Appendix 1

List of participants

Participants EFC WP15 virtual meeting 9th September 2020

Name	Surname	Company	Country
Arslanov	Marat	KBR	RUSSIA
Augustin	Christel	Total Refining & Chemicals	FRANCE
Bourguignon	Francis	Salzgitter Mannesmann Precision GmbH	GERMANY
Brandl	Ramona	OMV	GERMANY
Chernyavskiy	Petr	KBR	RUSSIA
Claesen	Chris J	Nalco Champion	BELGIUM
Corradini	Raffaele	Techint Engineering Construction	ITALY
De Landtsheer	Gino	Borealis	BELGIUM
de Marco	Marco	Istituto Italiano della Saldatura	ITALY
Farina	Carlo	CEFIT Corrosion Consultant	ITALY
Filaudeau	Emmanuel	ALLIASURE SAS	FRANCE
Fischbacher	Peter	Emerson Automation Solutions	ITALY
Fullin	Luna	Tenaris Dalmine	ITALY
Goti	Raphael	Total Refining & Chemicals	FRANCE
Groysman	Alec	Israeli Corrosion Forum	ISRAEL
Hermse	Chretien	Shell Global Solutions International	NETHERLANDS
Houben	John	ExxonMobil Chemical Holland BV	NETHERLANDS
Höwing	Jonas	Sandvik	SWESEN
Krabac	Lubomir	Borealis Polyolefine GmbH	AUSTRIA
Kuhn	Michael	PPG Protective & Marine Coatings	UK
Lheureux	Mathieu	NEOTISS	FRANCE
Lobaton Fuentes	Militza	Borealis Chimie SAS	FRANCE
Lucci	Antonio	Rina Consulting	ITALY
Magel	Chis	PPG Protective & Marine Coatings	UK
Meissner	Andreas	Salzgitter Mannesmann Precision GmbH	GERMANY
Monnot	Martin	Industeel	FRANCE
Patel	Amid		USA
Rodriguez Jorva	Javier	CEPSA	SPAIN
Ropital	François	IFP Energies nouvelles	FRANCE
Scanlan	Rob	BP	UK

Schempp	Philipp	Shell Deutschland Oil GmbH	GERMANY
Sharma	Prafull	Corrosion RADAR	UK
Soltani	Askar	South Pars Gas Complex	IRAN
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Tabaud	Frederic	BP RTE	NETHERLANDS
Van Rodijnen	Fred	Oerlikon metco	GERMANY
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vassileva	Vassilka	OMV Refining & Marketing GmbH	AUSTRIA
Vinogradov	Roman	KBR	RUSSIA
Vosecký	Martin	Nalco Champion	CZECH REPUBLIC
Wijnants	Geert Henk	Stork	NETHERLANDS
Wodarcyk	John	Conoco Phillips	USA

Appendix 2

EFC WP15 Activities

(Francois Ropital)

EFC guide line 55 « Corrosion Under Insulation » Flyer

EFC
EUROPEAN FEDERATION OF CORROSION

Welcome to the EFC Working Party Meeting

"Corrosion in Refinery and Petrochemistry" WP15

9 September 2020

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

EFC
EUROPEAN FEDERATION OF CORROSION

EFC Working Parties

http://www.efcweb.org

- WP 1: Corrosion Inhibition
- WP 3: High Temperature
- WP 4: Nuclear Corrosion
- WP 5: Environmental Sensitive Fracture
- WP 6: Surface Science and Mechanisms of corrosion and protection
- WP 7: Education
- WP 8: Testing
- WP 9: Marine Corrosion
- WP 10: Microbial Corrosion
- WP 11: Corrosion of reinforcement in concrete
- WP 14: Coatings
- WP 15: Corrosion in the refinery and petrochemistry industry
  (created in sept. 96 with John Harston as first chairman)
- WP 16: Cathodic protection
- WP 17: Automotive
- WP 18: Tribocorrosion
- WP 19: Corrosion of polymer materials
- WP 20: Corrosion by drinking waters
- WP 21: Corrosion of archaeological and historical artefacts
- WP 22: Corrosion control in aerospace
- WP 23: Corrosion reliability of Electronics
- WP24: CO_2 Corrosion in industrial applications
- Task Force on atmospheric corrosion
- NewTask Force Corrosion in green energies applications

Presentation of the activities of WP15

European Federation of Corrosion (EFC)

- Federation of 29 National Associations
- 22 Working Parties (WP) and 2 Task Forces
- Annual Corrosion congress « Eurocorr »
- Thematic workshops and symposiums
- Working Party meetings (for WP15 twice a year)
- Publications

for more information http://www.efcweb.org

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 Budapest-Hungary, 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
EUROPEAN FEDERATION OF CORROSION

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)

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EFC
EUROPEAN FEDERATION OF CORROSION

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

Proposal of an EFC Webinar on CUI (e.g. CUI and RBI methodology in practice, new insulation materials,….) ?

EFC WP15 annual meeting 9 September 2020

6

Publications from WP15

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

• 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 November 2020

Thank you to all the contributors for their work

Session at vitrual Eurocorr 2020

"Corrosion in refinery and petrochemistry" on

Wednesday 9 September 14h00 to 16h20

Information :
Future conferences related to refinery corrosion

19-23 April 2021
CORROSION 2021 NACE Conf Salt Lake City

19-23 September 2021
EUROCORR 2021 Budapest Hungary

28 August-1 September 2022
EUROCORR 2022 Berlin Germany

27-31 August 2023
EUROCORR 2023 Brussels Belgium

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

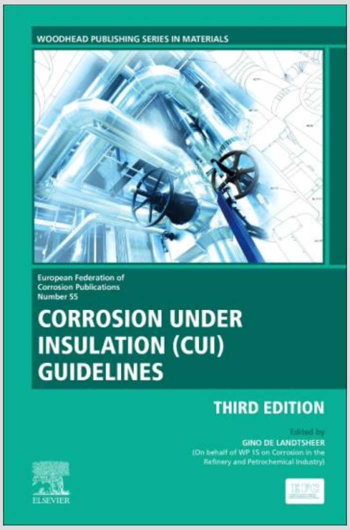
Joining EFC WP15 activities

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/



Corrosion Under Insulation (CUI) Guidelines, 3e

Technical Guide for Managing CUI

Edited by : **Gino De Landtsheer**, Senior Group Expert in Piping and Valves, Borealis Kallo

ISBN: 978-0-12-823332-0
PUB DATE: Aug 14, 2020
LIST PRICE: £170.00 / $220.00 / €195.00
DISCOUNT: Reference
FORMAT: Hardback
TRIM: 6w x 9h
PAGES: c. 156
Approx. 100 illustrations (40 in full color)

Offers an essential, comprehensive, and updated technical resource on how to manage and mitigate corrosion under insulation (CUI)

A Volume in the *European Federation of Corrosion (EFC) Series* Series

KEY FEATURES

- Provides revised and updated technical guidance on managing CUI provided by EFC Working Parties 13 and 15
- Discusses the standard approach to risk based inspection methodology
- Presents the argument that CUI is everywhere, and looks at mitigating actions that can be started from the onset
- Includes a wide array of concepts of corrosion mitigation

DESCRIPTION

Corrosion Under Insulation (CUI) Guidelines: Technical Guide for Managing CUI, Third Edition, Volume 55 builds upon the success of the first two editions to provide a fully up-to-date, practical source of information on how to monitor and manage insulated systems. In the first edition of this book published in 2008, the EFC Working Parties WP13 and WP15 engaged together to provide guidelines on managing CUI with contributions from a number of European refining, petrochemical, and offshore companies. The guidelines were intended for use on all plants and installations that contain insulated vessels, piping, and equipment, and cover a risk-based inspection methodology for CUI, inspection techniques, and recommended best practices for mitigating CUI.

The guidelines include design of plant and equipment, coatings and the use of thermal spray techniques, types of insulation, cladding/jacketing materials, and protection guards. Corrosion-under-insulation (CUI) refers to the external corrosion of piping and vessels that occurs underneath externally clad/jacketed insulation as a result of the penetration of water. By its very nature CUI tends to remain undetected until the insulation and cladding/jacketing is removed to allow inspection, or when leaks occur. CUI is a common problem shared by the refining, petrochemical, power, industrial, onshore and offshore industries.

9 780128 233320

WP WOODHEAD PUBLISHING

ENGINEERING
Technology
www.elsevier.com

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Appendix 3

Costs-effective proactive CUI Management; wish or truth?

(Geert Wijnants)

WORLD CLASS MAINTENANCE

EFC EUROPEAN FEDERATION OF CORROSION

EFC virtual Meeting
9 September 2020.

Corrosion under isolation

Costs-effective proactive CUI Management; wish or truth?

Samenvatting WCM projectgroep CUI
Rob de Heus (Sitech)
Paul van Kempen (WCM)
Geert Henk Wijnants (Stork)
Egbert Stremmelaar (ION)
Maarten Robers (DEKRA)

Review original in Dutch? https://www.youtube.com/watch?v=Zsv-UaJXVos&t=162s

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Corrosion under Insulation

Network for Smart Maintenance

CUI Project, information sessie, Sept. 9th 2020

Geert Henk Wijnants
Principal consultant. Secretaris WG BP CUI Management

Our goal: make our partners maintenance world champions

- Maintenance
- Asset Management
- Life Cycle Management

- Competiveneness
- Safety
- Sustainability

World Class Assets

WORLD CLASS MAINTENANCE

We believe in

WORLD CLASS MAINTENANCE

Open Innovation

Cross-sectoral cooperation

Cooperation of companies, knowledge & education institutes and government

Fieldlabs & projects

Knowledgde and info

Lobby & politics

Network

Pre-amble CUI Project

CUI-I
...2015

CUI-II
eind 2016

CUI-II
3-12-2018

Corrosion under Insulation

Objectives CUI project

Corrosion under Insulation

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

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

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

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Participating Industry

Steering group

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

Workgroup NDT

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

Workgroup Coatings

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

Workgroup Risk Based CUI

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

Ambition is in line with the Safety Delta Netherlands program

Corrosion under Insulation

SAFETY DELTA NETHERLANDS

To be the safest country in terms of process industry by 2030.
3 theme’s:

- Early stage leak detection
- The factor “human" (human action)
- Aging Assets, **Corrosion under insulation**

Knowledge ⟷ Innovation

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Planning

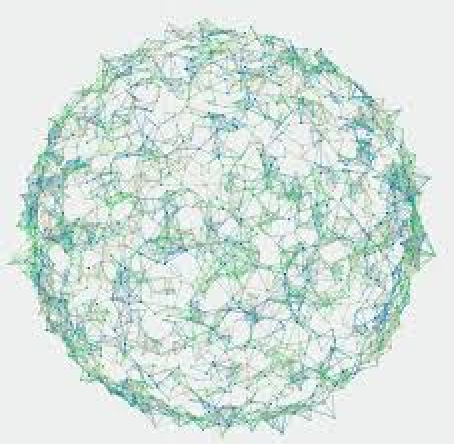
Corrosion under Insulation

11 feb.
CUI meeting internal

24 march
CUI meeting external

22 June
CUI webinar

SDN High level meeting
with demo CUI project icw Deployment matters



May 2020

CUI Safety Deal II
validate tools CUI-I
continue workgroups

- **Implementation projects** with current results
- **Data collection** from practice on service life of coatings, moisture measurements, coating status, insulation, base material, etc.
- **Continue current working groups** to keep results up to date, learn from incidents, best practices, etc.

