Appendix 1

List of participants

NAME	SURNAME	COMPANY	COUNTRY
Al Dossary	Yousef Ahmed	Saudi Aramco	SAUDI ARABIA
Augustin	Christel	Total Refining & Chemicals	FRANCE
Baak	Michael	Borealis Polyolefine GmbH	AUSTRIA
Bagliani	Emanuele Paravicini	Dalmine S.p.A	ITALY
Bond	Stuart	Nace Europe	UK
Bour Beucler	Valerie	Nalco Champion	FRANCE
Bourguignon	Francis	MANNESMANN PRECISION TUBES	FRANCE
Centenaro	Francesco	IMG ULTRASUONI SRL	ITALY
Claesen	Chris J	Nalco Champion	BELGIUM
Corradini	Raffaele	Techint Engineering Construction	ITALY
Daly	Simon	Hempel UK Ltd	UK
de Bruyn	Hennie	Saudi Aramco	SAUDI ARABIA
De Landtsheer	Gino	Borealis	BELGIUM
de Marco	Marco	Istituto Italiano della Saldatura	ITALY
De Schepper	Xavier	EDDYFI TECHNOLOGIES	FRANCE
Dicembre	Massimo	Eni s.p.a	ITALY
Dupoiron	François	Total Refining & Chemicals	FRANCE
Faraone	Nicola	Voestalpine Böhler Welding GmbH	ITALY
Farina	Carlo	CEFIT Corrosion Consultant	ITALY
Geraskin	Vitaly	Integrated Global Services	CZECH REPUBLIC
Gregoire	Vincent	Equinor	NORWAY
Grisoni	Eruccio	EDDYFI TECHNOLOGIES	FRANCE
Groysman	Alec	Israeli Corrosion Forum	ISRAEL
Hairer	Florian	Linde, Engineering Division	GERMANY
Hermse	Chretien	Shell Global Solutions International	NETHERLANDS
Höwing	Jonas	Sandvik	SWESEN
Jackson	Richard	3M Deutschland GmbH	GERMANY
Kawakami	Tadashi	Nippon Steel Europe GmbH	GERMANY
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Krabac	Lubomir	Borealis Polyolefine GmbH	AUSTRIA
Kus	Slawomir	Honeywell	UK
Leone	Antonino	Eni	ITALY
Links	Jan	Dow Benelux B.V.	NETHERLANDS
Lobaton Fuentes	Militza	Borealis Chimie SAS	FRANCE
Monnot	Martin	Industeel	FRANCE
Onodera	Yoichi	Mitsui & Co Ltd	JAPAN
Pestic	Ivica	Shell	NETHERLANDS
Poldi	Matteo	Eni	ITALY
Ropital	François	IFP Energies nouvelles	FRANCE
Scanlan	Rob	BP	UK
Schempp	Philipp	Shell Deutschland Oil GmbH	GERMANY
Schwemmer	Marcel	3M Deutschland GmbH	GERMANY
Thakur	Amita rani	National Aerospace Laboratories	INDIA
Van Dooren	Piet	Borealis	BELGIUM
Van Rodijnen	Fred	Oerlikon metco	GERMANY
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vosecký	Martin	Nalco Champion	CZECH REPUBLIC
Warnier	William	Sitech	NETHERLANDS
Wassink	Casper	Eddyfi Technologies	NETHERLANDS
Wold	Kjell	Emerson	NORWAY
Zakeri	Hadi	PetroIneos	UK
Zhang	Jian-Zhong	SABIC	UK
Zlatnik	Ivan	MITSUI & Co Deutschland	CZECH REPUBLIC

Appendix 2

EFC WP15 Activities

(Francois Ropital)

Welcome to the EFC Working Party Meeting

"Corrosion in Refinery and Petrochemistry" WP15

23 March 2021

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

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

Chairman: Francois Ropital Deputy Chairman: Johan Van Roij

Information Exchange – Forum for Technology
Sharing of refinery materials /corrosion experiences by operating company representatives (ie corrosion atlas).
Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences : organization of refinery session and joint session with other WPs (2021 Virtual, 2022 Berlin-Germany, 2023 Brussels-Belgium)

WP Meetings
One WP 15 working party meeting in Spring,
One meeting at Eurocorr in September in conjunction with the conference,

Publications - Guidelines

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

EFC Working Party 15 « Corrosion in Refinery and Petrochemistry »

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)

Publications from WP15 – Forum Platform

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

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

Proposal of a web global forum platform on the EFC website to exchange on CUI questions in relation with Nace CINI

Publications from WP15

•EFC Guideline n° 46 on corrosion in amine units Editor: Johan van Roij
The final document will be sent soon oublished

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

In progress by a task force : first version in May 2021

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/

WP15 – EFC Forum Platform on Corrosion Under Insulation (CUI)

- An important work has been performed for the third revision EFC Guideline n° 55 Corrosion Under Insulation - Editor: Gino de Landtsheer

- We would like to continue to exchange on this topic via
  - a Forum Platform on the EFC website in collaboration with Nace Europe, World Trust Maintenance, CINI
  - A group of moderators witch one dedicated to a subtopic
    - Best practices, practices to avoid
    - Experiences to be shared
    - Organization to mitigate CUI

7

Appendix 3

Development of a coating degradation sensor and its implication for CUI monitoring in the laboratory and on hydrocarbon facilities

(Simon Daly)

You probably remove, replace and dispose of a lot of insulation over the life of your assets?

Simon Daly
Hempel A/S

You might be surprised to know there is a better way! #makepainttalk

VALUE

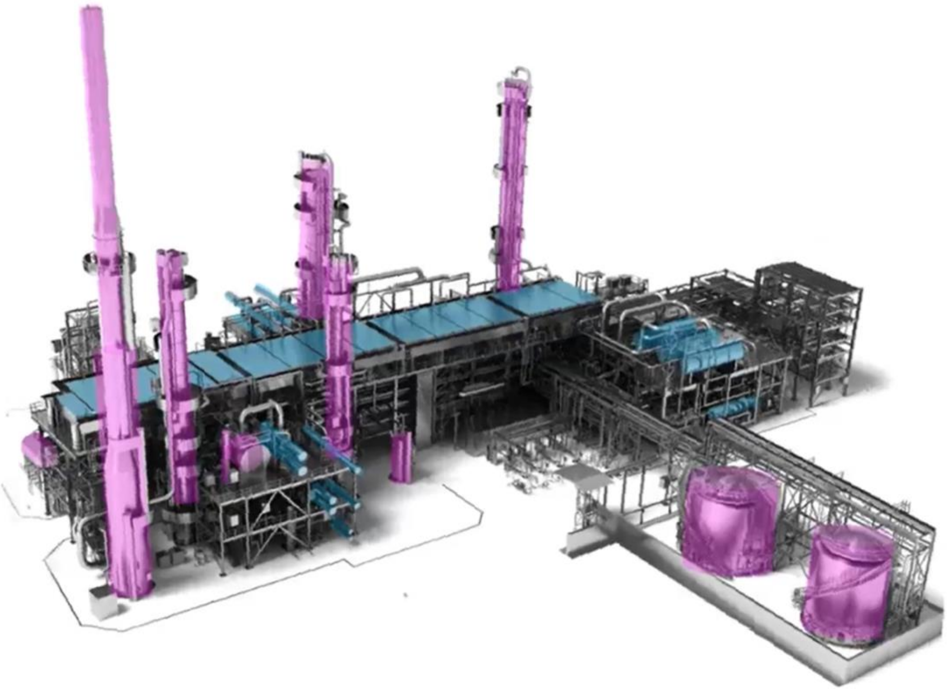
PROPOSITION

- Reactive to proactive
- Detection occurs well in advance of corrosion
- Reallocate detection budget to prevention
- Optimise maintenance / inspection plans for best cost efficiency
- Removes the probability element
- Consistency of reporting
- Data driven knowledge

The CUI problem is large and RBI approach has some challenges

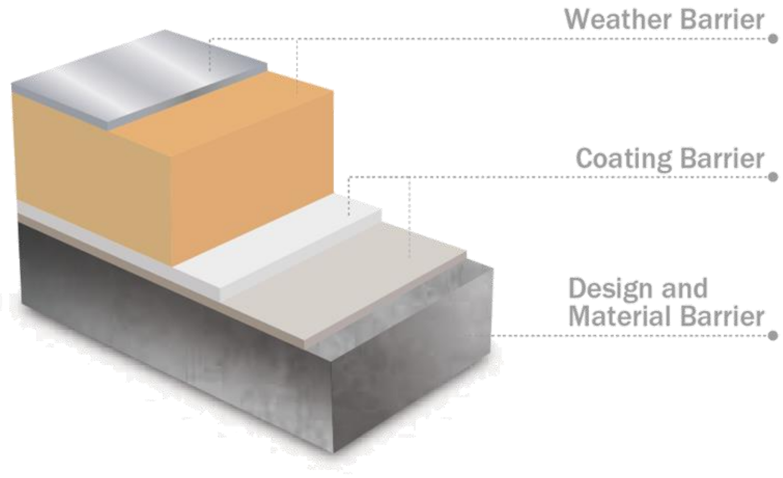
A typical 100k boepd European refinery invests*

- 83% on 9% of exposed surfaces that produce 10% of problems
- 16% on components leading to **78%** of leaks
- 1% on reliability bad actors



*Inspection costs.

Even the best CUI guidance has probability at its heart



4x

Barriers are used to calculate the probability of failure due to CUI

...but only two are fact based

Even the best CUI guidance has probability at its heart

Coating and weather barrier (probability) assessments based upon:

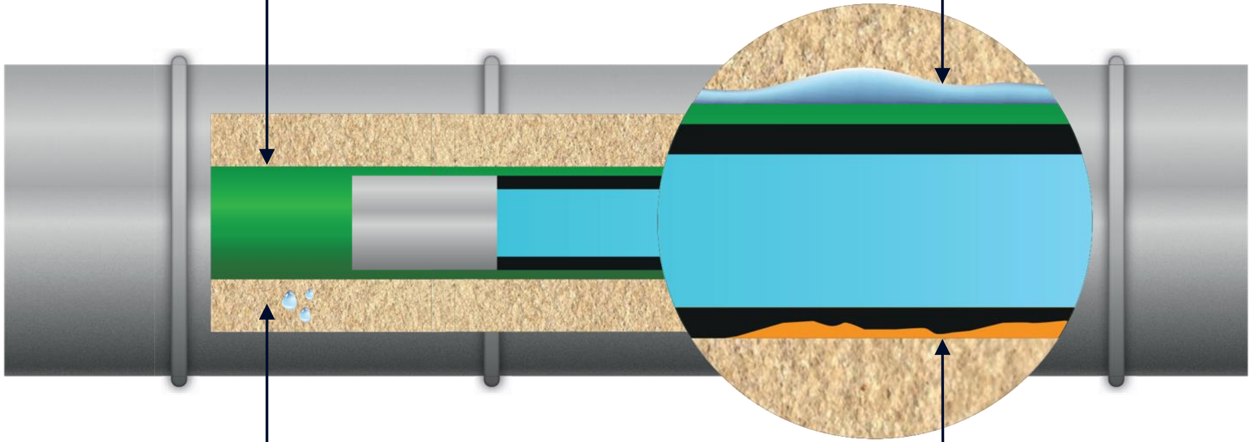
- Previous experience
- Accelerated testing
- Performance of similar materials

- Generic assumptions
- Very limited data
- Not updated
- Supplier bias

Sensors can assist us with condition monitoring

1. Insulation removal + close visual inspection (CVI)
Most commonly used
- Partial (< 5 years) Complete (older and high risk)

3. Time of wetness
(ToW) sensors monitoring the key corrosion driver

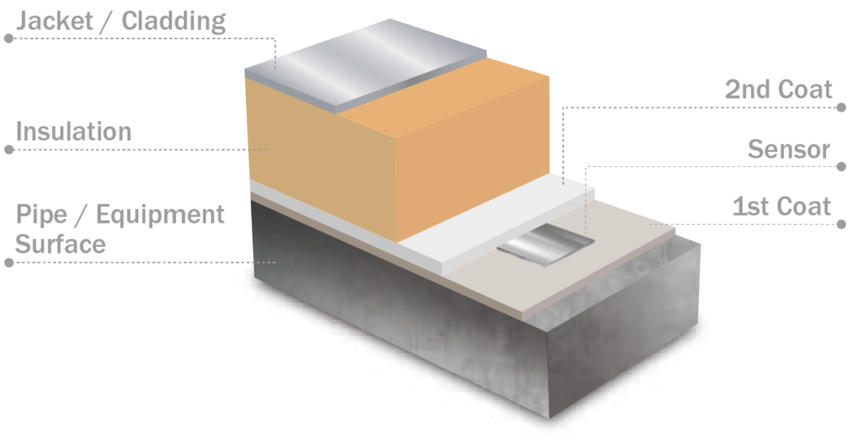


Data gap around **coating performance** may result in:
1. Continued insulation removal
2. Unnecessary moisture NDE
3. Premature deployment of corrosion sensing methods / NDE

2. Moisture
Sensors detecting the binary presence of liquid water
- NDE for moisture presence is included here

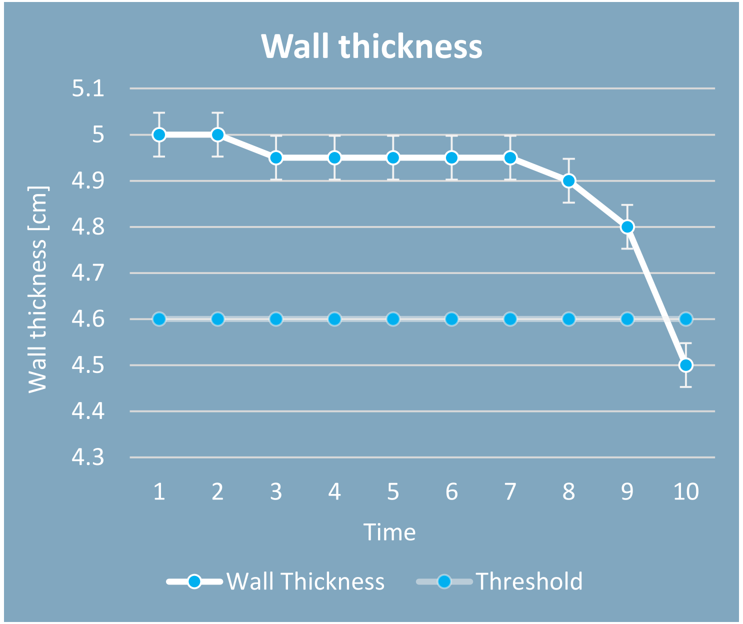
4. Corrosion sensing methods
Measure the actual outcome
- NDE for corrosion is included here

Why not use what's already there?



- (+) No penetration power required
- (+) Applied to many configurations
- (+) Monitor don't inspect
- (+) Water is what we are looking for
- (+) Identify key barrier degradation well in advance of corrosion
- (–) Interpretation expertise
- (–) Range

Coating sensor operates in advance of conventional wall thickness sensor



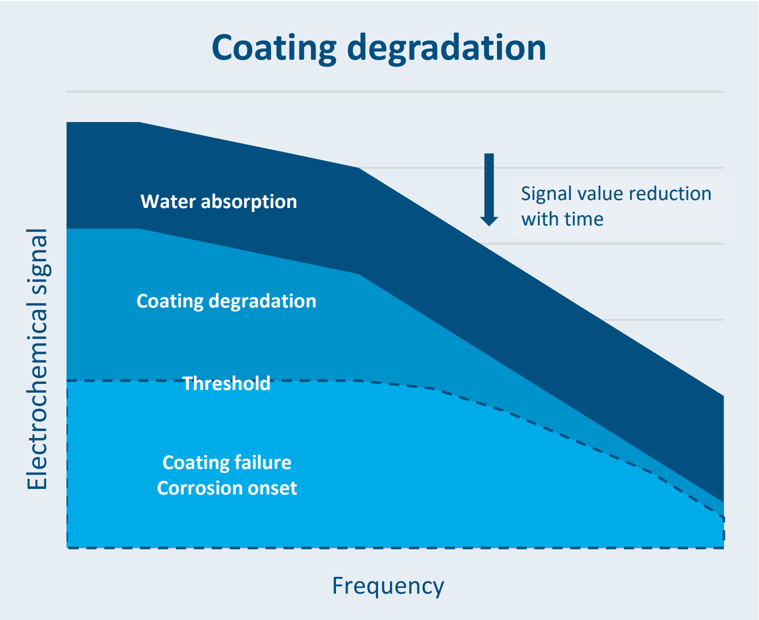
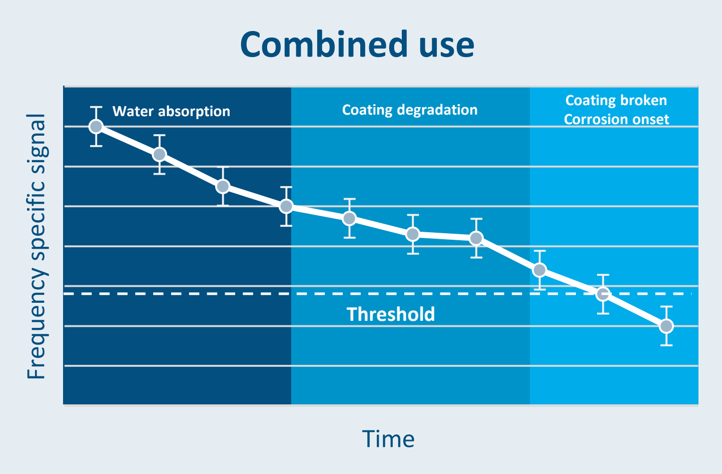
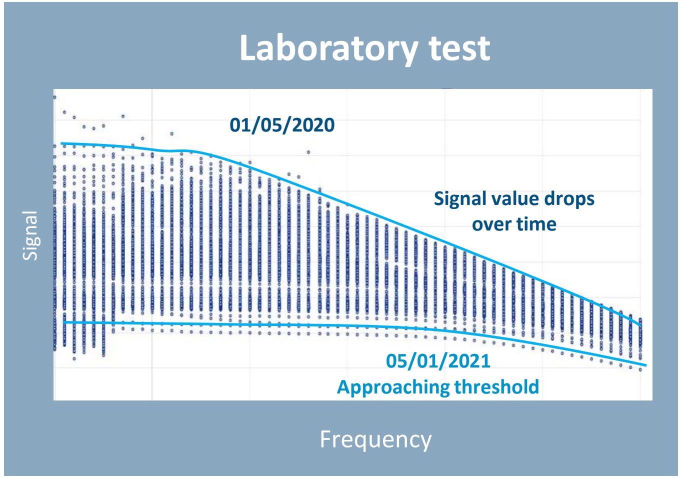


Illustration only. Not actual data.

Frequency specific analysis shows changes over time

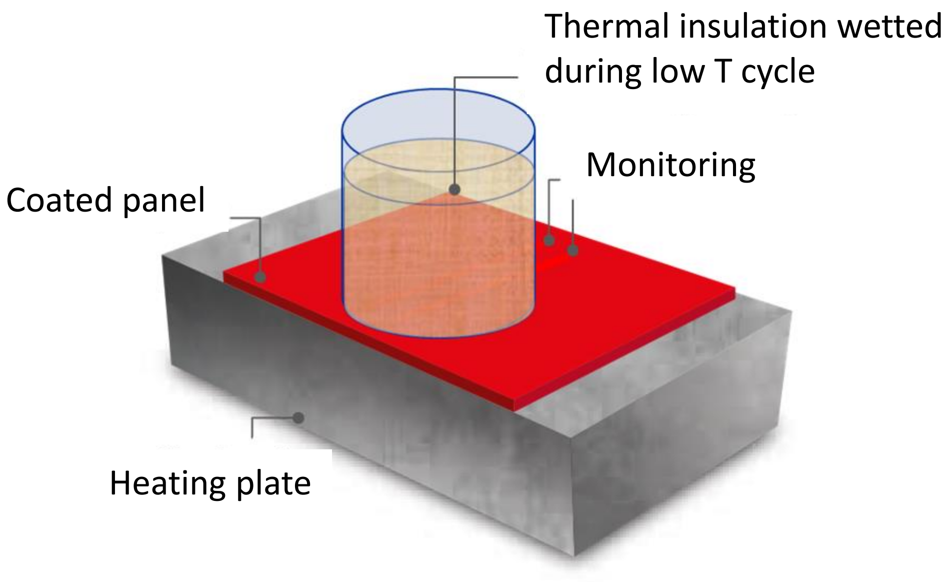


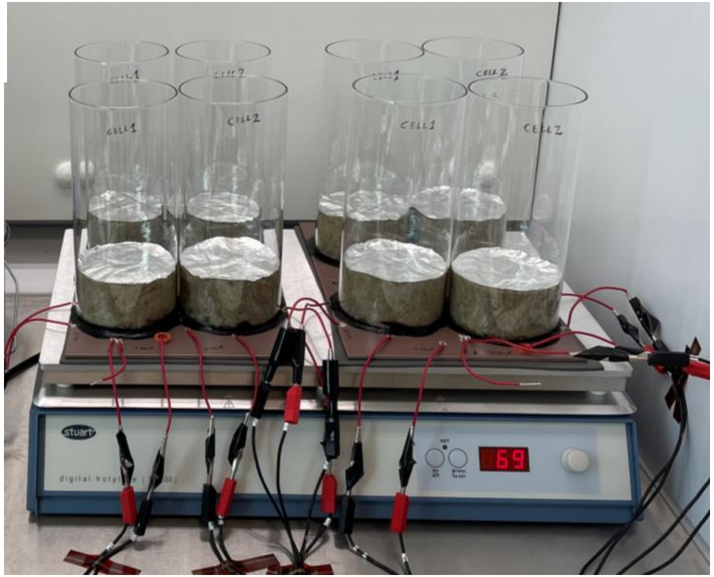


- Uses well established electrochemical impedance spectroscopy
  - Sensor rather than probe
- Electrochemical measurements can detect moisture, coating degradation and corrosion
- Move from probability based assumptions
- Gather data on remaining barrier performance

Illustration only. Not actual data.

Small scale CUI test development
- Flat panel test

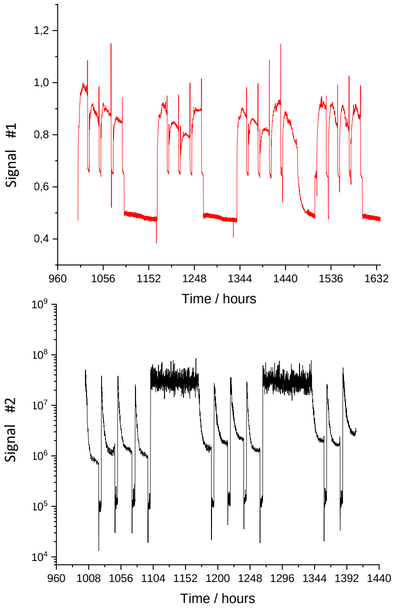


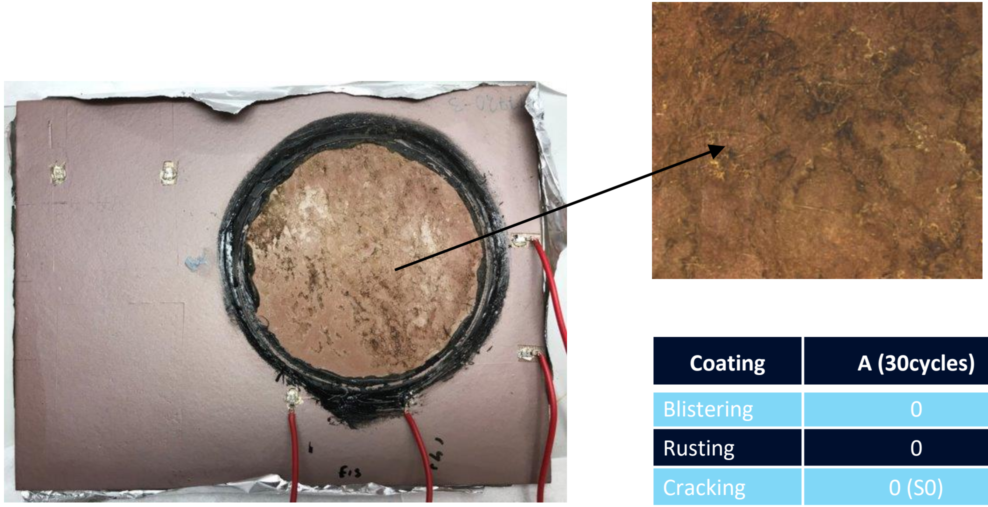


Small scale CUI test development

Response with no failure A

A Response with no failure



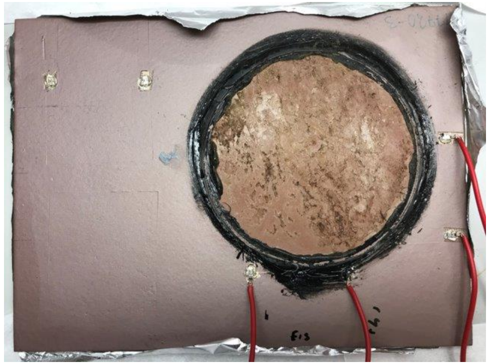


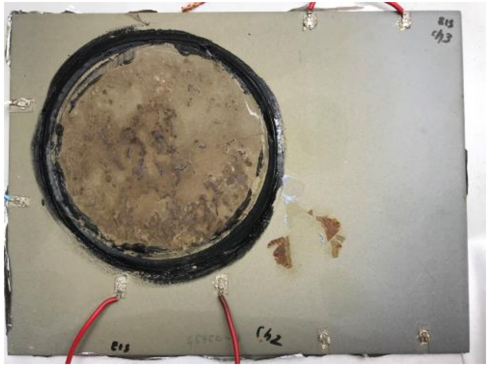
Coating	A (30cycles)
Blistering	0
Rusting	0
Cracking	0 (S0)
Flaking	0 (S0)
Chalking	0

Small scale CUI test development

Response with no failure

Able to distinguish between different degrees of failure by signal interpretation



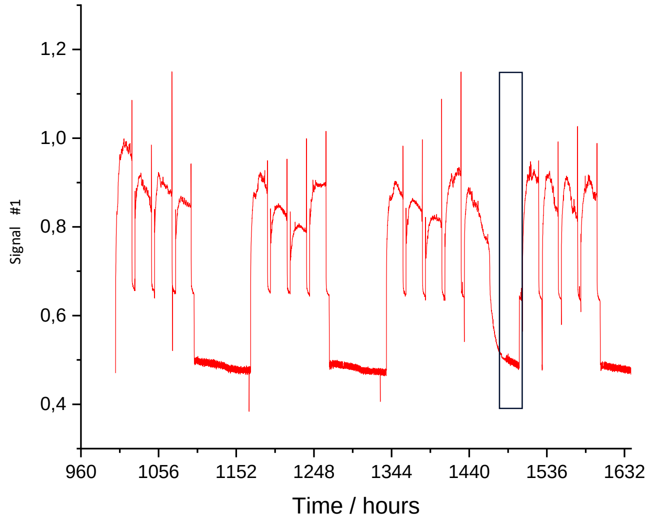


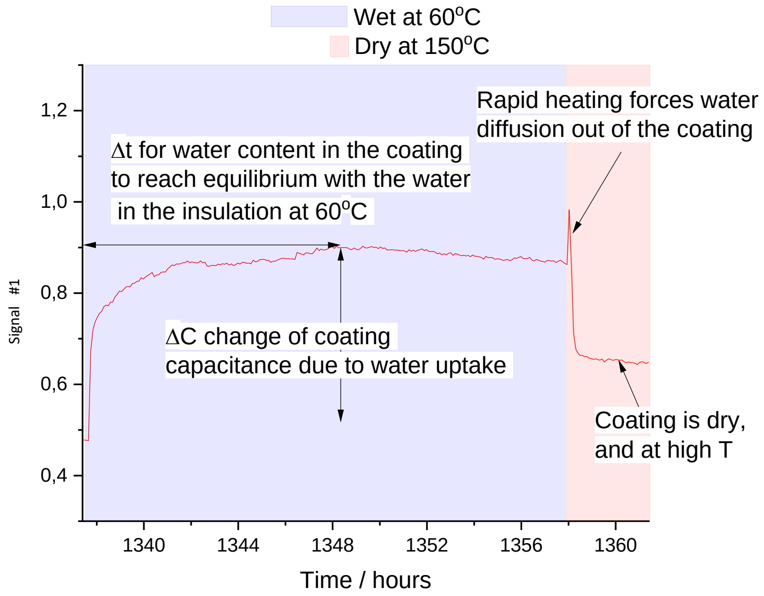
- Signal interpretation is complex
- Needs to be achieved to same or better level as CVI
- Requires extensive calibration with ani-corrosive testing
- Additional physical examination for knowledge building

Small scale CUI test development

Response with no failure

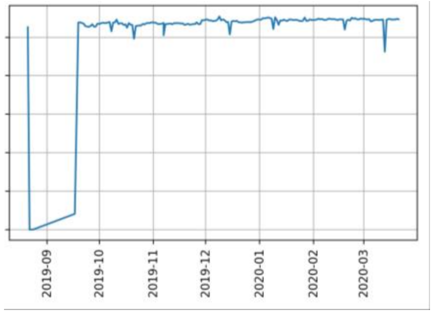
Tracking moisture



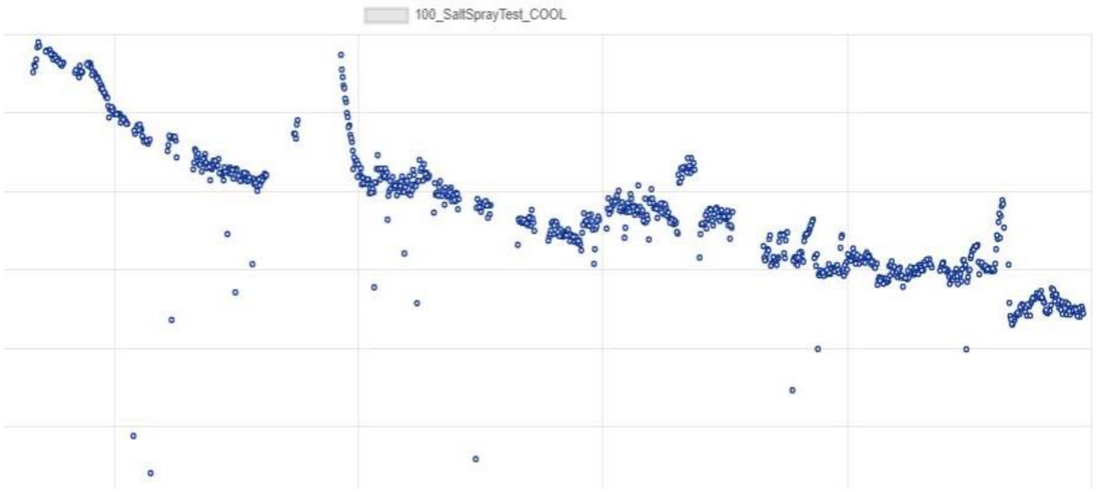


European refinery trial

- Equipment: Tank & Hot crude pipe
- Duration: 6 months to last evaluation
- # of sensor: 16 (multiple types)
- Electronics : 1st generation
- Conclusions
    - Similar signals from others sensors
        - Signal is robust
    - No change in signal
        - Coating performance is still good

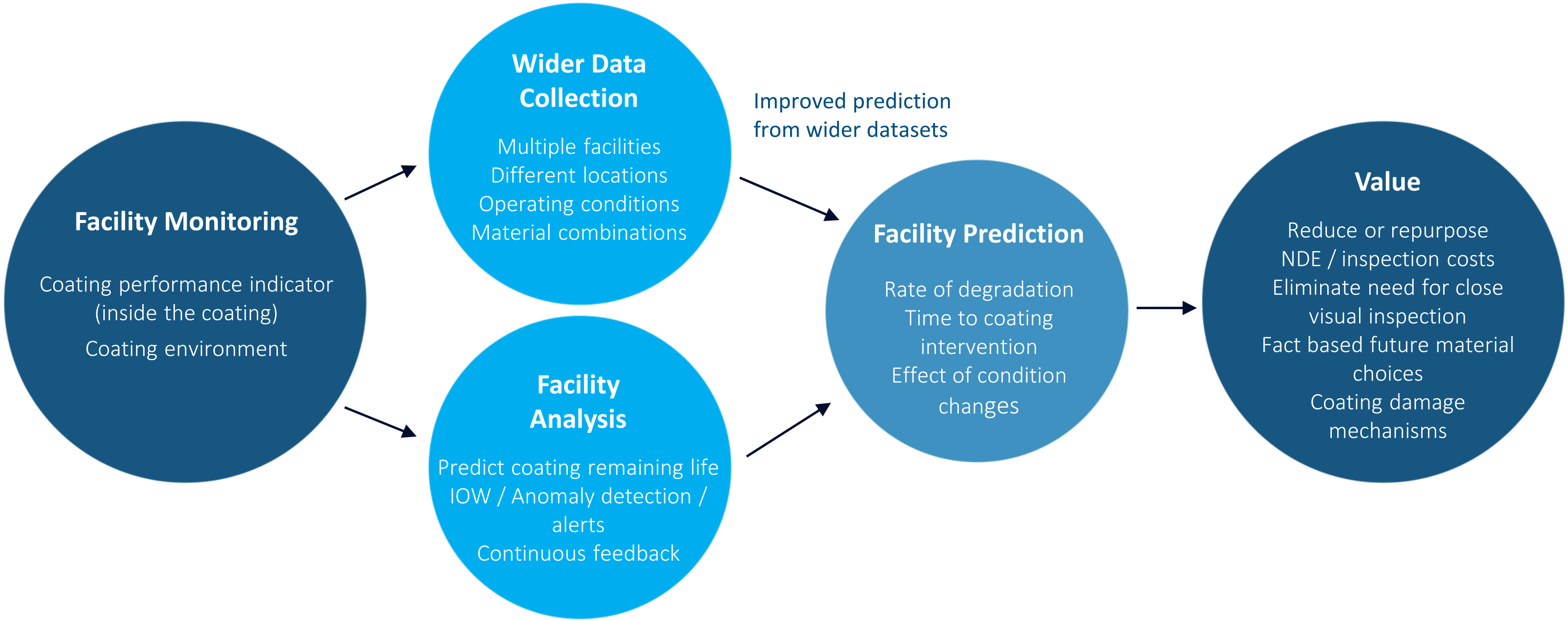


Hempel is currently seeking trial partners for its latest Hempasense SMART units



- 3rd generation units ready to ship for trial
- ATEX approved
- Advanced electronics offers even more data gathering options

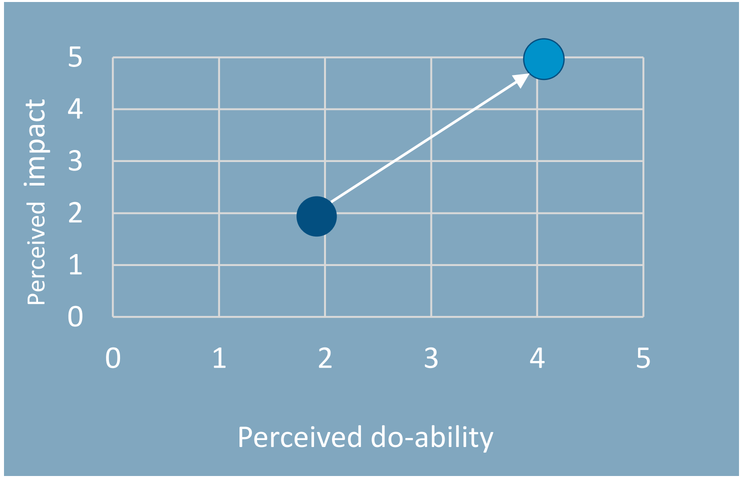
Data analysis and feedback

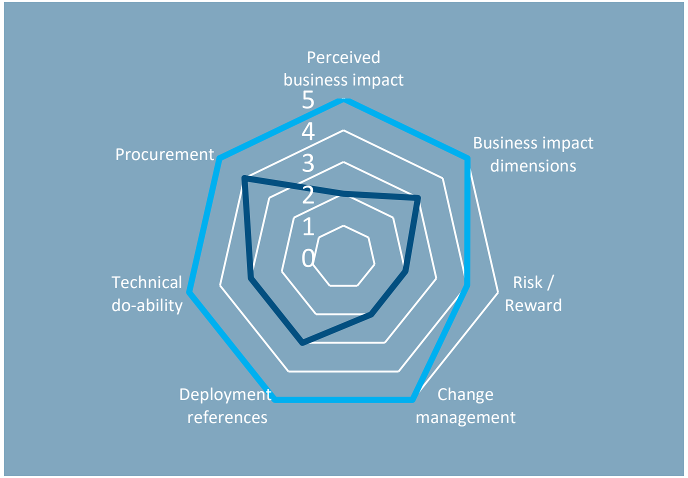


Is this possible? (this is the small print)

TECHNOLOGY
READINESS

- Technology readiness
- Integration maturity





Evaluation based upon [Guidance notes for technology qualification](). Lloyds Register, May 2017. Technology deployment analysis by Deployment Matters, NL.

