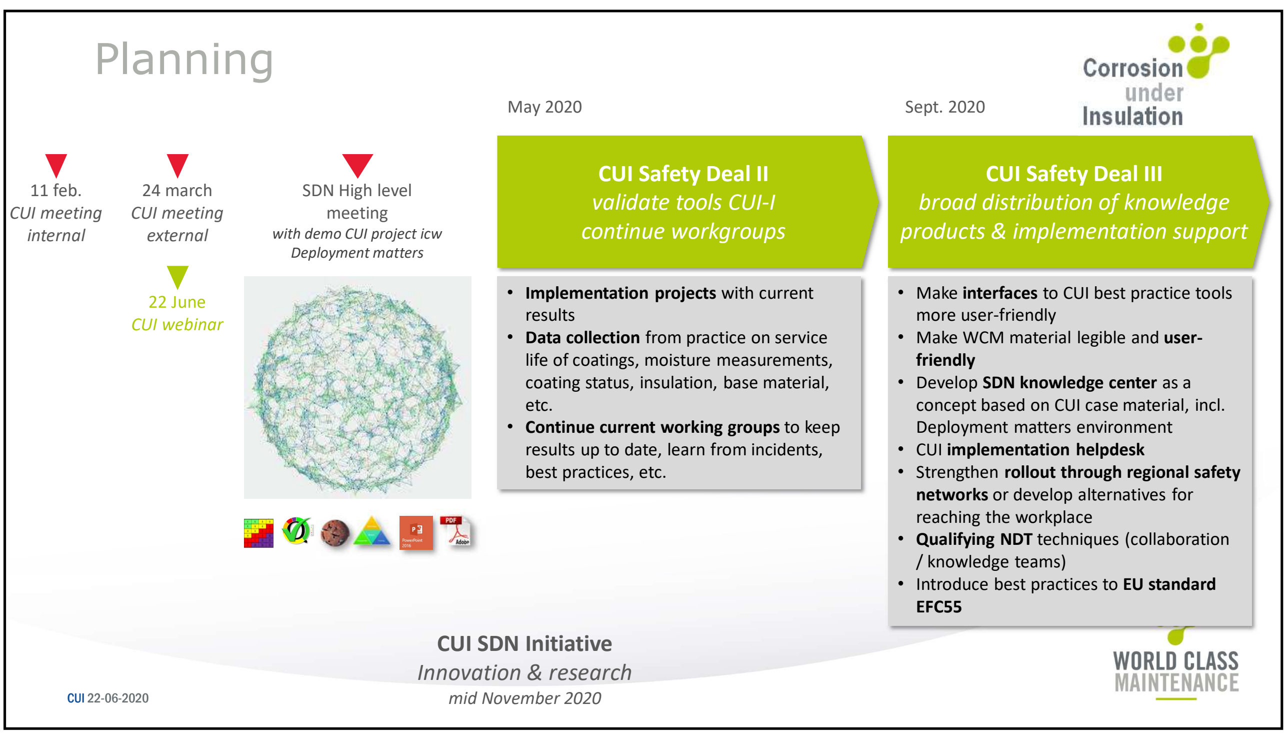
Workgroup Risk Based CUI
Bert Goffings / Jan Nijboer, Sabic (chairman)
Geert Henk Wijnants, Stork (technical secretary)
Danny Schepkens, Borealis
Richard Bosselaar, Yara
Peter Janssen, Sitech
Jacko Aerts, DSM

Corrosion under Insulation

WORLD CLASS MAINTENANCE

CUI 22-06-2020


Ambition is in line with the Safety Delta Netherlands program
Corrosion under Insulation
SAFETY DELTA NETHERLANDS
To be the safest country in terms of process industry by 2030.
3 theme's:
• Early stage leak detection
• The factor "human" (human action)
• Aging Assets, Corrosion under insulation
Knowledge
Innovation
WORLD CLASS MAINTENANCE
CUI 22-06-2020