Sept. 2020

CUI Safety Deal III
broad distribution of knowledge products & implementation support

- Make **interfaces** to CUI best practice tools more user-friendly
- Make WCM material legible and **user-friendly**
- Develop **SDN knowledge center** as a concept based on CUI case material, incl. Deployment matters environment
- CUI **implementation helpdesk**
- Strengthen **rollout through regional safety networks** or develop alternatives for reaching the workplace
- **Qualifying NDT** techniques (collaboration / knowledge teams)
- Introduce best practices to **EU standard EFC55**

CUI SDN Initiative
Innovation & research
mid November 2020

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More information (incl. Project deliverables) is available on the WCM website

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MENU

Corrosie onder Isolatie

Oplossingen voor een omvangrijk faalmechanisme in de procesindustrie

Corrosie onder Isolatie

Procesindustrie bestrijdt gezamenlijk onzichtbare vijand

Corrosie onder Isolatie is een degradatiemechanisme dat optreedt bij geïsoleerde leidingen en apparaten in het temperatuurbereik van ca. 0 tot 150 graden C. Het is een lastig te beheersen fenomeen, omdat de locaties waar het optreedt lastig te detecteren zijn. Ook is de snelheid van degradatie afhankelijk van vele factoren en

Nieuws

WCM Visie Missie Strategie 2020-2021
7 mei 2020

Safety Deals
9 maart 2020

Praktische tools voor het beheersen van corrosie onder isolatie
16 januari 2020

Groot aantal aanmeldingen WCM Summer School
25 juni 2019

Uitreiking eerste WCM jaarmagazine aan FME voorzitter Ineke Dezentjé
26 februari 2019

Meer project nieuws

Events

Webinar | Corrosie onder isolatie
22 juni 2020 @ 13:00 - 14:00

Meer project events

WORLD CLASS MAINTENANCE

WCM Project Corrosion under Insulation

Algehele context van het project

Corrosion under insulation

A very specific corrosion problem

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

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

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

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Corrosion under insulation

Invisible Assassin

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

Assassin who is well worth fighting

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Common approach for CUI

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

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

Enough reasons for WCM to start a joint CUI project

Inter-sectoral CUI Cooperation

By using proven knowledge from the industry

Rijksdienst voor Ondernemend Nederland

AIM CUI-project

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

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

Corrosion under Insulation

Workgroups CUI-project

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

Coatings
Insight into the duration of protection of coatings

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

Corrosion under Insulation

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Project results

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

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

- ➢ Standardized method for mapping risks

- ➢ The decision model in which risks from corrosion speed, coating life and applied inspection method are integrated.

- ➢ Gradation of CUI corrosion rate and risk assessment
- ➢ Assessment of the condition of isolation, effect on risk
- ➢ Effectiveness of NDT, influence on risk
- ➢ Awareness presentation in which the usefulness, necessity and impact of a CUI management program are highlighted.
- ➢ The best practice description according to “ISO high level structure” for RBI COI.

CUI: Assessment of risk level

Requirements:

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

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

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

Probability of Failure / Likelyhood

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

Notes:

* Small population = 20 to 50 items of equipment

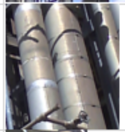
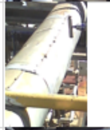
** Large population = More than 50 items of equipment

Consequence of Failure / Severity

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

CUI: Condition assessment insulation

Bijgaand referentie beelden voor de inspectie van isolatie.

Klasse:	Conditie:	Aktie:	Toelichting:	Concreet:	Referentiebeeld:
	Uitgangspunten:	Het gaat alleen om functionele eisen, voor de functie: afschermen van onderliggende isolatie tegen omgevingsinvloeden.			
		Dit betreft de inspectie van de toestand van de beplating met de waterdichte afwerking.			
		Hoofdvraag is daarmee: in welke mate is de isolatie in staat om inlek/inwateren te voorkomen; lekdicht = géén inwatering.			
	Opmerking:	Bij nieuwbouw kan een categorie 4 van toepassing zijn indien afwatering naar/in de isolatie mogelijk is.			
		Een beheersmaatregel kan eruit bestaan dat een risicoanalyse met Fitness For Purpose wordt uitgevoerd.			
0	Nieuw	Volgen gangbare inspectie regime voor CUI management.	Nieuw, nét geplaatst, voldoet aan nieuwbouw eisen (CINI etc).	Nieuwbouw kwaliteit zonder inwatering.	
1	Zeer goed	Volgen gangbare inspectie regime voor CUI management.	Gebruikt, voldoet aan alle eisen.	Niet vervormd, geen inwatering.	
2	Goed	Volgen gangbare inspectie regime voor CUI management.	Gebruikt, beperkte afwijking zonder gevolgen voor het voorkomen van inwateren.	Vervormd, geen inwatering.	
3	Matig	Aktie binnen maximaal 6 jaar.	Als 2, met afwijking die tot inwatering kan leiden.	Inwatering valt NIET uit te sluiten.	 
4	Slecht	Aktie binnen maximaal 3 jaar uitgevoerd.	Als 3, mét afwijking welke inwatering mogelijk maakt waardoor het plannen van een aktie noodzakelijk is.	Inwatering onder bepaalde weersomstandigheden	
5	Zeer slecht	Onmiddellijk maatregel, binnen maximaal 1 jaar uitgevoerd.	Als 4, mét dusdanige hoeveelheid inwatering dat binnen 1 jaar ingrijpen noodzakelijk is.	Inwateren en verzamelen (hold-up) van water.	
6	Onacceptabel	Direct onderzoek van de resterende integriteit is noodzakelijk.	Als 5 mét dermate inwatering & schadevorming dat lekkage van stoom en/of product naar buiten lekt.	Er is een acuut gevaar voor de integriteit.	

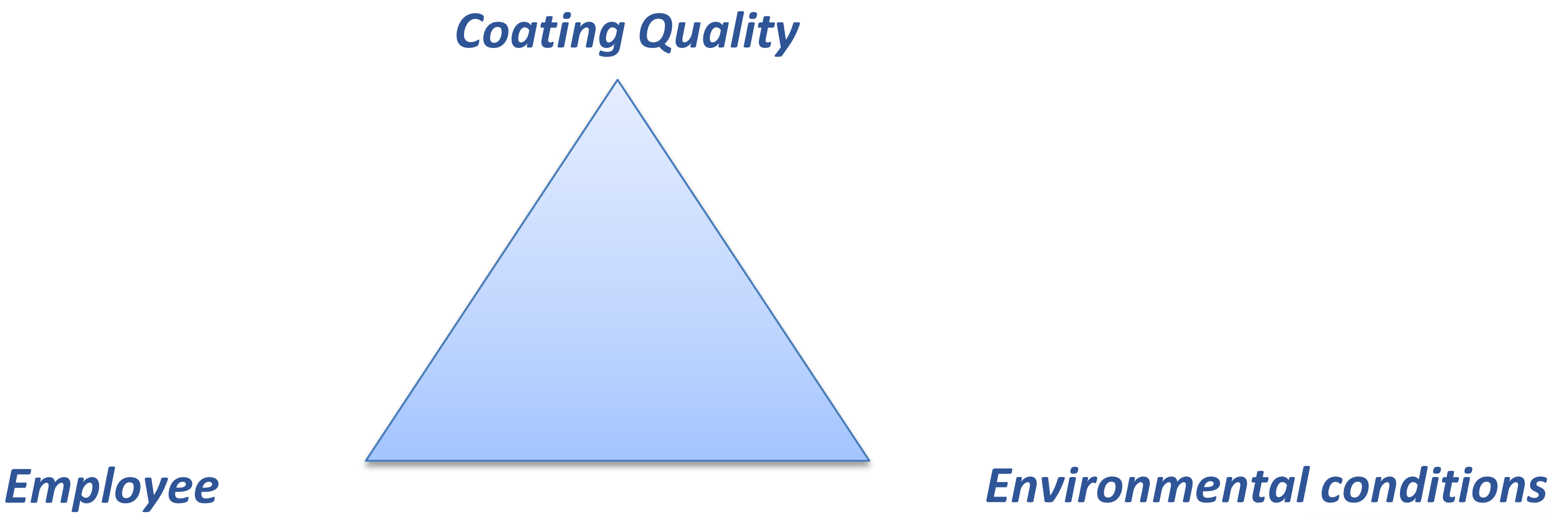
Toelichting | Installatie | NEN-EN 16991 | Faalkans | CorrosieModel | Isol.Cond.Class. | Coating bescherming | NDT Effectiviteit

Assessment of the condition of insulation, effect on risk

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

WORLD CLASS MAINTENANCE

CUI: Integration of influencing factors



CUI: Applied coating service-lifetimes

Influencing factors:

Experience

Quality of application

Accessibility *

Level of management **

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

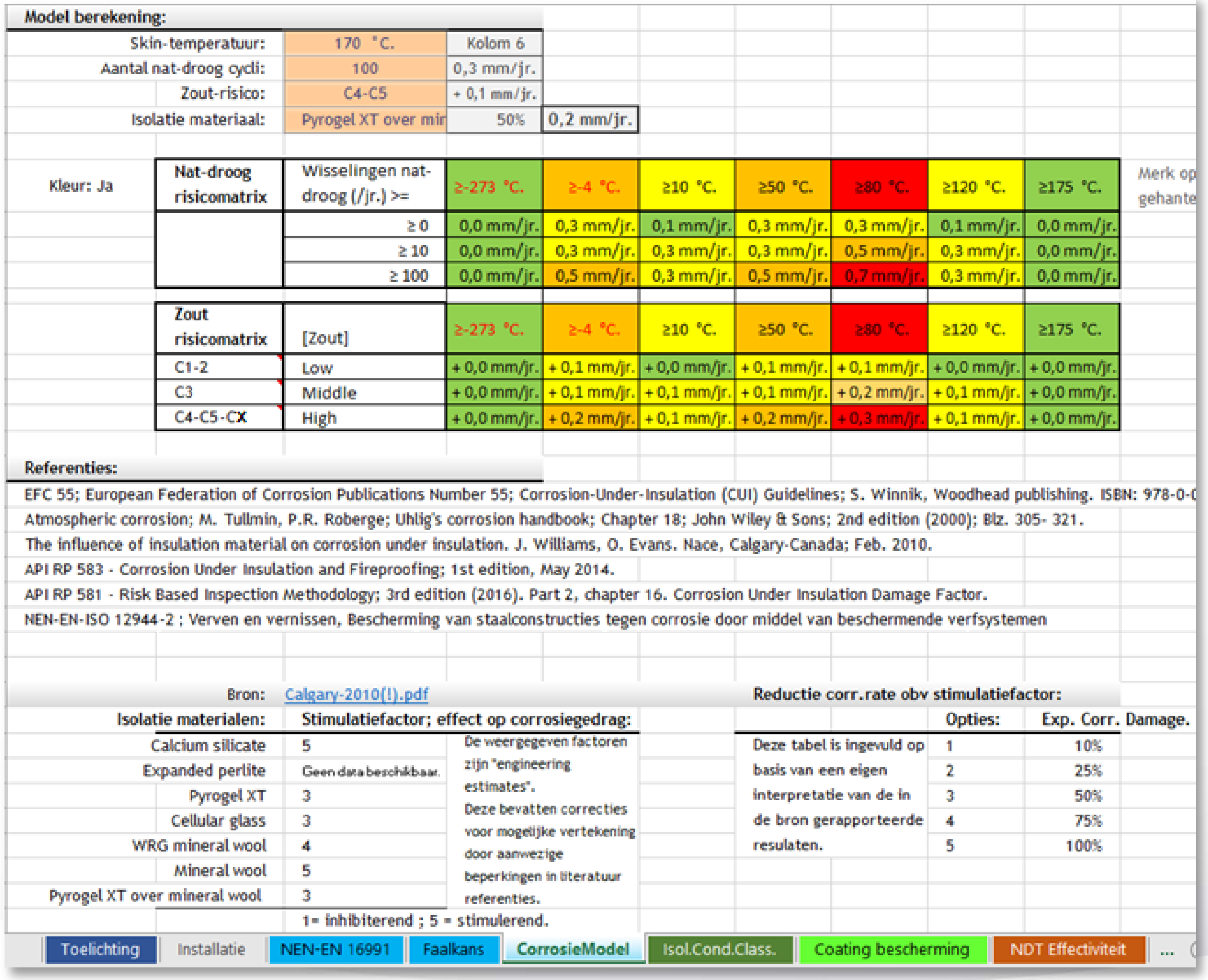
Optie #:	Product	Effect	Ontwerp	Effect	Proces&mens+uitvoering	Effect	isolatie	Effect
1	Getest (= voldoende tolerant)* en >10 jaar ervaring	0,05	Conserveerbaarheid object conform ISO 12944-3 en getoetst door coatingsdeskundige. Bereikbaarheid, toegankelijkheid is zodanig dat optimaal kan worden geconserveerd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