KEY

CONCLUSIONS

- Electrochemical measurements are a proven way to measure coating performance
- Technique can be modified for use with CUI
- Strong signal acquisition can be achieved using latest electronics
- Data suggests a strong correlation with coating performance
- Signal interpretation is complex
- Requires extensive “calibration” with anti-corrosive testing
- 3G units now available for trial partners

For further information contact sida@hempel.com

Appendix 4

Equinor's CUI management optimization by moisture monitoring under insulation

(Vincent Gregoire)

equinor

CUI Management optimization by moisture monitoring under insulation

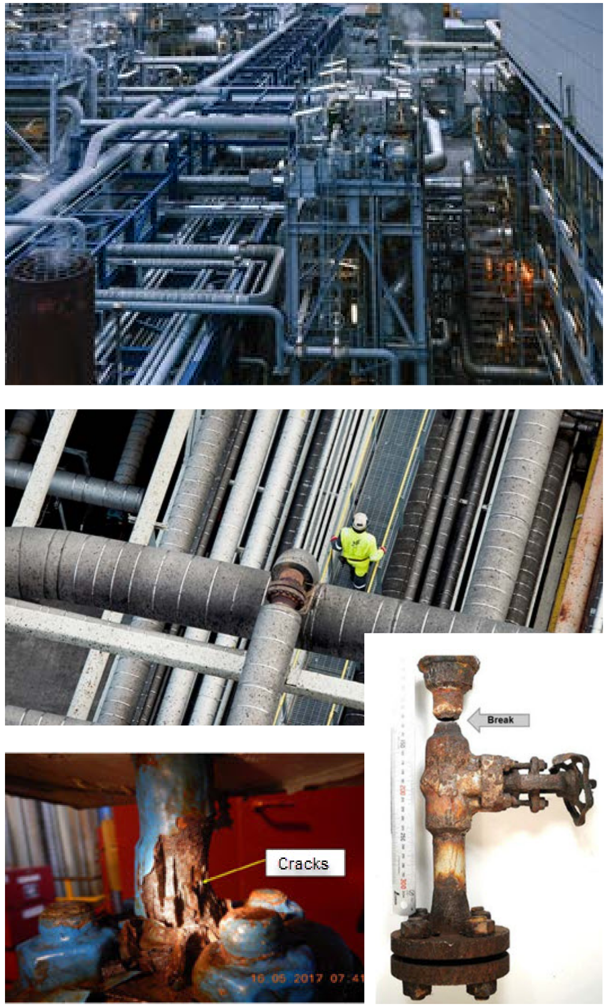
Vincent Gregoire
Thomas Levy
Andres Rivero

Content

- Introduction to the CUI challenge
- CUI mechanism in brief
- Equinor's CUI management
- Strategy to improve actual CUI management
- Water monitoring for CUI management
- Summary

Introduction to the CUI challenge

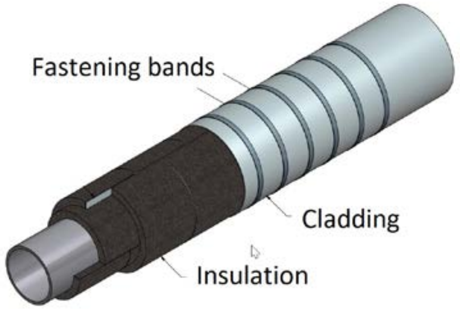
THE CHALLENGE



- One of the biggest threat to the Mechanical Integrity of the O&G facilities around the world
- Equinor's facilities in Norway have more than 5000 Km of insulated piping
- Location of the damage is scattered
- Extensive inspection / maintenance programs are developed based on the assumption that insulation material is always wet
- Surface maintenance cost in the order of 100 M$/year
- Despite these efforts leakages still occur

CUI mechanism in brief

THE MECHANISM



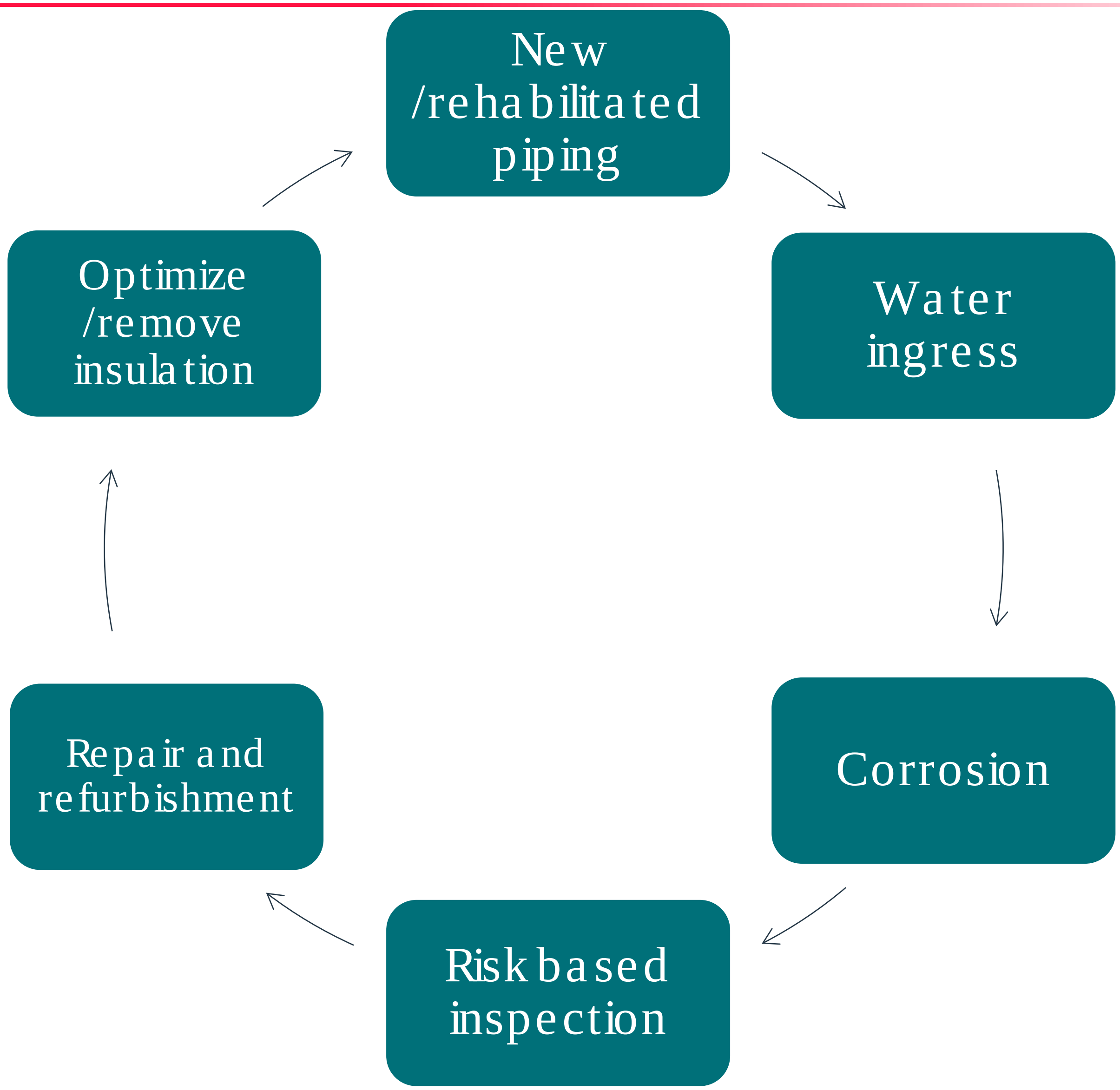
Insulation system

- Piping or other equipment
- Coating
- Insulation layer(s)
- Cladding / weather protection

CUI mechanism can be summarised in three steps:

- Water penetration
- Damages in coating
- Corrosion starts

Equinor's CUI management



Strategy to improve actual CUI management

THE TESTING RIGS

Coating/Insulation

NDE

Monitoring

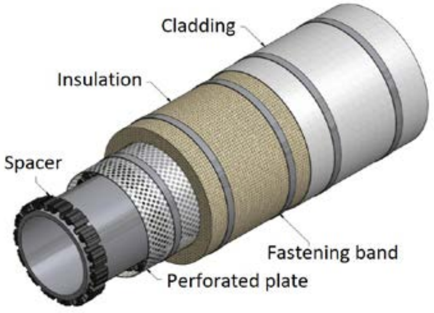
Three focus areas on R&D to improve CUI management:

- Testing of coating and insulation systems
  - How insulation systems affect CUI
  - How coating under insulations affect CUI
  - Qualify new insulation and coating systems

- CUI detection
  - CUI detection rig
  - State of the art on NDE
    - Results so far not satisfying enough to replace CVI

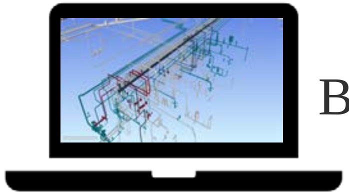
- Water Monitoring
  - CUI sensor rig
  - Long exposure in field

Strategy to improve actual CUI management

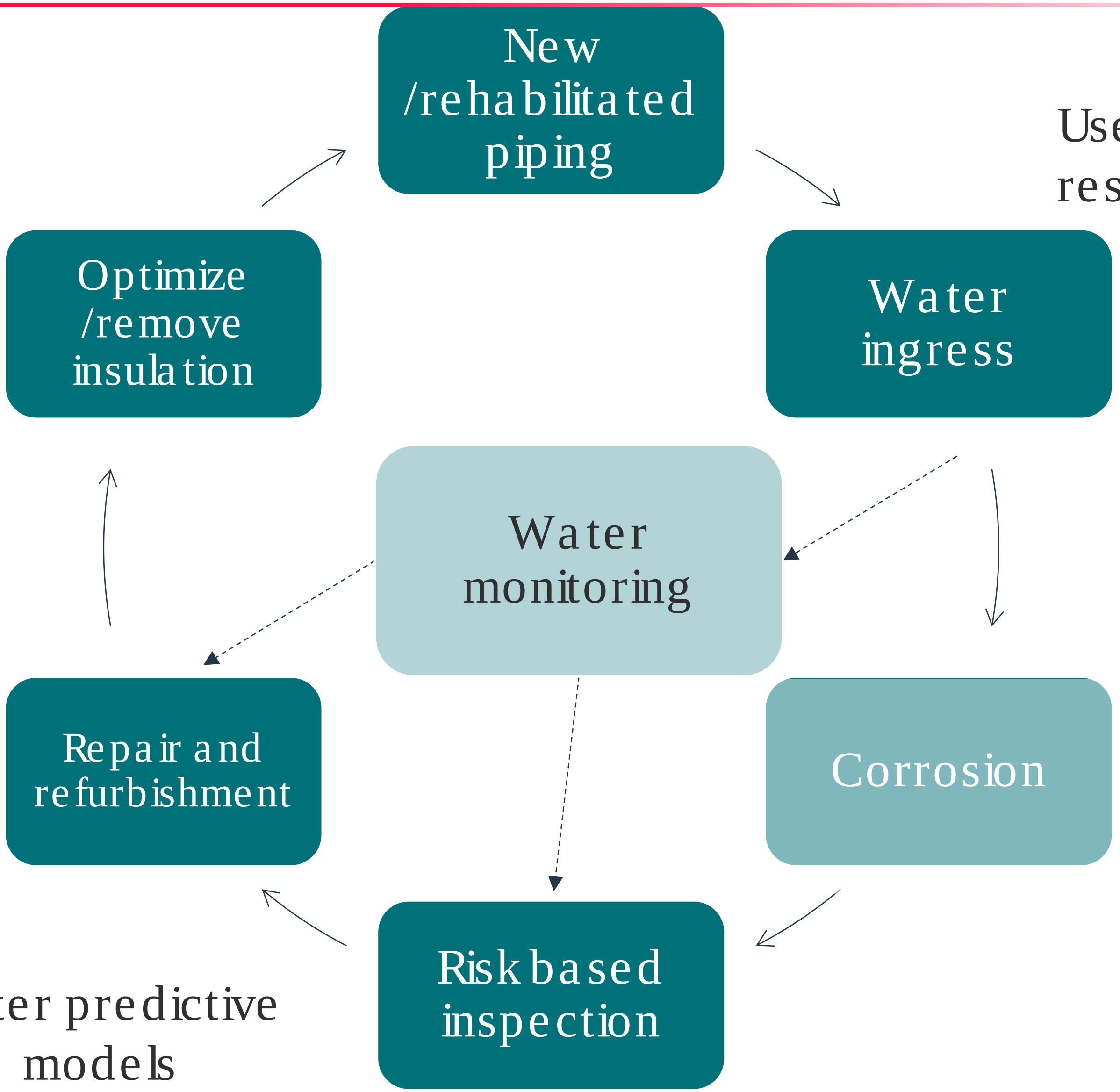


Better insulation

Better coating



Better predictive models



Use corrosion resistant alloys

Water Monitoring Management

THE TECHNOLOGY

- Equinor is moving from inspection to water monitoring, thanks to the monitoring technologies development.
- Preliminary tests showed that water under insulation can be detected and located by measuring relative humidity
- On-going work:
  - Qualify use of sensors:
    - Measure relative humidity
    - Wireless data transfer
    - Good battery lifetime
    - Easy installation
    - Minimum replacement
    - Low cost
  - Digital solution for management of data

Summary

THE OUTCOME

- Equinor has been running a R&D program for the last 6 years to improve CUI management
- Better coating and insulation systems have been implemented in technical requirements
- Good preliminary results for detecting water
- Optimized inspection programs
- Further development of water monitoring ongoing

CUI Management optimization by moisture monitoring under insulation

Vincent Gregoire
Thomas Levy
Andres Rivero

Appendix 5

On-line TSA option to prevent CUI on a running plant

(Vitaly Geraskin)

SAFE TSA Application in LIVE Plants

Mitigate CUI on Mission Critical Equipment

Vitaly Geraskin

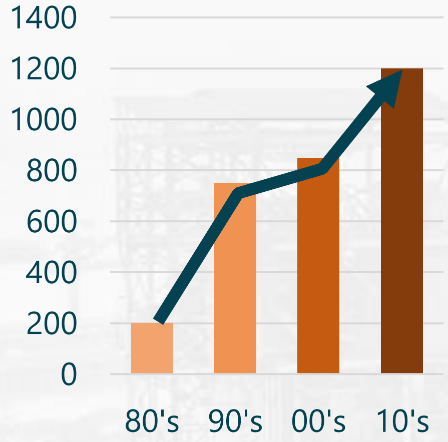
+420 735 750 500

vg@integratedglobal.com

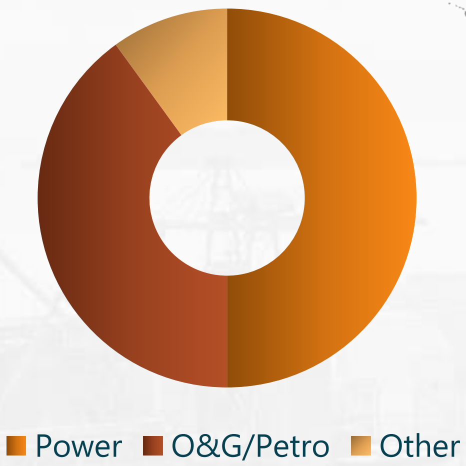
THE GLOBAL SOURCE for Reliable Surface Protection

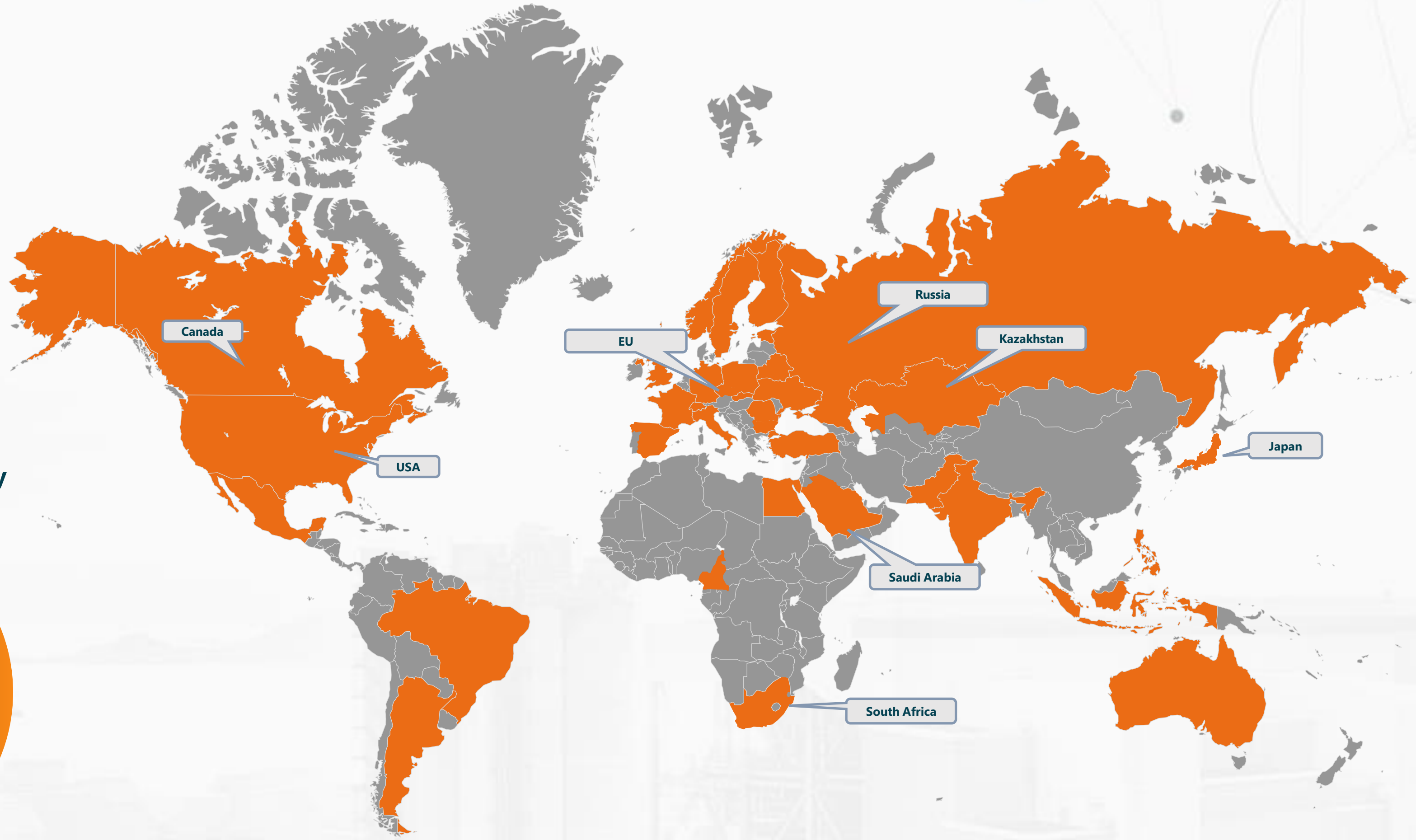
Our purpose is to partner with our customers to solve challenging metal wastage problems in mission critical equipment

Project Experience by Decade



Applications by Industry





Background – TSA

Abrasive blasting & TSA are disruptive to other turnaround activities

Can we **move TSA to a non-turnaround time**? This means blasting and coating live piping and vessels while petrochemical products may be flowing within

TSA in live operating plants has **proven to be safe** if protocols are followed.

IGS has developed methods to increase the safety factor even further with the **TSA online solution**

CUI on Nozzle

IGS Online TSA Solution

A specialized system providing the ability to do maintenance in an online (live plant) environment

For LNG, crude oil refineries and petrochemical plants suffering from CUI

Ensuring productivity and protection of client assets in the safest environment possible

IGS customizes the solution to the plant's needs

IGS Advantage

IGS is a premium TSA provider expertly servicing many major global companies

IGs has a dedicated team which has the know-how to safely apply high-quality TSA

Practical online TSA solution maintains temperature, humidity, and safe environment surrounding the abrasive blasting & TSA process

The IGS online TSA solution was developed together with and approved by a multinational oil company

Turnkey (and yet customizable) safety systems project, utilizing complex safety equipment such as automatic safety shutdown systems

Consists of 5 Elements:

1. IGS shrink wrap habitat
2. IGS automatic shutdown system
3. IGS gas jet extraction system
4. IGS certified technicians
5. IGS pressure and climate control solution

IGS Certified Technicians

All technicians have gone through an intensive and thorough training program to become certified habitat & safety technicians

The training ensures that our technicians understand what hot-work is and be professionals in all safety procedures

The technicians have the knowledge and experience to provide clients with the safest optimal solutions in any situation

The technicians are experts in how to assemble the habitat and set up the entire solution in the safest manner, under any circumstances and in an efficient time frame

Contact

Integrated Global Services, inc

Vitaly Geraskin

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www.integratedglobal.com

Appendix 6

Stress Corrosion Cracking of carbon and low alloy Cr Ni Mo steels in methanol

(Carlo Farina)

Stress Corrosion Cracking of carbon and low alloy Cr Ni Mo steels in methanol

Carlo Farina, Ubaldo Grassini
Donegani Anticorrosione Novara

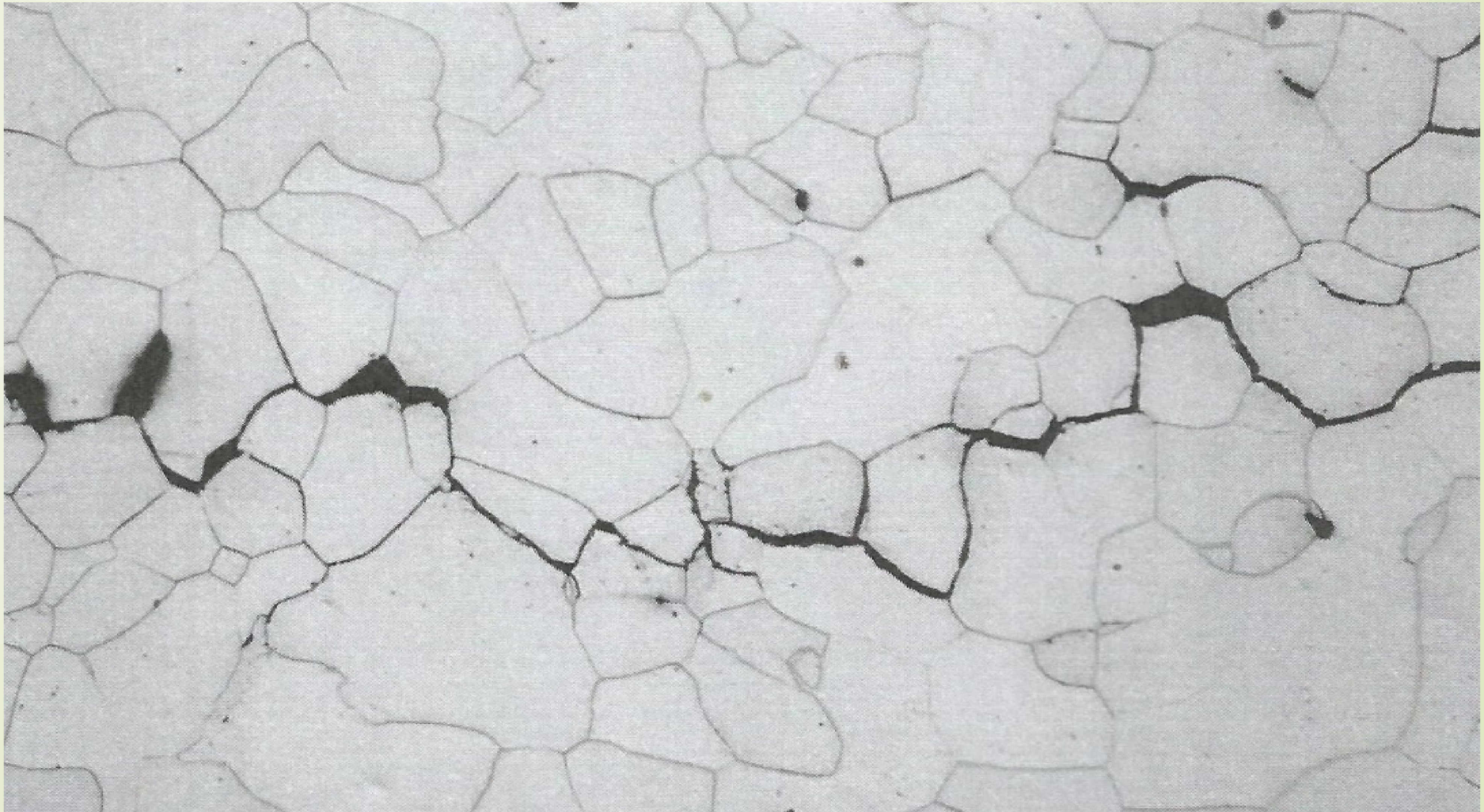
The situation

- Stress corrosion cracking (SCC) of carbon and low alloy Cr Ni Mo steels in methanol can occur in the range of industrial grade solvent.

- The cracking can be influenced by various impurities (Cl^-, H^+...), and can inhibited by small quantities of water which ensure a certain degree of protection.

Intergranular SCC of carbon steel in methanol I.

Intergranular SCC of carbon steel in methanol II.



Corrosion processes in water and in alcohols

- All the variables that affects corrosion in aqueous solutions can affect corrosion in organic solvents (temperature, oxygen, acid, bases…)
- Many solutions properties such as solvating power depend on the nature of the organic liquid.
- The protic nature of a given organic liquid will determine the solubility of various impurities and corrosion products.

The role of water and of oxygen

- The role of water is not completely clarified.
- In solutions with low water content the oxide film is dissolved due to acidity of the protic medium 2 MeOH ↔ $MeOH^{+}_{2}$ + MeO^{-}
- As water content increases a metal oxide forms from the water-metal bond, triggering off a new passive film: the corrosion process is therefore stopped.
- In deaerated conditions (oxgen < 30 ppb) much less susceptibility to SCC is reported, whereas cracking is reported in aerated environments (77 ppm of dissolved oxygen).

Water addiction, PWHT, low strenght material, the role of oxygen.

- Low residual stress (post weld heat treatment - PWHT), the use of low strenght material (e.g. ASTM A 516 gr. 60 max) are effective measures to prevent liquid phase stress corrosion cracking.
- The availability of oxygen to partecipate in corrosion reaction is expected to be greater in methanol, since its solubility is of an order of magnitude higher than that in water.
- SCC occurs over a range of oxidizing conditions, and therefore requires significant dissolved oxygen available

The role of water on SCC on liquid ammonia and methanol.

- The SCC in methanol was comparable in many ways to SCC in liquid ammonia, in that case suscepitibility can affected by small additions of water.

- Whereas the role water of SCC inhibitor in liquid ammonia is well proved, the same role in methanol solutions is not completely clarified.

SCC for carbon steel in liquid ammonia

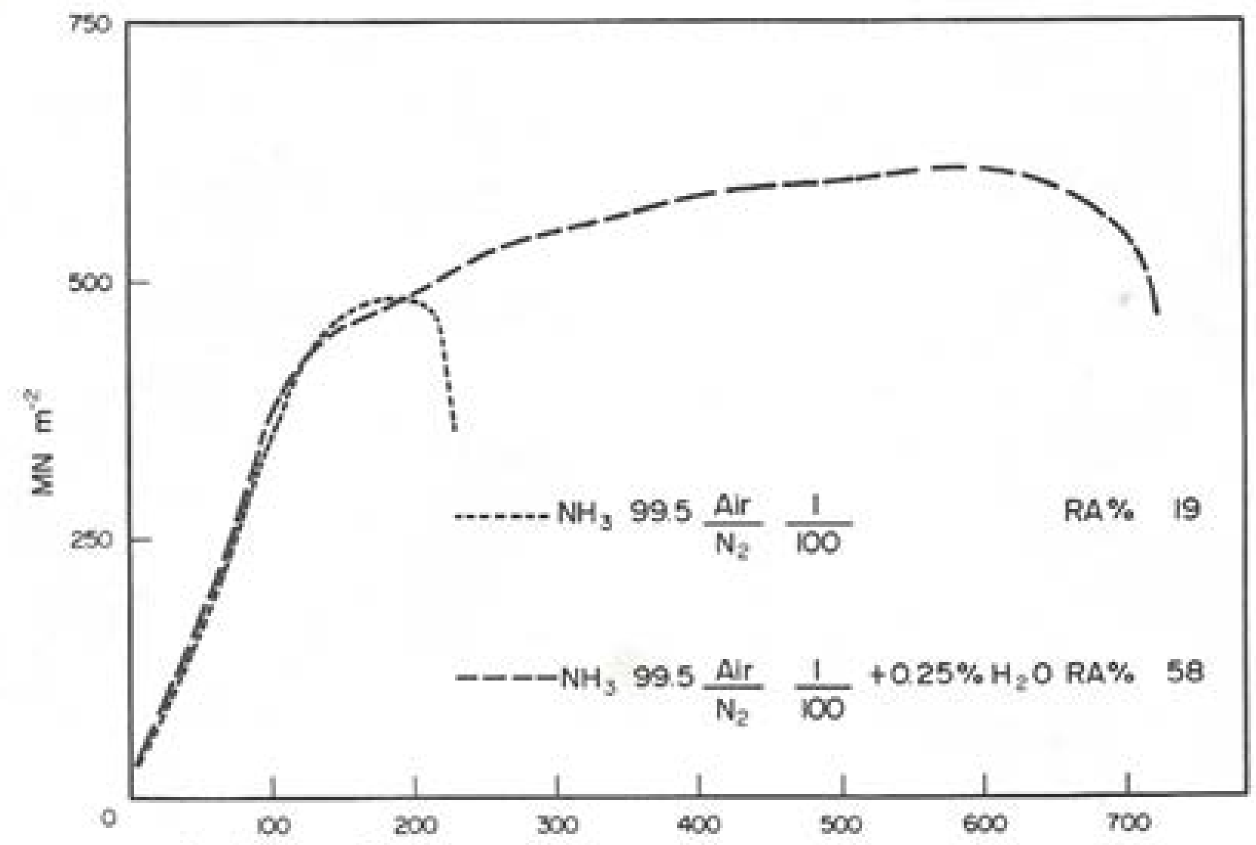
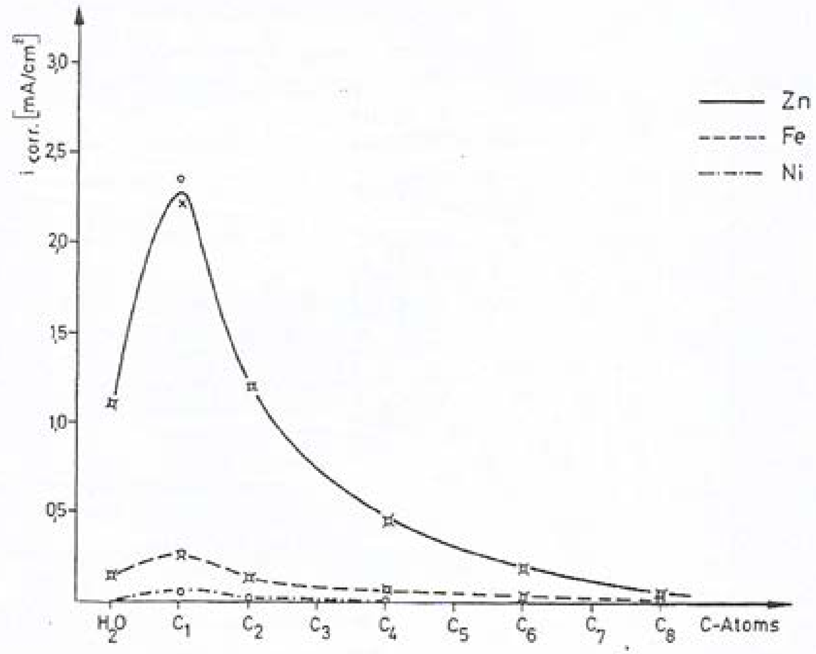


Fig. 5 Stress/time curves for carbon steel in liquid ammonia

Corrosion rate in primary alcohols versus carbon number of solvent.



Corrosion rate (i_{corr}) of Zinc, Iron and Nickel in Primary Alcohols Plotted versus Carbon Number of Solvent: Methanol (C =1); Ethanol (C = 2)

Fig. 4

Cracking in vicinity of the welds.

- Cracking is parallel or transversal to the weld.
- Cracks are tipically branched, and the intergranular path (also in ethanol) seems to indicate that an anodic mechanism is acting, with dissolution of the metal at metal boundaries.

Cracking on the bottom of a methanol tank.

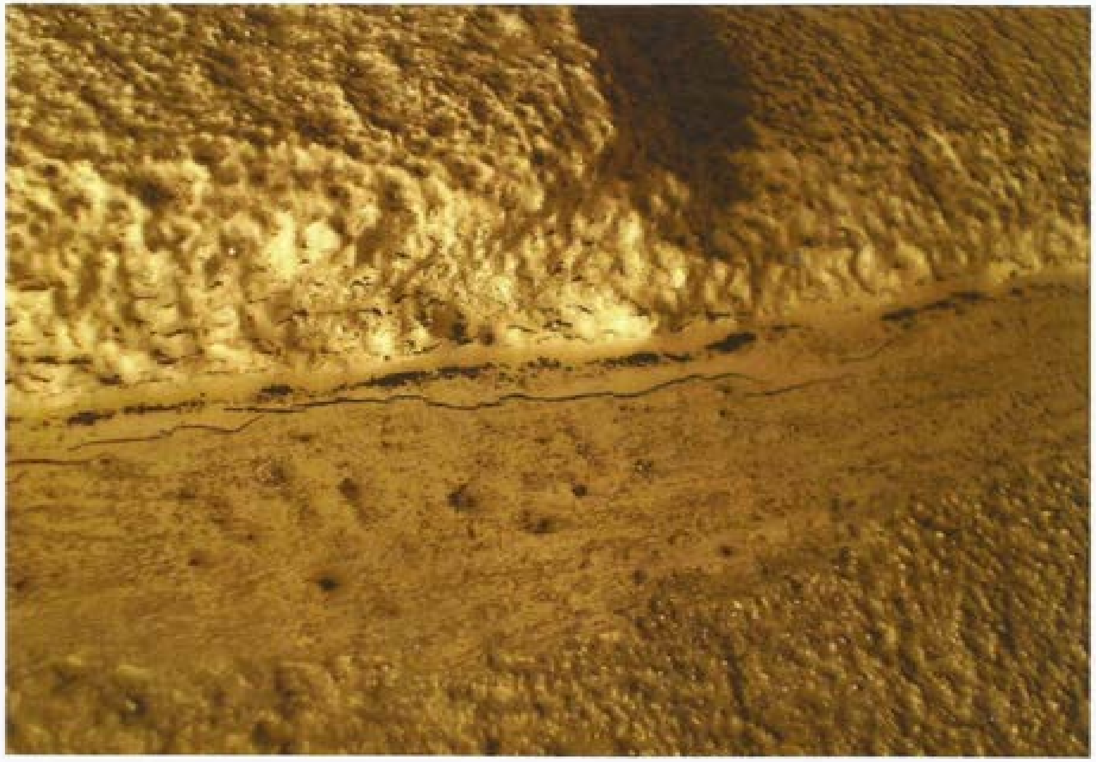


Fig. 3 Cracking on the bottom of a methanol tank

Stress corrosion cracking on the bottom of a methanol tank.

Fig. 6 Stress corrosion cracking observed on a welded vessel used as a storage for industrial grade methanol.

SCC in methanol (left) and ethanol (right): negative influence of chlorides and acidity, slow strain rate test, Ni Cr Mo alloy.