Planning
Corrosion under Insulation
May 2020
Sept. 2020
11 feb. CUI meeting internal
24 march CUI meeting external
22 June CUI webinar
SDN High level meeting
with demo CUI project icw Deployment matters
CUI Safety Deal II
validate tools CUI-I
continue workgroups
CUI Safety Deal III
broad distribution of knowledge
products & implementation support
• Implementation projects with current results
• Data collection from practice on service life of coatings, moisture measurements, coating status, insulation, base material, etc.
• Continue current working groups to keep results up to date, learn from incidents, best practices, etc.
• Make interfaces to CUI best practice tools more user-friendly
• Make WCM material legible and user-friendly
• Develop SDN knowledge center as a concept based on CUI case material, incl. Deployment matters environment
• CUI implementation helpdesk
• Strengthen rollout through regional safety networks or develop alternatives for reaching the workplace
• Qualifying NDT techniques (collaboration / knowledge teams)
• Introduce best practices to EU standard EFC55
CUI SDN Initiative
Innovation & research
mid November 2020
WORLD CLASS MAINTENANCE
CUI 22-06-2020


More information (incl. Project deliverables) is available on the WCM website
WORLD CLASS MAINTENANCE
MENU
Corrosie onder Isolatie
Nieuws
WCM Visie Missie Strategie 2020-2021
7 mei 2020
Safety Deals
9 maart 2020
Praktische tools voor het beheersen van corrosie onder isolatie
16 januari 2020
Groot aantal aanmeldingen WCM Summer School
25 juni 2019
Uitreiking eerste WCM jaarmagazine aan FME voorzitter Ineke Dezentjé
26 februari 2019
Meer project nieuws
Events
Webinar | Corrosie onder isolatie
22 juni 2020 @ 13:00 - 14:00
Meer project events
Oplossingen voor een omvangrijk faalmechanisme in de procesindustrie
Corrosie onder Isolatie
Procesindustrie bestrijdt gezamenlijk onzichtbare vijand
Corrosie onder Isolatie is een degradatiemechanisme dat optreedt bij geïsoleerde leidingen en apparaten in het temperatuurbereik van ca. 0 tot 150 graden C. Het is een lastig te beheersen fenomeen, omdat de locaties waar het optreedt lastig te detecteren zijn. Ook is de snelheid van degradatie afhankelijk van vele factoren en
100 % FREE
FREE
100 % GRATIS
WORLD CLASS MAINTENANCE
CUI 22-06-2020


WCM Project Corrosion under Insulation
WORLD CLASS MAINTENANCE
Algehele context van het project

Corrosion under insulation

A very specific corrosion problem

- External threat to all isolated assets
- Cause water (vapor) in case of leakage and changing temperatures.
- Temperature range between -10 and +175 degrees
- Poor insulation is a breeding ground for a corrosive environment

- Invisible -> inspect more extensively than necessary
- Inspection (at height) -> high costs and tendency to delay

Threat always present, extensive ➔ so can it be postponed?

WORLD CLASS MAINTENANCE

Corrosion under insulation

Invisible Assassin

- Safety risk for the entire process industry and environment
- Invisible and therefore difficult to locate failure mechanism
- Leads to unplanned downtime of assets
- Control is associated with high maintenance and downtime costs (hundreds of millions of euros annually in the Netherlands)

Assassin who is well worth fighting

WORLD CLASS MAINTENANCE

Common approach for CUI

- Calamity bad for the company, bad for the entire sector
- Industry feels responsibility and struggles with an approach.
- Broad perception that an effective approach to COI is lacking

- Much knowledge available within companies, but approach differs
- Lots of literature available, plenty of options
- Behavior coating, effective method NDT insufficiently available
- Risk based approach (RBI) not yet developed
- Awareness for COI is too meager

Enough reasons for WCM to start a joint CUI project

WORLD CLASS MAINTENANCE

Inter-sectoral CUI Cooperation

By using proven knowledge from the industry

World Class Maintenance, Sitech services, Stork, Rijksdienst voor Ondernemend Nederland, BASF, Shell, VNCI, Cuijpers, bp, Dow, KINT, TEMATI, OCI Nitrogen, sabic, KIC MPi, Venko Groep, DSM, Borealis, ION, Fluor, Shin-Etsu, Yara, goed isoleren, B Jond Innovation, Air Liquide, DEKRA, HIS Consult, IRIS group

WORLD CLASS MAINTENANCE

AIM CUI-project – finalized end 2020.