* : through additional extra –x yr. reduction

**: through specific reductionfactor depending of generation of coating.

WORLD CLASS MAINTENANCE

CUI: Applied Corrosion rates



Model berekening:

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

Kleur: Ja

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

Merk op gehante

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

Referenties:

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

Bron: Calgary-2010(1).pdf

Isolatie materialen:	Stimulatiefactor; effect op corrosiegedrag:
Calcium silicate	5
Expanded perlite	Geen data beschikbaar.
Pyrogel XT	3
Cellular glass	3
WRG mineral wool	4
Mineral wool	5
Pyrogel XT over mineral wool	3
	1= inhibiterend ; 5 = stimulerend.

De weergegeven factoren zijn "engineering estimates". Deze bevatten correcties voor mogelijke vertekening door aanwezige beperkingen in literatuur referenties.

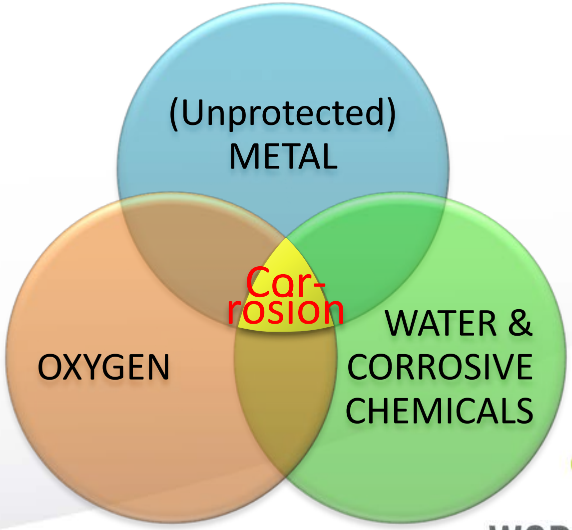
Reductie corr.rate obv stimulatiefactor:

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

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

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

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



WORLD CLASS MAINTENANCE

CUI: Effectivity of inspection techniques

Effective and efficient NDT plan:

- Risk determines required effectiveness of the inspection plan
  - API 581 basic (effectiveness class A to E)
  - With follow-up, this leads to risk reduction

- Costs of access to the property are dominant
  - Life cycle calculation for inspection and maintenance regime (reference numbers)

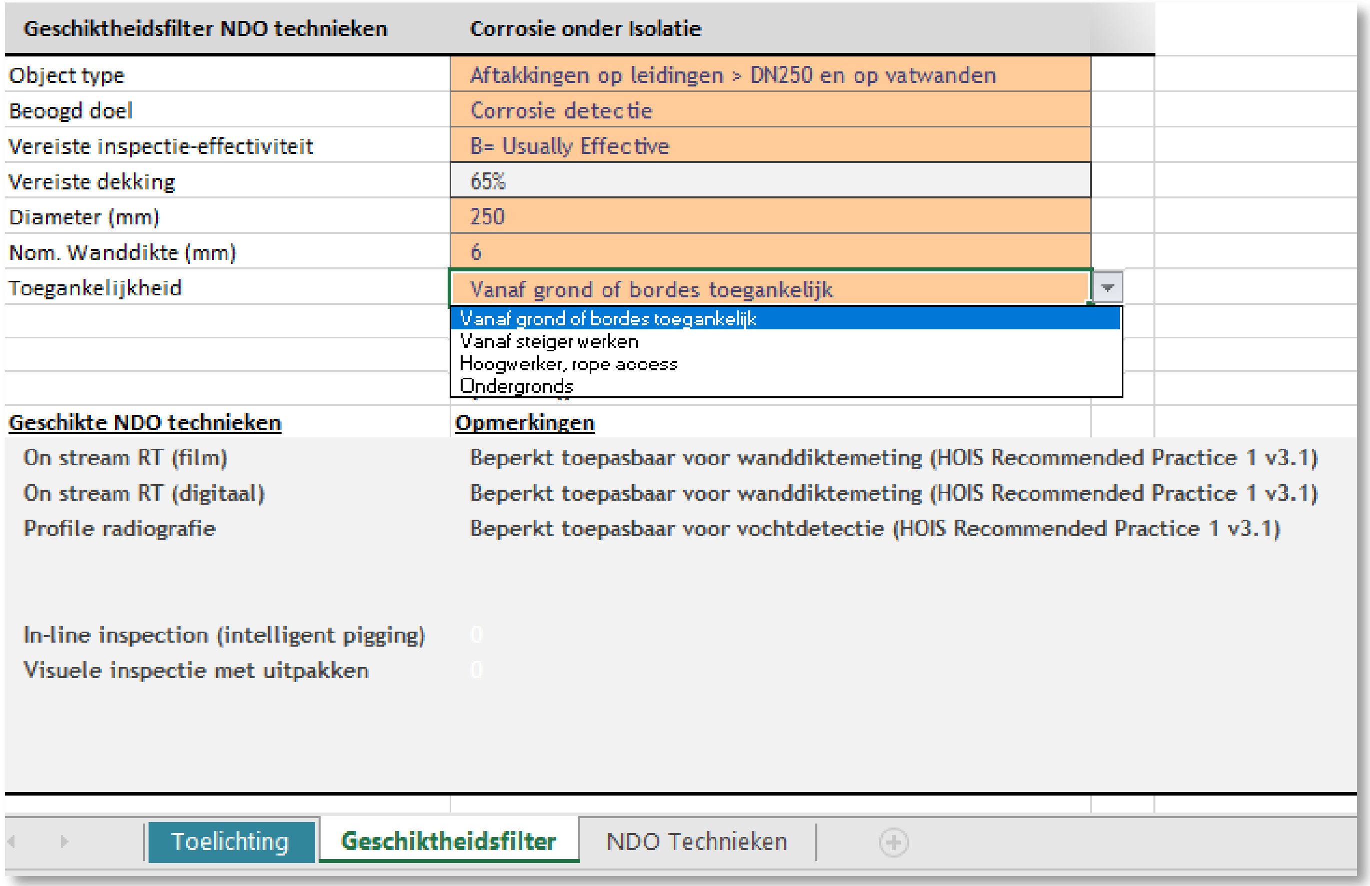
- Many construction, access and damage details only become apparent in the field
  - Pre-inspection in preparation for NDT or Selection of NDT technique in the field

- % Area coverage more important than accurate measurement
  - Potential locations based on design and damaged insulation
  - Then still considerable risk not covered

- Eligibility filter helps with initial selection of technique
  - Work out together with NDO Specialist

WORLD CLASS MAINTENANCE

CUI: Effectivity inspection techniques



Geschiktheidsfilter NDO technieken	Corrosie onder Isolatie
Object type	Aftakkingen op leidingen > DN250 en op vatwanden
Beoogd doel	Corrosie detectie
Vereiste inspectie-effectiviteit	B= Usually Effective
Vereiste dekking	65%
Diameter (mm)	250
Nom. Wanddikte (mm)	6
Toegankelijkheid	Vanaf grond of bordes toegankelijk

Vanaf grond of bordes toegankelijk
Vanaf steiger werken
Hoogwerker, rope access
Ondergronds

Geschikte NDO technieken	Opmerkingen
On stream RT (film)	Beperkt toepasbaar voor wanddiktemeting (HOIS Recommended Practice 1 v3.1)
On stream RT (digitaal)	Beperkt toepasbaar voor wanddiktemeting (HOIS Recommended Practice 1 v3.1)
Profile radiografie	Beperkt toepasbaar voor vochtdetectie (HOIS Recommended Practice 1 v3.1)
In-line inspection (intelligent pigging)	0
Visuele inspectie met uitpakken	0