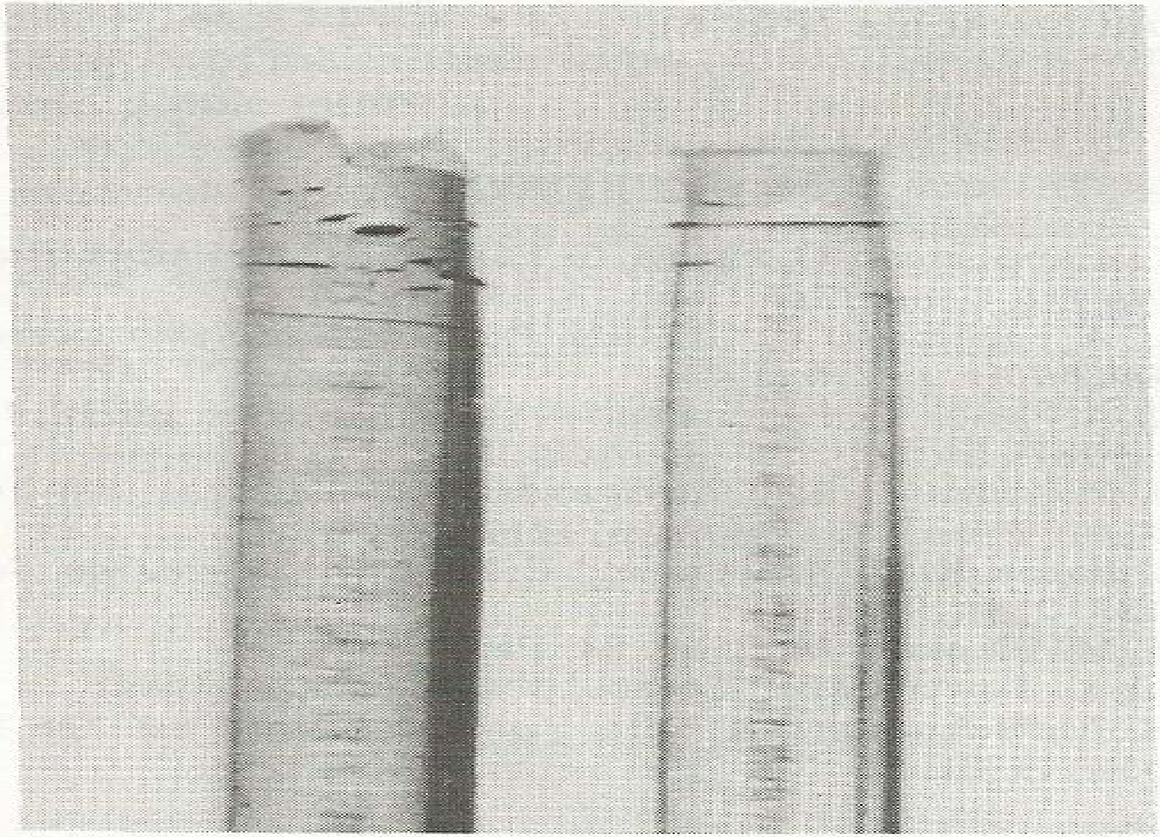


Fig. 7 Stress corrosion cracking of a Ni Cr Mo low alloy steel in methanol (left) and ethanol (right) (10^{-1} mol m^{-3} LiCl, 10^{-1} mol m^{-3} H_2SO_4)

Appendix 7

Recent HTHA inspection findings on low temperature shift converter and methanator vessels in hydrogen manufacturing unit

(Hadi Zakeri)

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Recent HTHA inspection findings on low temperature shift converter vessel in hydrogen manufacturing unit

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Background

- Steel process plant equipment that operate with hydrogen at elevated temperature and pressure can be weakened by a mechanism known as High Temperature Hydrogen Attack (HTHA)
- Following a catastrophic fire at the Tesoro refinery in USA in April 2010 CSB issued a safety alert prohibiting the use of carbon steels that operate above 400 °F (204 ° C), 50 psia (3.5 bar) hydrogen partial pressure. It said inspections should not be relied on to identify and control HTHA as successful identification of HTHA is highly dependent on the specific techniques employed and the skill of the inspector. It was also asserted that CS Nelson curve could not be relied upon in its current form to prevent HTHA.
- In response to CSB the 2016 API 941 edition featured a new curve for non-PWHT carbon steel welds.
- Petroineos took the approach to review all equipment at the refinery that operated or had design conditions above <u>the CSB recommended threshold.</u>
- Our strategic planning was:

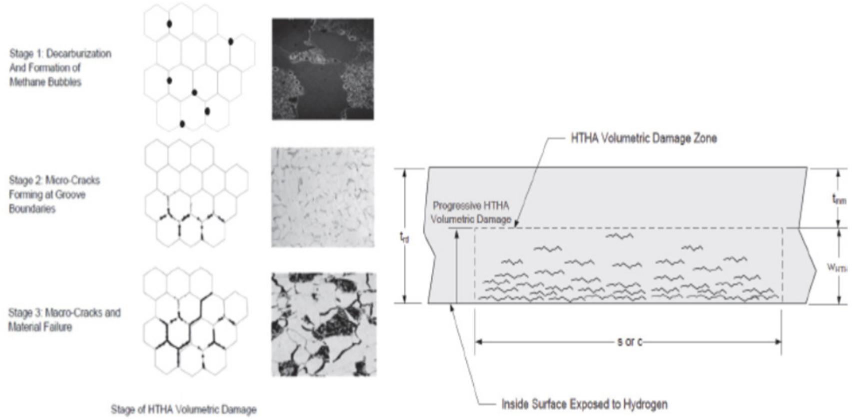
✓ If operating above Nelson :upgrade

✓ If operating below Nelson but design condition above then inspect and set OE

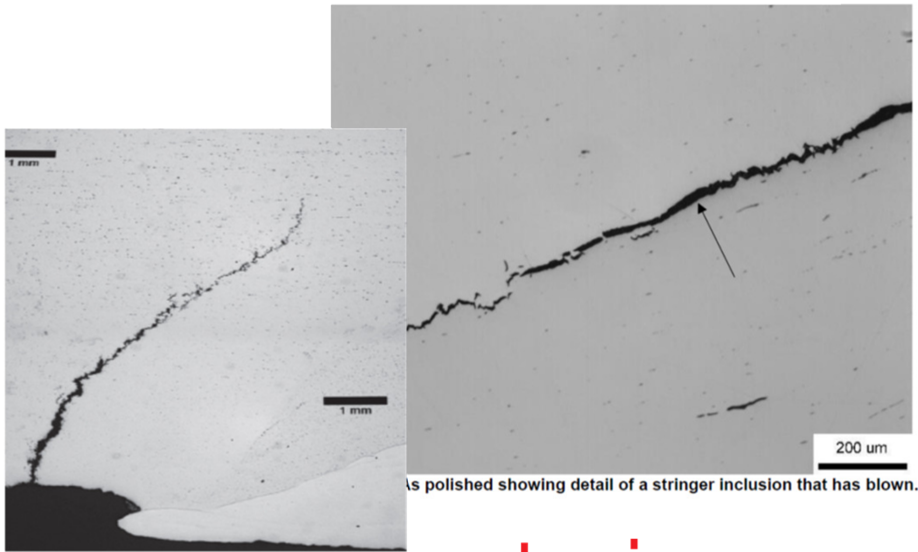
HTHA Characterisation

In Ultrasonic terms there are 3 stages of HTHA progression (slightly different than API 941-2020 Appendix E):

- 1- <u>Early stage HTHA </u>relates to micro fissuring that follows decarburisation/voiding stage. Micro fissures are detectable when they are of sufficient concentration to cause disruption to the propagation of ultrasound. Micro fissures may be coexistent with blistering or "blown" inclusions.
- 2- <u>Coalesced fissuring</u>: isolated fissures interlink forming complex 3D matrices of cracks. With "blown inclusions" <u>micro cracks</u> interlink in the direction of rolling to form longer flaws.
- 3- <u>Macro cracks</u>: physical separation



- ***Caveat about difficulty around discriminating between low levels of early-stage HTHA and metallurgical anomalies caused by steel manufacturing or welding process***



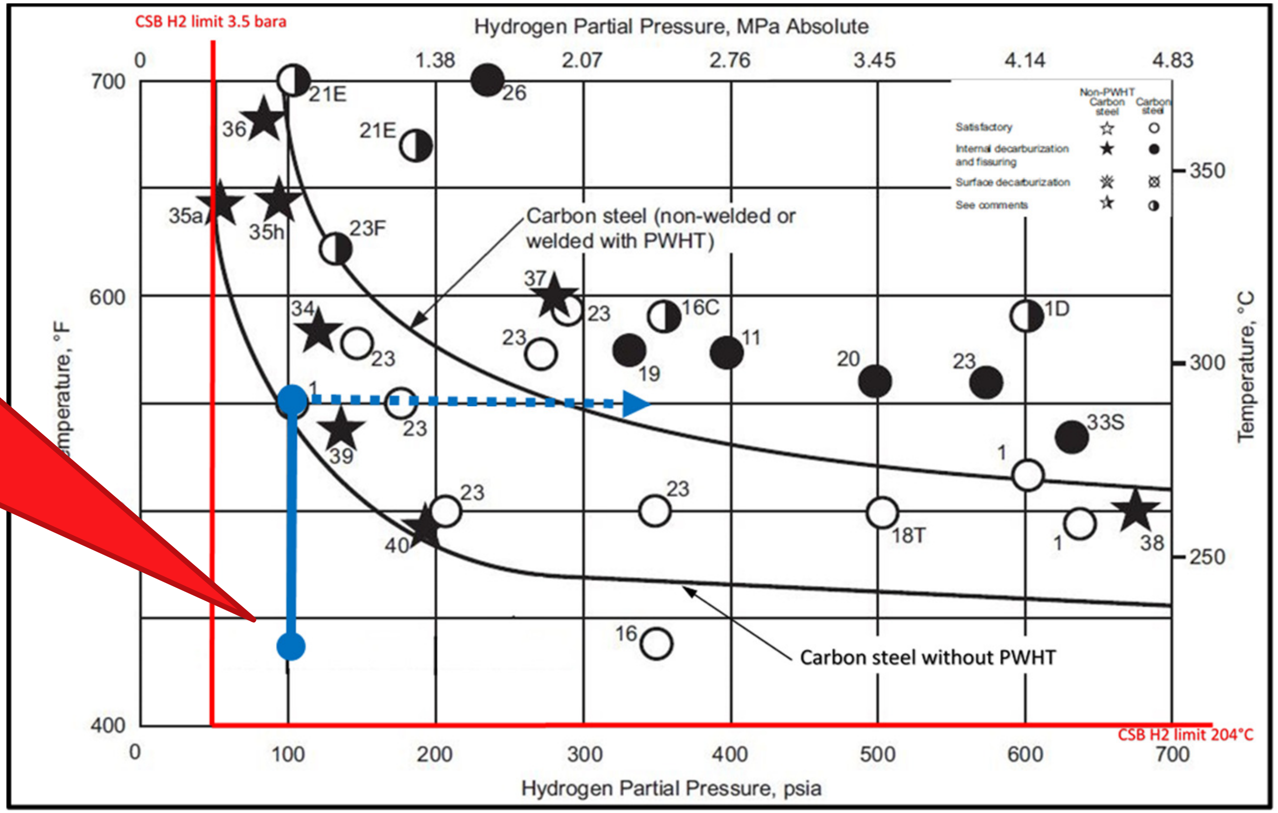
…s polished showing detail of a stringer inclusion that has blown.

- HTHA Inspection procedure employed TOFD and TFM/PAUT techniques

Low-Temperature Shift Converter

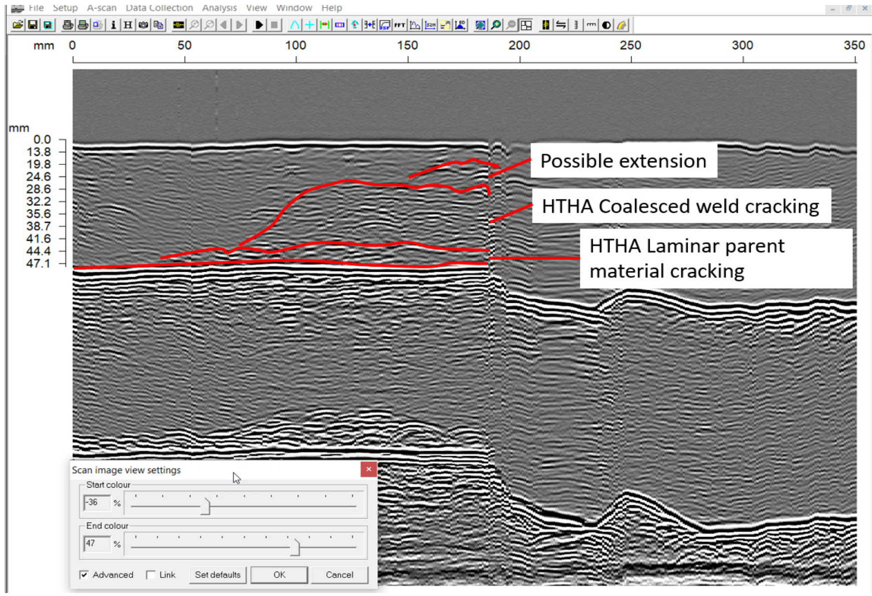
- CS vessel manufactured in 1968 , PWHT'ed, spot radiography – reported weld repairs
- Design pressure 23.8 barg (345 psig), design temperature 288℃ (550℉)
- Operating pressure 18 barg; Operating temperature 225℃
- Operating H2 partial pressure 7 bara (~100 psia).
- First inspection for HTHA at ~410 000 hrs

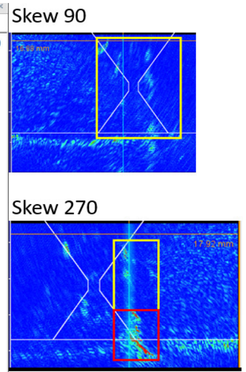
Even if the PWHT of the vessel had not been performed, the vessel **operates** at least 50℃ below the new non-PWHT curve in API RP 941 2016 edition. On this basis, it was **considered highly unlikely** that HTHA damage would be discovered in this item.

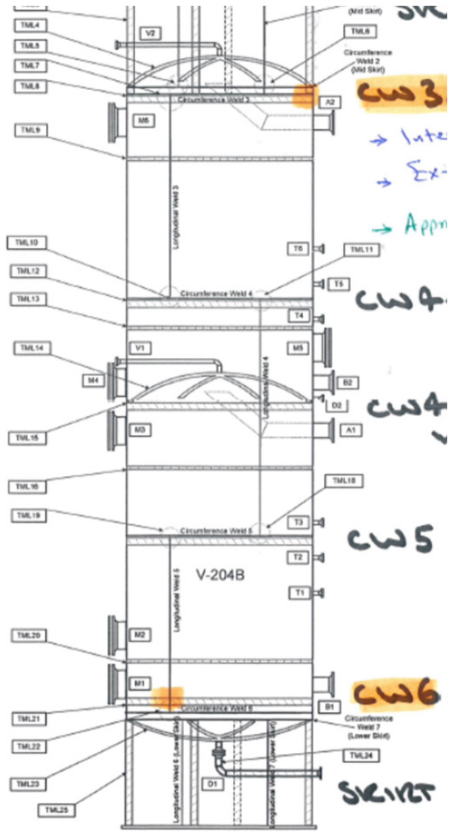


Inspection Findings

- Widespread lamellar HTHA cracking up to stage 3, extending up to 7 mm from ID (plate is 48mm thick)
- Minor fabrication flaws
- Early stage HTHA
- Coalesced vertical cracking stage 2 & 3 at circumferential/longitudinal intersection
- Replication confirmed grain boundary fissuring and low degree of decarburisation characteristic of HTHA
- Decision taken to remove from service as not practicable to attempt FFS







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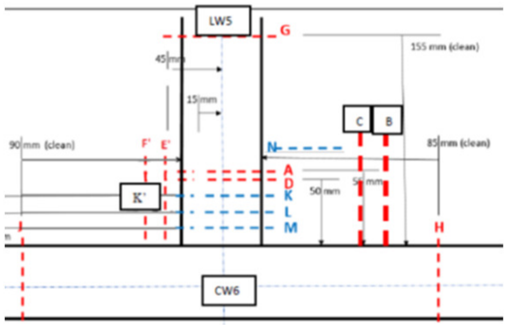
Post-event Destructive Testing

- Macro of suspect area showed
  - An asymmetric weld indicating a potential weld repair close to CW6
  - Large HAZ due to SAW welding process and possible subsequent repair
  - Large weld beads: high heat input



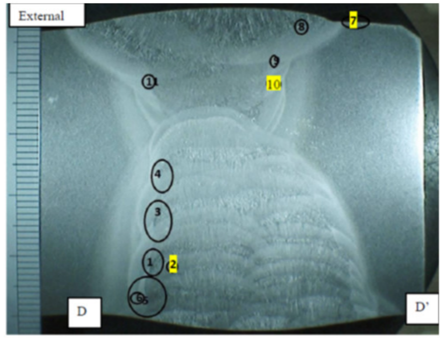
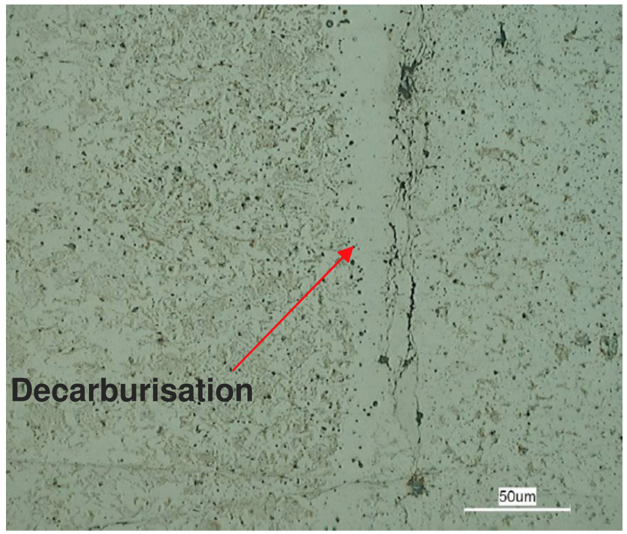


Figure 2.17 Macro of section D

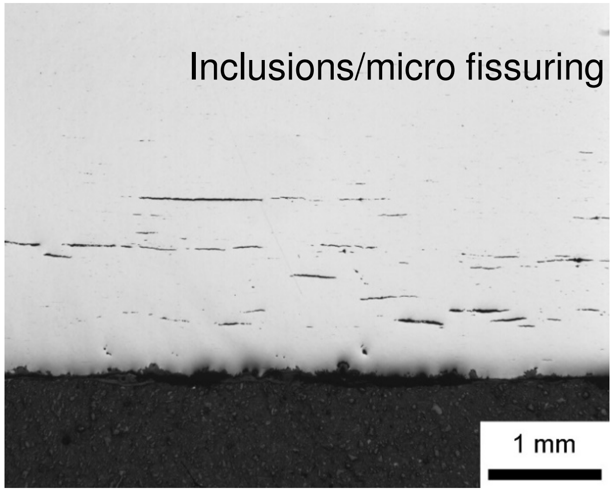
- Microscopic examination indicated:
  - Parent material showing gross inclusions up to 3mm long; Manganese sulphide and manganese silicates
  - Bands of decarburisation noted around inclusion stringers
  - Weld defects notes at the fusion line ~ >3mm long
  - Decarburisation and micro fissuring along the weld defect
  - Clusters of micro fissuring also noted within the weld metal

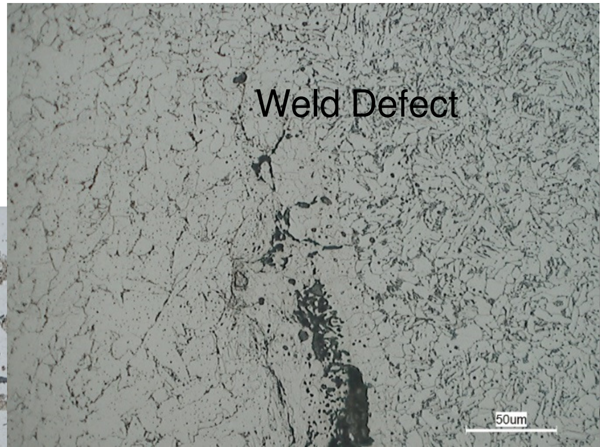


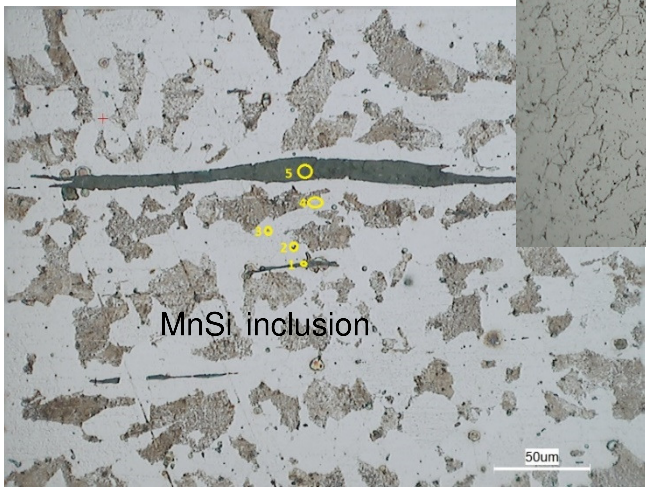
Section K, location 1, showing area of fissuring & decarburisation a
fusion line

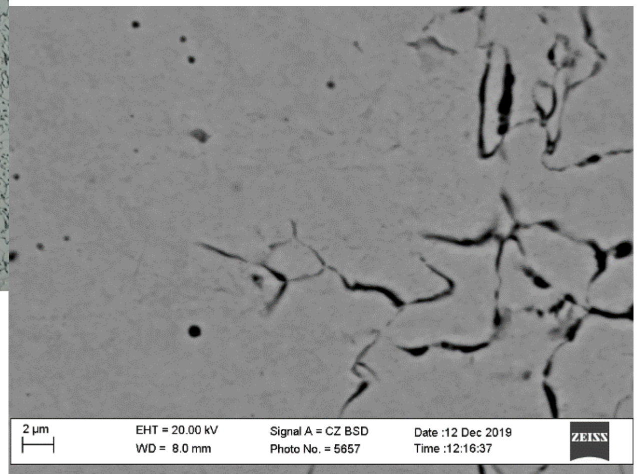
Metallurgical Examination

No evidence of significant stage 3 through-thickness cracking. Petroineos opinion therefore was that damage consisted of **early stage 1 HTHA micro-fissuring, with perhaps stage 2 coalescence in some areas**.









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Mechanical Test

	Yield (MPa)	UTS (MPa)	Elongation %
BS1501-151-28B (as-received)	Min 235	Min 430	10

Table 2.1 Tensile Test Results

Sample ID	Proof $Rp_{0.2}$ (MPa)	UTS R_m (MPa)	Elongation on G.L (5.65√A), %	Reduction of Area (%)
LW5 - D	405	494	21.0	57.0
LW5 - K	396	519	25.5	58.0
LW5 - L	436	458	9.5	30.0
LW5 - M	443	464	12.0	61.0
CW6 - J	364	437	19.0	50.0

Figure 2.1 – LW5 - D

- Material strength and ductility results exceeded the minimum material spec requirements
- Majority of the fracture in the weld metal

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Discussions

- The results showed that the new curve in 2016 &the latest 2020 editions of API 941 are not as conservative as the simple limits stated in the CSB safety alert.
- As stated in API TR 941-A HTHA methane reactions and void/crack formation can occur at temperatures as low as 400 ℉ (204 ° C).
- Another reminder that API database only records observed damage i.e. usually **severe** attack. Components with minor or subcritical damage are likely to go undetected and therefore not included in API database.
- Although the vessel clearly had suffered HTHA damage, it was not as severe as the ultrasonic assessment indicated. In our opinion the discrepancy between metallurgical examination and Ultrasound findings stemmed from the following:
  - HTHA detection in aged materials riddled with inclusions appears to be challenging from an NDT perspective, particularly for stages 1 and 2
  - Weld repair areas (e.g. from original fabrication repairs) can be more difficult to target and inspect, and can be more likely to exhibit signs of HTHA damage.
- Micro fissuring within the material didn't appear to have a significant impact on material strength and ductility.
- FFS considered not practicable because it would involve
  - Extension of scope of inspection to cover all welds; not achievable in TAR window
  - Refine first-pass calculations to consider factors such as thermal stress and local discontinuities
  - Take material samples and test to determine fracture toughness – no boat sampling equipment available at short notice
  - No guarantee of success!

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Conclusions & Recommendations

1. Managing HTHA risks through inspection is difficult and uncertain. Therefore any equipment operating within a 14℃ (25℉) margin of the relevant Nelson Curve should be replaced with a resistant alloy. For carbon steel and C-0.5Mo the limit in hydrogen service should be taken as 200℃. Screening criteria for HTHA in API 581 (RBI) is more conservative and appropriate (177 ℃ and 50 psia)
2. When planning HTHA inspections, the following factors should be considered:
   - Age of the steel i.e. steel cleanliness, inspection history of laminations/inclusions, MPI indications/defects etc. These factors can affect the ease and reliability of the inspection.
   - Any known weld repair areas should be included in the primary UT inspection scope. If manufacturing/maintenance records do not record repair positions, a close visual inspection of the weld beads may reveal locations of repair welding.
3. If UT inspection finds indications of HTHA the following steps should be taken:
   - For minor / isolated surface indications (i.e. on the ID or close to ID) material removal by grinding up to the minimum thickness limitation followed by surface replication to look for decarburisation or micro fissuring – note that HTHA with no decarburisation has been experienced in industry
   - For any major UT indications through the wall breaching min t, boat sampling or full material removal should be carried out in order to analyse the indications destructively.
   - Logistic difficulties of boat sampling to be considered in planning stages, possibility that weld repair or insertion of a dummy nozzle may be necessary.
4. Lack of published methodology for HTHA FFS creates difficulties should need arise. Work is ongoing through a Joint Industry Project (JIP) led by few consultancy companies to standardise a FFS technique to HTHA.

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Parting shot from API TR 941 Appendix B 6.0

The potential for long term HTHA of refinery equipment is of practical concern, but long-term experiments in hydrogen are inconvenient, costly and dangerous. Investigators usually do not run long-term tests because of these impediments. Instead, they accelerate attack by increasing temperature and/or pressure and using samples exposed to hydrogen on all surfaces for pre-selected, usually short times. The result is a poor simulation of service conditions that typically involve single-side exposures for long times at temperatures where nucleation and void growth rates are governing. Also, data have not been systematically analysed since critical variables such as, methane pressure, carbon activity, hydrogen content and the like are not easily measured, monitored, understood or controlled. The result is a patchwork of data and models and few, long term systematic studies with adequate information to develop the necessary predictive tools

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Appendix 8

Optimized ultrasonic techniques for HTHA inspection

(Casper Wassink)

NEW UT TECHNIQUES FOR HTHA DETECTION - LESSONS FROM THE FIELD

CASPER WASSINK, FREDERIC REVERDY, GUILLAUME NEAU AND OLIVIER ROY

Introduction

NEW NDT TECHNIQUE IN API RP 941 ADDENDUM 1

- HTHA has occurred in conditions where it was not expected
- As a result inspections are required
- HTHA is hard to detect with any NDT in early stages
- Several NDT techniques have been introduced into API RP 941 addendum 1
- Although these techniques are not new in themselves, they need to be configured and optimized for HTHA inspection

NDT techniques

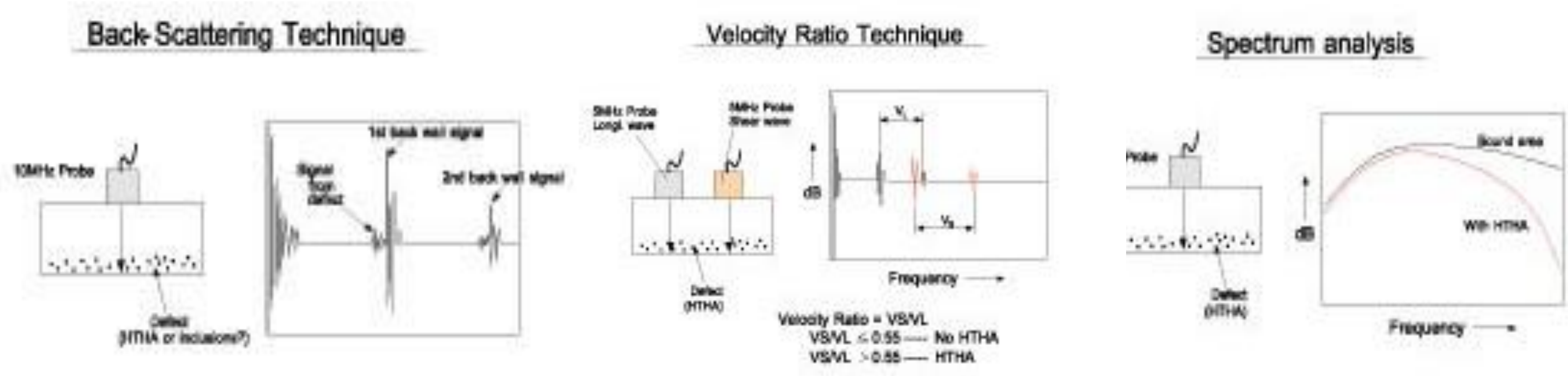
OLD AND NEW

- AUBT (Advanced Ultrasonic Backscatter Technique)
  - Back scatter
  - Spectrum Analysis
  - Velocity ratio
- Time-of-Flight Diffraction (TOFD)
- Phased Array Ultrasonic Testing (PAUT)
- Full Matrix Capture / Total Focussing Method (FMC/TFM)

- All are techniques in the ultrasonic NDT method and are based on the same physics

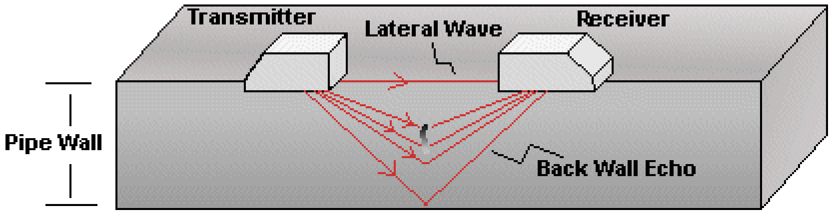
AUBT

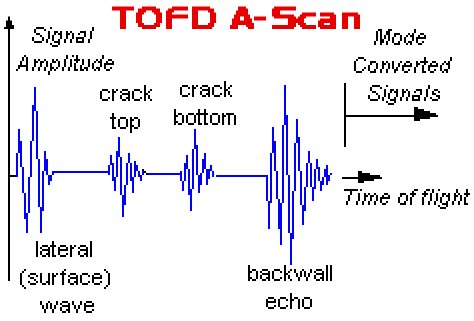
ORIGINALLY DEVELOPED FOR THE HTHA CHALLENGE

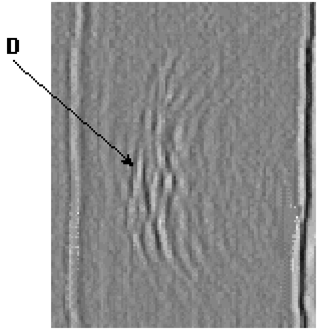


TOFD

DEVELOPED FOR SIZING OF FLAWS, SELECTED FOR EXCELLENT DETECTION



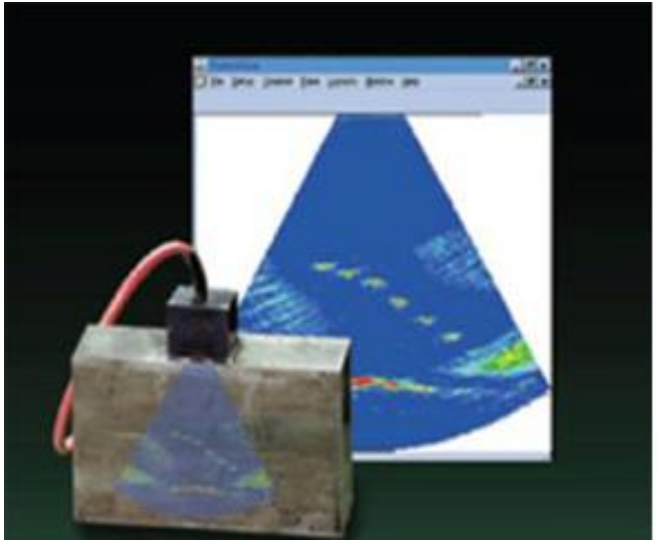


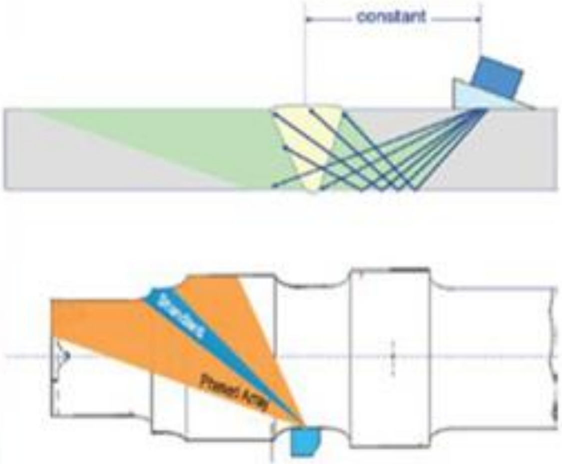


TOFD Scan of Butt Weld and Defect

PAUT

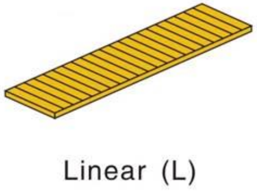
EASY TO UNDERSTAND, BUT DECEPTIVE REALIABILITY

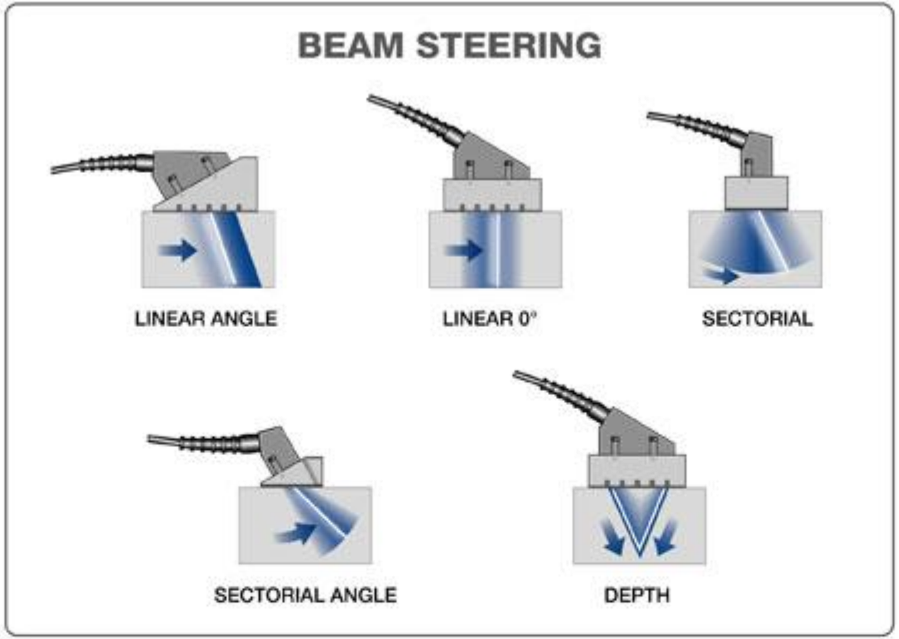


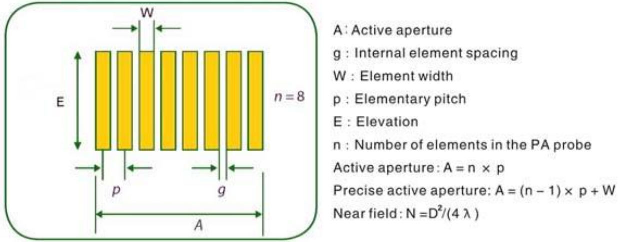


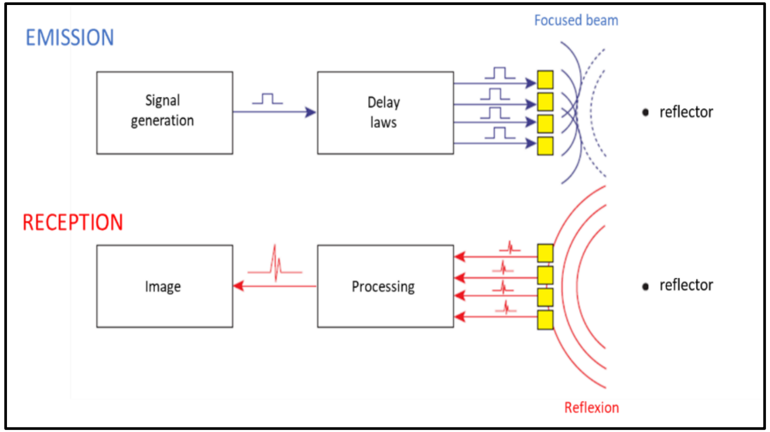
Phased Array working principle

DELAY LAWS



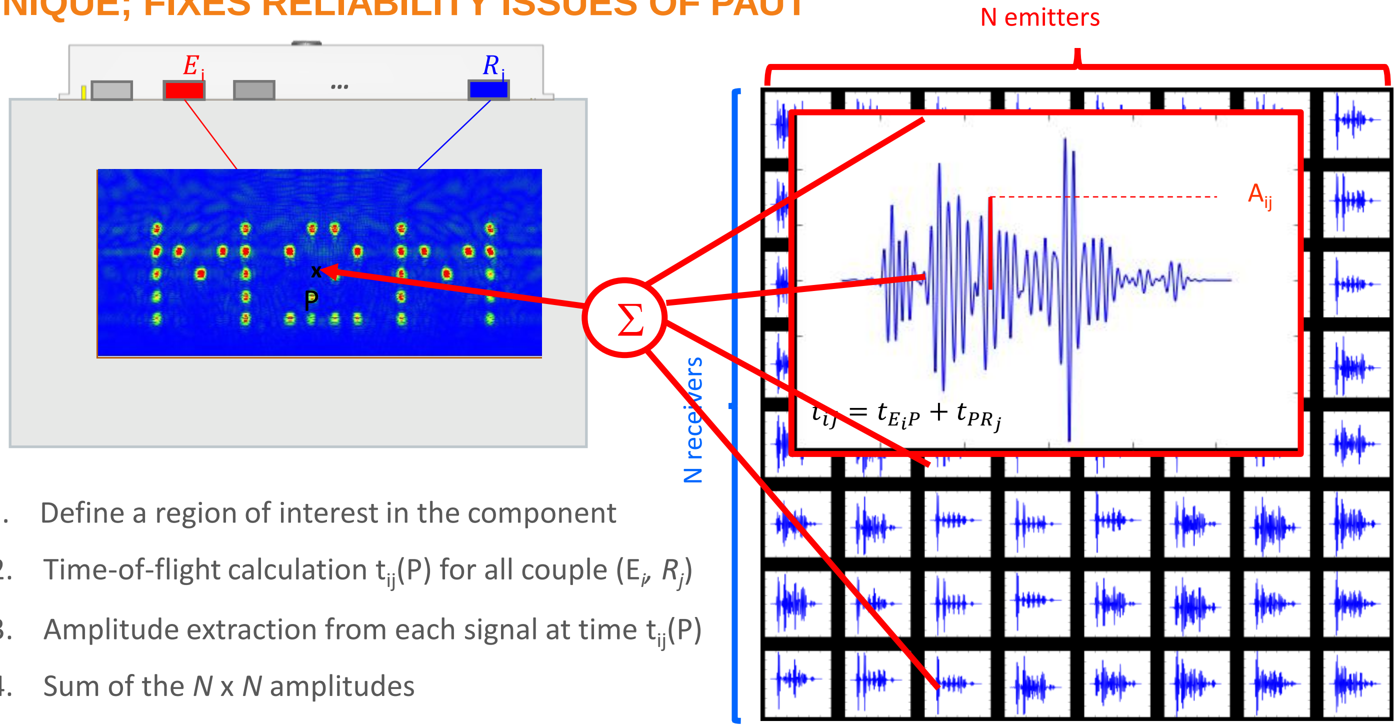






FMC/TFM

NEW TECHNIQUE; FIXES RELIABILITY ISSUES OF PAUT



1. Define a region of interest in the component
2. Time-of-flight calculation t_{ij}(P) for all couple (E_i, R_j)
3. Amplitude extraction from each signal at time t_{ij}(P)
4. Sum of the *N* x *N* amplitudes
5. Perform the steps above for all pixels