Develop a **decision model** (best practice)
for **cost-effective control**
of the risk of **corrosion under insulation**

- COI from unpredictable to manageable management system
- Create broad support within the Netherlands and beyond
- Use shared knowledge, while retaining your own choices
- Decision model can be properly integrated within existing standards of Asset owners

Corrosion under Insulation

WORLD CLASS MAINTENANCE

Workgroups CUI-project

Non-destructive testing (NDT)
Quantification of the effectiveness of inspection techniques

Coatings
Insight into the duration of protection of coatings

Risk Based CUI Management
Prioritization method based on CUI risk associated with environment, condition and level of isolation

Corrosion under Insulation

WORLD CLASS MAINTENANCE

Project results

Management decision model / Best Industry Practice for and by the total industry

The main components of- or modules in- the management decision model:

- Standardized method for mapping risks
- The decision model in which risks from corrosion speed, coating life and applied inspection method are integrated.
- Gradation of CUI corrosion rate and risk assessment
- Assessment of the condition of isolation, effect on risk
- Effectiveness of NDT, influence on risk
- Awareness presentation in which the usefulness, necessity and impact of a CUI management program are highlighted.
- The best practice description according to "ISO high level structure" for RBI COI.

WORLD CLASS MAINTENANCE

CUI: Assessment of risk level

Requirements:

- Standardized method
- Agreement with legal framework
- In line with an international perspective

⇨EN 16996 (European approach wrt inspections) (adapted on some small details)

Risk matrix; Table 3; NEN-EN 16991; Voor betekenis van termen, ga in een cel staan.

Probability of Failure / Likelyhood

MOTBF	U_Limit	PoF annual	PoF_U_Limit	Qualitative	Description:		Cat.					
< 1 Year	0 Yr.	$> 10^{-2}$	≤ 1,E+00	Very probable	In a small population*, one or more failures can be expected annually.	Failure has occurred several times a year in location.	5					Very High risk
1-5 Years	1 Yr.	10^{-3} to 10^{-2}	≤ 1,E-02	Probable	In a large population**, one or more failures can be expected annually.	Failure has occurred several times a year in operating company.	4				High risk	
5-25 years	5 Yr.	10^{-4} to 10^{-3}	≤ 1,E-03	Possible	Several failures may occur during the life of the installation for a system comprising or a small number of equipment.	Failure has occurred in company.	3			Medium risk		
25-120 years	25 Yr.	10^{-5} to 10^{-4}	≤ 1,E-04	Unlikely	Several failures may occur during the life of the installation for a system comprising of a large number of equipment	Failure has occurred in industry	2		Low risk			
> 125 years	125 Yr.	$< 10^{-5}$	≤ 1,E-05	Very unlikely	Failure is not expected	Failure has not occurred in industry.	1	Very low (negligible risk)				
								A	B	C	D	E

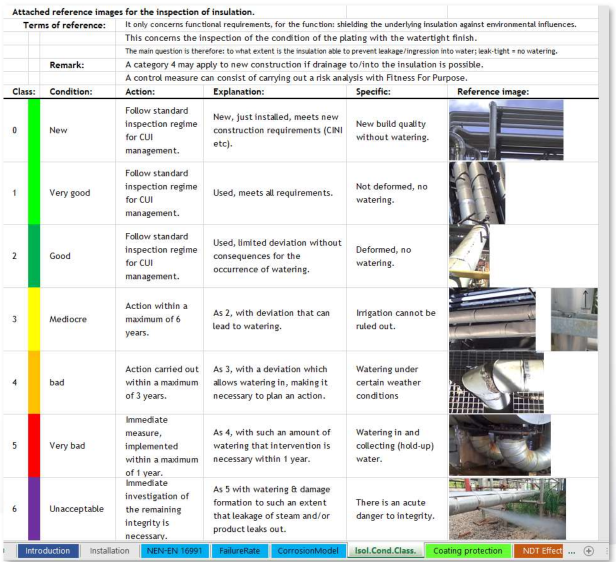
Notes:
* Small population = 20 to 50 items of equipment
** Large population = More than 50 items of equipment

Consequence of Failure / Severity

Health	Safety	Environment	Business (€	Security	Loss of reputation	Public disruption		
Warning issued. No effect.	No aid needed. Work disruption.	Negligible impact.	< 10 k€	None	None	None	A	1
Warning issued. Possible impact.	First aid needed. No work disability.	Impact (e.g. spill) contained.	< 100 k€	On-site (Local)	Minor	Negligible	B	0,7
Temporary health problems, curable	Temporaty work disability.	Minor impact (e.g. spill)	< 1.000 k€	On-site (General)	Bad publicity	Minor	C	0,5
Limited impact on public health, threat of chronic diseases	Permanent work disability.	On-site damage.	< 10.000 k€	Off site	Company issue	Small community	D	0,3
Serious impact on public health, life threatening illness	Fatalities.	Off-site damage. Long term effect.	> 10.000 k€	Society threat	Political issue	Large community	E	0,1

WORLD CLASS MAINTENANCE

CUI: Condition assessment insulation



Attached reference images for the inspection of insulation.