Toelichting | Geschiktheidsfilter | NDO Technieken

Required effectiveness

- Leads to required coverage

Intended purpose

- Moisture, corrosion, wall thickness

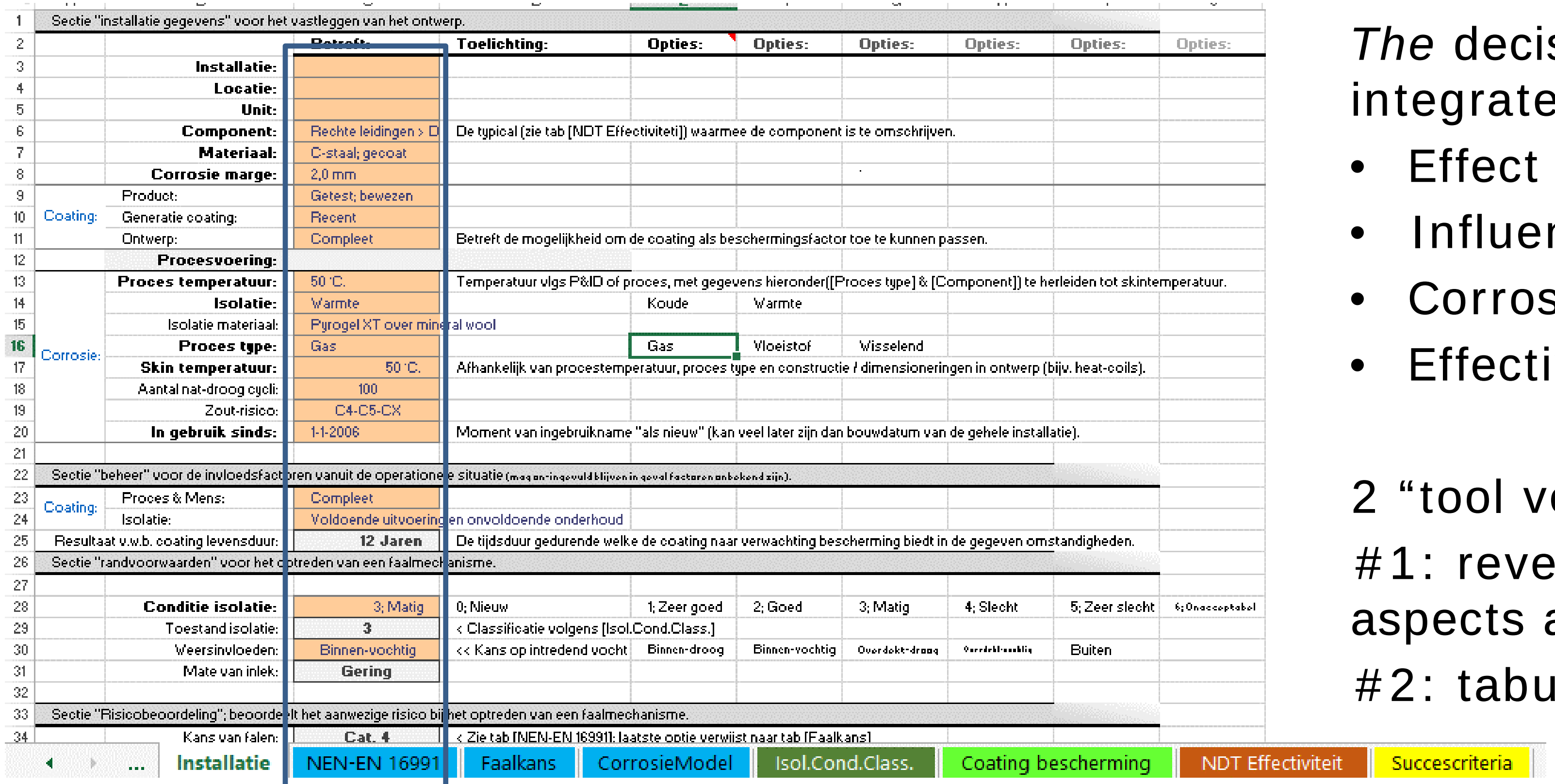
Object type and geometry

- Pipeline, vessel, branches, ...
- Nominal wall thickness

Accessibility

First estimate what should be applied

CUI: Integration of influencing factors



#			Betreft:	Toelichting:	Opties:	Opties:	Opties:	Opties:	Opties:	Opties:
1	Sectie "installatie gegevens" voor het vastleggen van het ontwerp.									
3		Installatie:								
4		Locatie:								
5		Unit:								
6		Component:	Rechte leidingen > D	De typical (zie tab [NDT Effectiviteit]) waarmee de component is te omschrijven.						
7		Materiaal:	C-staal; gecoat							
8		Corrosie marge:	2,0 mm							
9	Coating:	Product:	Getest; bewezen							
10		Generatie coating:	Recent							
11		Ontwerp:	Compleet	Betreft de mogelijkheid om de coating als beschermingsfactor toe te kunnen passen.						
12		Procesvoering:								
13	Corrosie:	Proces temperatuur:	50 °C	Temperatuur vlgs P&ID of proces, met gegevens hieronder([Proces type] & [Component]) te herleiden tot skintemperatuur.						
14		Isolatie:	Warmte		Koude	Warmte				
15		Isolatie materiaal:	Pyrogel XT over mineral wool							
16		Proces type:	Gas		Gas	Vloeistof	Wisselend			
17		Skin temperatuur:	50 °C	Afhankelijk van procestemperatuur, proces type en constructie / dimensioneringen in ontwerp (bijv. heat-coils).						
18		Aantal nat-droog cycli:	100							
19		Zout-risico:	C4-C5-CX							
20		In gebruik sinds:	1-1-2006	Moment van ingebruikname "als nieuw" (kan veel later zijn dan bouwdatum van de gehele installatie).						
21										
22	Sectie "beheer" voor de invloedsfactoren vanuit de operationele situatie (mag on-ingevuld blijven in geval factoren onbekend zijn).									
23	Coating:	Proces & Mens:	Compleet							
24		Isolatie:	Voldoende uitvoering en onvoldoende onderhoud							
25		Resultaat v.w.b. coating levensduur:	12 Jaren	De tijdsduur gedurende welke de coating naar verwachting bescherming biedt in de gegeven omstandigheden.						
26	Sectie "randvoorwaarden" voor het optreden van een faalmechanisme.									
27										
28		Conditie isolatie:	3; Matig	0; Nieuw	1; Zeer goed	2; Goed	3; Matig	4; Slecht	5; Zeer slecht	6; Onacceptabel
29		Toestand isolatie:	3	< Classificatie volgens [Isol.Cond.Class.]						
30		Weersinvloeden:	Binnen-vochtig	<< Kans op intredend vocht	Binnen-droog	Binnen-vochtig	Overdekt-droog	Overdekt-vochtig	Buiten	
31		Mate van inlek:	Gering							
32										
33	Sectie "Risicobeoordeling"; beoordeelt het aanwezige risico bij het optreden van een faalmechanisme.									
34		Kans van falen:	Cat. 4	< Zie tab [NEN-EN 16991]; laatste optie verwijst naar tab [Faalkans]						

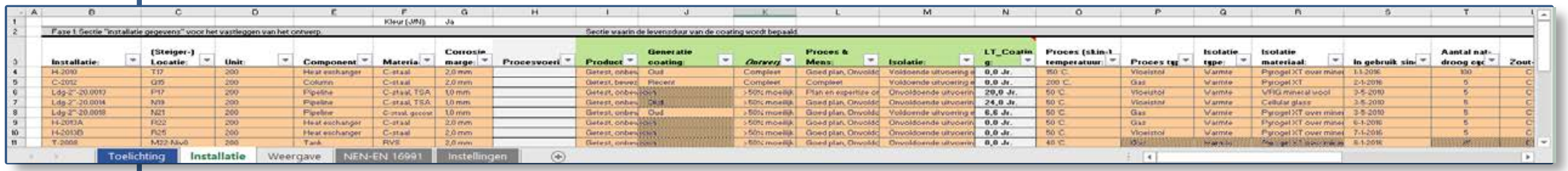
The decision model in which risks are integrated.

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

2 “tool versions”:

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

#2: tabular form, for planning purposes.



CUI: Integration of influencing factors

28		**Conditie isolatie:**	3; Matig	0; Nieuw	1; Zeer goed	2; Goed	3; Matig	4; Slecht	5; Zeer slecht	6; Onacceptabel
29		Toestand isolatie:	3	< Classificatie volgens [Isol.Cond.Class.]						
30		Weersinvloeden:	Binnen-vochtig	<< Kans op intredend vocht	Binnen-droog	Binnen-vochtig	Overdekt-droog	Overdekt-vochtig	Buiten	
31		Mate van inlek:	Gering							
32										
33	Sectie "Risicobeoordeling"; beoordeelt het aanwezige risico bij het optreden van een faalmechanisme.									
34		Kans van falen:	Cat. 5	< Zie tab [NEN-EN 16991]; laatste optie verwijst naar tab [Faalkans]						
35	Gevolgen van falen:	Health:		< Zie tab [NEN-EN 16991];						
36		Safety:	C							
37		Environment:	A							
38		Business (€):	C							
39		Security:								
40		Loss of reputation:								
41		Public disruption:	A	**Eindresultaat (gevolgen): 3**	(5 is maximaal, 1 is minimaal)					
42		**Aanwezig risico:**	1.100,0 k€/jr.	<< Risico op dit moment in €'s, zónder toepassing van beheersmaatregelen. Bij Kans klasse 6 faalt de installatie normatief.						
43			High	<< Risico op dit moment, kwalitatief uitgedrukt vlgs EN 16991, zónder toepassing van beheersmaatregelen.						
44				N.b.: "Very high", betekent dat een aantoonbaar effectieve beheersmaatregel noodzakelijk is!						
45	Sectie "risicoreductie": Beoordeling aanwezige risico bij toepassen van een NDO techniek.							Per saldo ook doelmatigheids beoordeling....BP-6.		
46		Toe te passen beheersmaatregel:	5) Guided Waves / Lon	<< de toegepaste techniek, waarmee de conditie wordt onderzocht, met de vereiste dekking (zie tab [NDT Effectiviteit]).						
47		Vereiste dekking*:	100%	<< de mate van dekking die nodig is bij gebruik van de techniek, om de component te onderzoeken met max. effectiviteit.						
48		Mate van risico reductie:	99%	<< de te behalen risico reductie, wanneer de conditie van de component (het faalmechanisme) wordt onderzocht.						
49		**Aanwezig rest-risico:**	11,0 k€/jr.	<< dit is het best resultaat, indien de [mogelijke conditie] in werkelijkheid een betere [werkelijke conditie] blijkt te zijn.						
50			Medium	Effectiviteit beheersmaatregel is ingericht obv 3 niveau's/levels, met POD berekening op level III						
51		Inspectie interval:	0,1 Jaren	<< Inspectie termijn volgens de risicotabel [NEN-EN 16991] en wettelijke regeling uit het PrdA referentie instrument.						
52				Structuur voor verwerking van de ineffectiviteit (False calls & Fail2Detect) is aangebracht en niet uitgewerkt.						
53		*: In alle gevallen is bij toepassing van een techniek OOK 100% visuele inspectie van de isolatie op "verdachte plaatsen" benodigd (zie API 581(2016) Tabel C.2.10.3).								
54	**Samenvatting van de verkregen resultaten:**					(betreft herhaling van de hierboven weergegeven informatie)				
55										

		Vooraf:	Met inspectietechniek:	5) Guided Waves / Long Range UT	
56		Vooraf:	Met inspectietechniek:	5) Guided Waves / Long Range UT	
57	Risico:	High	Medium	**Risk Based Inspectie termijn:**	0,13 Jr.
58	Faalkans:	Cat. 5	Cat. 3	**Inspectie dekking:**	100%
59	Kostenniveau:	1.100,0 k€/jr.	11,0 k€/jr.		
60	Kosten reductie:	99%	1.089 k€/jr.		

61

62 Toelichting op dit werkblad:

Het bovenste gedeelte van dit tabblad (eerste sectie) karakteriseert de procesomstandigheden.