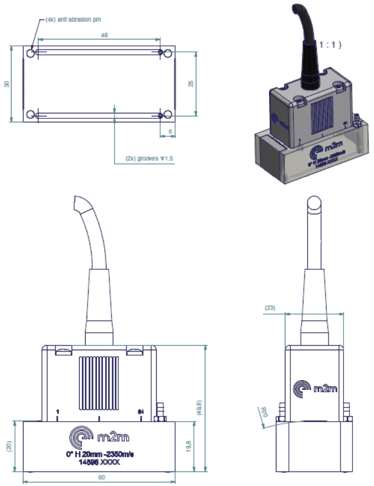
Comparison of technique

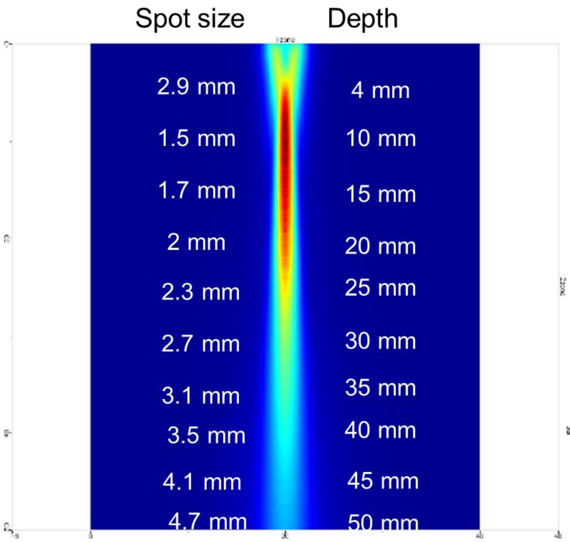
Technique	AUBT	TOFD	PAUT	FMC/TFM
Coverage	Full	Dead zone near surface	Only in the focus area	Full
Resolution	Limited, reliance on indirect detection	Limited	High in the focus area	High
Scanning speed	Manual (slow)	Very high	High	High
Main Advantage	Many different tools for advanced diagnostics	High detectability due to reliance on diffraction echoes	Availability, recognizable display style	Highest resolution possible
Main disadvantage	Operator variability, time consuming	Limited resolution, dead zone near surface, idiosyncratic display	Deceptive coverage	High data volume

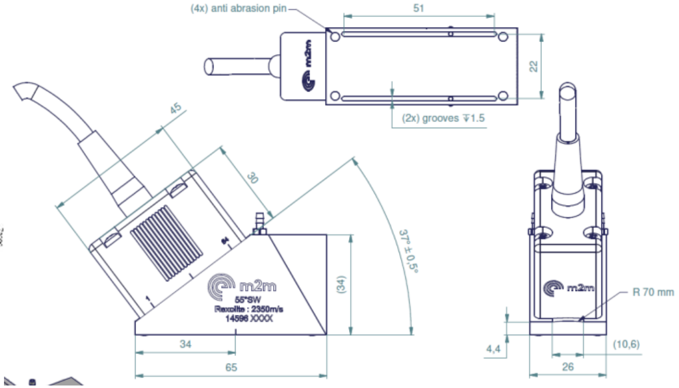
Available probes

OPTIMIZATION FOR DETECTION OF SMALL VOIDS

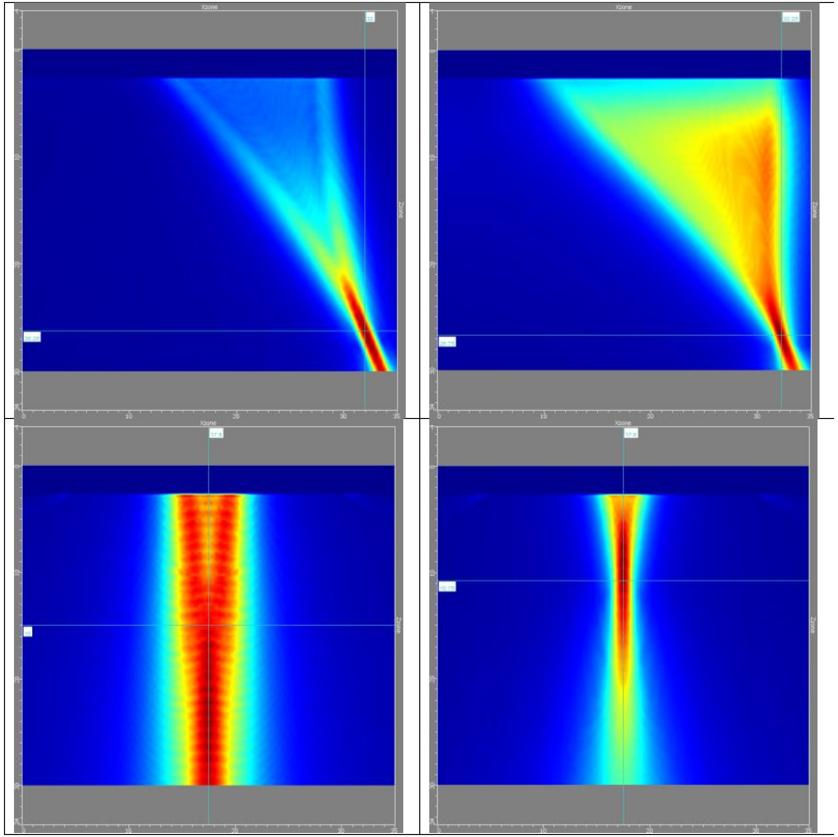
- Standard PAUT probe 64L10-G2 with L0 wedge. The pitch is 0. 35 mm, the elevation 8 mm, rexolite wedge is 20 mm high.
- Special PAUT probe 64L10: the pitch is 0.5 mm, the elevation 10 mm and it is cylindrically focused along the passive plane, rexolite wedge is 20 mm. While the central frequency is supposed to be 10 MHz, it was measured experimentally at 7.4 MHz from a side-drilled hole located at 15 mm.



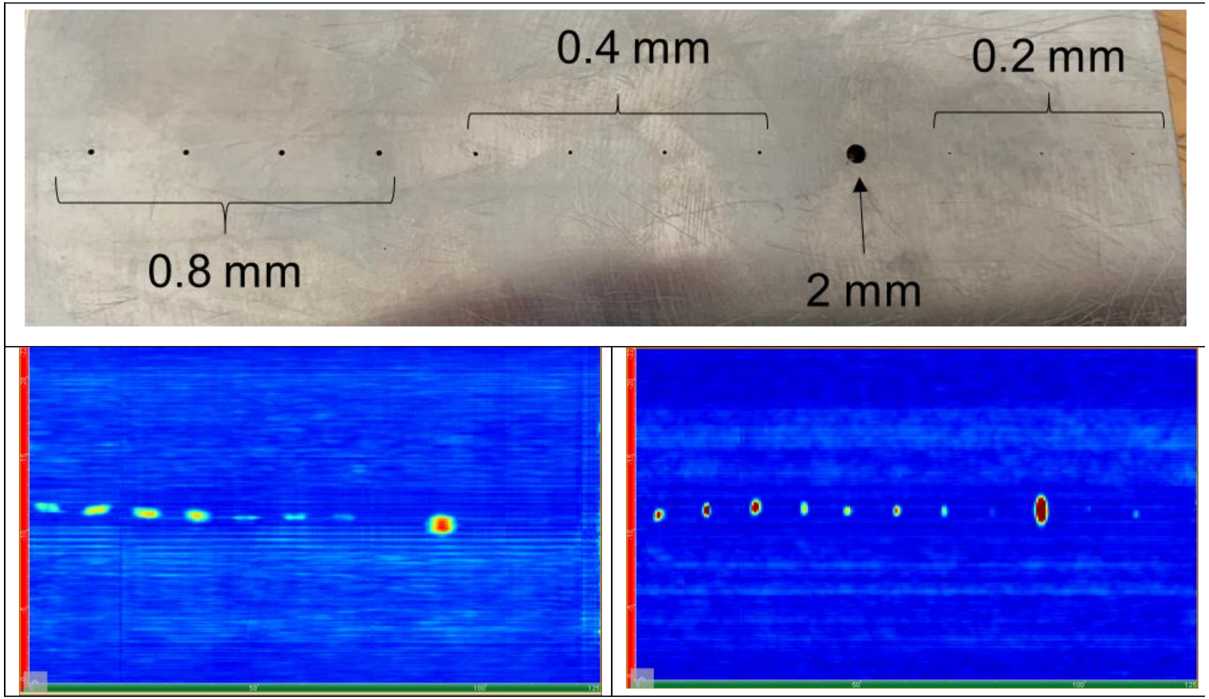




Beam profiles of the two probes

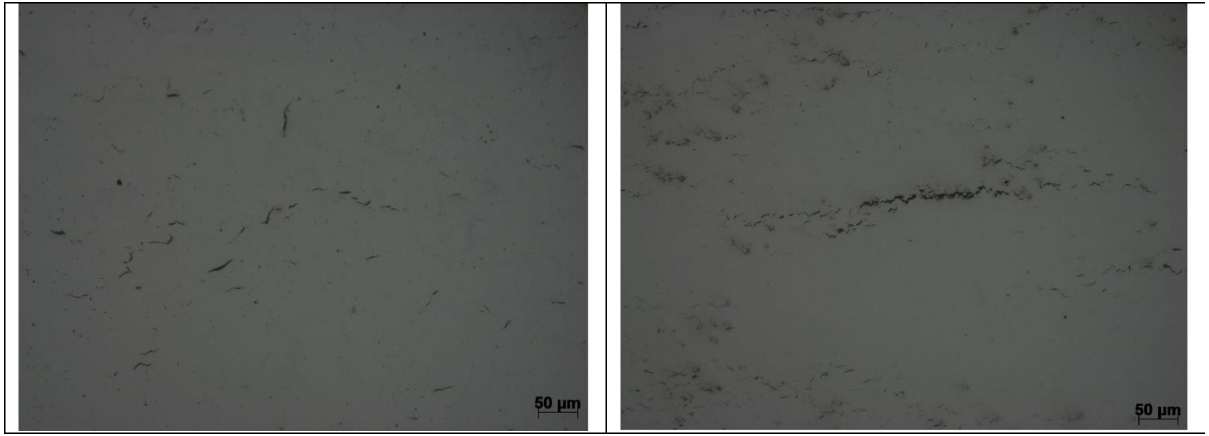


Results on side drilled holes



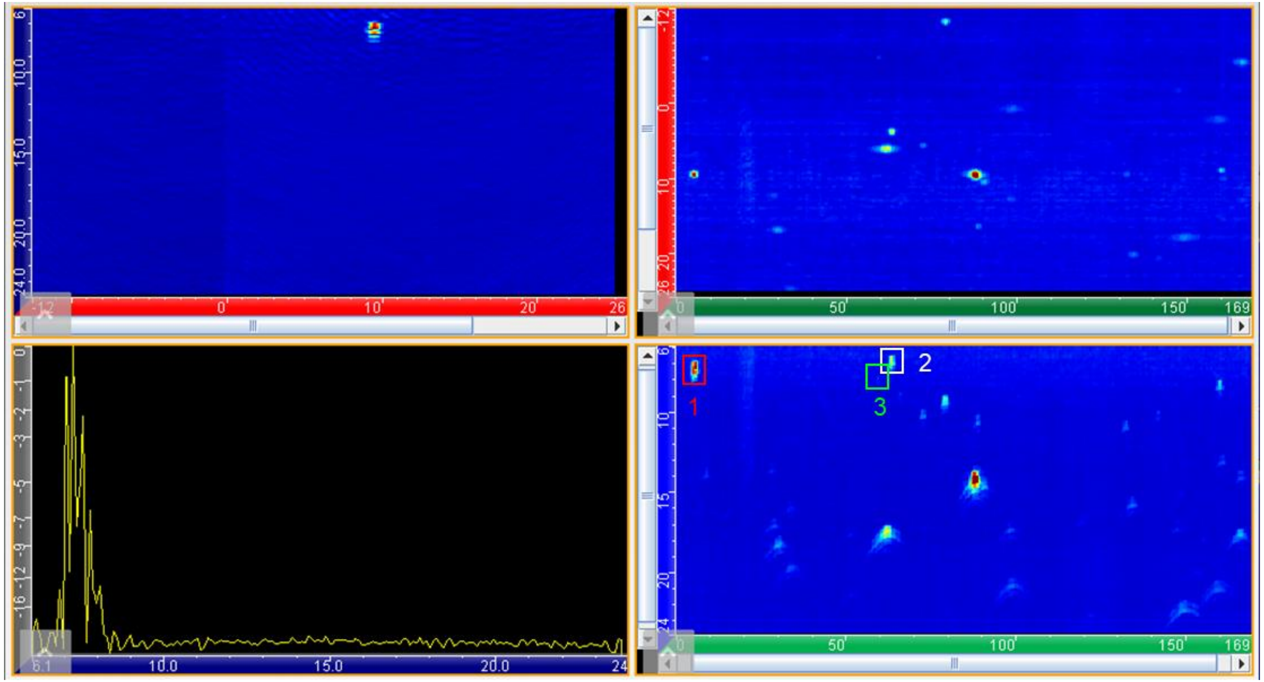
Results on artificial HTHA

SAMPLE METALOGRAPHY



Results on artificial HTHA

FMC/TFM RESULTS WITH OPTIMIZED PROBE



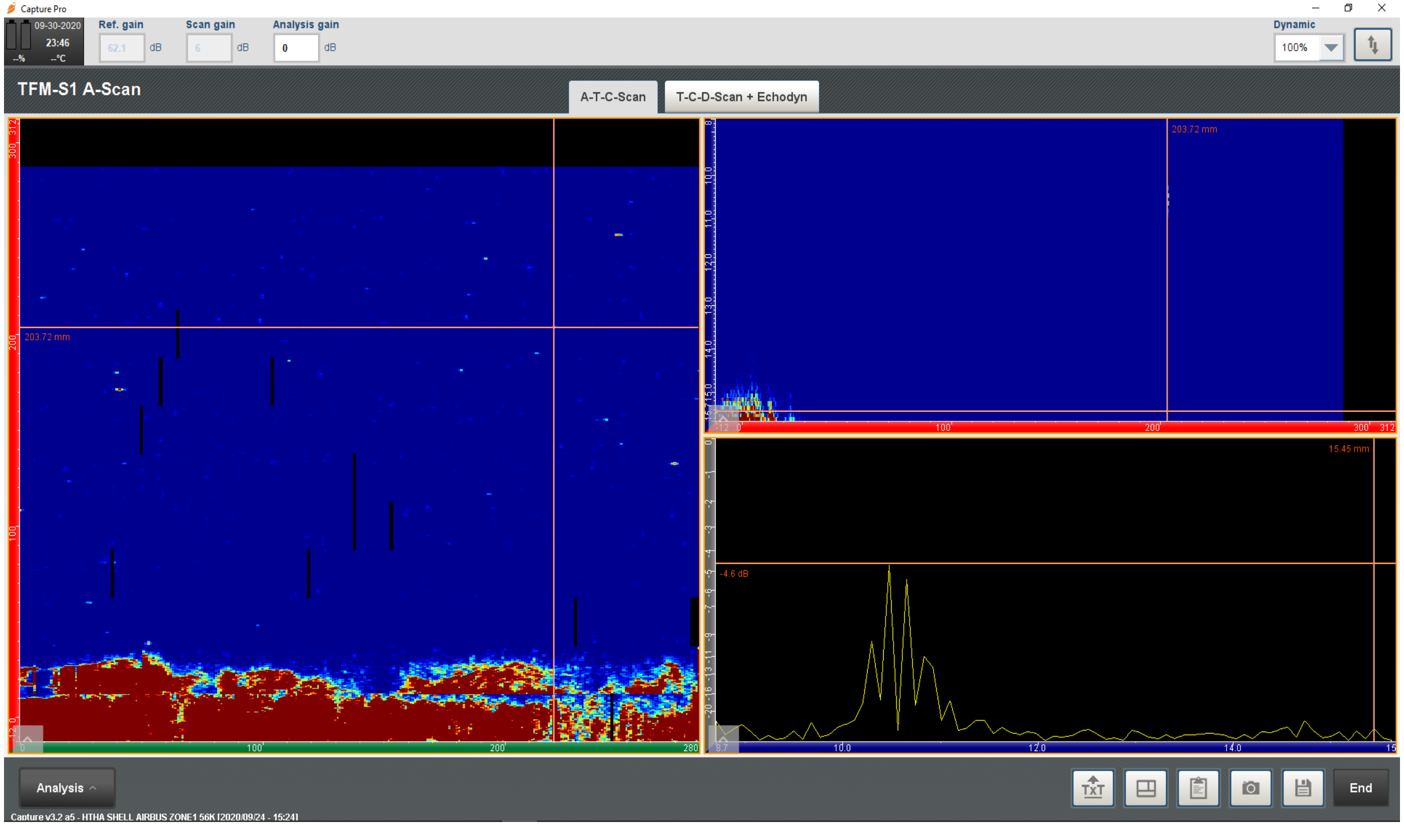
Field case

SAMPLE FROM THE FIELD

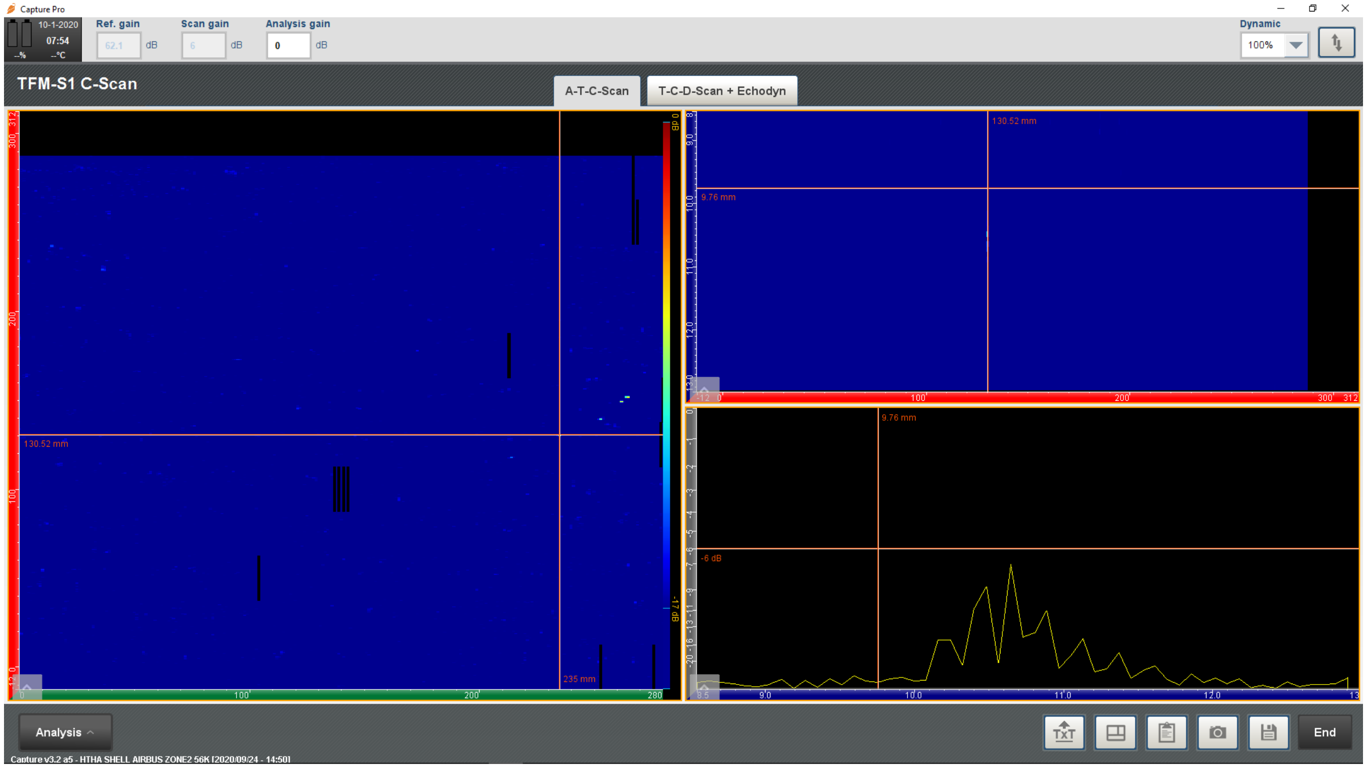
- HTHA suspicion before inspection
- HTHA not detected with field NDT
- HTHA confirmed in laboratory tests

- NDT was only able to find HTHA with optimized probes and procedures

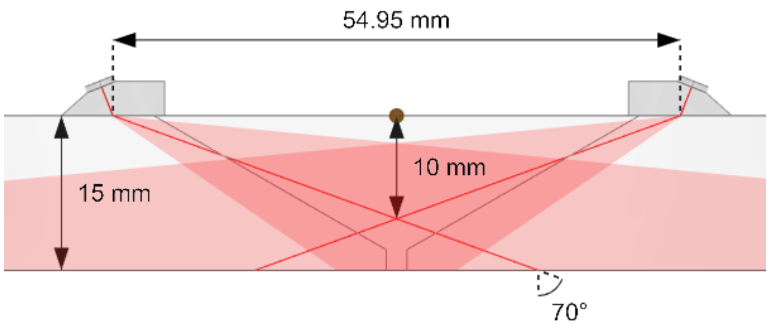
NDT results zone 1

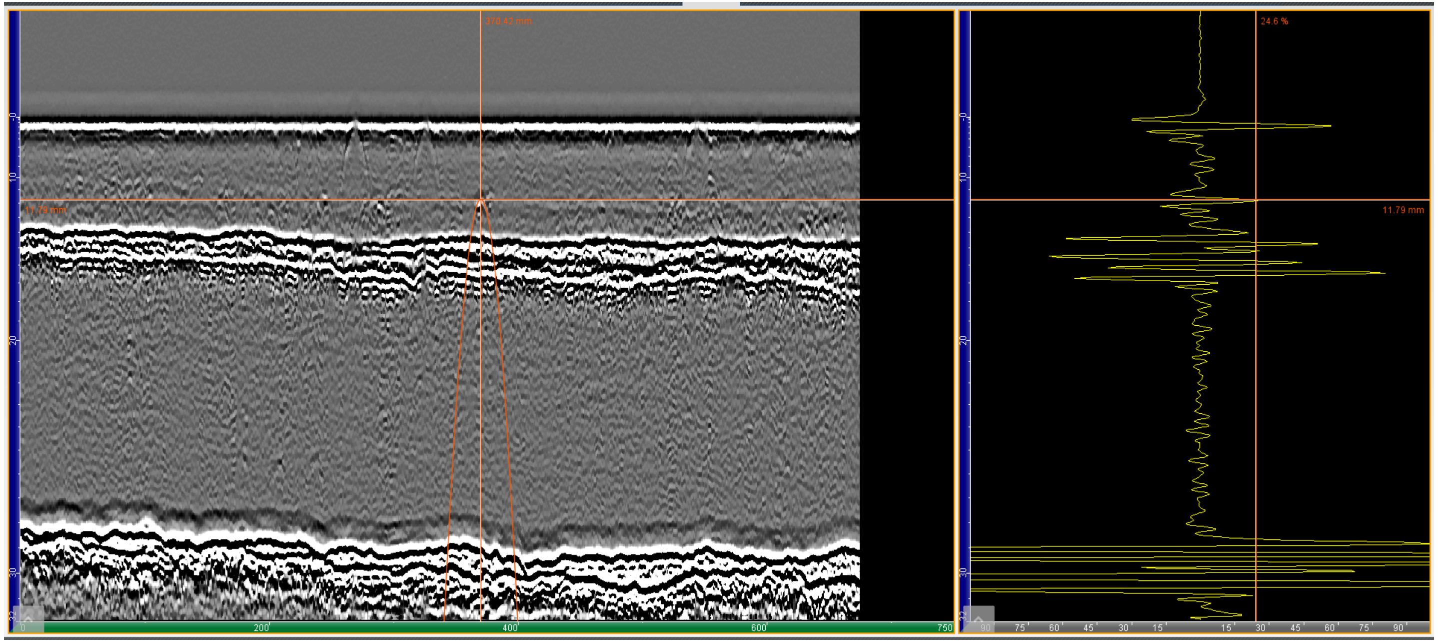


NDT results zone 2



NDT results TOFD on weld





Conclusion

- Optimized array probes and FMC/TFM are highly beneficial for HTHA inspection
- HTHA successfully detected where field NDT was unable to confirm flaws
- Characterization of flaws would have been possible with optimized probes and procedures
- Optimizations are not described in the update to API RP 941

Appendix 9

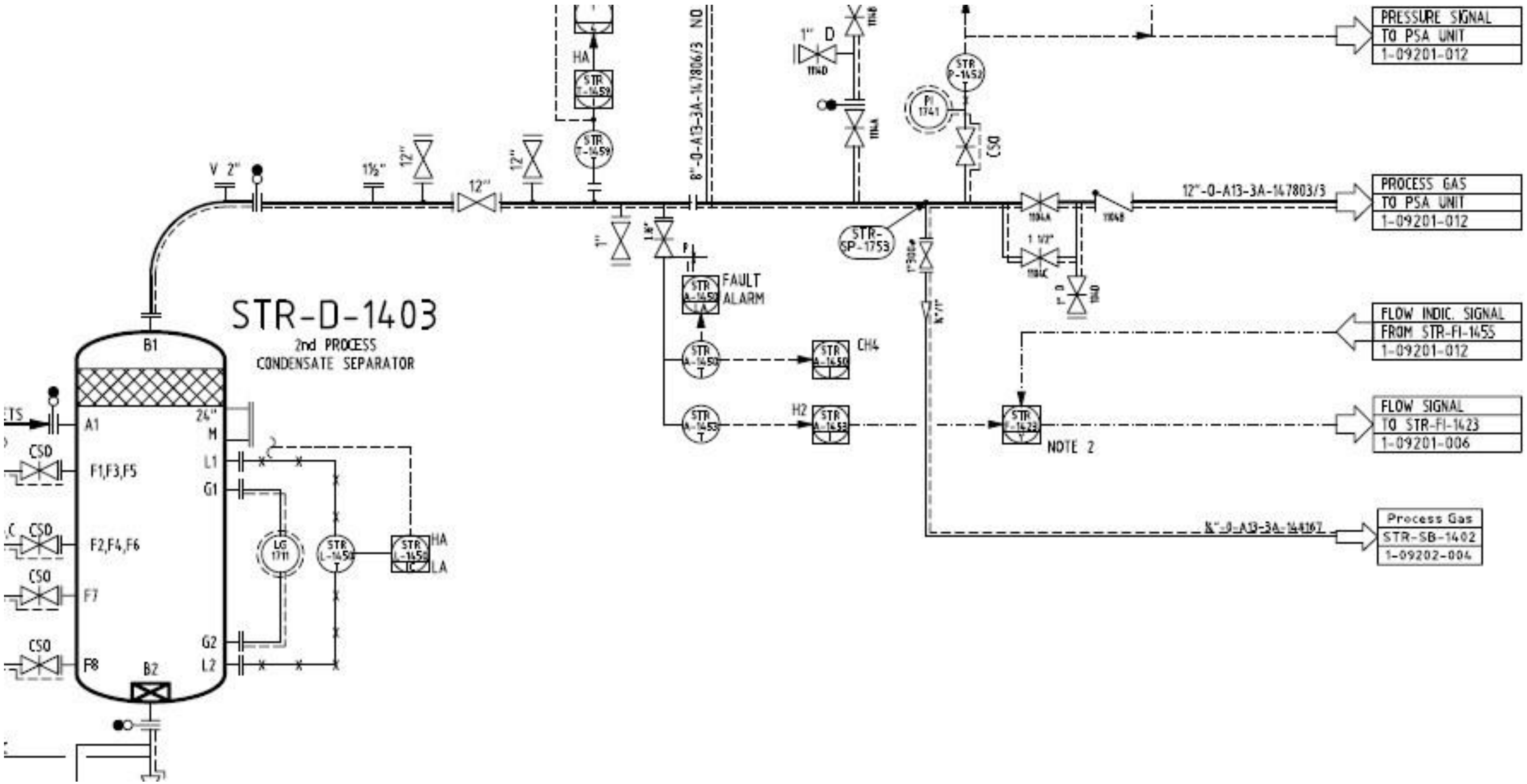
Leakage at the steam reformer piping system

(Swen Koller)

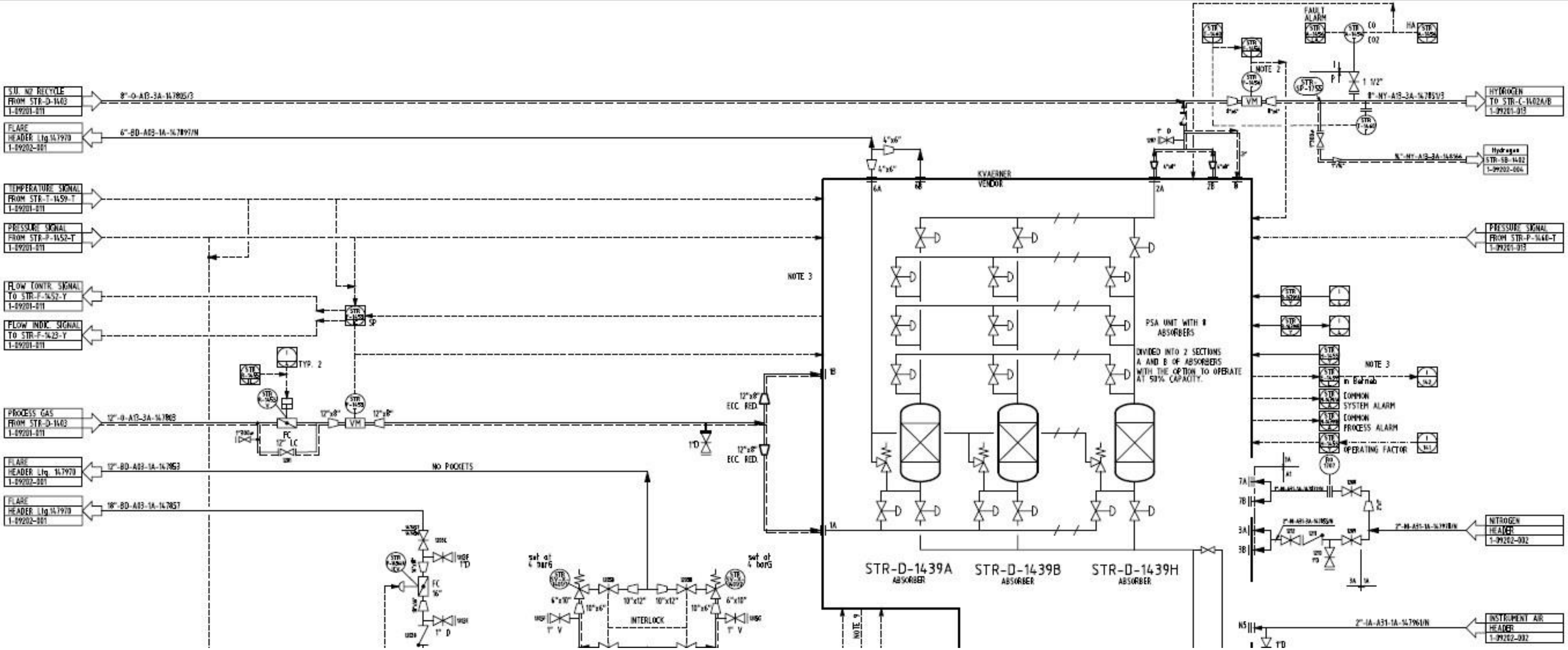
Leakage at the steam reformer piping system

HOLBORN EUROPA RAFFINERIE
GMBH

Affected piping system



Affected piping system



Technical details

Piping system

- Working pressure: 20 bar
- Working temperature: 30 °C
- Material: ASTM A105 /A 106 Gr. B
- Electrical heating system

Medium

Density 15 °C calc.	Kg/m³	0,46
Hydrogen	% (Mol)	75,3
Oxygen		<0,01
Nitrogen		<0,01
Carbonmonoxide		2,38
Carbondioxide		18,62
Methan		3,68

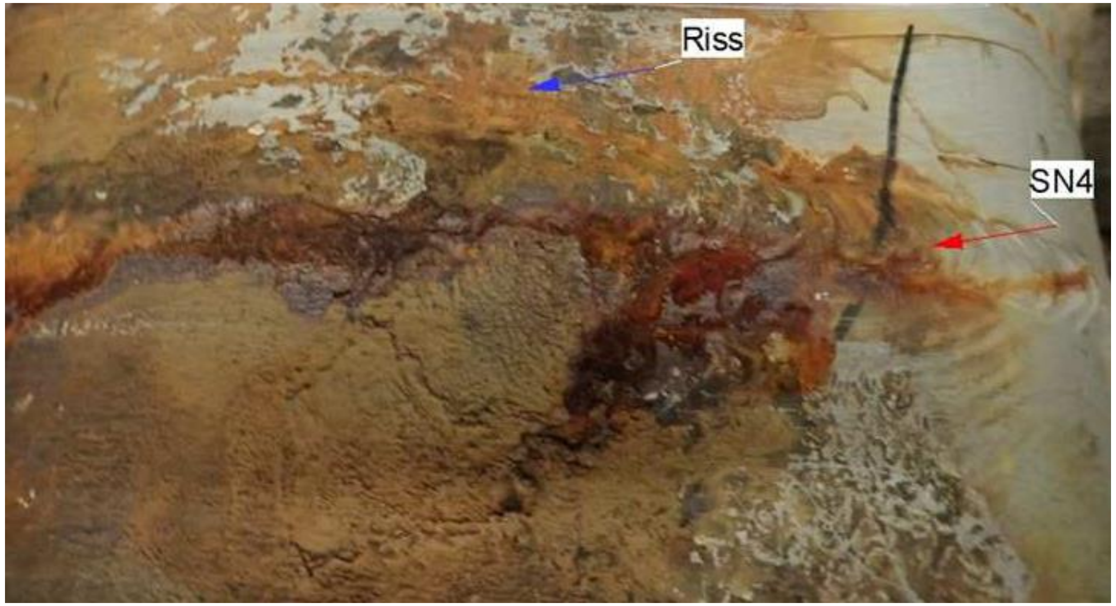
Leakages

Leakage 1

Leakage 2

Leakages

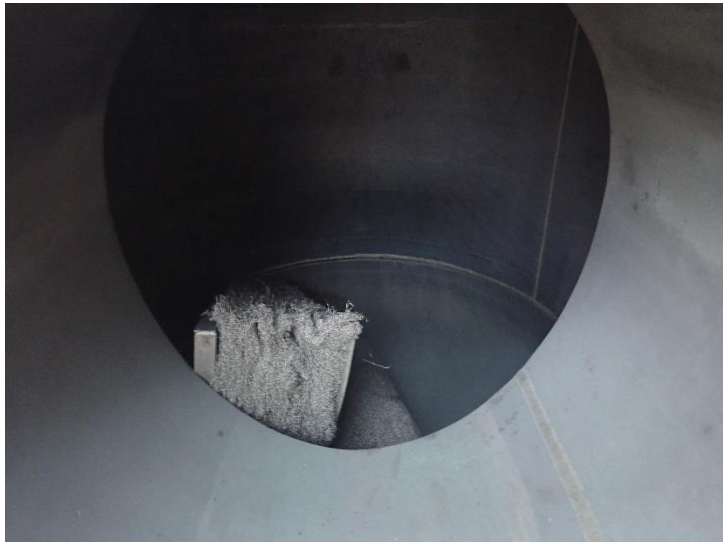
Leakage 1



Leakage 2

Result of root cause analysis:

- Demister of knock out drum STRD1403 was destroyed
- Without demister wet droplets were enabled to enter the subsequent line system causing stress corrosion cracking
- Root cause for destroyed demister in knock out drum: After 17 years in service without objections a thunderstorm in July 2019 (lightning strike near Steamreformer) triggered the emergency shut down of the plant causing a back flow in STRD1403 by sudden depressurizing




Appendix 10

Corrosivity of Stripped Sour Water: what are the most relevant corrosion related contaminants?

(M. De Marco)

ISTITUTO ITALIANO
DELLA SALDATURA

Il Gruppo

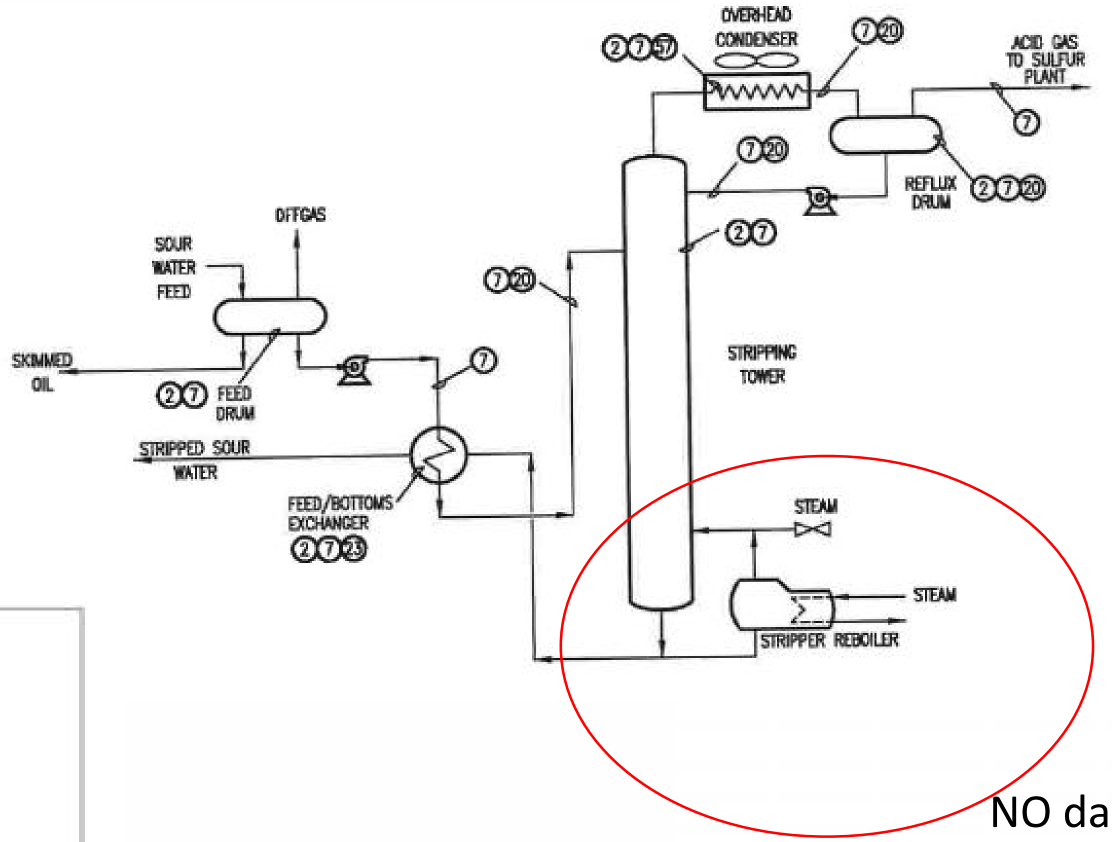
Corrosivity of Stripped Sour Water: what are the most relevant corrosion related contaminants?