Terms of reference:	It only concerns functional requirements, for the function: shielding the underlying insulation against environmental influences.
	This concerns the inspection of the condition of the plating with the watertight finish.
	The main question is therefore: to what extent is the insulation able to prevent leakage/ingression into water; leak-tight = no watering.
Remark:	A category 4 may apply to new construction if drainage to/into the insulation is possible.
	A control measure can consist of carrying out a risk analysis with Fitness For Purpose.

Class:	Condition:	Action:	Explanation:	Specific:	Reference image:
0	New	Follow standard inspection regime for CUI management.	New, just installed, meets new construction requirements (CINI etc).	New build quality without watering.	
1	Very good	Follow standard inspection regime for CUI management.	Used, meets all requirements.	Not deformed, no watering.	
2	Good	Follow standard inspection regime for CUI management.	Used, limited deviation without consequences for the occurrence of watering.	Deformed, no watering.	
3	Mediocre	Action within a maximum of 6 years.	As 2, with deviation that can lead to watering.	Irrigation cannot be ruled out.	
4	bad	Action carried out within a maximum of 3 years.	As 3, with a deviation which allows watering in, making it necessary to plan an action.	Watering under certain weather conditions	
5	Very bad	Immediate measure, implemented within a maximum of 1 year.	As 4, with such an amount of watering that intervention is necessary within 1 year.	Watering in and collecting (hold-up) water.	
6	Unacceptable	Immediate investigation of the remaining integrity is necessary.	As 5 with watering & damage formation to such an extent that leakage of steam and/or product leaks out.	There is an acute danger to integrity.	

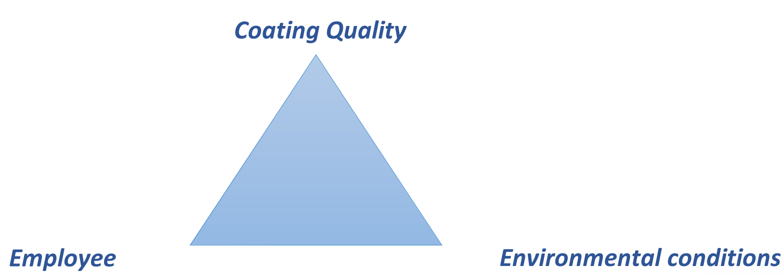
Introduction | Installation | NEN-EN 16991 | FailureRate | CorrosionModel | Isol.Cond.Class. | Coating protection | NDT Effect ...

Assessment of the condition of insulation, effect on risk

- Condition classification of the visual state of the sheeting according to NEN 2767
- Standard characterization was absent
- Correct / False assessment nuanced in 6 classes
- Moistening = Trigger criterion

WORLD CLASS MAINTENANCE

CUI: Integration of influencing factors



WORLD CLASS MAINTENANCE

CUI: Applied coating service-lifetimes

Influencing factors:
Experience
Quality of application
Accessibility *
Level of management **

Beoordelingsaspect:	Keuze:	Opties:					Score:				Opmerking:
Product	Getest; onbewezen	[illegible]	Getest; onbewezen	[illegible]		0,05	0,1	0,5		
Generatie coating	Recent	Oud	Recent			0,9	0,5			Nieuwe generatie heeft langere levensduur.
Ontwerp	> 80% moeilijk	Compleet	> 50% moeilijk	> 80% moeilijk		0,05	0,75	0,9		
Proces&Mens	Plan en expertise onvold	Compleet	Goed plan; Onvoldoende expertise	[illegible]	Plan en expertise onvoldoende	0,1	0,5	0,25	0,9	
Isolatie	Voldoende uitvoering en	[illegible]	Voldoende uitvoering en onvoldoende onderhoud	[illegible]	Uitvoering én onderhoud onvoldoende	0,1	0,5	0,25	0,9	
Levensduur klasse	Middel	Laag	Middel	Hoog	Zeer hoog	0	5	10	15	Referentie beoordeling van coating levensduren
	Score:	60%								
Referentie levensduur:	15 Jaar	6 Jaar								