De sectie "randvoorwaarden" daaronder, geeft weer of degradatie mogelijk is wat betreft isolatie én omgevingsfactoren (aanwezigheid vocht)

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

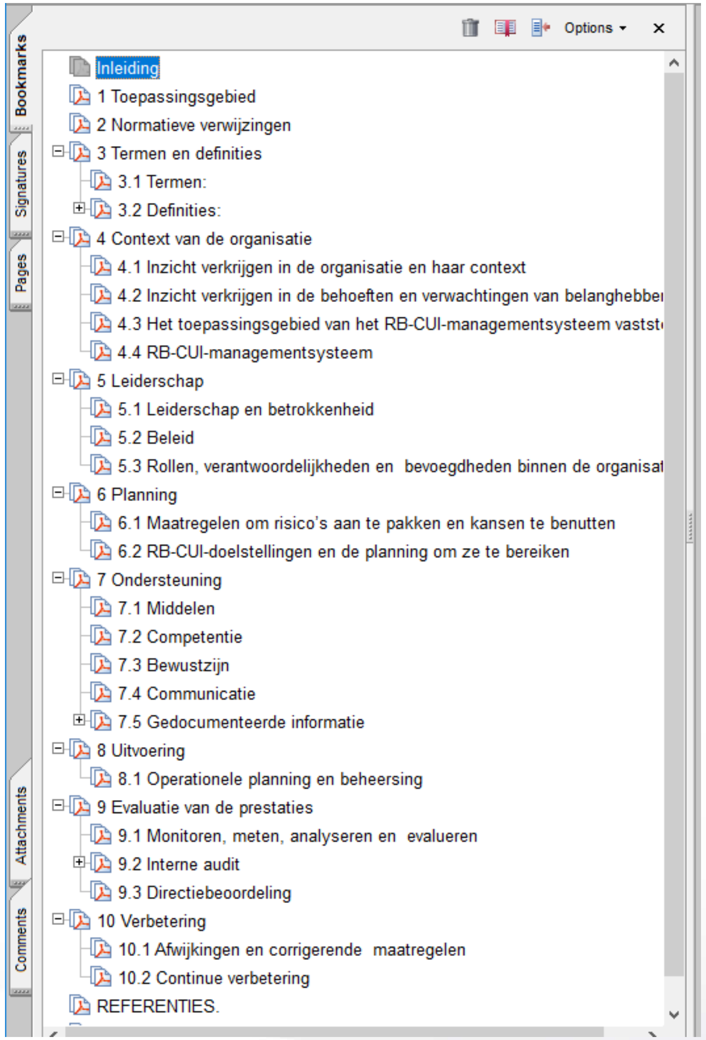
Cost effective and proactive? #How?.

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

2 “types of result”:

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

CUI: Best practice CUI management



The best practice description for RB CUI.

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

WORLD CLASS MAINTENANCE

Now: Start with CUI-projects

Workshops CUI
- Relay workshops

Kick-start CUI-projects
- First launch / approach
- Intensive consultancy

Review CUI-approach
- GAP Analysis of the applied method

WORLD CLASS MAINTENANCE

Current status of users (complete or partly).

Partly

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

Complete

- Shell Catalysts (BE)

Other downloads (end Aug. '20)

- Akzo Nobel Eng
- BosQman
- Corio
- CorrosionRadar
- Endures
- Engie
- Forbo
- Fuji
- Indorama
- Lloyds
- Mainnovation
- Maxgrip
- Merck
- Nederlandse Gasunie
- Neste
- Nouryon
- Rockwool
- Solvay
- Sirris
- Synerlogic
- Synres
- Tata
- Taqa
- TNO
- Umicore
- Vandemoortele
- VIB
- Yara

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

- Nog yet applied

WORLD CLASS MAINTENANCE

Now: Objective with respect to dissemination

EFC 55 & RB CUI Best Practise (BP)

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

Question in this phase

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

Review CUI-approach

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

WORLD CLASS MAINTENANCE

WORLD CLASS MAINTENANCE

Thanks for you attention

More information: www.worldclassmaintenance.com

Appendix 4

Digitalisation with corrosion monitoring: uses cases for CUI, coatings, RBI

(Pratfull Sharma)

EFC Work Party 15
Corrosion In Refinery and Petrochemicals
Annual Meeting
Online

Digitalisation with Corrosion Monitoring

Use Cases to CUI, Coatings and RBI

Dr Prafull Sharma, CorrosionRADAR Ltd (UK)

www.corrosionradar.com

AGENDA

Objective - Content

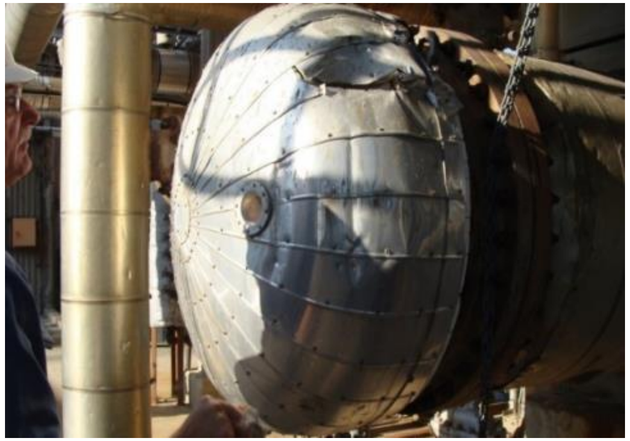
1. Why – Introduction

2. What – Solution

3. Where – Case Studies

4. How – ROI



1. WHY - Introduction

The era of Inspection 4.0

Enabled by IIOT and Predictive analytics

Inspection 1.0
Manual observation,
Leaks

Inspection 2.0
Visualisation,
NDT instruments

Inspection 3.0
Statistics, RBI

Inspection 4.0
Automated,
Analytics, Prediction

Manual → Automated

Detection → Prediction

Reaction → Prevention

Predictive Corrosion Management - Opportunity

Enabled by IIOT and Predictive analytics

CURRENT PRACTICE
Reactive

Human judgement + guessed risk ↔ Periodic Manual Inspection

Reactive Maintenance

- Labour Intensive
- Unscheduled Shutdowns
- Safety Risk
- High cost

Sensors

Connectivity

Inspection 4.0
Automated, Analytics, Prediction

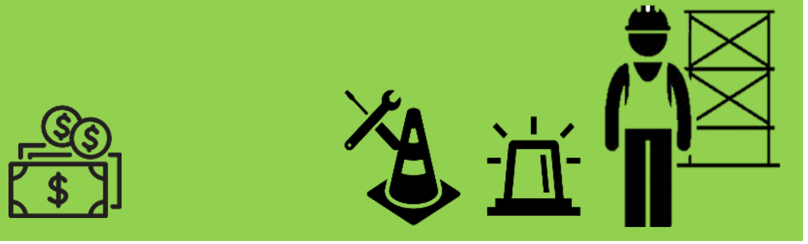
Knowledgebase

Analytics / ML

Continuous Monitoring ↔ Automated risk profiling

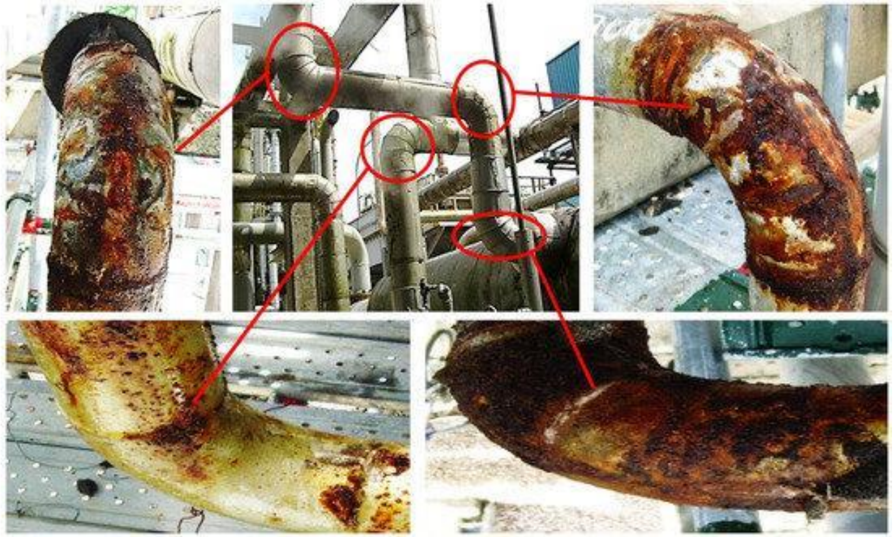
Predictive Maintenance

- Minimal labour effort
- Scheduled Maintenance
- Improved safety
- Reduced cost



First Application - Corrosion Under Insulation (CUI)

CUI IS THE FIRST STRATEGIC TARGET SEGMENT FOR CR



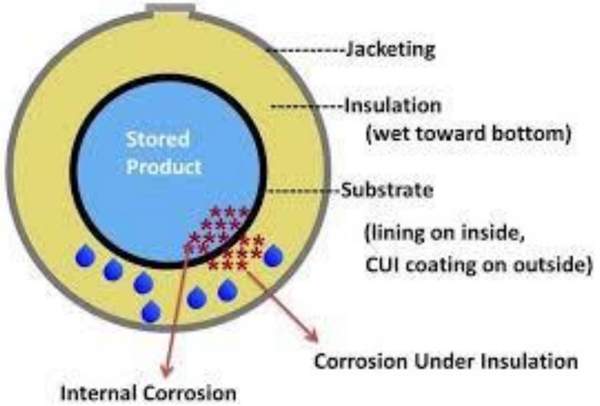
CUI is #1 asset integrity issue in O&G and Petrochemicals

60% of all pipeline failures are due to CUI

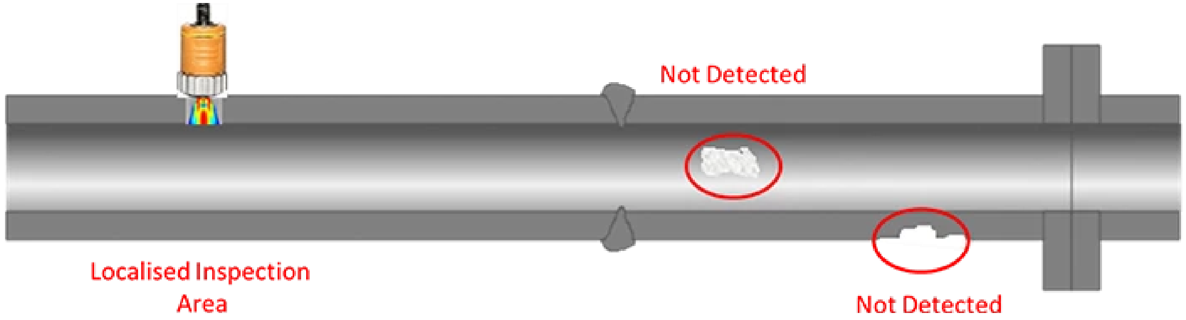
10% of the overall offshore platforms maintenance cost