Marco De Marco, IIS

Sour water stripper – Damage mechanisms

- ***Typical SWS UNIT***
- ***Damage mechanism defined by API 571***

- **Stripped sour water**
- T = 120 – 170 °C
- Typically High pH
- Low Sulfides (few ppm)
- Low ammonia (< 50 ppm)
- Low chlorides (few ppm?)
  - Cyanides?
  - Phenols?
  - OH – alkalinity (NaOH)
  - Others?



NO damage mechanisms

Key to Damage Mechanisms

- (2) Wet H_2S Damage (Blistering/HIC/SOHIC/SSC)
- (7) Ammonium Bisulfide
- (20) Erosion / Erosion-Corrosion
- (23) Chloride Stress Corrosion Cracking
- (57) Titanium Hydriding

Failure case #1

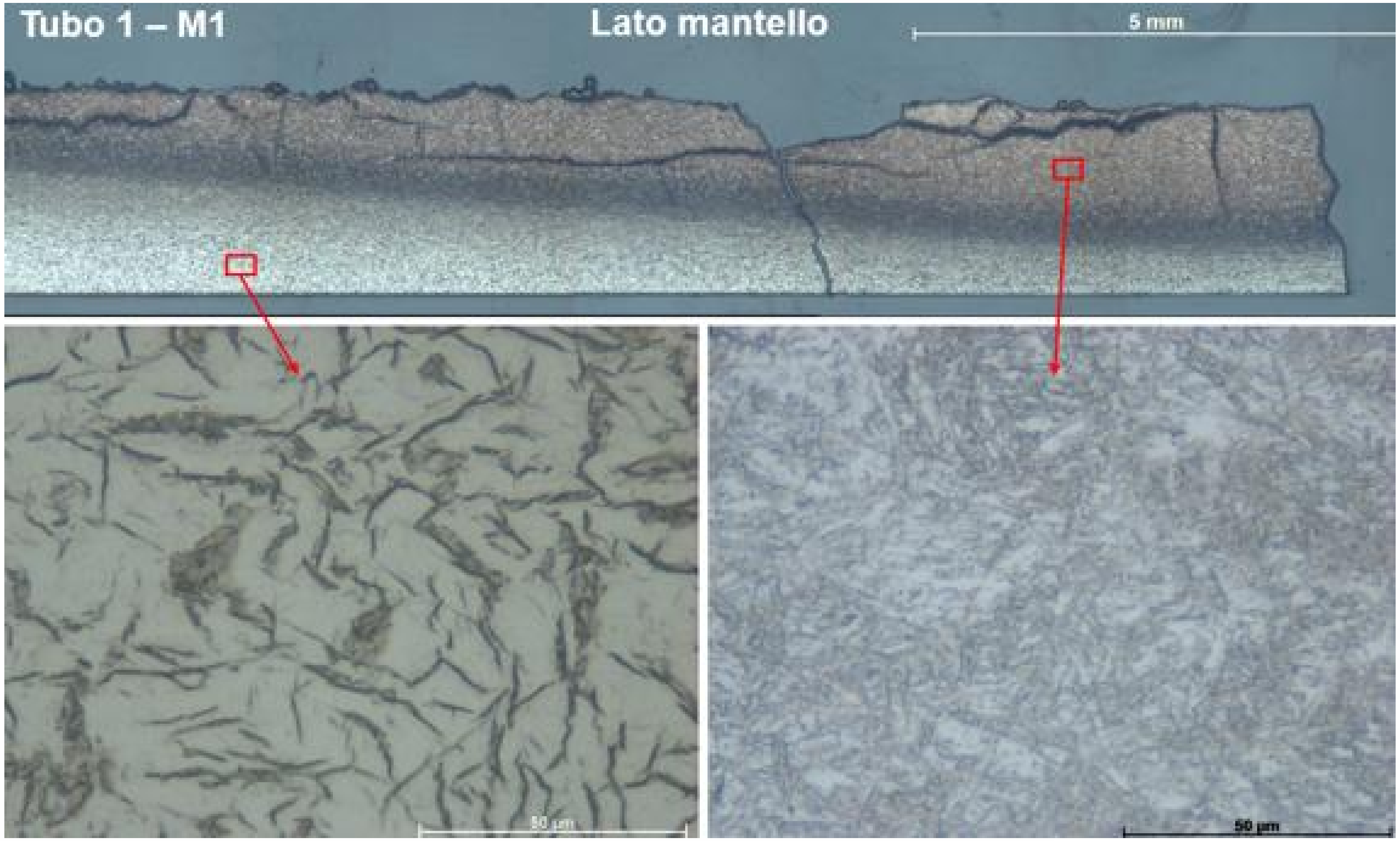
- ***SWS Column reboiler tube (NO KETTLE)***
- Material: titanium Gr. 7 (Pd alloyed….$!)
- Age: 5
- In past: carbon steel, 316 SS and Superduplex 2507 (max 5 years life)
- Service T: 170 °C
- Extensive damages in some specific area of the bundle
- Heavy deposits

Failure case #1

- ***Deposits and cracking***
- ***No evident metal loss***

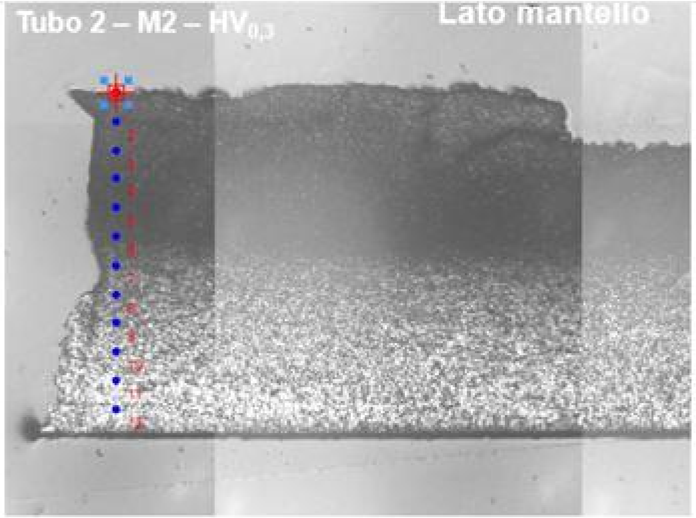
Failure case #1

- *Extensive cracking in the external surface (shell side)*
- *Metallurgical degradation*
- *Severe brittleness*

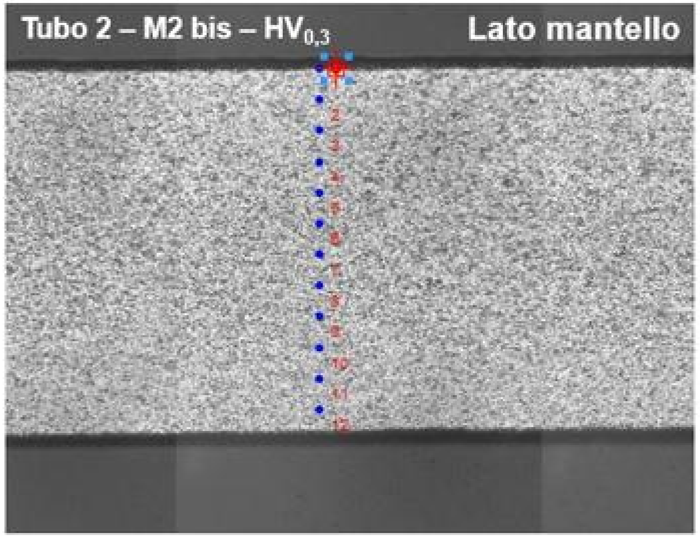


Failure case #1

- ***Hardness profiles revealed increased hardness in external surface of degraded zones***



1	253
2	254
3	250
4	263
5	246
6	238
7	215
8	220
9	205
10	198
11	193
12	184



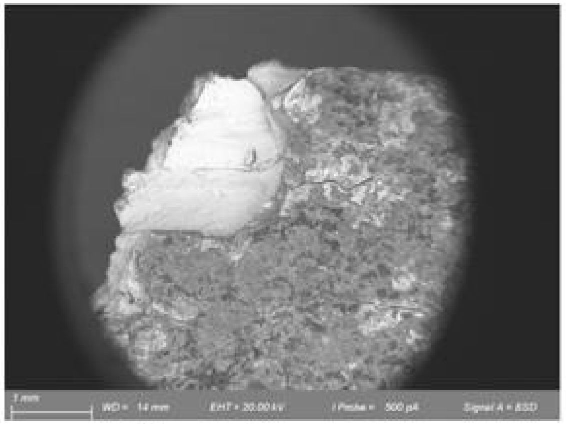
1	147
2	149
3	152
4	147
5	149
6	144
7	147
8	139
9	169
10	173
11	171
12	166

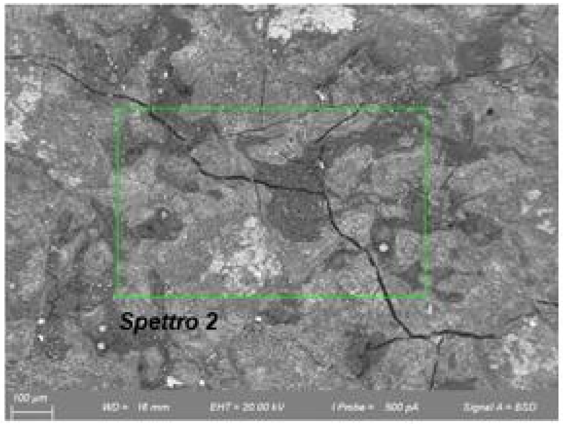
Failure case #1

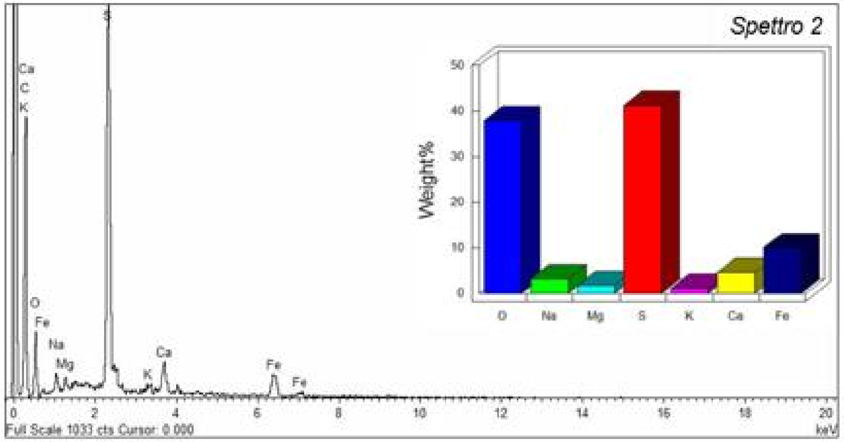
➢ ***Deposits water extract analysis***

Parameter	Results
pH (upH)	7,11
Chlorides (mg/kg)	620
Fluorides (mg/kg)	184
Phosphates (mg/kg)	< 50
Sulphates(mg/kg)	9070
Nitrates (mg/kg)	81,4
Nitrites(mg/kg)	18,3
Soluble Ammonium (mg/kg)	6,24
Calcium (mg/kg)	6007
Magnesium (mg/kg)	1127
Potassium (mg/kg)	178
Sodium (mg/kg)	2252

➢ ***SEM EDS***

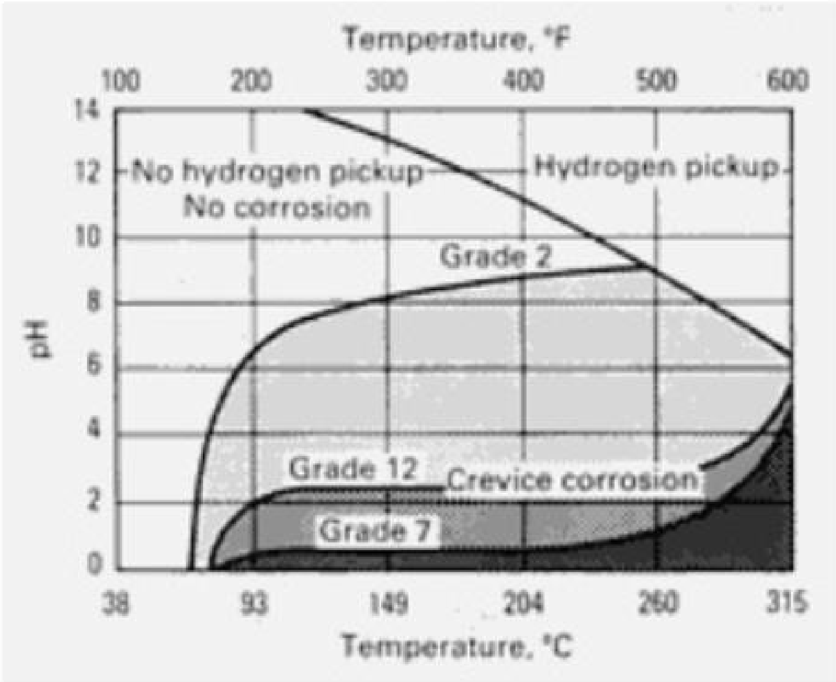






Failure case #1

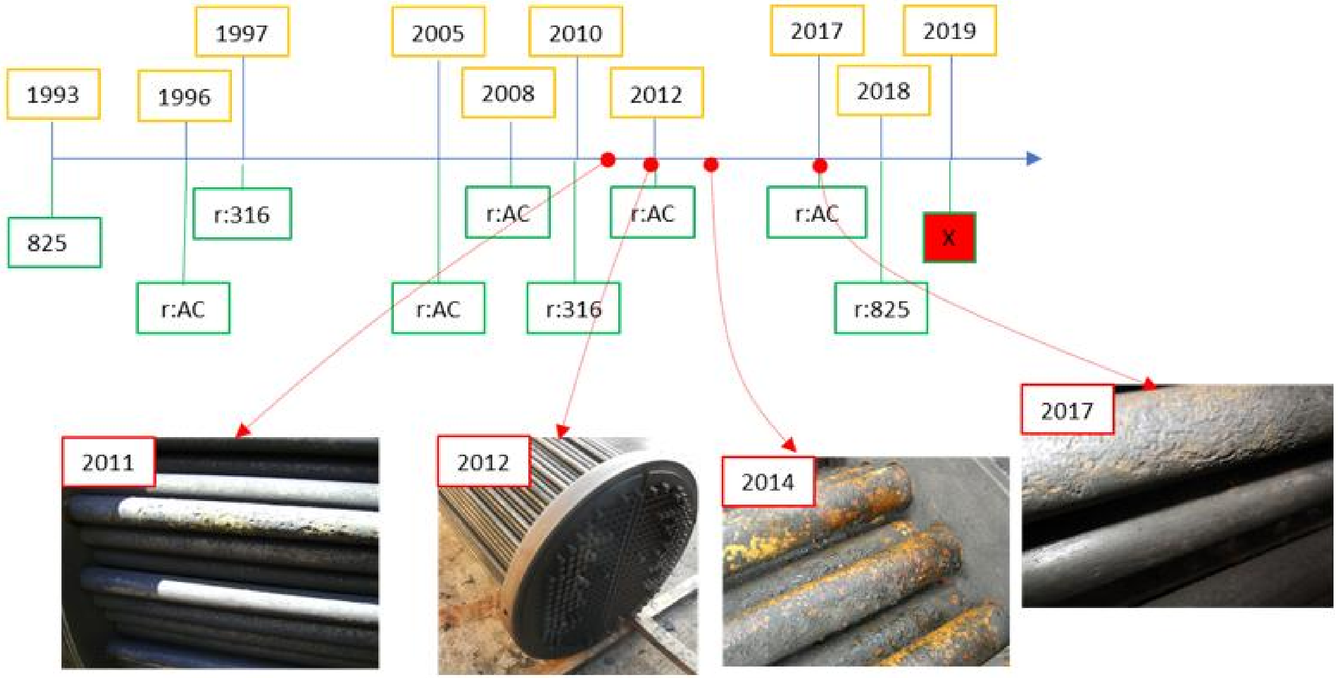
- Titanium brittleness
- Hydrides formation
- Corrosion/hydrogen pick-up in alkaline environment (supposed…no info about pH)
- Corrosion species: OH- alkalinity ? Other salts?
- Galvanic couple to 316 SS baffles?
- Fouling could have increased aggressive compounds concentration (e.g. alkalinity, salts) on external surface → Evaporation effects?



Failure case #2

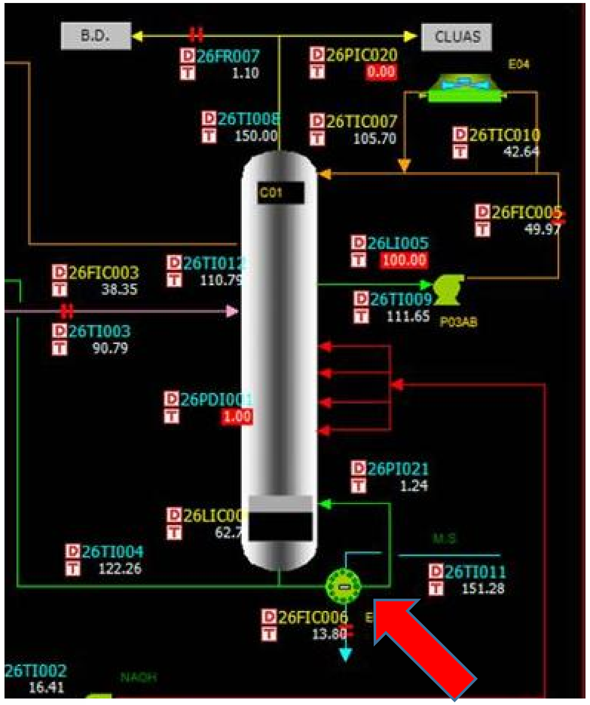
- ***SWS Column reboiler tube (NO KETTLE)***

- Material: Alloy 825 (different materials in the past)
- Service T: 170 °C
- Age: 12 months
- Extensive corrosion from process side



Failure case #2

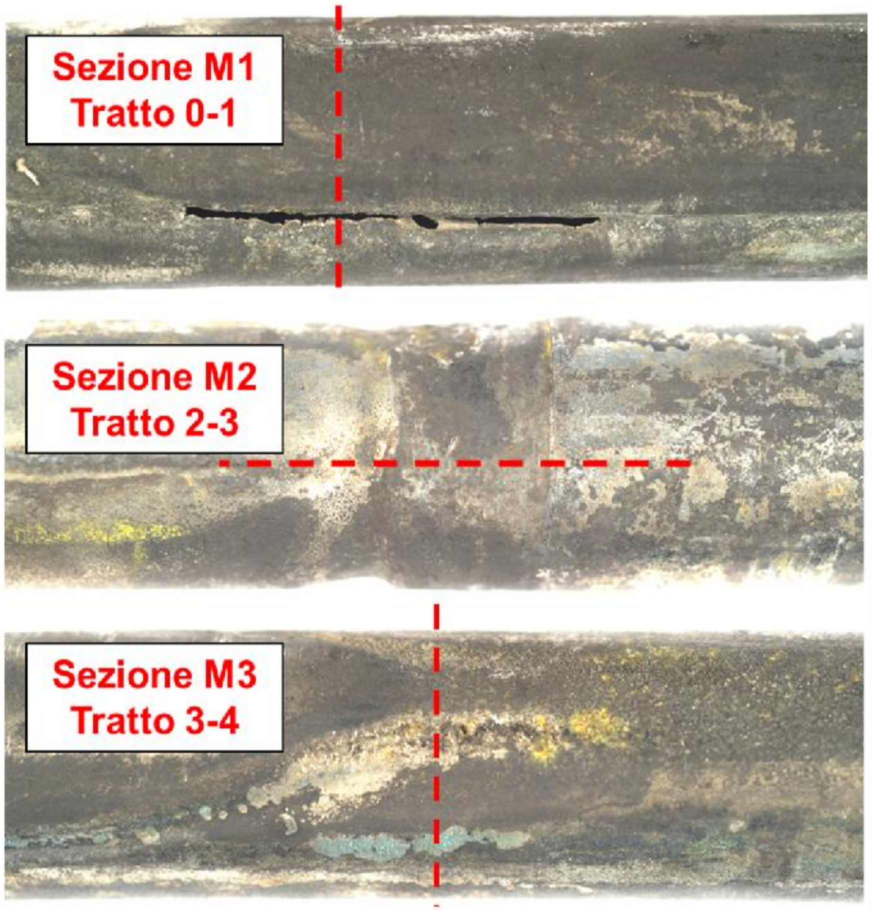
- Stripped sour water
- High pH (> 10)
- Low Sulfides
- Low ammonia
- Low chlorides
- Some Alkalinity
- No others specific analyses carried out

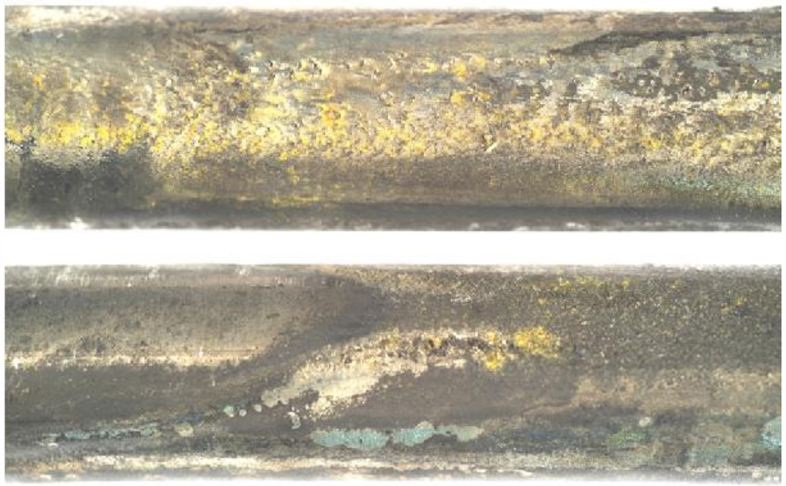


campione: ANCI#ACQUA_STRIPPATA_2600														
Analisi	[u.d.m.]	11/12/2019 03:00 200731731	11/12/2019 12:00 200731851	12/12/2019 03:00 200731886	12/12/2019 12:00 200731974	13/12/2019 03:00 200732022	13/12/2019 12:00 200732093	14/12/2019 03:00 200732129	15/12/2019 03:00 200732269	15/12/2019 12:00 200732349	16/12/2019 03:00 200732379	16/12/2019 12:00 200732468	17/12/2019 03:00 200732521	17/12/2019 12:00 200732602
pH	[---]	11,00	11,00	9,40	10,80	11,00	10,00	10,70	10,00	10,00	10,30	10,50		9,00
Solfuri in H2O	[ppm]	21	23	2	18	35	15	15	11	8	5	7		2
Azoto ammoniacale (come NH4)	[mg/l]	28,00		18,00		35,00		36,00	22,60		25,00			
Alcalinità Forte	[ppm]	105		78		140		124	95		95			
Azoto	[mg/l]													
Cloruri (come Cl-)	[mg/l]	5		8,8		6,4		<0.2	4,3		10,3			

Failure case #2

- ***External (shell side) corrosion attack upper rows of bundle***





Failure case #2

- ***SEM EDS examination***

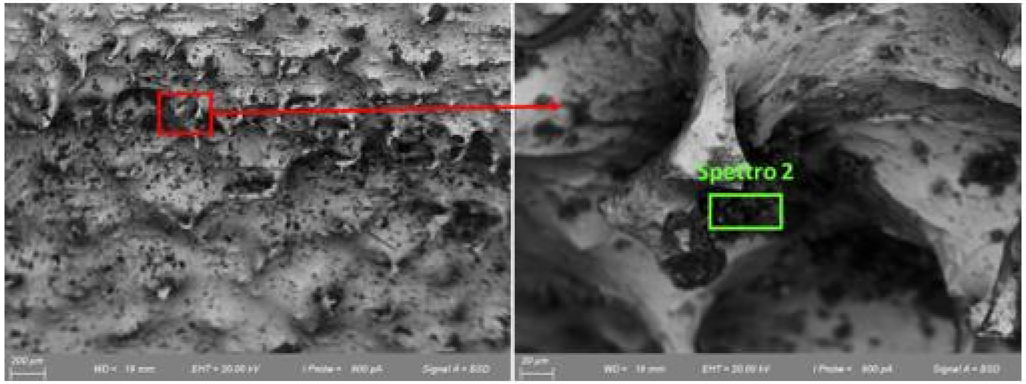
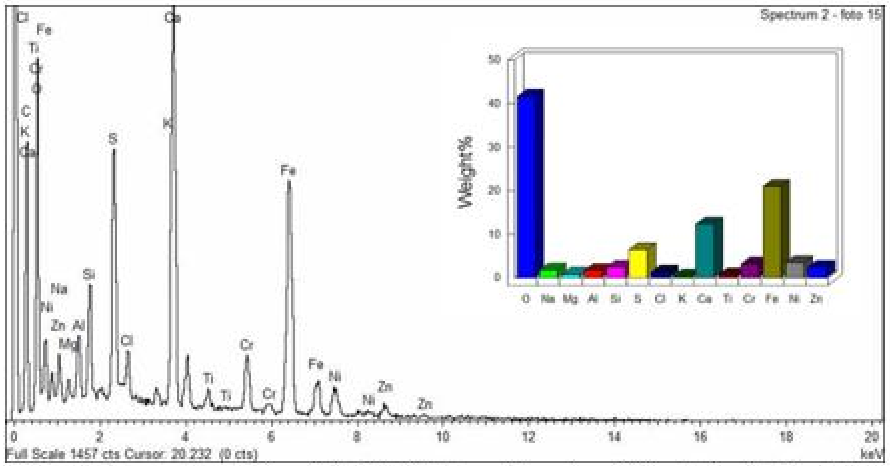


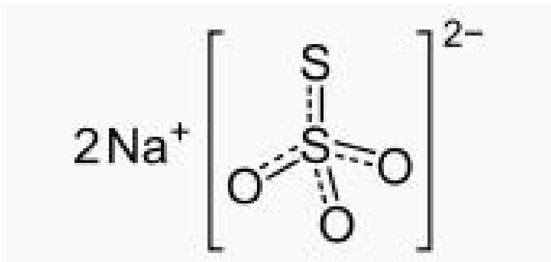
Fig. 3.3.3 – Dettaglio della superficie esterna del tubo (tratto 0-1) indagata mediante SEM-EDS



Failure case #2

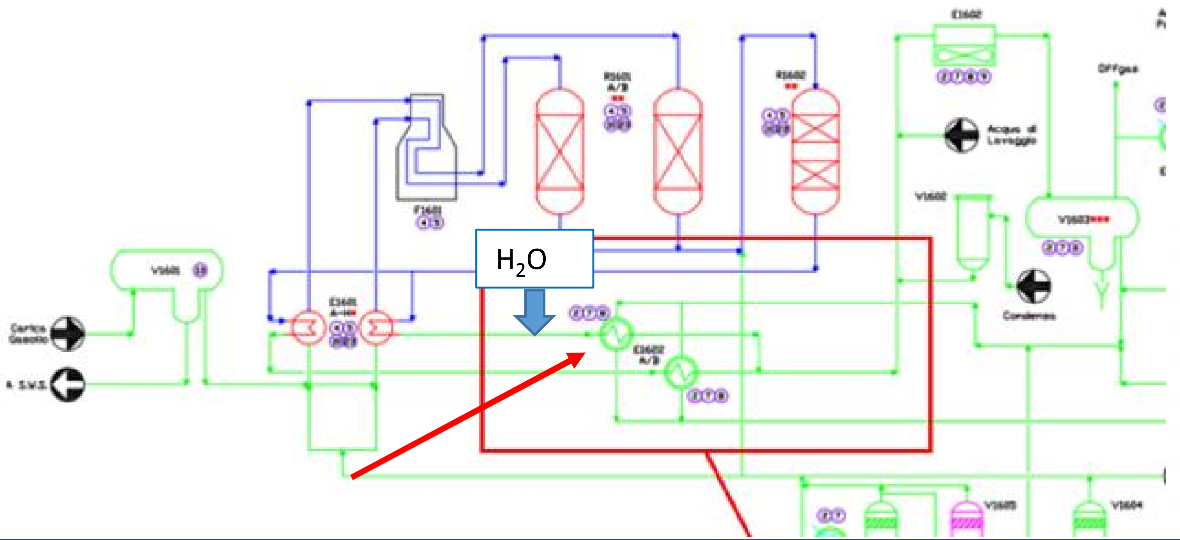
- Corrosion in alkaline environment
- Very high pH
- Incipient evaporation and aggressive compounds & concentrations effects (e.g. alkaline salts) on external surface of upper rows
- Which Corrosion species?
  - OH- alkalinity ? T and pH are high enough for alkaline corrosion under concentration evaporative effects
  - Cyanides? Chlorides? Phenols ?
  - Other corrosive salts? thiosulphates? Formates? …
- Heat Stable Salts (HSS) can be present in SWS (as in Amine solutions).
- Sodium salts? Neutralization of HSS by NaOH?
- Ammonia is stripped but in solution remain low volatile salts (corrosive?)

Sodium thiosulfate

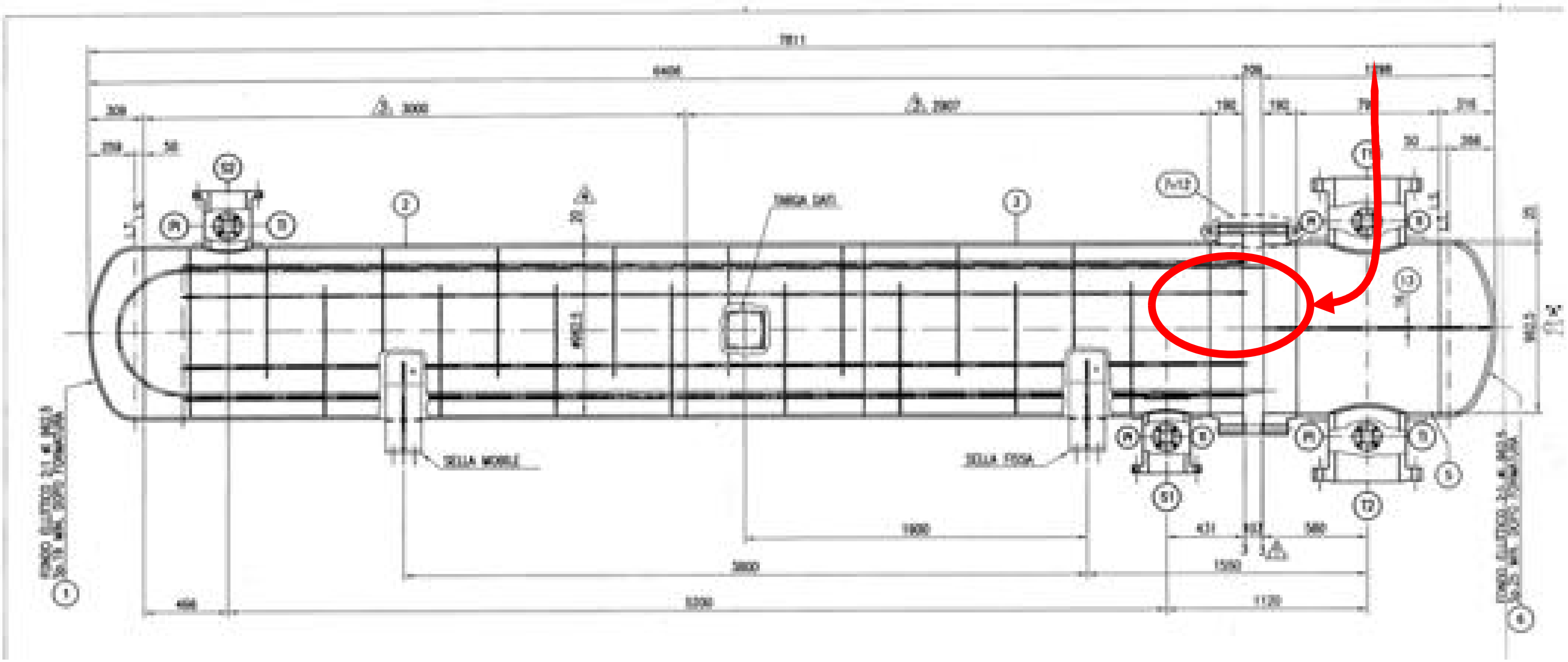


Failure case #3

- ***HDS effluent heat exchanger tube***
- Downstream of wash water injection point (Stripped sour water as washing water)
- Internal corrosion in the first rows (close to process fluid inlet → reactor effluent + SWS wash water)
- Material: carbon steel
- Service T: 170 °C (in) – 120 °C (out)
- Age: 10 years
- Corrosion more severe after wash water implementation

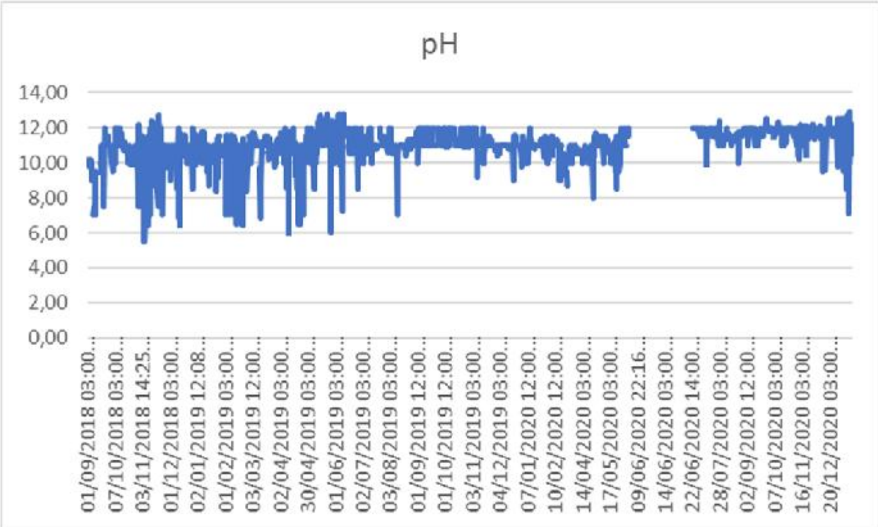


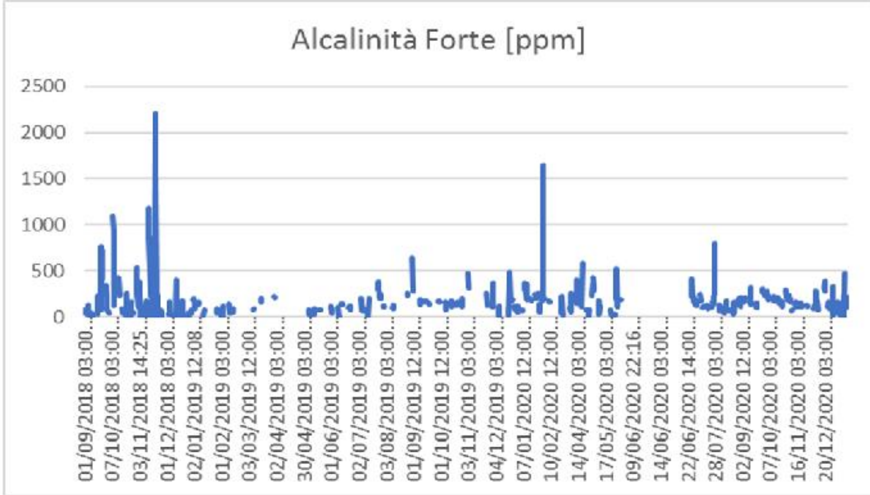
Failure case #3

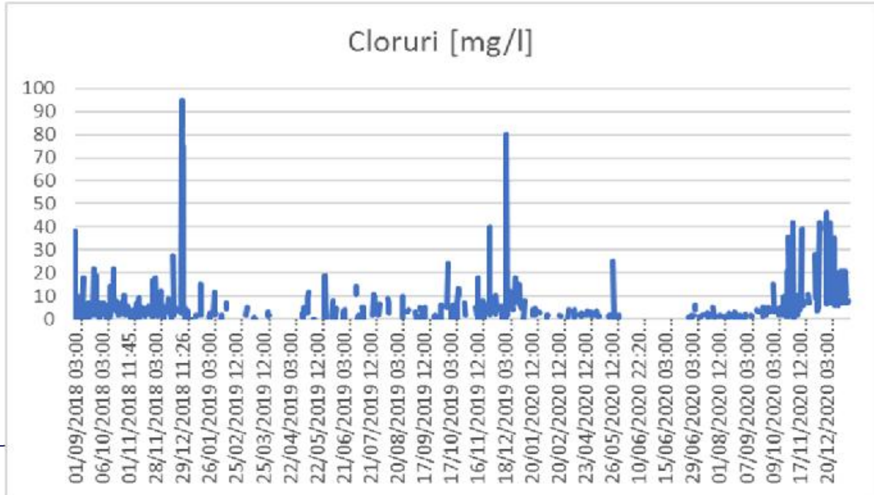


Failure case #3

- *Sws - High pH*
- *Average low chlorides*







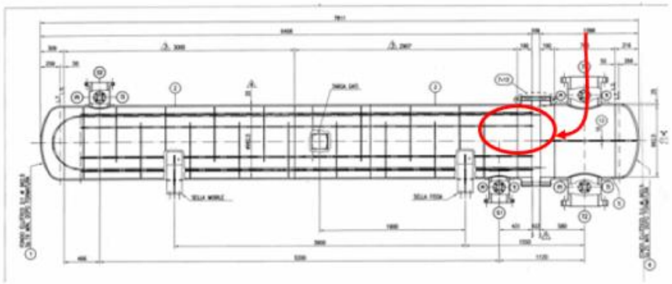
API Guidelines for HDS washing waters

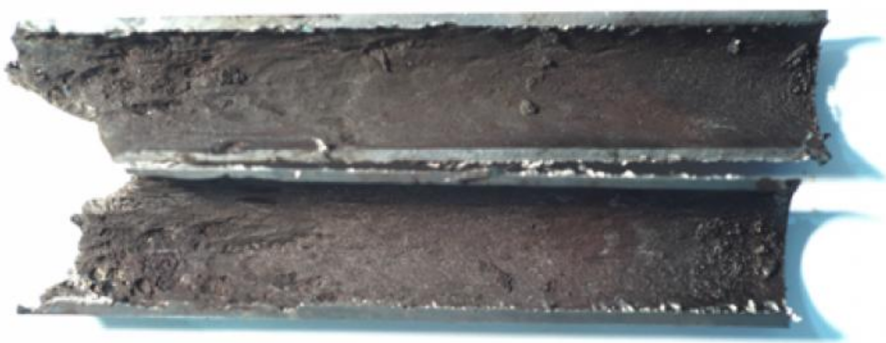
Parameter	Maximum	Desirable Target
Oxygen (ppbw)	50	15
pH	9.5	7.0 – 9.0
Total Hardness (ppmw as Ca hardness)	2	< 1
Dissolved Iron (ppmw)	1	0.1
Chlorides (ppmw)	100	5
H_2S (ppmw)	--	< 1000[a]
NH_3 (ppmw)	–	< 1000[a]
Free Cyanide (ppm)	–	0
Total Suspended Solids (ppm)	0.2	Nil

[a]Target and maximum concentrations are system-specific as H_2S and NH_3 are additive to the process stream concentrations.