Optie #:	Product	Effect	Ontwerp	Effect	Proces&mens+uitvoering	Effect	isolatie	Effect
1	Getest (= voldoende tolerant)* en >10 jaar ervaring	0,05	Conserveerbaarheid object conform ISO 12944-3 en getoetst door coatingsdeskundige. Bereikbaarheid, toegankelijkheid is zodanig dat optimaal kan worden geconserveerd	0,05	100% doordacht en haalbaar proces. Getoetst door coatingsdeskundige Goed plan; voldoende expertise	0,1	Complete uitvoering en voldoende onderhoud	0,1
2	Volledig getest en geen langdurige ervaring	0,1	Conserveerbaarheid is op 50% van het object moeilijk Bijv. Liften bij oplegpunten. Plaatselijk niet te raken.	0,75	Goed plan; onvoldoende expertise	0,5	Voldoende uitvoering en onvoldoende onderhoud	0,9 (oude generatie coatings) 0,5 ?(huidige generatie)
3	Onvolledig getest maar geen ervaring Nieuwe systemen	0,5	Conserveerbaarheid is op >80% van het object moeilijk Bijv. Liften bij oplegpunten. Plaatselijk niet te raken.	0,9	Onvoldoende plan; voldoende expertise	0,25	Onvoldoende uitvoering, voldoende onderhoud	0,25
4	~~Deels getest en geen ervaring~~				Onvoldoende plan; onvoldoende expertise	0,9	Onvoldoende uitvoering, onvoldoende onderhoud	0,9

* : through additional extra –x yr. reduction
**: through specific reductionfactor depending of generation of coating.

WORLD CLASS MAINTENANCE

CUI: Applied Corrosion rates

Model berekening:

Skin-temperatuur:	170 °C.	Kolom 6	
Aantal nat-droog cycli:	100	0,3 mm/jr.	
Zout-risico:	C4-C5	+ 0,1 mm/jr.	
Isolatie materiaal:	Pyrogel XT over mir	50%	0,2 mm/jr.

Kleur: Ja

Nat-droog risicomatrix	Wisselingen nat-droog (/jr.) >=	≥-273 °C.	≥-4 °C.	≥10 °C.	≥50 °C.	≥80 °C.	≥120 °C.	≥175 °C.
	≥ 0	0,0 mm/jr.	0,3 mm/jr.	0,1 mm/jr.	0,3 mm/jr.	0,3 mm/jr.	0,1 mm/jr.	0,0 mm/jr.
	≥ 10	0,0 mm/jr.	0,3 mm/jr.	0,3 mm/jr.	0,3 mm/jr.	0,5 mm/jr.	0,3 mm/jr.	0,0 mm/jr.
	≥ 100	0,0 mm/jr.	0,5 mm/jr.	0,3 mm/jr.	0,5 mm/jr.	0,7 mm/jr.	0,3 mm/jr.	0,0 mm/jr.

Merk op gehante

Zout risicomatrix	[Zout]	≥-273 °C.	≥-4 °C.	≥10 °C.	≥50 °C.	≥80 °C.	≥120 °C.	≥175 °C.
C1-2	Low	+ 0,0 mm/jr.	+ 0,1 mm/jr.	+ 0,0 mm/jr.	+ 0,1 mm/jr.	+ 0,1 mm/jr.	+ 0,0 mm/jr.	+ 0,0 mm/jr.
C3	Middle	+ 0,0 mm/jr.	+ 0,1 mm/jr.	+ 0,1 mm/jr.	+ 0,1 mm/jr.	+ 0,2 mm/jr.	+ 0,1 mm/jr.	+ 0,0 mm/jr.
C4-C5-CX	High	+ 0,0 mm/jr.	+ 0,2 mm/jr.	+ 0,1 mm/jr.	+ 0,2 mm/jr.	+ 0,3 mm/jr.	+ 0,1 mm/jr.	+ 0,0 mm/jr.

Referenties:

EFC 55; European Federation of Corrosion Publications Number 55; Corrosion-Under-Insulation (CUI) Guidelines; S. Winnik, Woodhead publishing. ISBN: 978-0-(
Atmospheric corrosion; M. Tullmin, P.R. Roberge; Uhlig's corrosion handbook; Chapter 18; John Wiley & Sons; 2nd edition (2000); Blz. 305- 321.
The influence of insulation material on corrosion under insulation. J. Williams, O. Evans. Nace, Calgary-Canada; Feb. 2010.
API RP 583 - Corrosion Under Insulation and Fireproofing; 1st edition, May 2014.
API RP 581 - Risk Based Inspection Methodology; 3rd edition (2016). Part 2, chapter 16. Corrosion Under Insulation Damage Factor.
NEN-EN-ISO 12944-2 ; Verven en vernissen, Bescherming van staalconstructies tegen corrosie door middel van beschermende verfsystemen