How CUI happens

Water ingress into insulation



Unpredictable location



Suitable temperature

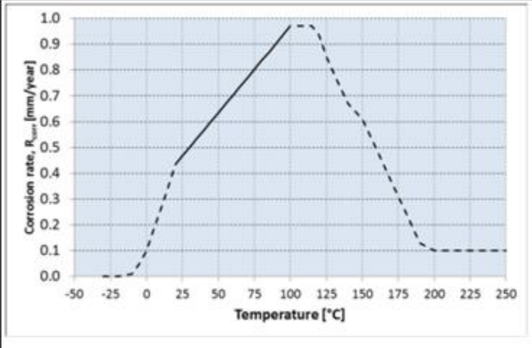


Figure A-3: Corrosion rate (Rcorr) vs. temperature

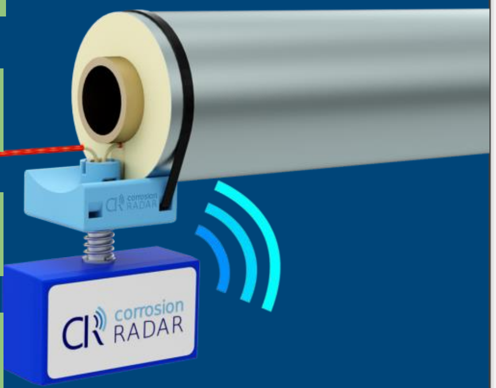
2. WHAT - Solution

CorrosionRADAR Solution

PREDICTIVE CORROSION MANAGEMENT USING IIOT

DETECT

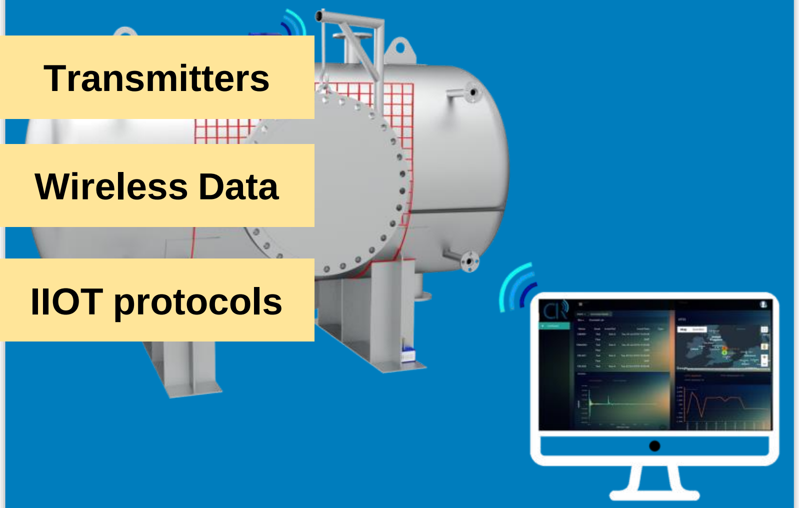
- CR Moisture
- CR Corrosion
- CR Coating**
- Other Sensor**



- Distributed Corrosion & Moisture Sensors
- Long Range Coverage
- Cost Effective Installation
- Covering Complex Pipe works

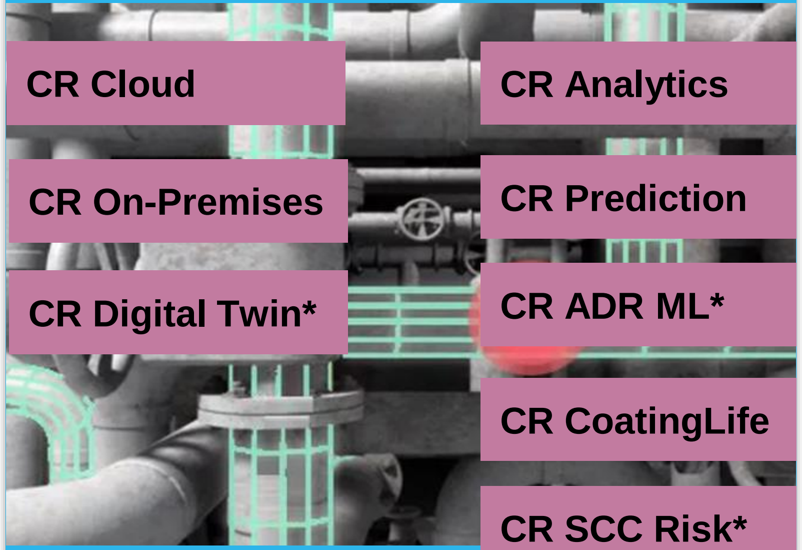
CONNECT

- Transmitters
- Wireless Data
- IIOT protocols



- Long-Life Battery Powered
- Remote Wireless Communications
- Continuous Monitoring
- Dashboard for Actionable Intelligence

PREDICT



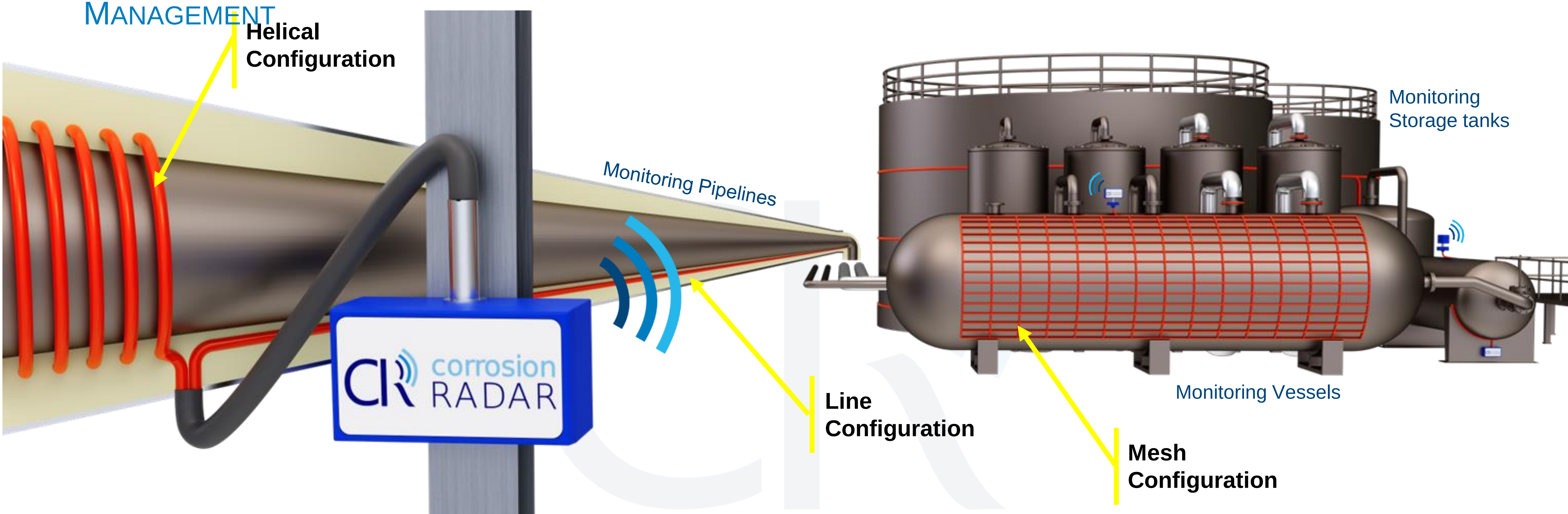
- CR Cloud
- CR Analytics
- CR On-Premises
- CR Prediction
- CR Digital Twin*
- CR ADR ML*
- CR CoatingLife
- CR SCC Risk*

- Predictive Asset Management
- Asset life extension
- Effective Risk Management
- Historical Data & Analytics

***Prototype **Future products**

Detect - Sensors

Corrosion and Moisture Sensors for Predictive CUI Management



Sensors

Sensors Type	1) Corrosion 2) Moisture
Sensor Length	1) Up to 100m 2) 50m
Temperature Range	-50 to 1) +300 °C 2)+200 °C

Embedded Sensors = **Long-range & Modular** (each sensor unit can cover up to 100 m) + **Unaffected by Complex Geometries** (e.g. vessels, pipe bends, flanges...) + **Cost Effective for Mass Deployment**

Connect - Electronics

ATEX COMPLIANT PRODUCT FOR HAZARDOUS ENVIRONMENT

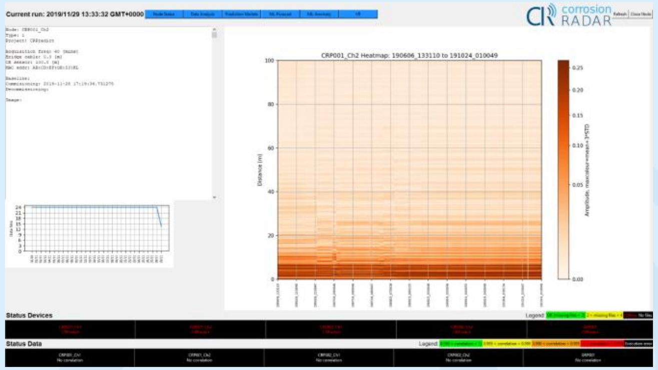
Corrosion & Moisture Monitoring System - Electronics

ATEX/IECEx Certification	II 2 GD Ex db IIB+H2 T3-T6 Gb Ex tb IIIC T85°C - T150°C Db
Ingress Protection	IP66
Power Source	Mains
Temperature Range (°C)	- 20 to +60
Communications	Wireless: Wifi/Cellular/WirelessHART/LoRa Other options: USB
Approx. Dimensions (mm):	284H X 245W X 169D (Without Antenna)
Approx. Weight	11.2 Kg