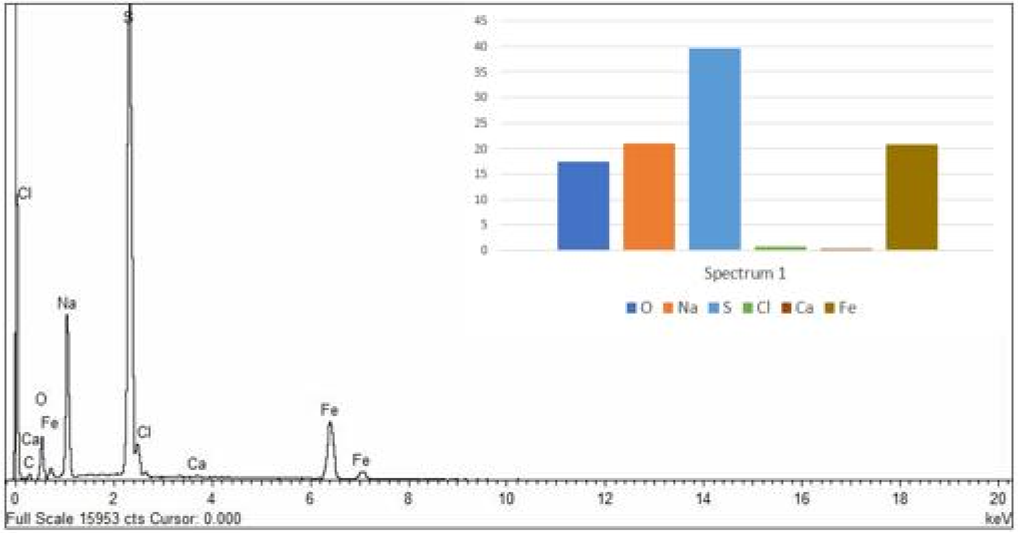
Failure cases

- ***Internal corrosion close to tubesheet (inlet area)***

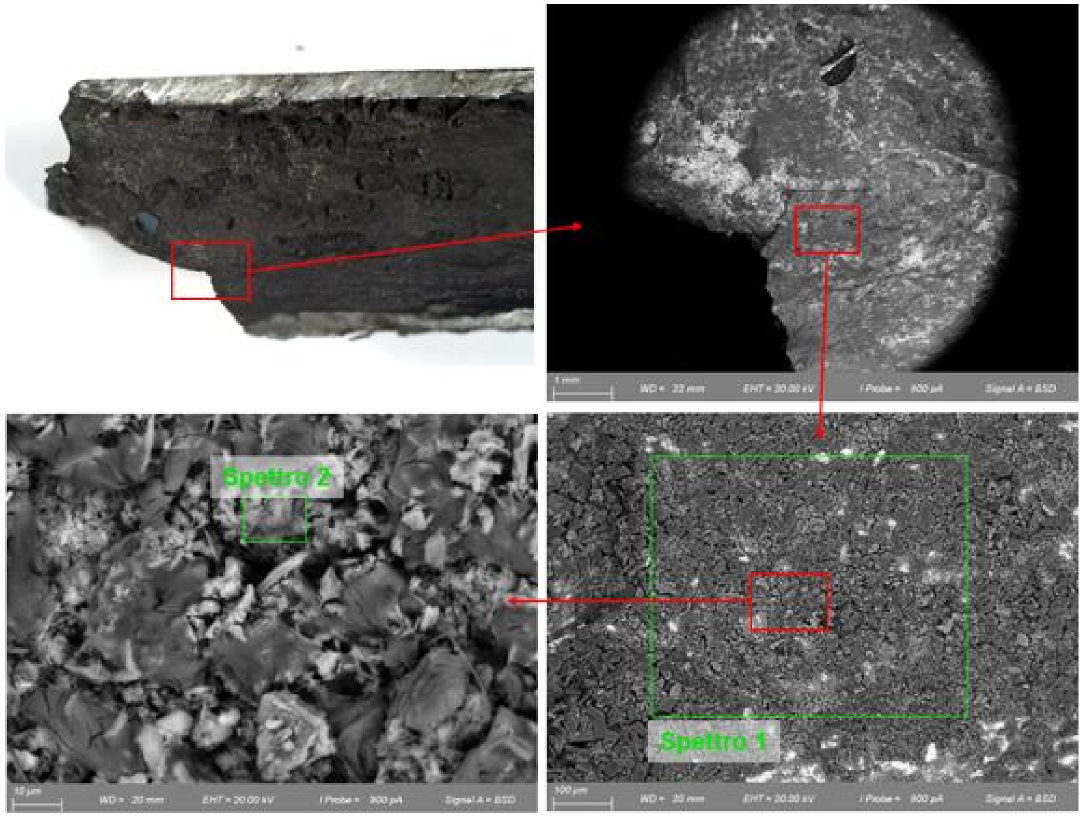




- ***SEM EDS***



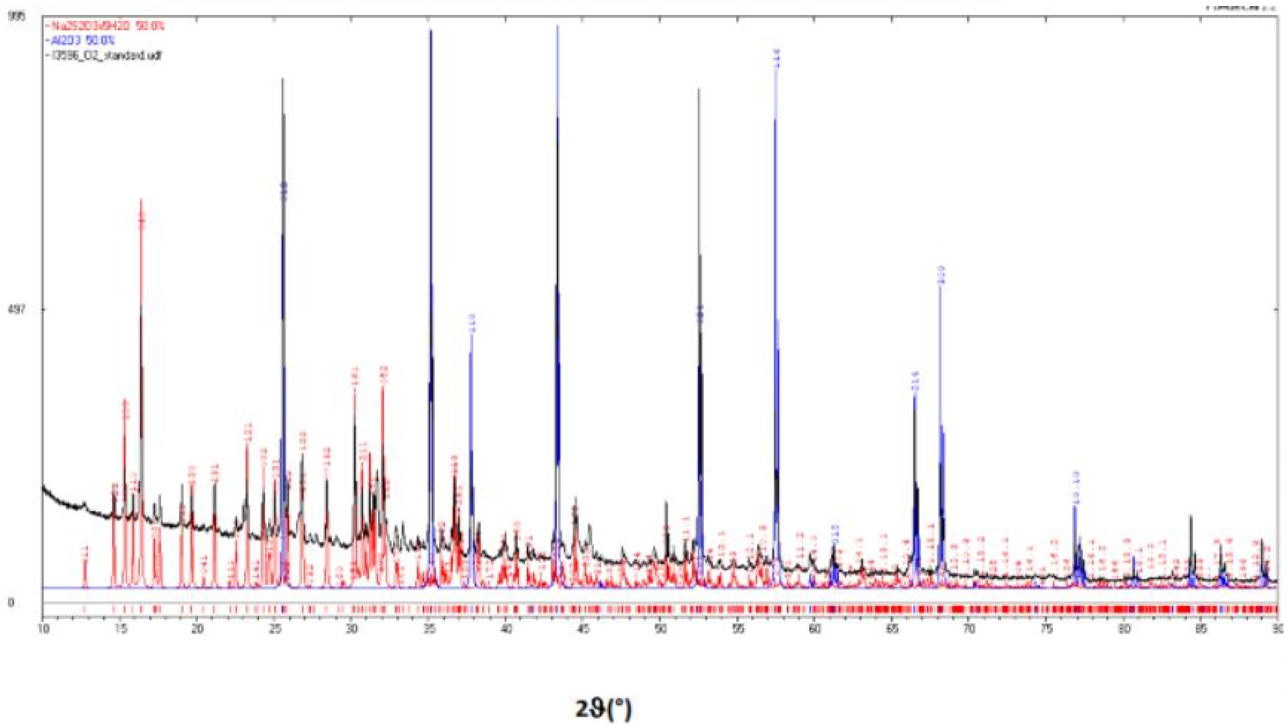
S
Cl
Na
O
Fe
Ca
C
Cl
Ca
Fe
Fe
0
2
4
6
8
10
12
14
16
18
20
keV
Full Scale 15953 cts Cursor: 0.000
Spectrum 1
O Na S Cl Ca Fe



Spettro 2
Spettro 1

Failure cases

- ***Deposits XRD***
- Al_2O_3
- $Na_2S_2O_3$ (sodium thiosulfate)



Failure cases

- ***Deposits Water extract***

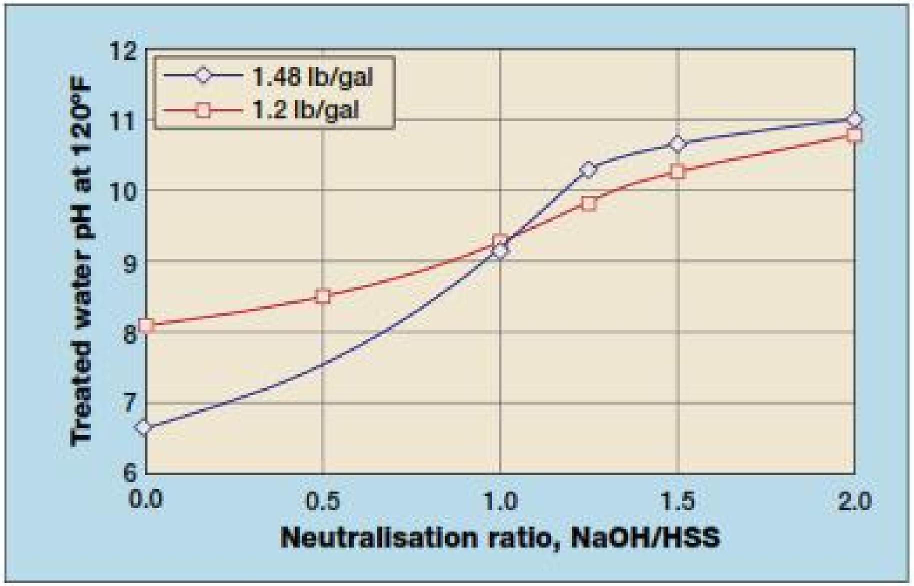
pH (upH)	9,20
Chlorides (mg/kg)	536
Fluorides (mg/kg)	353
Phosphates (mg/kg)	< 30
Sulphates (mg/kg)	12960
Nitrates (mg/kg)	14,2
Nitrites(mg/kg)	80,7
Ammonium soluble (mg/kg)	40,7
Calcium (mg/kg)	1,12
Magnesium (mg/kg)	< 0.50
Potassium (mg/kg)	938
Sodium (mg/kg)	6305

Failure cases

- Corrosion in alkaline environment
- Very high pH of injected water (> API guidelines)
- Partial water evaporation after injection and aggressive compounds concentrations effects (e.g. salts)
- Sour water injection accelerated corrosion; most probable cause of corrosion
  - OH- alkalinity ? T and pH are high enough for alkaline corrosion under concentration evaporative effect
  - Cyanides? Chlorides? Phenols ?
  - Other corrosive salts? thiosulphates? Formates? …
- Sodium salts? Neutralization of HSS by NaOH (sodium thiosulfate is corrosive to CS at high pH)

Mitigation?

- Reboiler tube bundles
  - Kettle type HX (less evaporation on tube)?
  - Control SWS pH , better control NaOH dosing (if possible…)
  - Use CRA with high Ni (for OH-) and Cr and Mo (for salts)
  - Perform periodic analysis of aggressive salts in SWS (HSS, cyanides, phenols…)



* Weiland – Hatcher 2012

Mitigation?

- HDS effluent HX
  - Change wash water type.
  - Change point of injection and feed rate
  - Perform periodic analysis of aggressive salts in SWS (HSS, cyanide, phenols…)
  - Perform analysis in separated water at cold separator in HDS

Appendix 11

Sanicro® 35, a new grade for demanding applications within the process industry

(Jonas Höwing)

SANICRO® 35

A NEW AUSTENITIC GRADE FOR DEMANDING APPLICATIONS

SAFETY FIRST

Sandvik's objective is zero harm to our people, the environment we work in, our customers and our suppliers.

PROTECTIVE EQUIPMENT

FIRST AID KIT

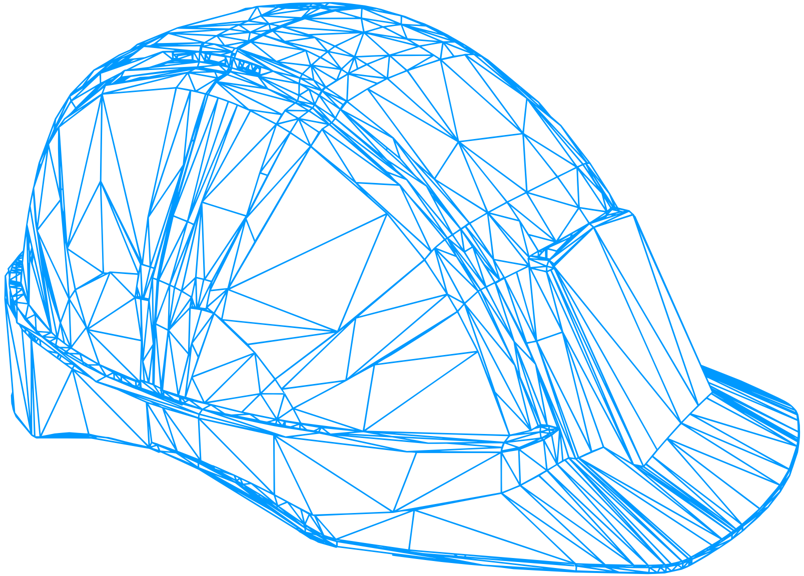
ALARM

EMERGENCY NUMBER

EMERGENCY EXIT

ASSEMBLY POINT

PSYCHOLOGICAL SAFETY



SANDVIK

AGENDA

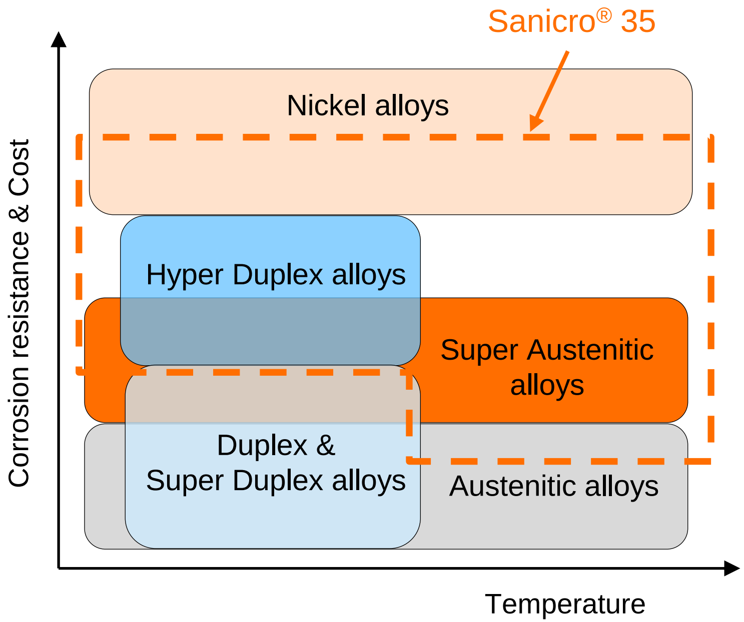
- Introduction
- Mechanical properties
- Corrosion properties
- Summary

SANICRO® 35 INTRODUCTION

SANDVIK

SANICRO® 35 – INTRODUCTION

TARGET AREA



FULLY INTEGRATED PRODUCTION

MELTING & BAR PRODUCTION

Sweden ☑

EXTRUSION

Sweden ☑

COLD WORKING & ANNEALING

Europe ☑

SANDVIK

SANICRO® 35

CHEMICAL COMPOSITION (NOMINAL)%

C	Mn	P	S	Si	Cr	Ni	Mo	Cu	N	Fe	PRE*
0.030	1.2	0.030	0.020	0.5	27	35	6.5	0.4	0.3	Remainder	≥52

*PRE = %Cr + 3.3×%Mo + 16×%N

BALANCED CHEMISTRY => HIGH STRUCTURAL STABILITY

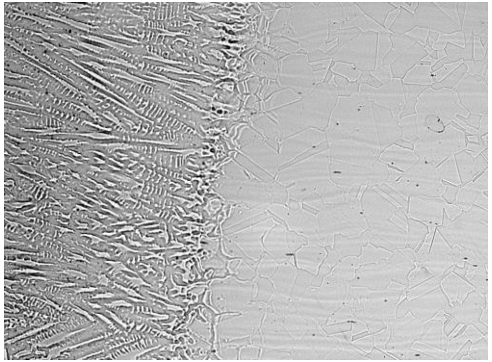
- Not prone to intermetallic phases or precipitates

SANDVIK

WELDABILITY

- Weldability verified in ASME IX testing
  - Welded joints excellent mechanical properties and corrosion resistance

- Welding recommendations
  - Filler metal Alloy 59 (ERNiCrMo-13, NiCr23Mo16).
  - TIG welding (GTAW).
  - Shielding/backing gas Ar+2-3% N_2
  - No preheating.
  - Interpass temperature max 100°C.
  - Heat input 1.2 kJ/mm.



SANDVIK

STANDARDS & APPROVALS

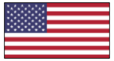
STANDARDS

- UNS N08935
- Compliance with NACE MR0175/ISO 15156-3:2015[1], for type 4a and type 4c materials.
- Compliance with ANSI/NACE MR0103/ISO 17495-1:2016[2] for high alloyed austenitic stainless steels and nickel alloys.

PRODUCT STANDARD

- Seamless tube and pipe: ASTM B163

APPROVALS



- ASME Code Case 2982. Boiler and Pressure Vessel Code, Section VIII, Division I and II.

- Pre-approval for Particular Material Appraisal (PMA), TÜV file 1326W043219

1) Petroleum, Petrochemical, and Natural Gas Industries - Materials for Use in H_2S-Containing Environments in Oil and Gas Production - Part 3: Cracking-Resistant CRAs (Corrosion-Resistant Alloys) and Other Alloys
2) Petroleum, petrochemical and natural gas industries-Metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments

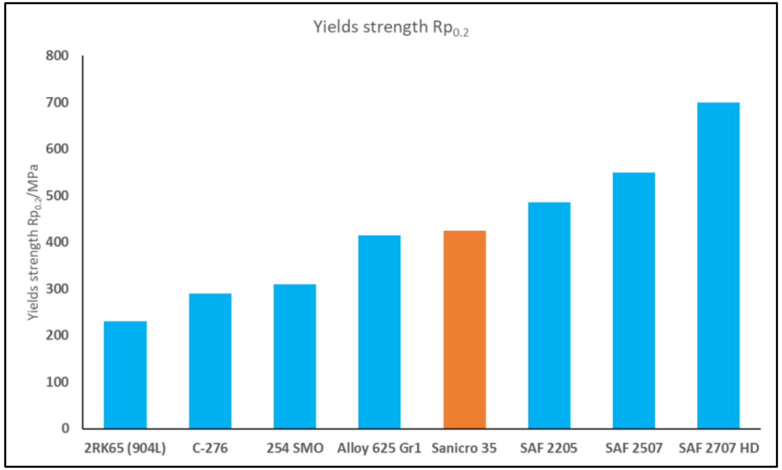
SANDVIK

SANICRO® 35 MECHANICAL PROPERTIES

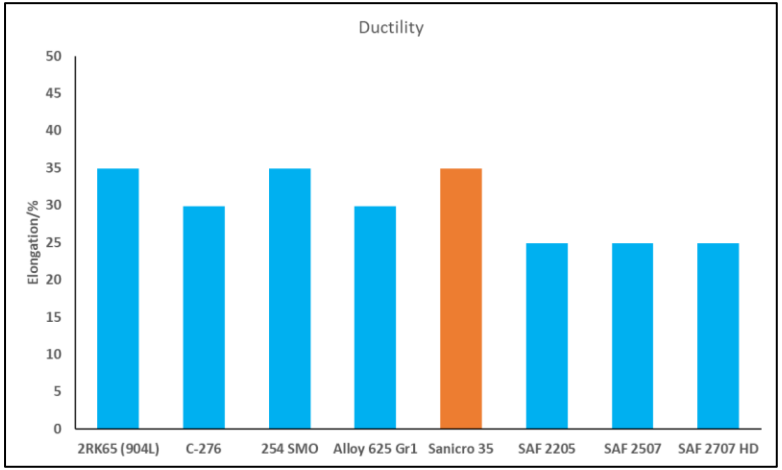
SANDVIK

MECHANICAL PROPERTIES

- Sanicro® 35 has $Rp_{0.2}$ = 425 MPa
  - High yield strength compared to austenitic stainless steels and nickel base alloys.



- Sanicro® 35 has $A_{2"}$ = 35%
  - Good ductility, comparable to austenitic stainless steel and better than nickel alloys.



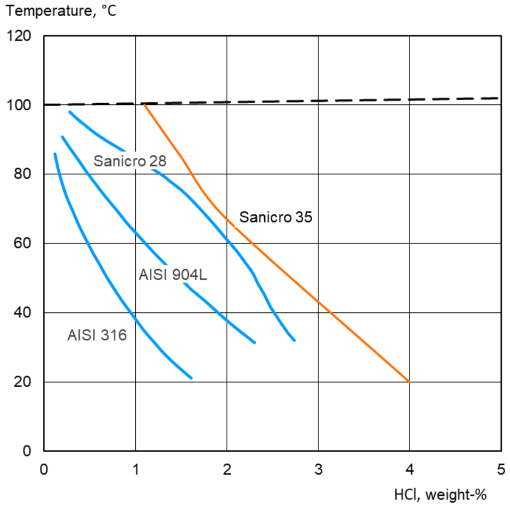
SANDVIK

SANICRO® 35 CORROSION PROPERTIES

GENERAL CORROSION

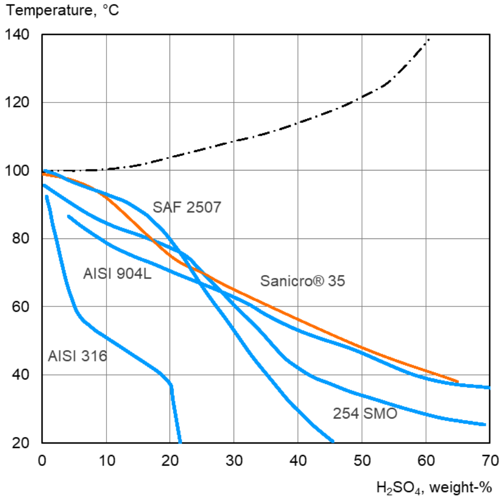
HYDROCHLORIC ACID

- Sanicro® 35 has good corrosion resistance towards hydrochloric acid.



SULPHURIC ACID

- Sanicro® 35 has good corrosion resistance towards sulphuric acid.



Iso-corrosion diagrams drawn at 0.1mm/y corrosion rate.

LOCALISED CORROSION

PITTING CORROSION

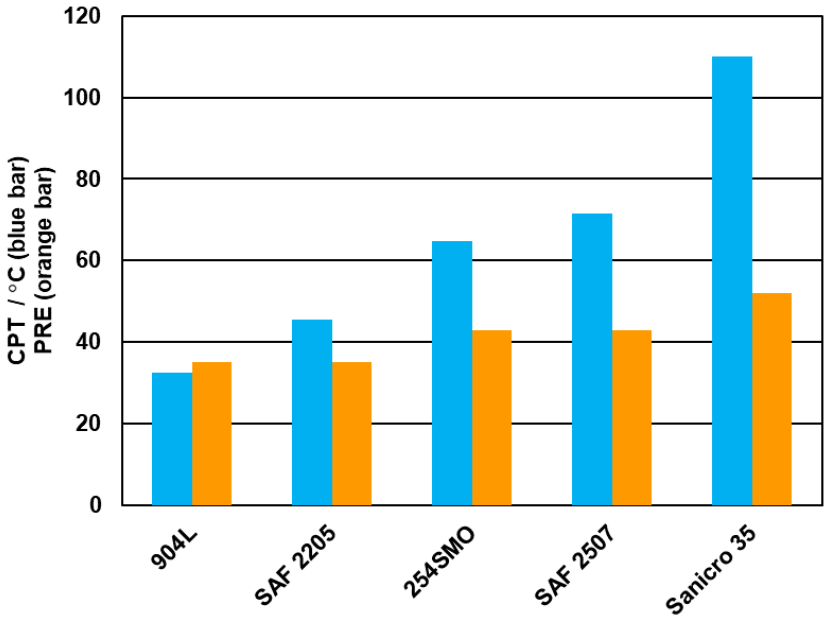
ASTM G150$_{mod}$

Electrochemical testing

3 M $MgCl_2$

- Higher chloride concentration
- Lower pH
- Higher boiling point

Polished samples (P600)



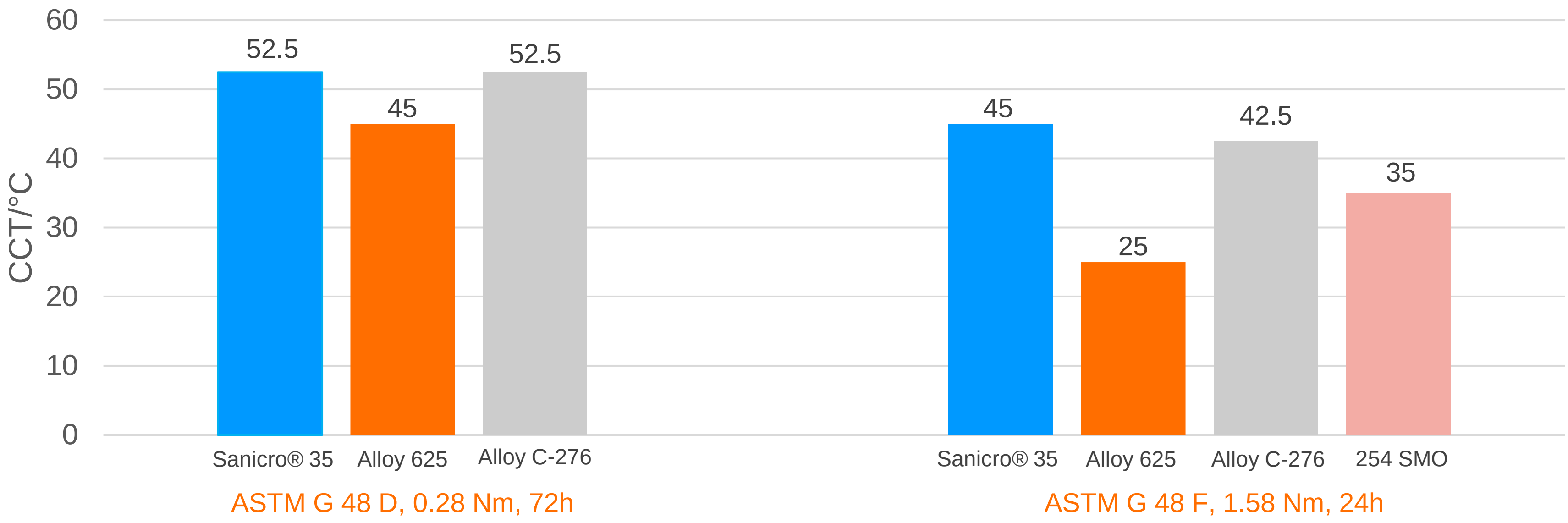
PRE = %Cr + 3.3x%Mo + 16x%N

[1]Corrosion 2018, “Comparison of Critical Pitting Temperatures of Stainless Steels in different Salt Solutions”, A. Delblanc *et al*, paper number 10846

CREVICE CORROSION PROPERTIES

ASTM G48 6% $FeCl_3$

GROUND SAMPLES (P120)



Crevice corrosion resistance of Sanicro® 35 higher than that of Alloy 625 and at least on par with C-276.

SEAWATER CORROSION TESTING

Seawater condition	Sanicro® 35		Alloy 625	
	Pitting	*Crevice*	*Pitting*	*Crevice*
30°C Natural	OK	OK	OK	Not OK
45°C chlorinated (0.5 ppm Cl)	OK	OK	OK	OK
80°C Chlorinated (0.5 ppm Cl)	OK	-	OK	-

- In natural seawater at 30ºC.
  - Sanicro® 35 has excellent pitting and crevice corrosion resistance
  - Showed better crevice corrosion resistance than Alloy 625
- In chlorinated seawater Sanicro® 35 is:
  - Resistant to crevice corrosion at 45ºC.
  - Resistant to pitting corrosion at 80ºC.

SANDVIK

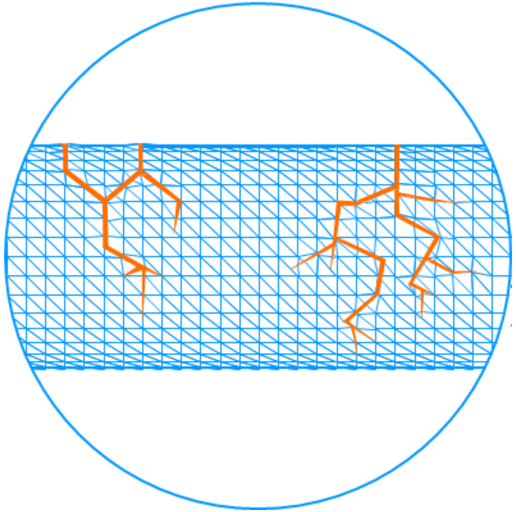
ENVIRONMENTAL INDUCED CRACKING

CHLORIDE STRESS CORROSION CRACKING

SCC Testing

- Test in 40% calcium chloride ($CaCl_2$) solution.
- 500 hours at constant load
- 90% of the actual ultimate tensile strength
- 100°C

➢ No cracking or corrosion.



SANDVIK

ENVIRONMENTAL INDUCED CRACKING

HYDROGEN EMBRITTLEMENT

- Test conditions:
  - Constant load at 100% and 120% of yield strength.
  - Applied potential = -1050 mV_{SCE}
  - 3% NaCl at 4°C.
- No cracking observed after 500h.
- Resistant to hydrogen induced stress cracking (HISC).

SOUR SERVICE

- H_2S testing at NACE Test Level VI.
  - Slow strain rate testing (SSRT).
    - Cold worked material 140 ksi & 180 ksi.
  - 500 psi H_2S
  - 500 psi CO_2
  - 20 wt-% NaCl
  - 175°C
- No indication of SCC.

NACE MR0175/ISO 15156-3:2015 Material Type 4a & 4c

SANDVIK

SANICRO® 35 SUMMARY

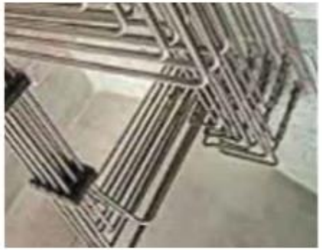
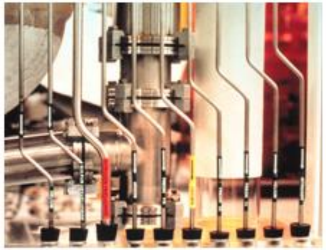
SANDVIK

SANICRO® 35 – A VERSATILE GRADE

- Multi-purpose grade:
  - Heat exchangers.
    - REAC's.
  - Hydraulic & instrumentation systems.
  - Process piping.

- Suitable for many different industries and conditions.

- Many product forms possible.
  - Available as seamless tubes for HX and H&I.
  - Plate and pipe is coming.


SANDVIK

BRIDGING THE GAP BETWEEN STAINLESS STEELS AND NICKEL ALLOYS

Appendix 12

Steam generator. eROI (water, energy, CO_2 emission saving) petrochemical plant case study

(Valerie Bour-Beucler)

Steam Generation Energy, Water and CO2 emission savings

Valerie Bour Beucler

EFC WP15 Spring Meeting 23/032021

Agenda

- Introduction of Nalco **e**$^{\mathbf{ROI}}$
- Presentation of calculation tool
- Case studies (refiney and petrochemical plant in Europe)
- Questions

e^{ROI} introduction

What is it?

Nalco e^{ROI} Environmental Return On Investment

Savings in renewable resources: FRESH WATER

Sustainability KPI #1: Volume of water saved (t/year)
Sustainability KPI #2: Value of water saved (€/year)
Sustainability KPI #3: Equivalence to human consumption (Water needs of number of people/year)

Savings in non-renewable resources: ENERGY

Sustainability KPI #1: Amount of electricity saved (kWh/year)
Sustainability KPI #2: Value of electricity saved (€/year)
Sustainability KPI #3: Equivalence to Scope 2 CO_2 emissions (tonnes/year)

Savings in non-renewable resources: PROTECTION OF ASSETS

Sustainability KPI #1: Reduction in corrosion rate (mpy) and scale formation
Sustainability KPI #2: Reduction in maintenance and downtime (days/year)
Sustainability KPI #3: Profit improvement and savings achieved (€/year)

BOILER ENERGY SAVINGS

NALCO

ENERGY STAR PARTNER

Boiler Energy & Water Savings

Company: Nalco

Plant:

City:

Boiler 1431

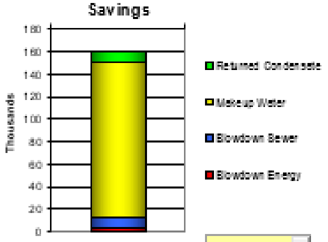
Attention:

Copy:

Date:

Prepared by:

NALCO Copy to:



€/year

Input Values

Input	SI Units	Value
Sewer Cost	l/m³	1.00
Make Up Water Cost	l/m³	6.00
Makeup Water Temp.	°C	25.0
Return Condensate Temp.	°C	80.0
Fuel Cost — natural gas	l/GJ	2.39
Boiler Efficiency	%	80.8%
Operating Days per Year	Days	365

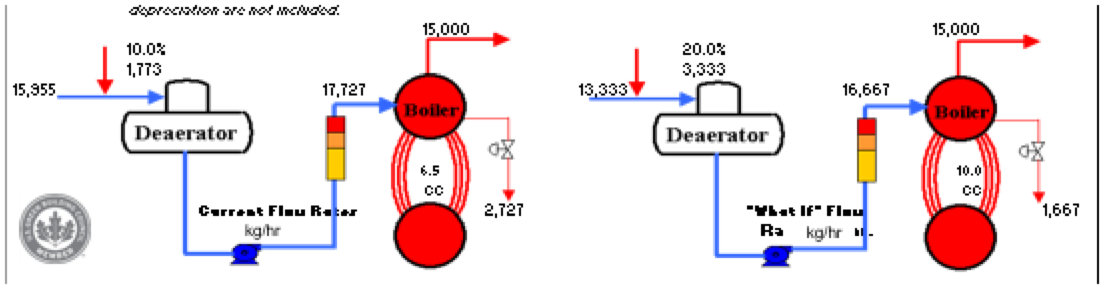
Boiler System Operation

		Current Operation	"What If" Analysis	Savings
		Value	Value	from Current
BD Heat Recovery	Yes or No	YES	yes	
Heat Recovery % Efficiency	%	80.0%	80.0%	
% Condensate Return	%	10.0%	20.0%	
Boiler Cycles	Cycles	6.5	10.0	
Steam Rate	kg/hr	15,000	15,000	
Steam Pressure	barg	9.0	9.0	
Steam Temperature	sat'd 180 °C	-	180	
Steam Enthalpy	kJ/kg	2,777	2,777	
Blowdown Enthalpy	kJ/kg	763	763	
Makeup Flow	kg/hr	15,955	13,333	2,621
Return Condensate Flow	kg/hr	1,773	3,333	(1,561)
Feedwater Flow	kg/hr	17,727	16,667	1,061
Blowdown Flow	kg/hr	2,727	1,667	1,061

Energy & Water Costs and Credits

Blowdown Energy Cost	l/year	9,300	5,684	3,617
Blowdown Sewer Cost	l/year	23,906	14,609	9,297
Makeup Water Cost	l/year	839,113	701,253	137,860
Sub Total (Costs)	**l/year**	**872,320**	**721,546**	**150,774**
Returned Condensate Fuel (Credit)	l/year	-10,577	-19,889	9,312
NET SAVINGS or (COSTS)	**l/year**	l/year		**160,085**
Calculated Cost of Steam*	l/1000 kg	14.46	13.24	1.22

NET CO_2 EMISSION SAVINGS (INCR)	fuel is natural gas	metric ton CO2 / yr	**270**
NET WATER SAVINGS (INCR)		Million liters / yr	**23.0**
NET ENERGY SAVING (INCR)		GJ /yr	**5,409**



DATA COLLECTION BEFORE CALCULATIONS

Input Values

Input	SI Units	Value
Sewer Cost	€/m³	
Make Up Water Cost	€/m³	
Makeup Water Temp.	°C	
Return Condensate Temp.	°C	
Fuel Cost — natural gas	€/GJ	
Boiler Efficiency	%	
Operating Days per Year	Days	

- #1 or #2 fuel oil
- #4, #5, or #6 fuel oil
- coal
- coke
- LPG
- natural gas
- waste heat

NOTE: US DOE Averages DOE 71563

Natural Gas	80.8%
Oil	84.7%
Coal	83.9%
Bark or chips	75.0%
Wood or paper	70.0%
Bagasse or refuse	70.0%

BOILER SIZE SPECIFIC TABLE (watertube)

HINT: Answer YES if you have a working BD Heat Exchanger and/or BD Flash tank hooked to the deaerator or LP Steam header. If Yes, fill in cell E27 below.