Bron: Calgary-2010(!).pdf

Isolatie materialen:	Stimulatiefactor; effect op corrosiegedrag:	
Calcium silicate	5	De weergegeven factoren zijn "engineering estimates". Deze bevatten correcties voor mogelijke vertekening door aanwezige beperkingen in literatuur referenties.
Expanded perlite	Geen data beschikbaar.	
Pyrogel XT	3	
Cellular glass	3	
WRG mineral wool	4	
Mineral wool	5	
Pyrogel XT over mineral wool	3	
	1= inhibiterend ; 5 = stimulerend.	

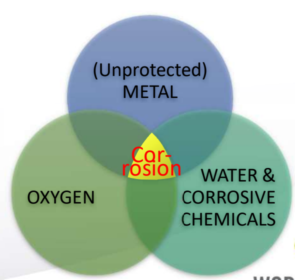
Reductie corr.rate obv stimulatiefactor:

	Opties:	Exp. Corr. Damage.
Deze tabel is ingevuld op basis van een eigen interpretatie van de in de bron gerapporteerde resulaten.	1	10%
	2	25%
	3	50%
	4	75%
	5	100%

Toelichting | Installatie | NEN-EN 16991 | Faalkans | CorrosieModel | Isol.Cond.Class. | Coating bescherming | NDT Effectiviteit | ...

Gradation of COI corrosion rate and risk assessment, depending on parameters:

- Temperature (steel)
- Wet-dry cycles
- Corrosion classes ('salty')
- Type of insulation



WORLD CLASS MAINTENANCE

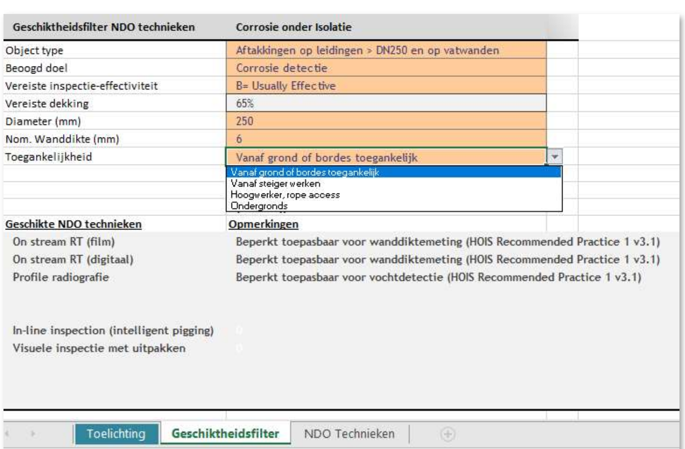
CUI: Effectivity of inspection techniques

Effective and efficient NDT plan:

- Risk determines required effectiveness of the inspection plan
  - API 581 basic (effectiveness class A to E)
  - With follow-up, this leads to risk reduction
- Costs of access to the property are dominant
  - Life cycle calculation for inspection and maintenance regime (reference numbers)
- Many construction, access and damage details only become apparent in the field
  - Pre-inspection in preparation for NDT or Selection of NDT technique in the field
- % Area coverage more important than accurate measurement
  - Potential locations based on design and damaged insulation
  - Then still considerable risk not covered
- Eligibility filter helps with initial selection of technique
  - Work out together with NDO Specialist