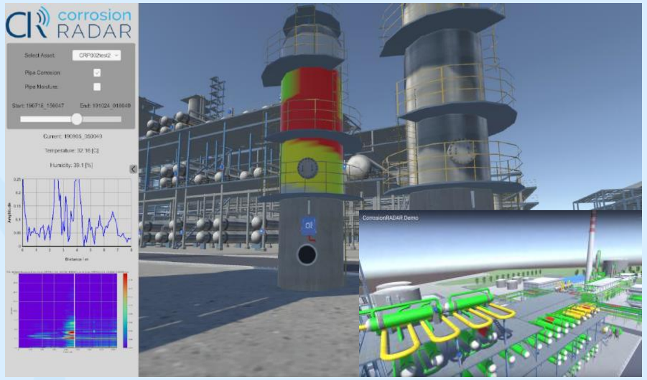
Predict - Analytics Platforms

CR Predict IIOT Cloud platform

CR Predict On-Prem Software platform

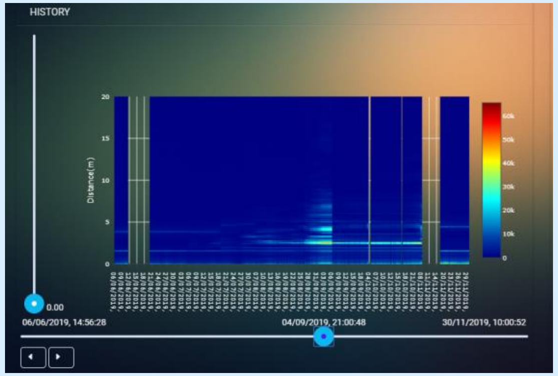


CR Predict Digital Twin platform

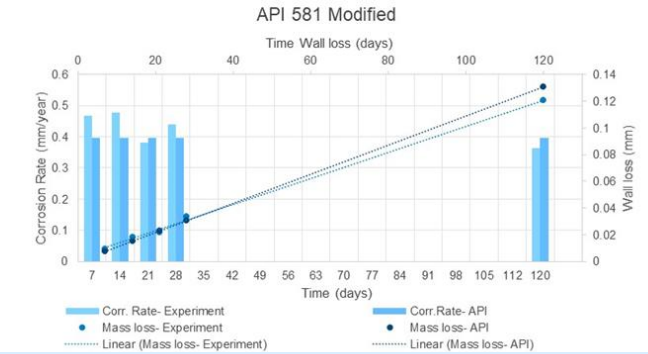


CR Predict Add-on Algorithm Products

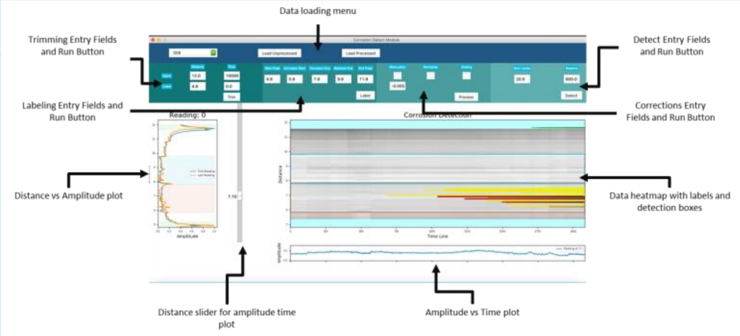
CR Analytics Module



CUI Prediction Module enabled by new improved models



CR Automated Defect Recognition Module using Machine Learning

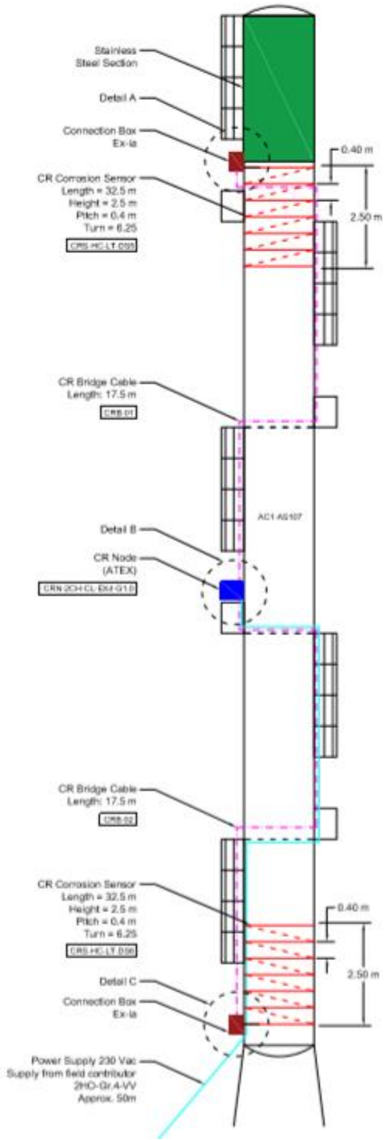


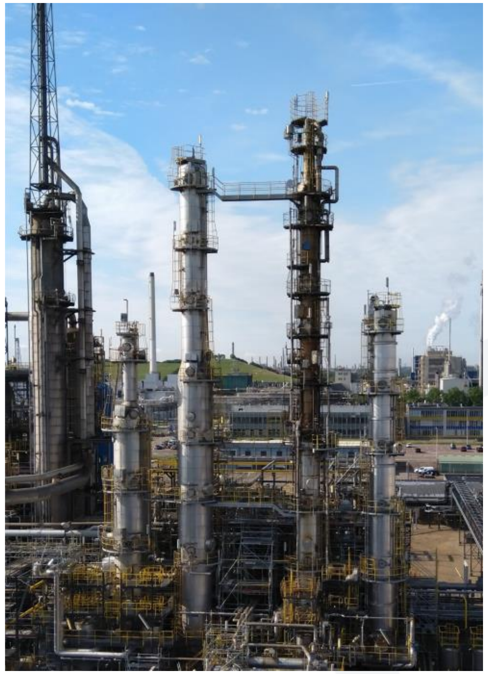
3. WHERE –

Case Studies

Case Study A

PRODUCTION COLUMN CORROSION MONITORING (ATEX)

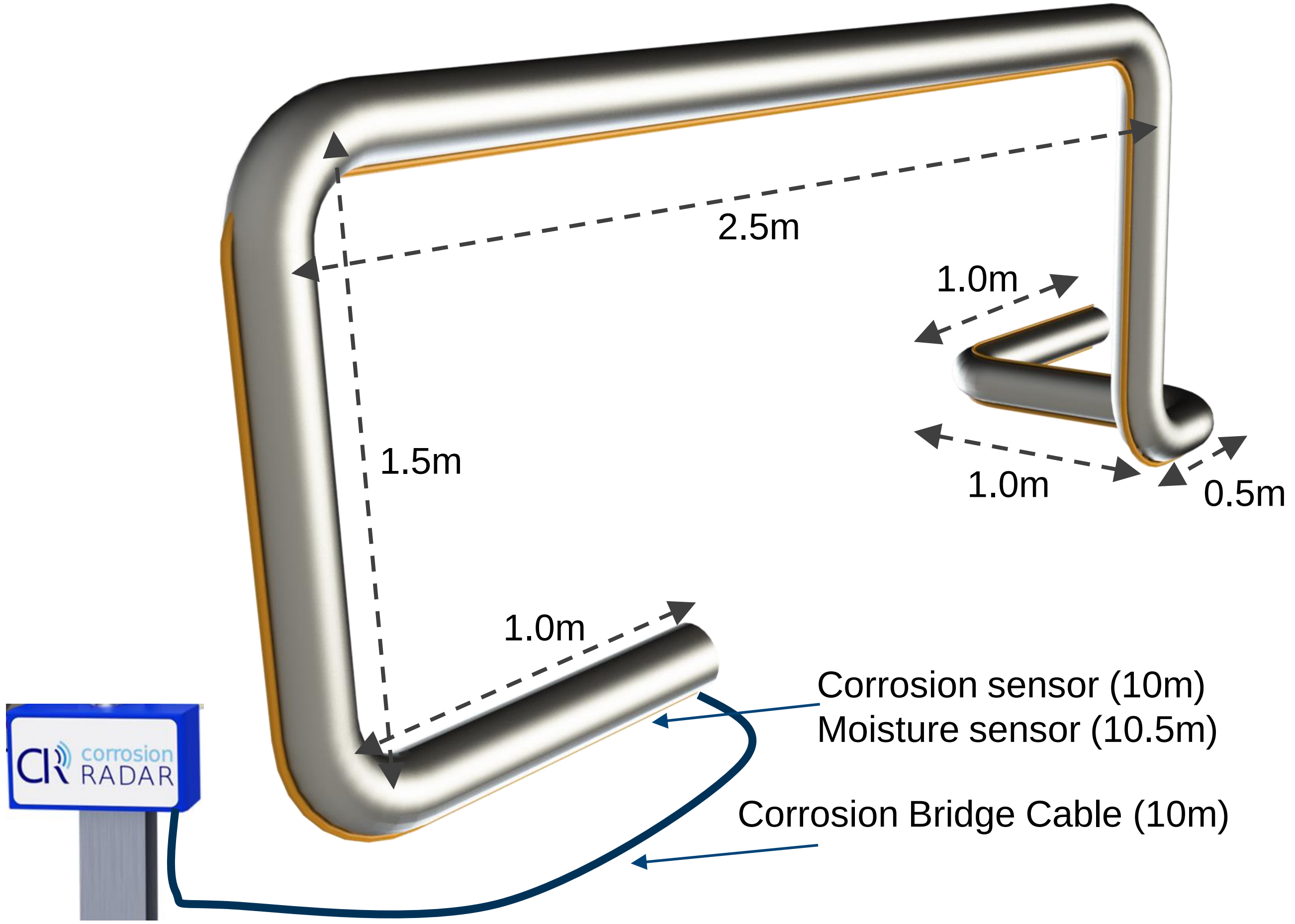


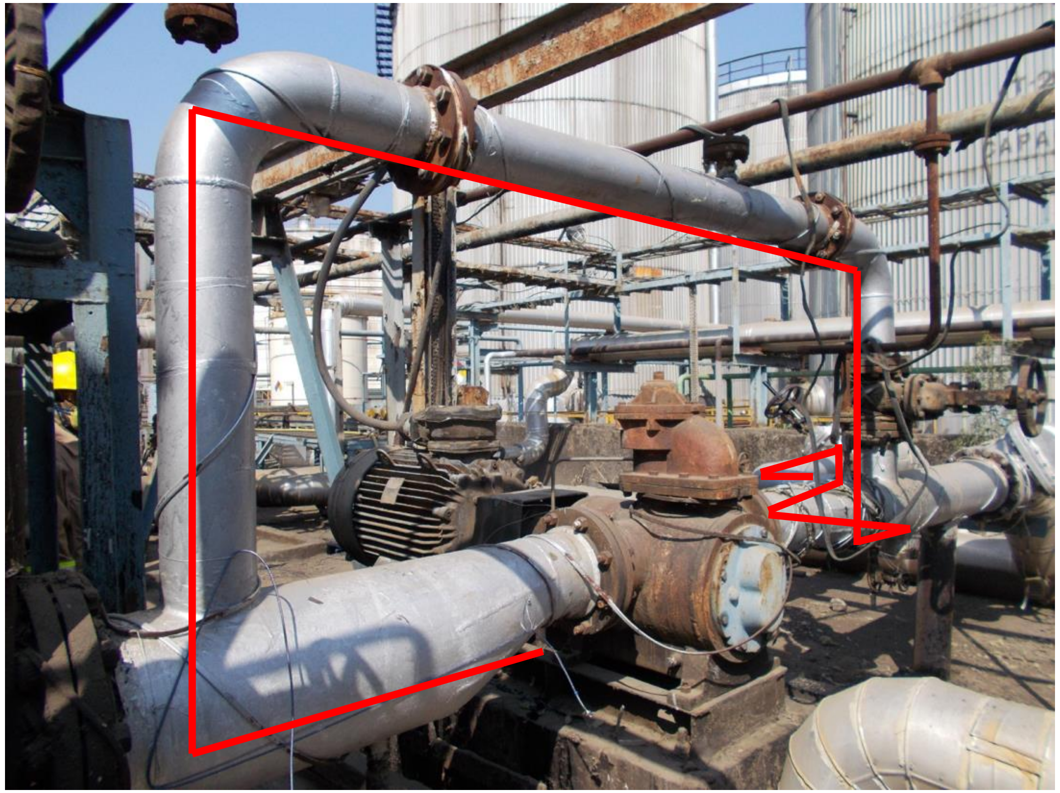


Case Study B

INSTALLATION OF CR SYSTEMS

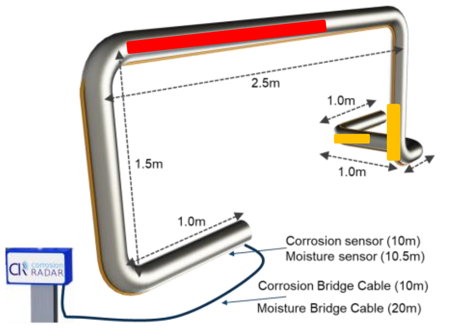
Installed layout of both CR Corrosion and Moisture monitoring systems