Boiler System Operation

		Current Operation
		Value
BD Heat Recovery CHANGE INPUT ->	Yes or No	
Heat Recovery % Efficiency		
% Condensate Return	%	
ADJUST CYCLES --->	Cycles	
Steam Rate	kg/hr	
Steam Pressure	barg	
Steam Temperature	sat'd 100 °C	
Steam Enthalpy	kJ/kg	2,676
Blowdown Enthalpy	kJ/kg	419
Makeup Flow	kg/hr	-
Return Condensate Flow	kg/hr	-
Feedwater Flow	kg/hr	-
Blowdown Flow	kg/hr	-

HINT: Use 90% for a CLEAN BD Heat Exchanger. For a system with only a BD Flash Tank connected to the Deaerator use 30 to 60%.

Note: this should include all condensate, including steam flow sent to a deaerator

HINT: Convert from Boiler Horsepower by multiplying by 15.6 to get kg/hr

HINT: Valid range is from 0 to 124 barg

HINT: CLEAR CELL or ENTER ZERO if you want to run saturated steam
Maximum is 787 C

"What If" Analysis
Value
-
-
100
2,676
419
-
-
-
-

FROM DATA TO CALCULATIONS

- Minimum of information to get from local management :
  - ✓ Sewer cost
  - ✓ Make up water cost and temperature
  - ✓ Combustible type and cost
  - ✓ Return condensate % and temperature
  - ✓ Steam rate and pressure
  - ✓ Blowdown Flash tank or blowdown heat exchanger?

NALCO

ENERGY STAR PARTNER

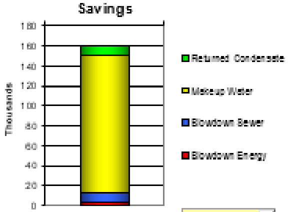
Boiler Energy & Water Savings

Company:
Plant:
City:
Attention:
Copy:

Date:
Prepared by:
NALCO Copy to:

Input Values

Input		SI Units	Value
Sewer Cost		l/m	1.00
Make Up Water Cost		l/m	6.00
Makeup Water Temp.		'C	25.0
Return Condensate Temp.		'C	80.0
Fuel Cost	natural gas	l/GJ	2.39
Boiler Efficiency		%	80.8%
Operating Days per Year		Days	365



€/year

Boiler System Operation

		Current Operation	"What If" Analysis	Savings
		Value	Value	from Current
BD Heat Recovery	Yes or No	YES	yes	
Heat Recovery % Efficiency	%	80.0%	80.0%	
% Condensate Return	%	10.0%	20.0%	
Boiler Cycles	Cycles	6.5	10.0	
Steam Rate	kg/hr	15,000	15,000	
Steam Pressure	barg	9.0	9.0	
Steam Temperature	sat'd 180 'C	-	180	
Steam Enthalpy	kJ/kg	2,777	2,777	
Blowdown Enthalpy	kJ/kg	763	763	
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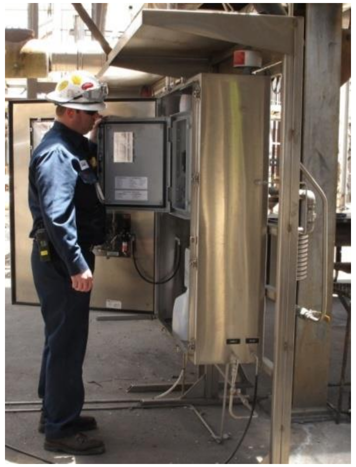
Returned Condensate Fuel (Credit)	l/year	-10,577	-19,889	9,312
NET SAVINGS or (COSTS)	**l/year**	l/year		**160,085**
Calculated Cost of Steam*	l/1000 kg	14.46	13.24	1.22

NET CO_2 EMISSION SAVINGS (INCR)	fuel is natural gas	metric ton CO2 / yr	**270**
NET WATER SAVINGS (INCR)		Million liters / yr	**23.0**
NET ENERGY SAVING (INCR)		GJ /yr	**5,409**

HOW TO ACHIEVE CALCULATED SAVINGS

- System audit
- Automation
  - Automated blowdown
  - Traced chemistry
    - Internal treatment
  - Oxygen scavenger injection on demand
- Pre treatment improvement
- Condensates system audit
- Communication
- Monitoring
  - Dissolved oxygen monitoring
  - pH and conductivity

CASE OF SOUTH OF EUROPE REFINERY



Company:

Plant:

City:

Attention:

Copy:

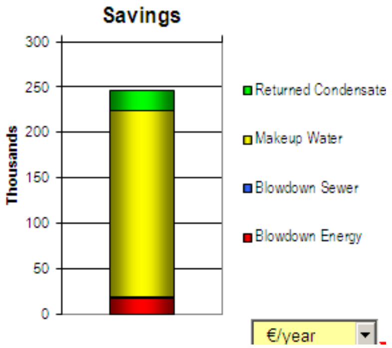
Date:

Prepared by:

NALCO Copy to:

Input Values

Input		SI Units	Value
Sewer Cost		€/m³	0.25
Make Up Water Cost		€/m³	6.00
Makeup Water Temp.		°C	12.0
Return Condensate Temp.		°C	90.0
Fuel Cost	natural gas	€/GJ	2.00
Boiler Efficiency		%	80.0%
Operating Days per Year		Days	270



€/year

Boiler System Operation

		Current Operation	"What If" Analysis	Savings
		Value	Value	from Current
BD Heat Recovery	Yes or No	NO	NO	
Heat Recovery % Efficiency				
% Condensate Return	%	30.0%	40.0%	
Boiler Cycles	Cycles	25.0	50.0	
Steam Rate	kg/hr	45,000	45,000	
Steam Pressure	barg	60.0	60.0	
Steam Temperature	sat'd 277 °C		277	
Steam Enthalpy	kJ/kg	2,784	2,784	
Blowdown Enthalpy	kJ/kg	1,220	1,220	
Makeup Flow	kg/hr	32,813	27,551	5,261
Return Condensate Flow	kg/hr	14,063	18,367	(4,305)
Feedwater Flow	kg/hr	46,875	45,918	957
Blowdown Flow	kg/hr	1,875	918	957

CASE OF SOUTH OF EUROPE REFINERY

Energy & Water Costs and Credits

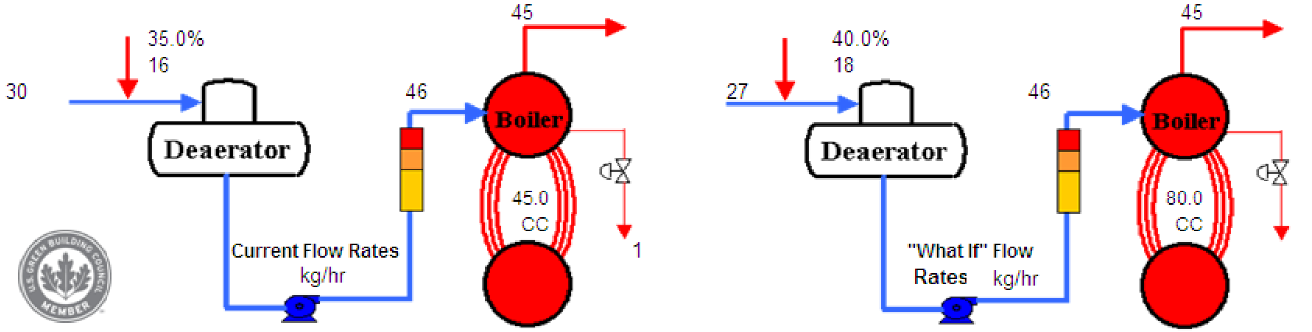
Blowdown Energy Cost	€/year	35,517	17,396	18,121
Blowdown Sewer Cost	€/year	3,039	1,489	1,551
Makeup Water Cost	€/year	1,276,575	1,071,876	204,699
Sub Total (Costs)	**€/year**	**1,315,131**	**1,090,761**	**224,370**
Returned Condensate Fuel (Credit)	€/year	-74,397	-97,171	22,775
NET SAVINGS or (COSTS)	**€/year**	€/year		**247,145**
Calculated Cost of Steam*	€/1000 kg	11.09	10.24	0.85

NET CO_2 EMISSION SAVINGS (INCR) fuel is natural gas metric ton CO2 / yr **1,020**

Comments:

Cycles optimisation depends for a big part of silica 'pollution'. Return condensate optimisation depends of their quality after steam use

**Includes only fuel, cost of water, and cost of blowdown sewer. Chemical treatment, maintenance, labor, and depreciation are not included.*



NALCO Water
An Ecolab Company

Case of South of Europe petrochemical plant

NALCO

ENERGY STAR PARTNER

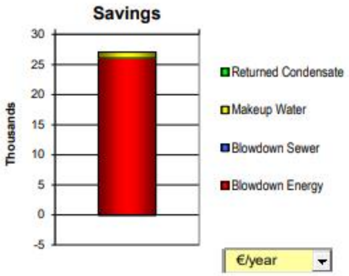
Boiler Energy & Water Savings

Company:
Plant:
City:
Attention:
Copy:

Date: **17-juin-20**
Prepared by: **Valerie Bour Beucler**
NALCO Copy to:

Input Values

Input	SI Units	Value
Sewer Cost	€/m³	0,00
Make Up Water Cost	€/m³	0,20
Makeup Water Temp.	°C	15,0
Return Condensate Temp.	°C	70,0
Fuel Cost natural gas	€/GJ	4,28
Boiler Efficiency	%	83,0%
Operating Days per Year	Days	325



Boiler System Operation

		Current Operation	"What If" Analysis	Savings
		Value	Value	from Current
BD Heat Recovery CHANGE INPUT ->	Yes or No	no		
Heat Recovery % Efficiency		80,0%		
% Condensate Return	%	21,8%	23,0%	
Boiler Cycles	Cycles	13,0	37,0	
Steam Rate	kg/hr	11 650	11 650	
Steam Pressure	barg	36,0	36,0	
Steam Temperature	super heat °C	395	395	
Steam Enthalpy	kJ/kg	3 138	3 138	
Blowdown Enthalpy	kJ/kg	1 064	1 064	
Makeup Flow	kg/hr	9 866	9 220	646
Return Condensate Flow	kg/hr	2 755	2 754	1
Feedwater Flow	kg/hr	12 621	11 974	647
Blowdown Flow	kg/hr	971	324	647

Energy & Water Costs and Credits

Blowdown Energy Cost	€/year	39 110	13 037	26 073
Blowdown Sewer Cost	€/year	0	0	0
Makeup Water Cost	€/year	15 400	14 392	1 008
Sub Total (Costs)	**€/year**	**54 510**	**27 429**	**27 082**
Returned Condensate Fuel (Credit)	€/year	-25 518	-25 507	-11
NET SAVINGS or (COSTS)	**€/year**	€/year		**27 071**
Calculated Cost of Steam*	€/1000 kg	16,17	15,88	0,30

Energy & Water Costs and Credits

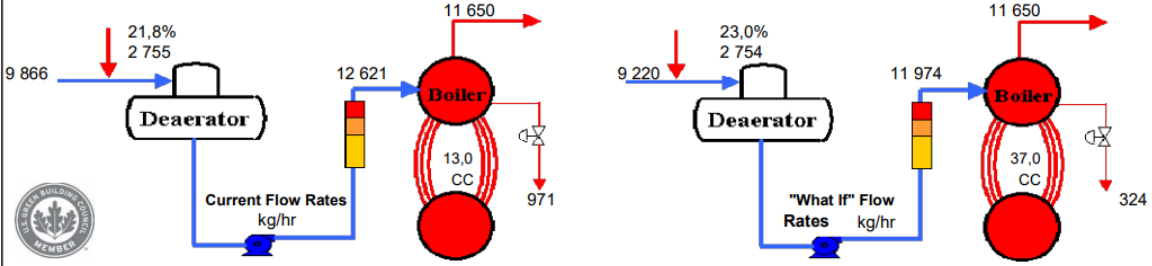
Blowdown Energy Cost	€/year	39 110	13 037	26 073
Blowdown Sewer Cost	€/year	0	0	0
Makeup Water Cost	€/year	15 400	14 392	1 008
Sub Total (Costs)	**€/year**	**54 510**	**27 429**	**27 082**
Returned Condensate Fuel (Credit)	€/year	-25 518	-25 507	-11
NET SAVINGS or (COSTS)	**€/year**	€/year		**27 071**
Calculated Cost of Steam*	€/1000 kg	16,17	15,88	0,30

air water energy

NET CO_2 EMISSION SAVINGS (INCR)	fuel is natural gas	metric ton CO2 / yr	**304**
NET WATER SAVINGS (INCR)		Million liters / yr	**5,0**
NET ENERGY SAVING (INCR)		GJ /yr	**6 089**

Comments:

Includes only fuel, cost of water, and cost of blowdown sewer. Chemical treatment, maintenance, labor, and depreciation are not included.



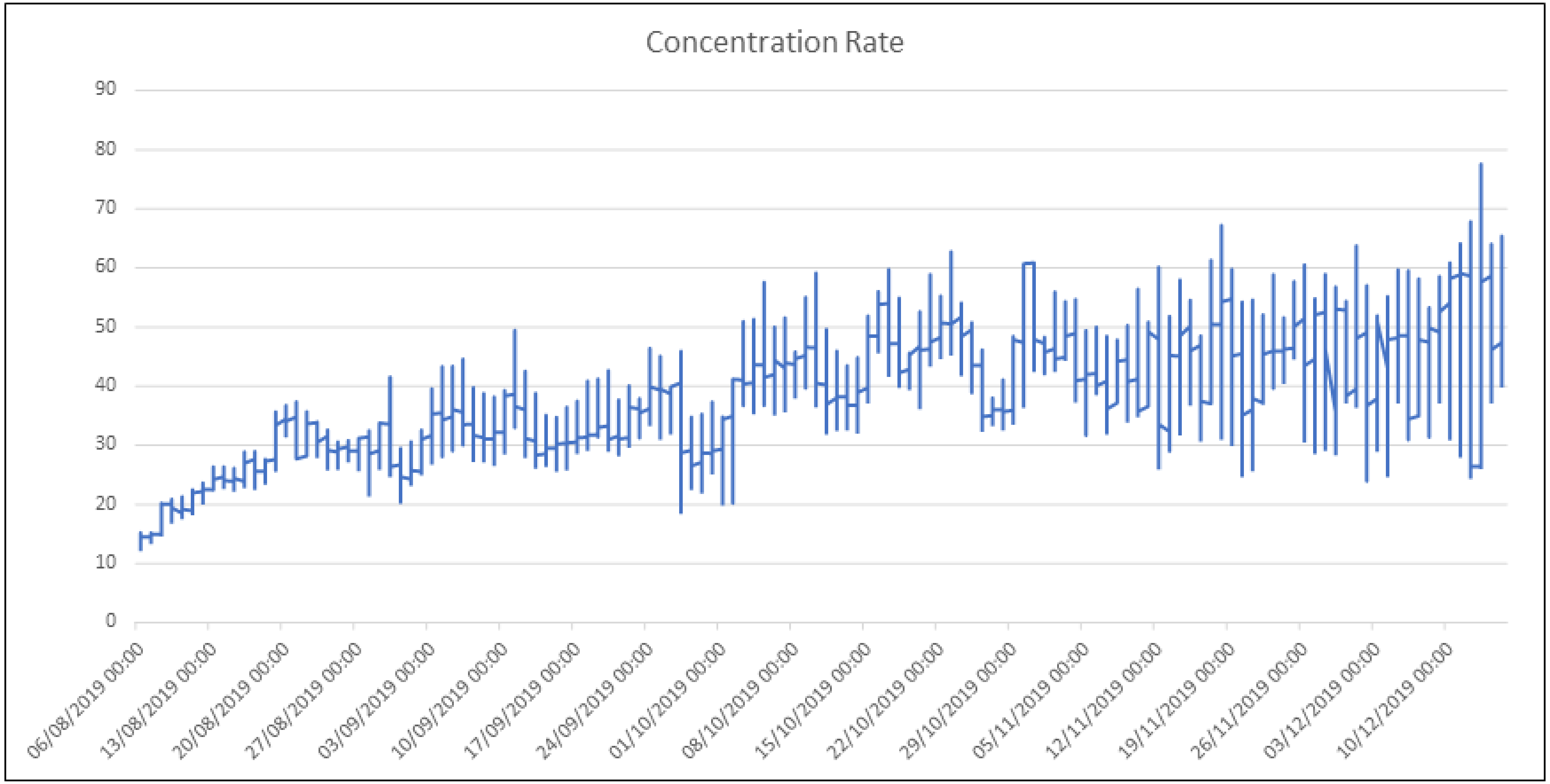
SOUTH EUROPE PETROCHEMICAL PLANT SAVINGS

- Real data after monitoring implementation
- Automated blowdown
- Traced chemistry
- Oxygen scavenger dosed on demand (NCSM)
- Condensates return improvement

Savings / Natural Gas period 4 / period 2 (6 months savings)			
			Hours number
38.29	Nm3/H average		4380
38,29 x 4380 x 11,464 x 17,6/1000		33,840 €	Energy
Water savings /blowdown / period 4 / period 2 (6 months savings))			
0,1575 M3/h average			
0,1575 x 4380 x 0,02		15 €	Water
CO2 emission savings/ period 4 / period 2 (6 months savings)			
137 T / CO2		6,850 €	CO2 emission
(calculed based on natural gas savings)			
Internal Treatment and oxygen scavenger savings / period 4 / period 2 (6 months savings)			
voir détail ci-dessous		8,042 €	produits
6 months savings		48,747 €	

NALCO Water
An Ecolab Company

CYCLE IMPROVEMENT



Appendix 13

Development of ISO standards for use of Eddy Current Arrays in lieu of magnetic particle testing

(Casper Wassink)

EDDY CURRENT ARRAYS IN LIEU OF MAGNETIC PARTICLE TESTING
IIW WORKING GROUP

CASPER WASSINK, MICHAEL SIROIS

Agenda

1. Eddy Current Arrays
2. Background, scope and applications
3. Comparison studies
4. Continued work

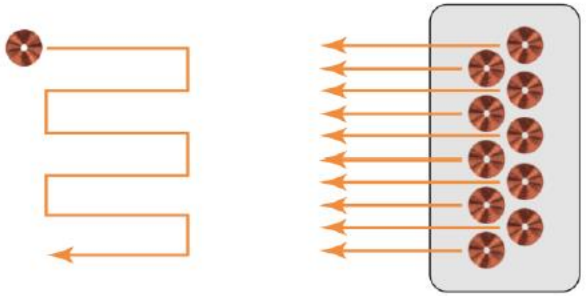
Eddy Current Arrays

Eddy Current Array

WHAT IS IT?

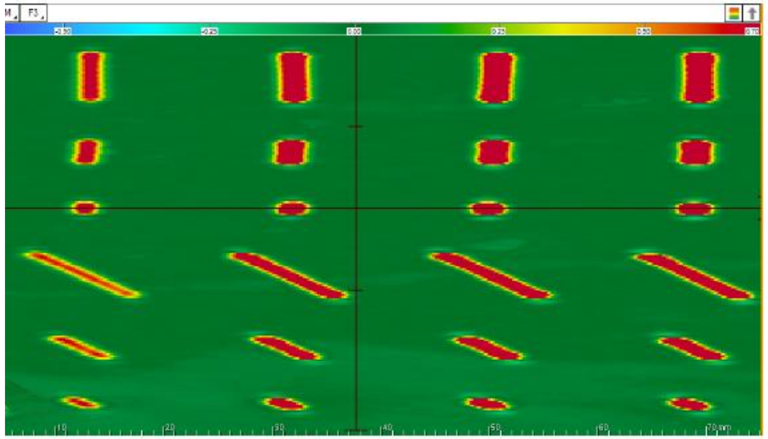
Eddy Current Array is Eddy Current Testing

- Array enables signal processing
- 256 channels
- 600 mm/s
- 250 µm defects



Slow raster scans (1-coil ECT)

Fast, single-pass scans (ECA)

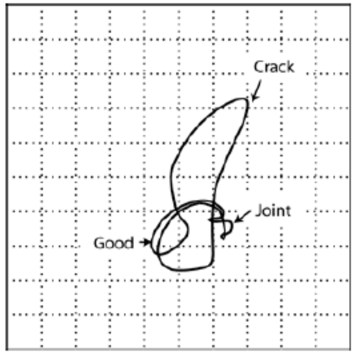


Eddyfi Technologies
Beyond current

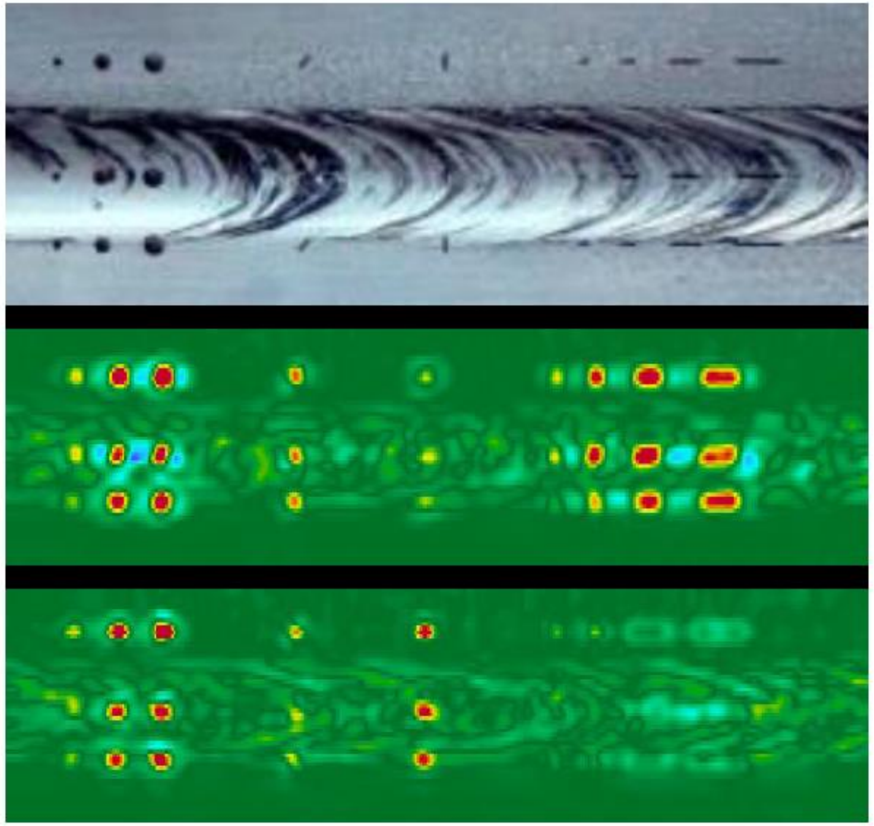
Signal processing

SMART USE OF ARRAY DATA

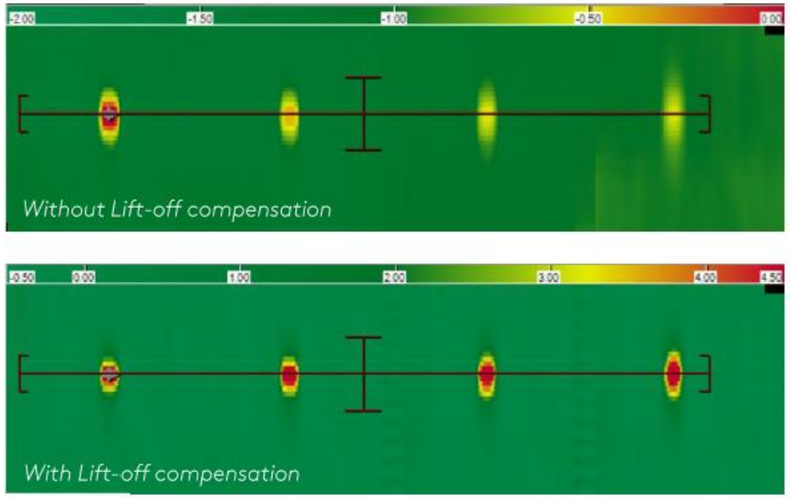
Previously



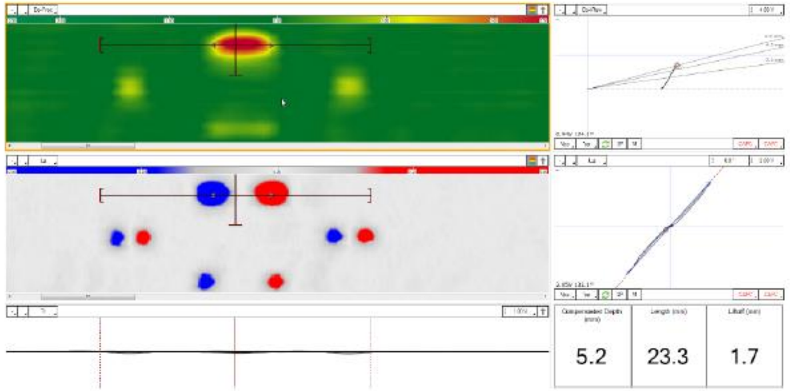
Combining coils



Data collected from the same defect scanned with four different lift-off

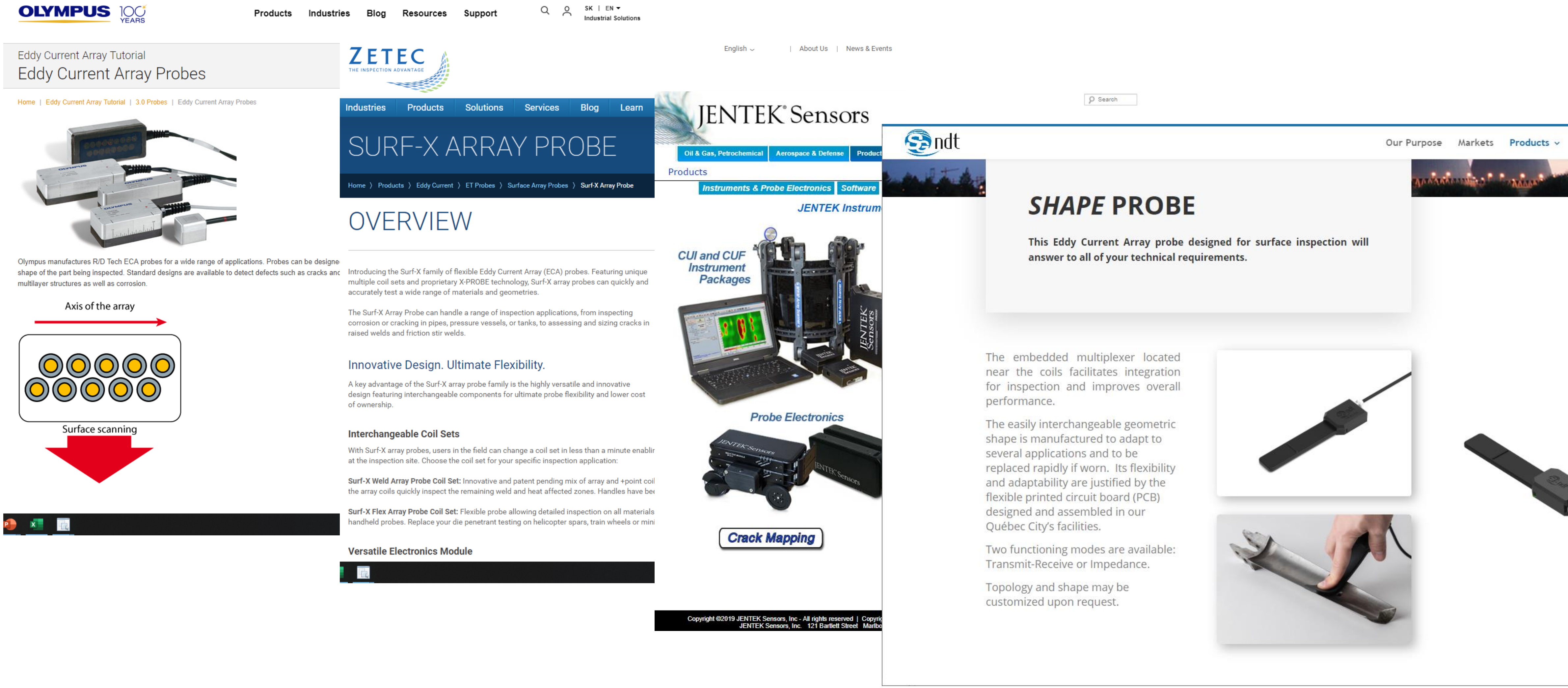


Typical crack signal using TECA



Availability

COMPETITORS ARE AVAILABLE



IIW working group on ECA

IIW WG CVE

Roster IIW committee on Eddy Current Array testing

Last name	First Name	Organization
Banbini	Massimiliano	GE
Brannan	John	Babcock international
Burke	Terence	Olympus
Cho	Younho	ICNDT
Gac	Herve	SG NDT
Hansen	John	Ether NDT
Maggy	Lance	Zetec
Morais	Ghislain	Olympus OSSA
Pelkner	Matthias	BAM
Rivero Aguilar	Andres	Equinor
Samson	Rock	SG NDT
Sharifian	Arya	Weld Australia
Shiva	Majidnia	TWI
Siewert	Thomas	Nist
Sirois	Michael	Eddyfi
Smith	Mike	Eddyfi
Wassink	Casper	Eddyfi
Zaal	Dennis	Shell
Kreutzbruck	Marc	Uni Stuttgard
Nourrit	Nicolas	Institute de Soudure
Denorme	Sebastien	Institute de Soudure
Gonzales	Simon	SG NDT
Casperson	Ralf	BAM
de Keijzer	Theo	Dekra
Spicer	Malcolm	TWI

IIW working group
Background, scope and applications

Surface testing

EDDY CURRENT ARRAY IN LIEU OF MT AND PT

Current technologies

- MT
  - Low cost, widely available
  - Fast
  - Coating and paint removal
  - Flux alignment
- PT
  - Low cost, widely available
  - Complex geometries
  - Chemicals and fumes
  - Cleaning, coating and paint removal
  - Errors

Eddy Current Array

- Easy to use
- Very fast
- No consumables: “Green”
- Minimal surface preparation
- Detection of some sub-surface flaws
- No demag and post-cleaning
- Digital technology
  - Automation
  - Integration
  - Record keeping

Existing standards

ISO, ASME AND ASTM

ISO standards on Eddy Currents

- ISO 20339:2017 for Eddy Current Array equipment

ASME BPVC 2019

- Document on weld testing with Eddy Current Array (ASME V, Art. 8, MA X)
- Document on base material testing with Eddy Current Array (ASME V, Art. 8, MA IX)

ASTM

- ASTM E2884 – 17 - Standard Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays
- ASTM E3052 – 16 - Standard Practice for Examination of Carbon Steel Welds Using Eddy Current Array

Scope

INTENTION FOR WORKING GROUP

Division into three document

- General principles
    - Including application example
        - Stress corrosion cracking
        - Fatigue cracking
        - Railway applications
- Weld testing (in lieu of MT and PT)
    - ISO 5817 / ISO 17635 framework
- Acceptance criteria

Materials

- Emphasis: Carbon Steel / Ferrous materials
- Other conducting materials

Eddyfi Technologies
Beyond current

ISO system structure

EDDY CURRENT TESTING IS NOT ON THE LIST

ISO 5817 Specify quality levels (based on actual imperfections size and character)

ISO 17635 : Specify how to relate quality levels to NDT requirements

NDT standards « good workmanship » (type & size of indications)

NDT Method General NDT	**General NDT standard** ISO TC135/SC3	**NDT on welds** Testing Levels ISO TC44/SC5	**NDT on welds** Acceptance levels ISO TC44/SC5
VT	ISO 13018	ISO 17637	ISO 5817
RT film	ISO 5579	ISO 17636-1	ISO 10675- 1 (steel..) ISO 10675- 2 (Al..)
RT digital	ISO 16371-1&2	ISO 17636-2	
UT	ISO 16810 ISO 16811 ISO 16823 ISO 16826	ISO 17640 ISO 23679 (*) ISO 22825 (*)	ISO 11666
PT	ISO 3452-1	ISO 3452-1	ISO 23277
MT	ISO 9934-1	ISO 17638	ISO 23278
UT TOFD	ISO 16828	ISO 10863	ISO 15626
PAUT	ISO 18563-1 to 3 ISO 19675	ISO 13588 ISO 20601	ISO 19285 ISO NP XXXX?
UT TFM/FMC	Pr ISO 23865 (IIW)	Pr ISO 23864 (IIW)	ISO 19285?

Comparison studies

TWI reports 24931/5/15 and 24931/6/15

POD OF EDDY CURRENT ARRAY IN 2015

Samples

- 8 ACFM training samples
- Mastered with MPI
- Tested with MPI, ACFM and ECA

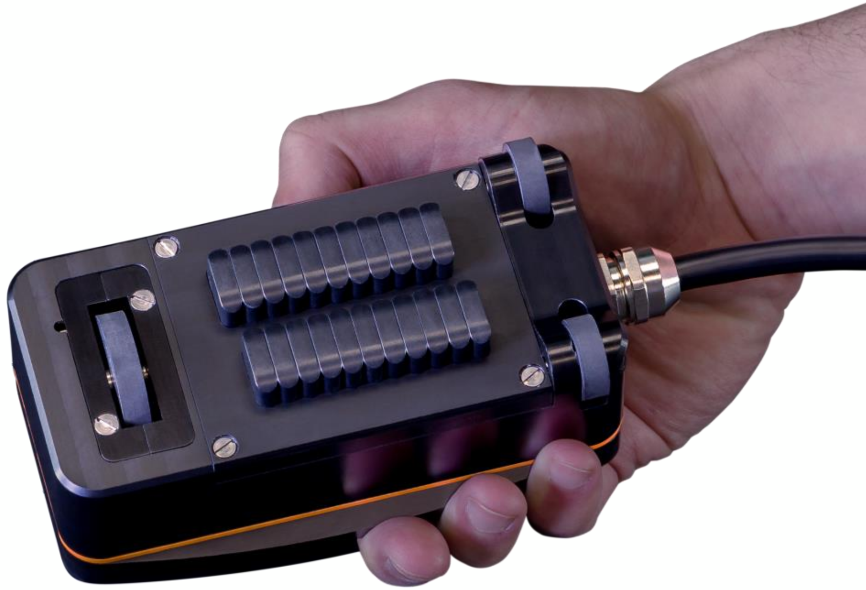
Previous generation technology

Duration

- Eddy Current Array testing in minutes
- MPI testing took many hours

Detection

- MPI detected 8 our of 13 indication + 5 false calls
- Eddy Current Array detected all indications



POD and sizing data

MPI VS. ECA

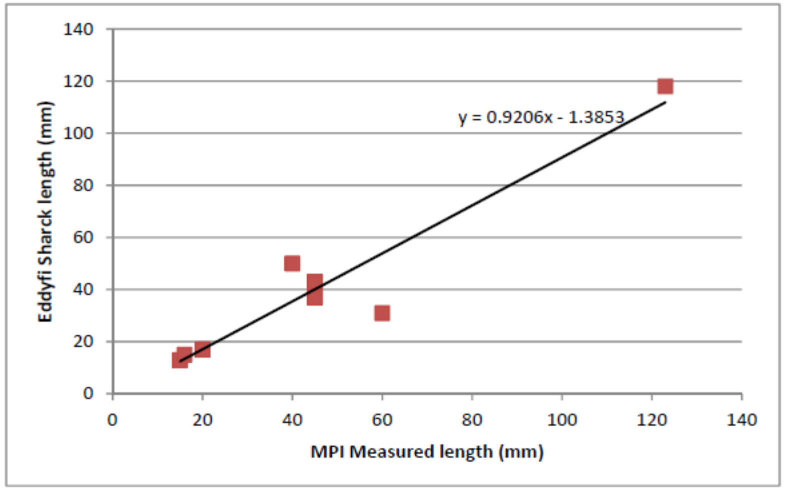


Figure 1 Comparison of length sizes given by both methods of inspection.