WORLD CLASS MAINTENANCE

CUI: Effectivity inspection techniques



Required effectiveness
- Leads to required coverage

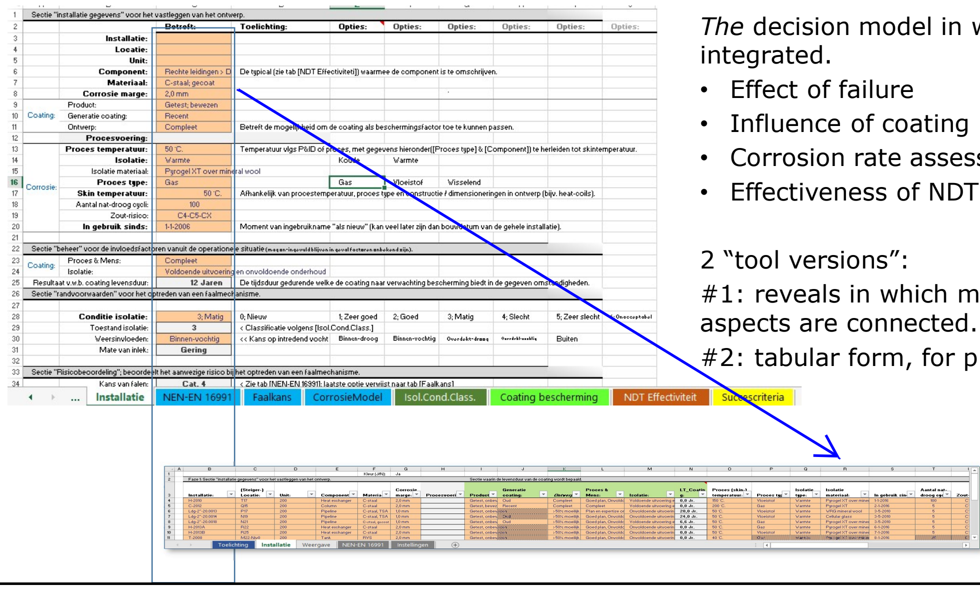
Intended purpose
- Moisture, corrosion, wall thickness

Object type and geometry
- Pipeline, vessel, branches, ...
- Nominal wall thickness

Accessibility

First estimate what should be applied

CUI: Integration of influencing factors



The decision model in which risks are integrated.

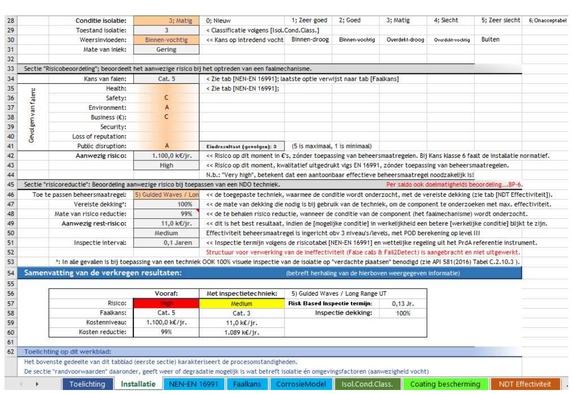
- Effect of failure
- Influence of coating lifespan rating
- Corrosion rate assessment
- Effectiveness of NDT

2 "tool versions":

#1: reveals in which manner the various aspects are connected.

#2: tabular form, for planning purposes.

CUI: Integration of influencing factors



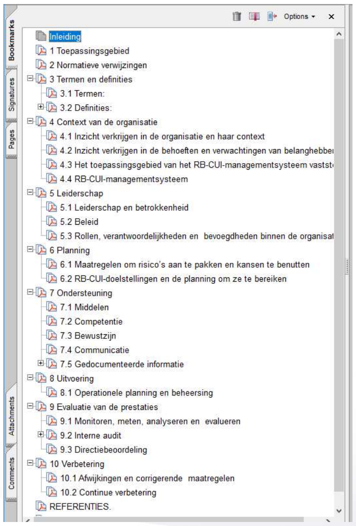
Cost effective and proactive? #How?.

- Risk of doing nothing
- Consideration in advance by LCC with respects to Inspection or Upgrade
- Traceable effectiveness through an open approach
- Based on effectiveness of "chain links"

2 "types of result":

- "As-is" risk in the current situation
- "To-be" risk and costs in case of effective control

CUI: Best practice CUI management

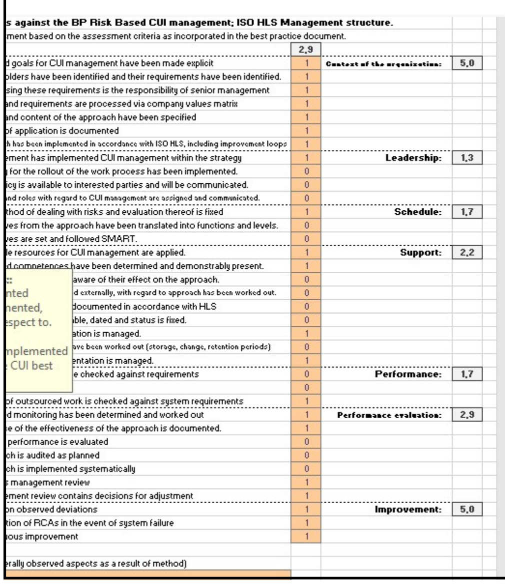


The best practice description for RB CUI.

- Based on ISO HLS (High Level Structure)
- Integration in Asset Management structure of ISO 55001

WORLD CLASS MAINTENANCE

CUI: Gap analysis tool.



s against the BP Risk Based CUI management; ISO HLS Management structure.			
ment based on the assessment criteria as incorporated in the best practice document.			
	2,9		
d goals for CUI management have been made explicit	1	Context of the organization:	5,0
olders have been identified and their requirements have been identified.	1		
sing these requirements is the responsibility of senior management	1		
and requirements are processed via company values matrix	1		
and content of the approach have been specified	1		
of application is documented	1		
h has been implemented in accordance with ISO HLS, including improvement loops	1		
ement has implemented CUI management within the strategy	1	Leadership:	1,3
for the rollout of the work process has been implemented.	0		
icy is available to interested parties and will be communicated.	0		
nd roles with regard to CUI management are assigned and communicated.	0		
thod of dealing with risks and evaluation thereof is fixed	1	Schedule:	1,7
ves from the approach have been translated into functions and levels.	0		
ves are set and followed SMART.	0		
le resources for CUI management are applied.	1	Support:	2,2
d competences have been determined and demonstrably present.	1		
aware of their effect on the approach.	0		
d externally, with regard to approach has been worked out.	0		
documented in accordance with HLS	0		
ble, dated and status is fixed.	0		
ation is managed.	1		
ave been worked out (storage, change, retention periods)	0		
entation is managed.	1		
e checked against requirements	0	Performance:	1,7
	0		
of outsourced work is checked against system requirements	1		
d monitoring has been determined and worked out	1	Performance evaluation:	2,9
e of the effectiveness of the approach is documented.	1		
performance is evaluated	0		
ch is audited as planned	0		
ch is implemented systematically	0		
s management review	1		
ement review contains decisions for adjustment	1		
on observed deviations	1	Improvement:	5,0
tion of RCAs in the event of system failure	1		
uous improvement	1		
erally observed aspects as a result of method)			

nted
nented,
espect to.
nplemented
CUI best

Comparison of approach with the best practice description for RB CUI.
Two lines of sight of comparison:

- Implementation of critical elements as required in order to identify the risk.
- Compliance with ISO HLS requirements (High Level Structure)

WORLD CLASS MAINTENANCE

Now: Start with innovative CUI-projects

Workshops CUI
- Relay workshops

Kick-start CUI-projects
- First launch / approach
- Development of Best Practise for Insulation inspection
    - Classification as per CUI BP with wrapping up as per system.

Review CUI-approach
- GAP Analysis of the applied method

Launch of web-site
- GAP Analysis of applied method and benchmarking with others / sector

WORLD CLASS MAINTENANCE

Current status of users (complete or partly).

Partly
- All 15 companies (Asset Owners / Service suppliers) from the project (have used their own, already applied approaches)

Air Liquide
BASF
Borealis
Cuijpers
DEKRA
DOW
DSM
Fluor
HIS Consult
Iris
Sabic
Shin Etsu
Sitech
STORK
Venko

Complete
- Shell Catalysts (BE)

Other downloads (end Aug. '20)
- Akzo Nobel Eng
- BosQman
- Corio
- CorrosionRadar
- Endures
- Engie
- Forbo
- Fuji
- Indorama
- Lloyds
- Mainnovation
- Maxgrip
- Merck
- Nederlandse Gasunie
- Neste
- Nouryon
- Rockwool
- Solvay
- Sirris
- Synerlogic
- Synres
- Tata
- Taqa
- TNO
- Umicore
- Vandemoortele
- VIB
- Yara

Review CUI-approach by means of short GAP Analysis (4 days processing time)
- Nog yet applied

WORLD CLASS MAINTENANCE

Now: Objective with respect to dissemination

EFC 55 & RB CUI Best Practise (BP)
- Provide available info for use & feedback
- Supply tooling as add-on to manuals / guidelines
- By BP, focus on application rather than information
- Adaptability to one's own approach by modular setup
- Capability to benchmark w.r.t. BP

Question in this phase
- How do you appraise what you've seen?
- What do you miss?
- Are you willing to support dissemination in a joint effort?
- Which aspect(s) should be implemented on short notice (focus)

Review CUI-approach
- GAP Analysis of the applied methods for optimized fit-for-purpose approach

WORLD CLASS MAINTENANCE

WORLD CLASS MAINTENANCE

Thanks for you attention

More information: www.worldclassmaintenance.com