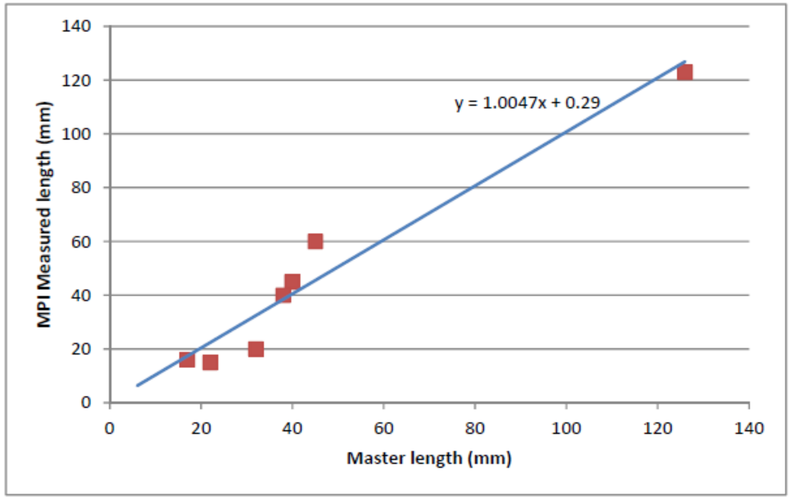


Figure 3 Comparison of length sizes given by the MPI and the master data.

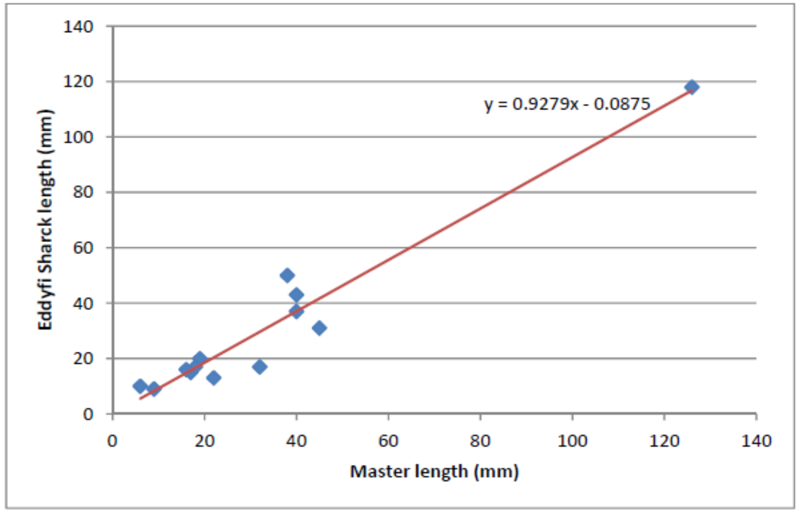


Figure 2 Comparison of length sizes given by the Sharck™ array probe and the master

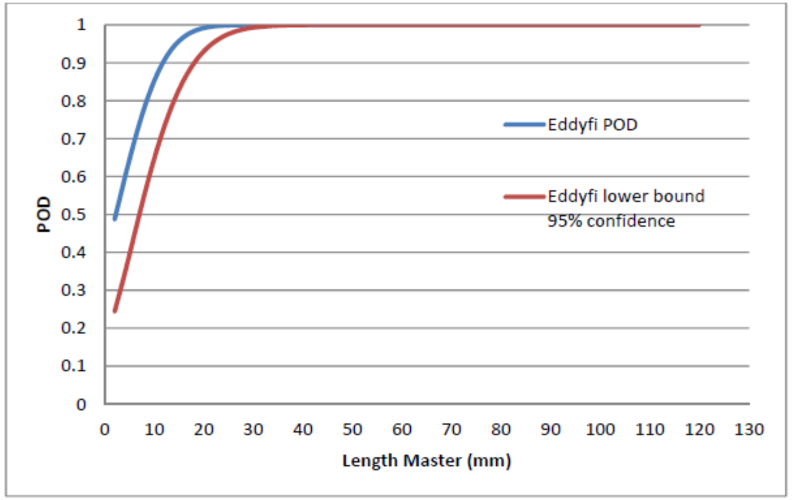


Figure 4 Comparison of Lengths plotted by POD.

Detail on POD

Flaw size

- POD generated with response vs. size method and 2mm threshold
- POD 90%, 95% lower bound confidence for defect length 12mm

Could be improved with high number of samples

Depth sizing within 1mm of the master sheet

Improvements with Sharck G2 probes

Probability of detection

Compared to MT and PT

- Few head-to-head comparisons in literature
- Good overview reports on POD of MT and PT
- Several dedicated POD studies on ECA

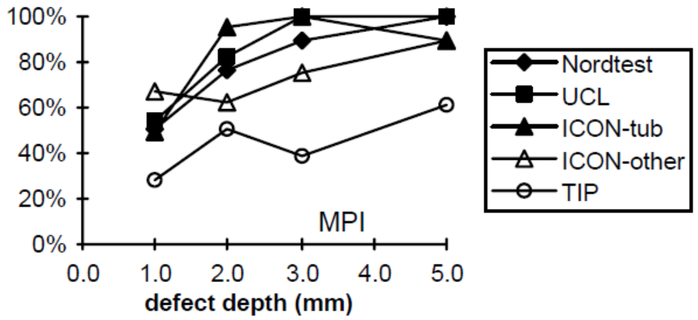


Figure 1.1 MPI: POD for surface defects

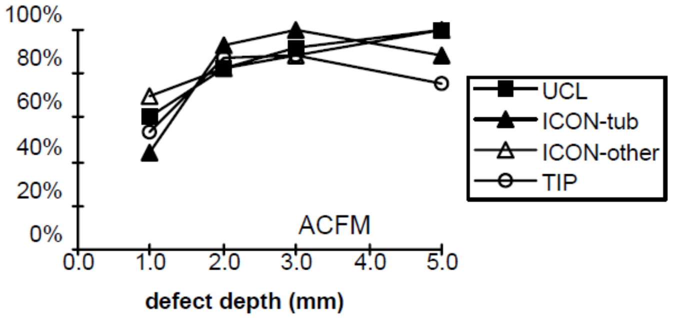


Figure 1.2 ACFM: POD for surface defects

Source:
HSE, POD/POS curves for non-destructive examination

POD comparison ECA vs PT

BASED ON LITERATURE

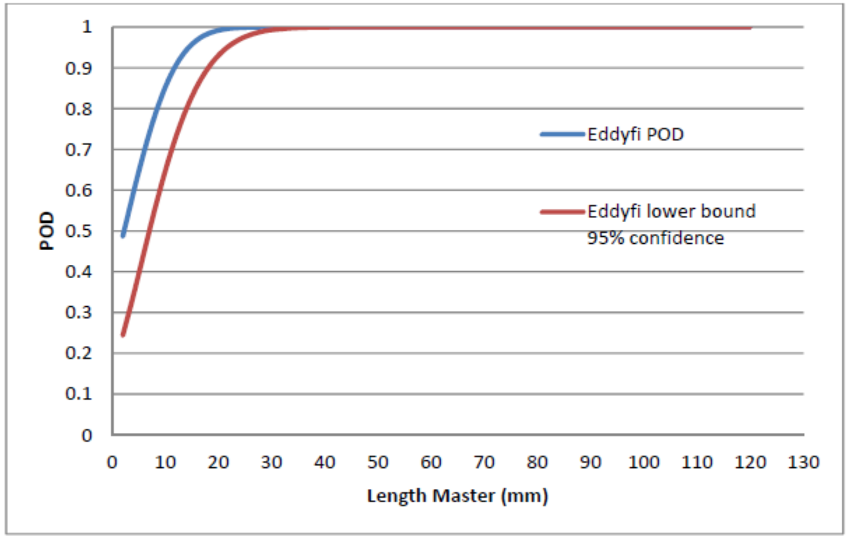
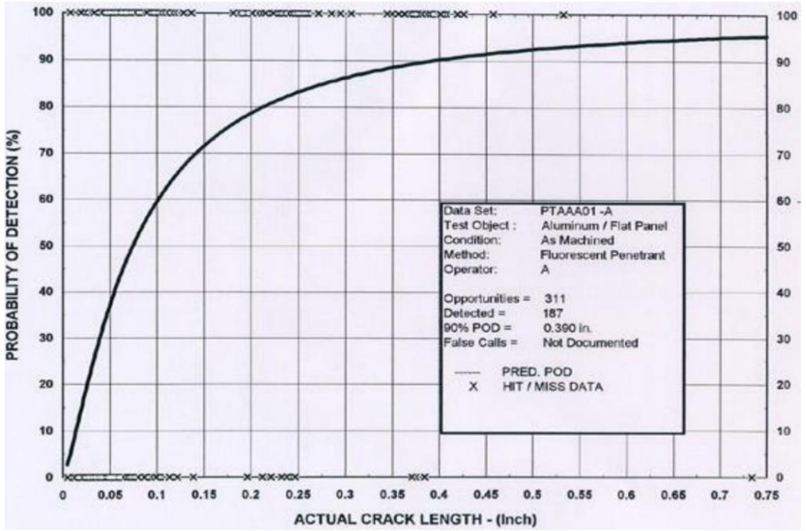


Figure 4 Comparison of Lengths plotted by POD.



ECA: POD 90/95 at 12mm defect length

PT: POD 90 at 10mm defect length

Sources:
POD ECA: TWI report 24931/6/15;
POD PT: Dr. Ala Hijazi, introduction to Liquid penetrant testing

Preliminary conclusion on POD

- POD of conventional ECT, ACFM, MT and PT is roughly equal (baseline)
- Consistent baseline across methods is probably cause by object based constraints and not by the NDT method
- Modern ECA/ACFM implementations are better than baseline
- ECA can be adapted for higher POD by changing array parameters
- However, the value is this is doubtful given the constraints on performance created by the object surface condition

Enbridge field validation

FIELD PERFORMANCE

Pipeline indications

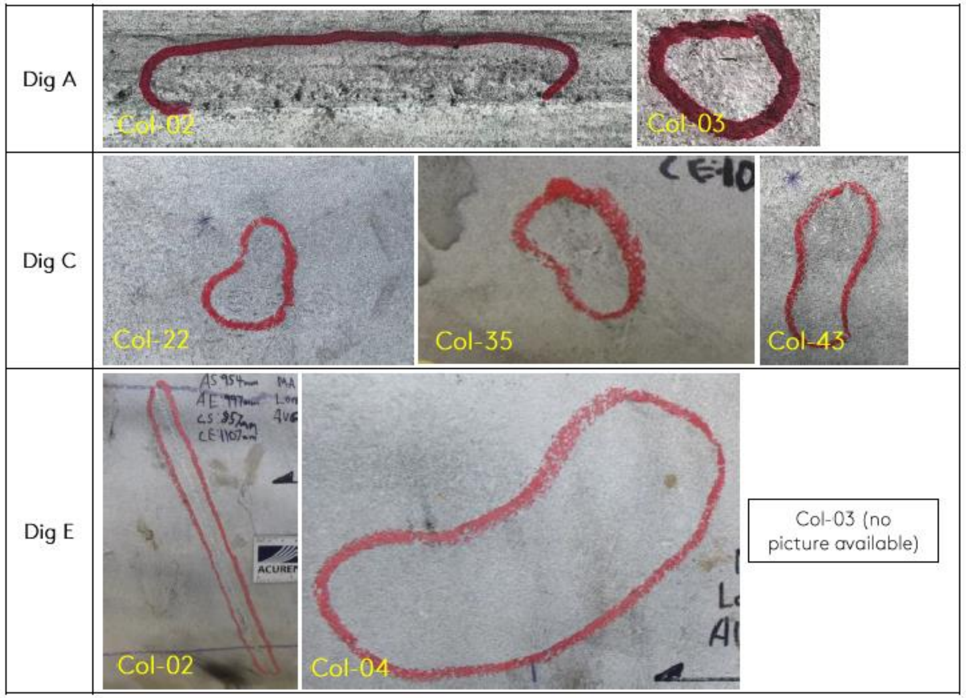
- In-the ditch verification
- Frequently in long-seam / spiral weld

Screening with Spyne, sizing with Sharck

6 dig comparison to MPI

Dig ID	A	B	C	D	E
Colonies detected both by MPI and Eddyfi	9	13	26	-	1
Colonies detected by Eddyfi and missed by MPI	3	6	4	Spiral tape lines	> 25
Colonies detected by MPI and missed by Eddyfi	0	0	0	0	0
Individuals cracks shorter than 3 mm detected by MPI and missed by Eddyfi (see pictures below)	2	0	3	0	3

Left: Eddyfi's Spyne probe used for the detection of SCC; Right: Eddyfi's Sharck HR butt weld probe used for the detection and sizing of cracks along the seam weld.



In-depth findings

MPI missed many defects on the bottom of the pipeline

Eddy Current Array missed some small single cracks

- Smaller than 3mm length and 1mm depth
- In-line with threshold set in instrument

Results clearly show issue with MPI and human factors

Further trials and implementations at 30 pipeline owners

Continued work and conclusions

Proposed working group programme

1. Survey of performance
   - Comparison to MT and PT
   - Multiple equipment vendors
   - Scan some additional (reference) samples if necessary
2. Analysis of advantages and limitations
   1. Compared to requirements from ISO 17635
   2. Compared to MT and PT
3. Preparation of three draft standards
   1. General technique description and application examples
   2. Weld testing standard
   3. Acceptance criteria

Eddyfi Technologies
Beyond current

Appendix 14

Effects of mercury in crude feed in refinery plants. Is it possible to set a target limit?

(M. De Marco)

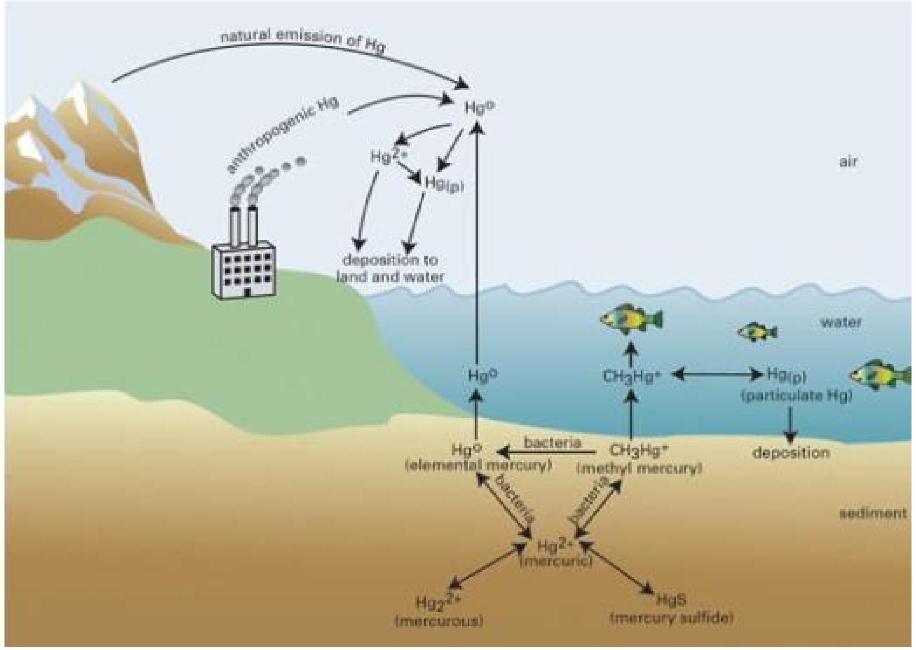
Effects of mercury in crude feed in refinery plants. Is it possible to set a target limit?

Marco De Marco, IIS

Mercury in biosphere

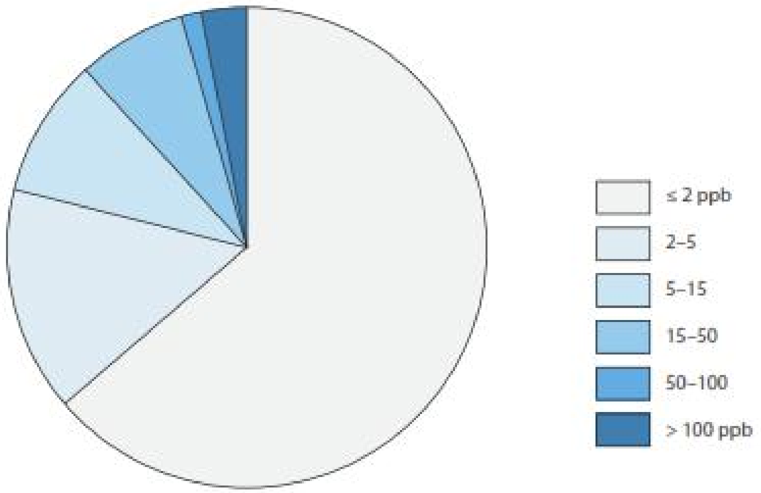
- ***Mercury in the biosphere***
  - Natural component of the earth
  - Natural emissions in biosphere (e.g. volcanoes)
  - Anthropogenic

- *Elemental Mercury (Hg^0)*
- *Mercury Sulphide (HgS)*
- *Mercury Sulphate ($HgSO_4$)*
- *Mercury mercaptides (RS-Hg-SR)*
- *Organic Mercury (R-Hg-R)*
- *Mercury chloride (Cl-Hg-R)*



Mercury in crude oil

- ***Some numbers : example of range of mercury content in crude oils***



Statistics

Range (ppb)	*Count*	*%*
≤2	284	64
2–5	68	15
5–15	42	10
15–50	33	7
50–100	6	1
>100	13	3
	446	100%

***IPIECA study*

Mercury in crude oil

- ***Range of mercury content in regional crude oils***

Crude region	Count	Median Hg level (ppb)	Percentage of crudes and condensates containing specific ranges of mercury (ppb of mercury)					
			≤2 ppb	2–5 ppb	5–15 ppb	15–50 ppb	50–100 ppb	>100 ppb
Africa	90	1.0	72%	15%	9%	3%	1%	-
Eurasia	95	1.2	74%	10%	6%	4%	1%	5%
Middle East	34	1.0	79%	18%	3%	-	-	-
North America	95	1.2	64%	21%	9%	6%	-	-
Pacific and Indian Ocean	93	3.0	41%	13%	16%	18%	4%	8%
South America	39	1.4	69%	12%	8%	8%	-	3%

**IPIECA study*

Reported levels of total mercury in crude oil

Source	Amount, ppb w/w
California (Cymric)	30 000
Alberta	2–400
North Sea	2.5–9.3
Libya	0.1–12.2
West Africa	1.5–3.5
Angola	1.5–2.7

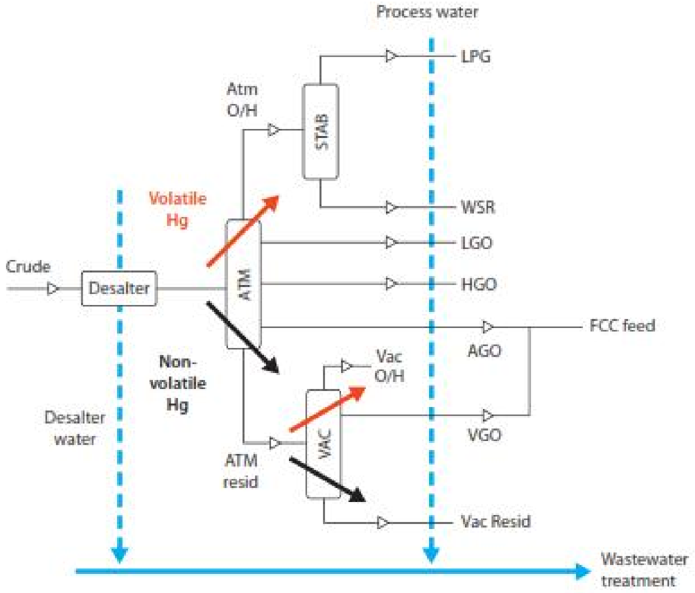
**Steve Catchpole 2009*

Mercury in refineries

- ***Some studies showed that in crude containing relatively high Hg (e.g. > 50 ppb)…***

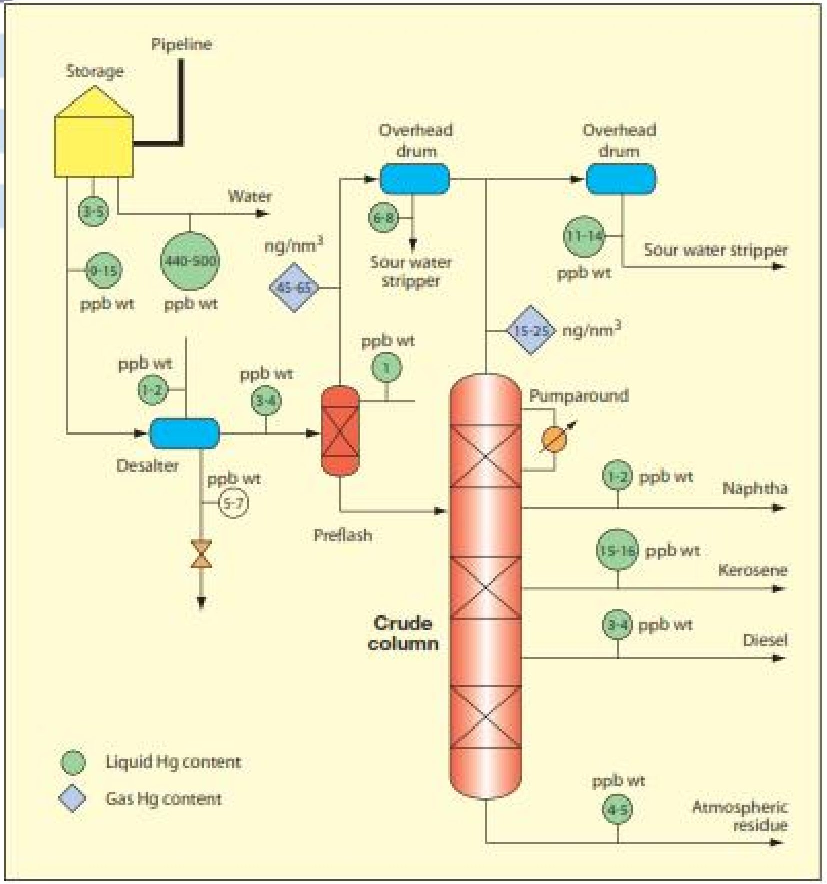
⬇

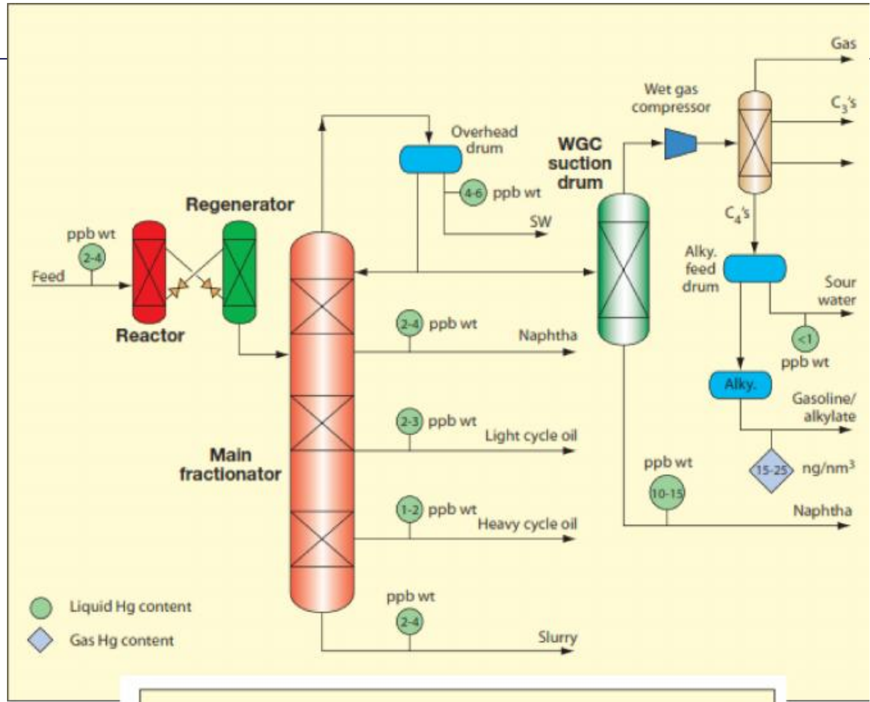
- ❑ ***<u>Low S crude</u> -*** ***elemental Hg in crude column overhead (light ends C_3-C_6) - high vapour pressure Hg migrates to light ends***
- ❑ ***<u>High S crude</u> -*** ***HgS in residuum ; converted in Hg in secondary conversion (to light ends C_3-C_6)***

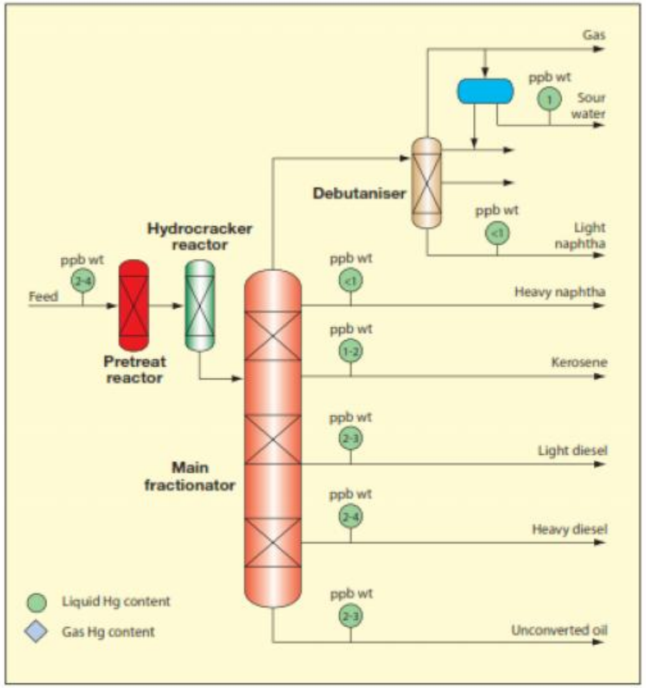


- *Elemental Mercury (Hg^0)*
- *Mercury Sulphide (HgS)*

Mercury in refineries







**Steve Catchpole 2009*

Mercury in refineries - Problems

- *Hg can accumulate in equipment (e.g. low spot in Heat Exchanger – HX)*

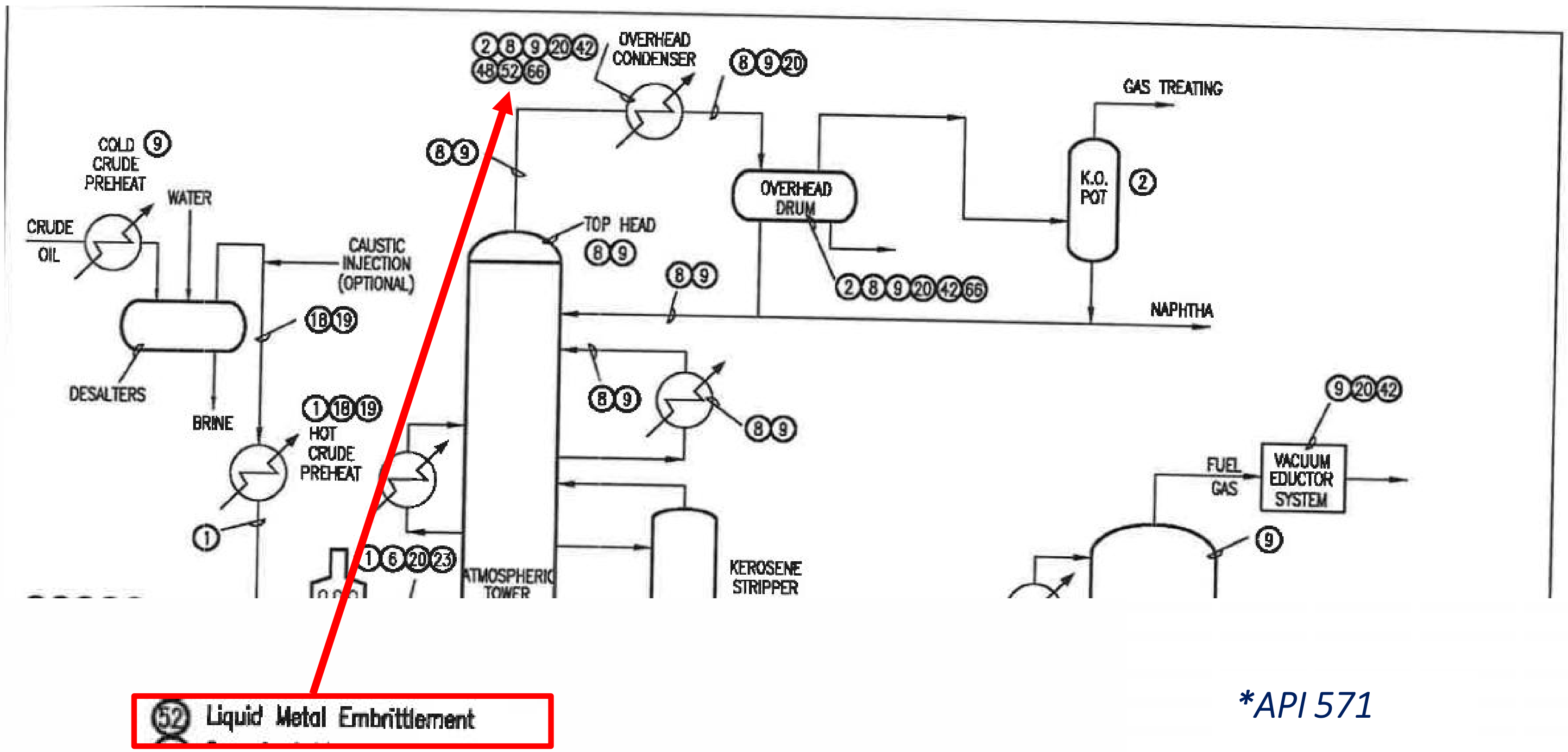
	Potential annual accumulation		
Mercury in crude, µg/kg (ppb)	1 µg/kg	10 µg/kg	200 µg/kg
50,000 bbls/day — 'small' refinery	0.5 kg/year	5 kg/year	90 kg/year
250,000 bbls/day — 'large' refinery	2.5 kg/year	25 kg/year	450 kg/year

**IPIECA study*

- *Liquid Metal Embrittlement (LME)*
  - *Al alloys in LPG plants HX - Many reported incidents*
  - *Copper alloys in condenser HX (e.g. overhead) - Less experiences across the industry (in my opinion…audience?)*
  - *9% Ni steels (storage tank) - Some experimental evidence*
  - *Ti? Monel ?*

Mercury in refineries - Problems

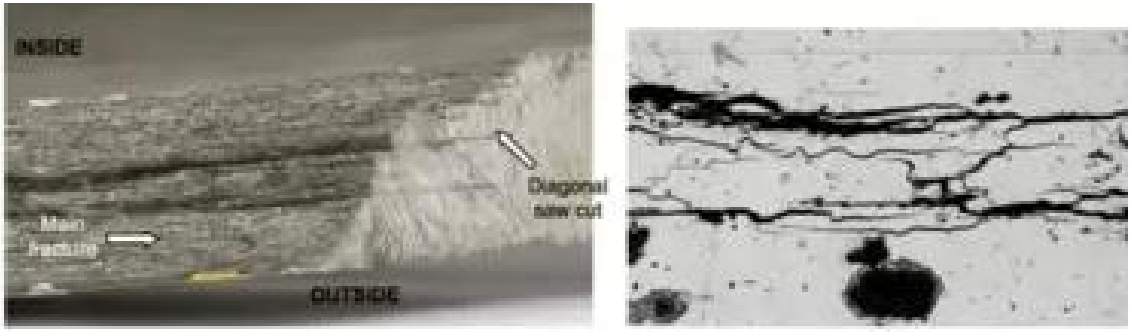
- ***Liquid Metal Embrittlement LME in Crude Unit overhead***



**API 571*

Mercury in refineries - Problems

- ***Aluminum LME heat exchanger in LNG plant***

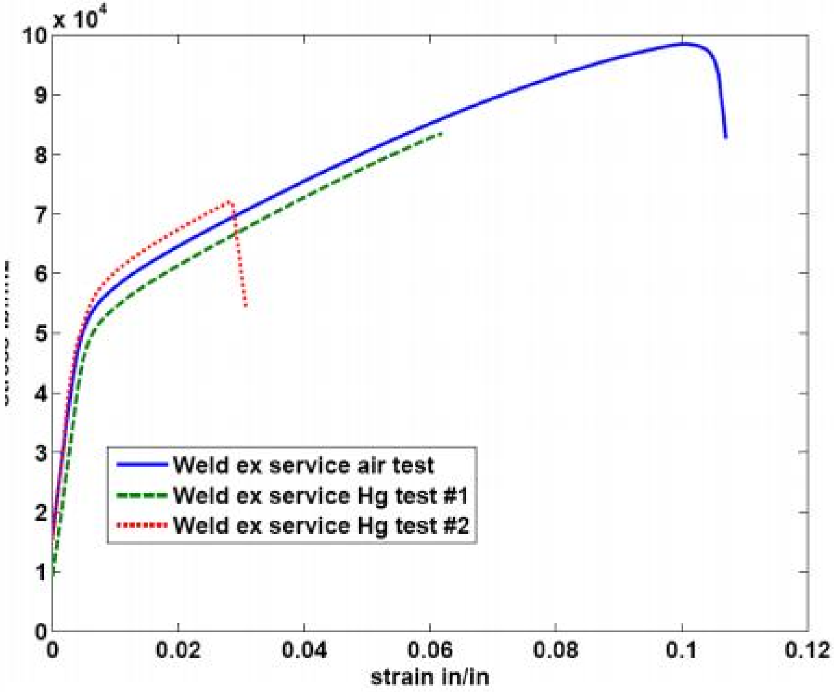


(a) (b) 165x

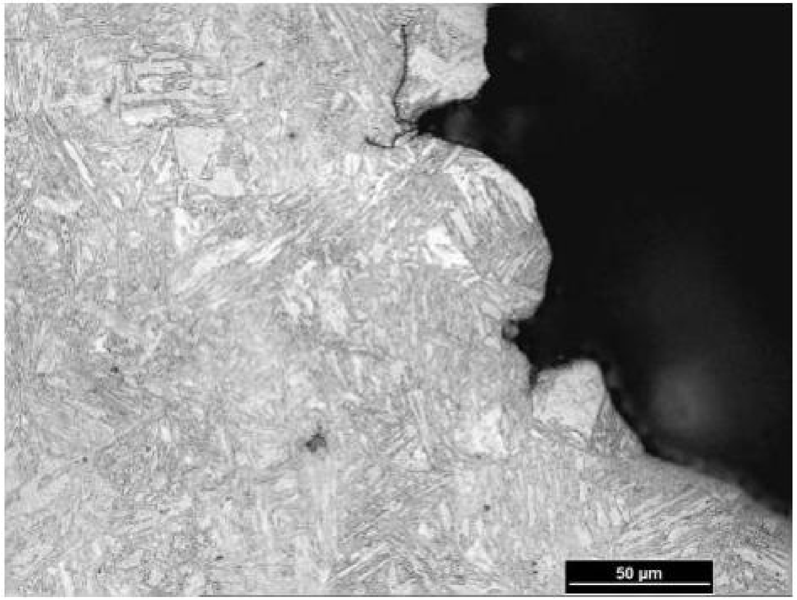
** Russel Coade 2017*

Mercury in refineries - Problems

- ***Slow Strain Rate Test (SSRT) in 9 Ni % Steel in Hg environment***



Stress-Strain curves for welded A353 plate SSR tested in air and in Hg.



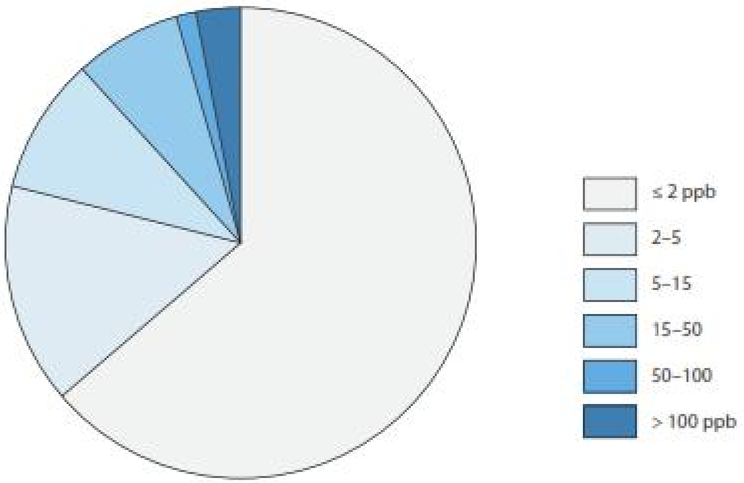
**McIntyre 2013*

Mercury in refineries - Problems

- ***Catalyst poisoning***
- ***Health and safety***
  - *Emissions*
  - *Waste waters*
  - *Hot work, grinding, blasting on Hg contaminated surfaces*

Mercury in refineries – Operating Windows

- ***Set operating windows for incoming Hg ?***
  - *Average basis*
  - *Individual crude charge?*



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>100	13	3
	446	100%

- ***"We are receiving a crude oil with 120 ppb Hg, can we accept (buy) it ???"***