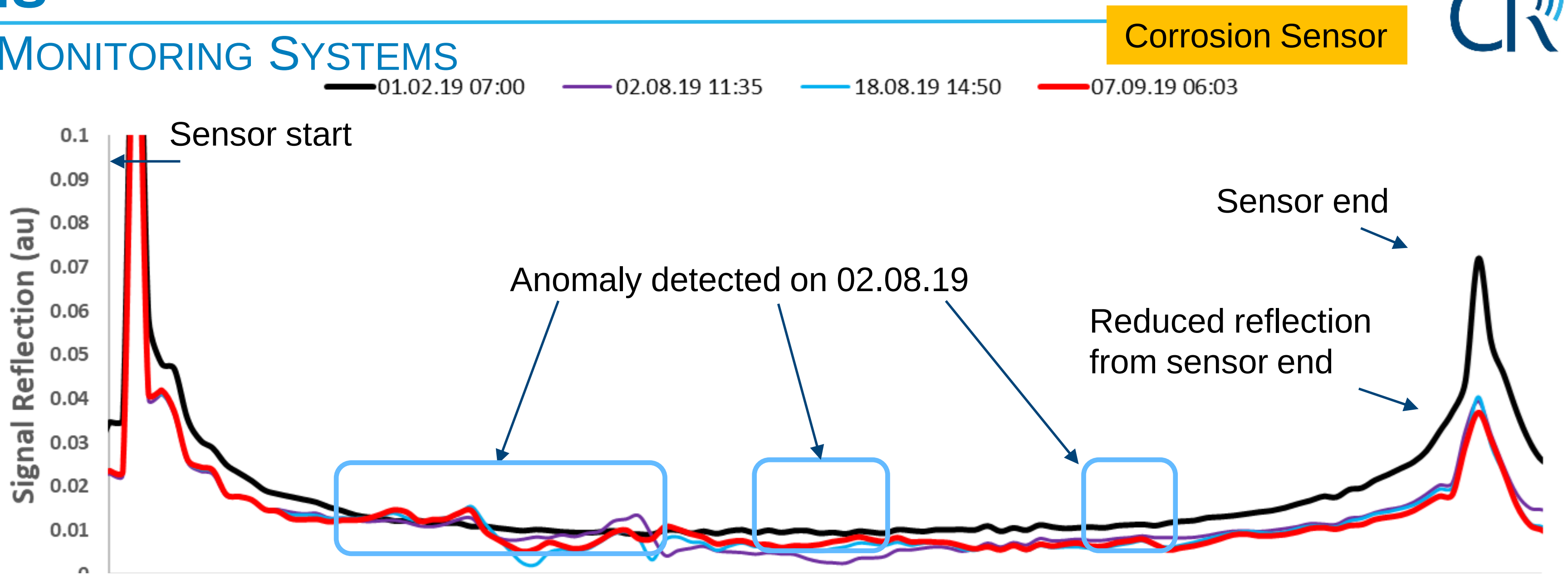


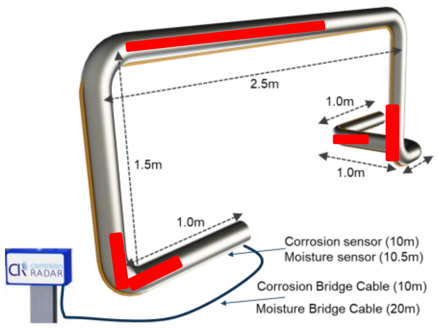


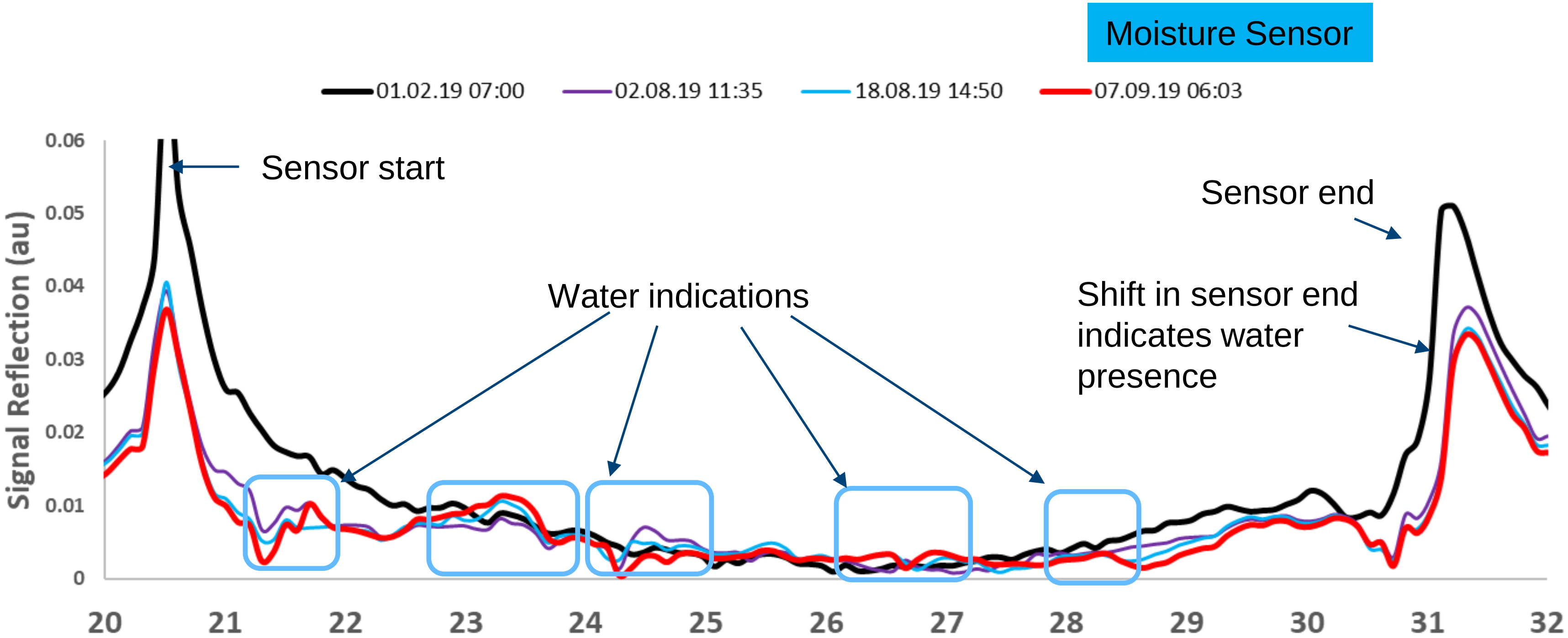
Data after 9 months

Corrosion and Moisture Monitoring Systems

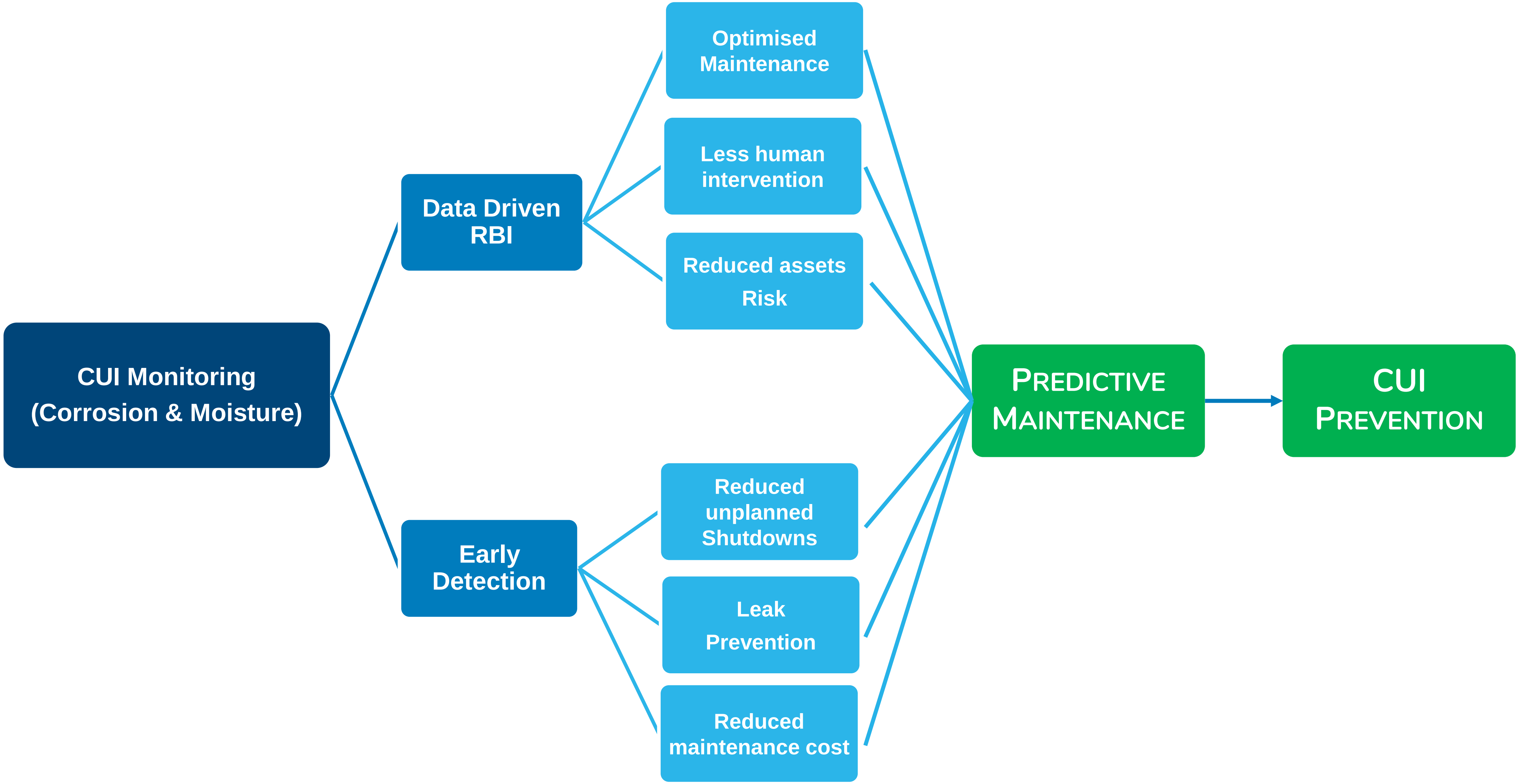








Benefits of CUI Monitoring



Dynamic CUI risk assessment with CR sensors

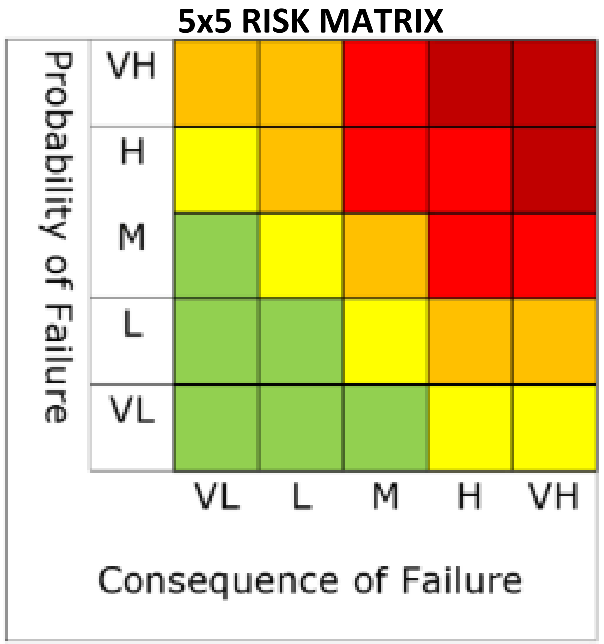
DNVGL-RP-G109

From Probability of failure to Risk assessment:

$$Risk_{CUI} = f(PoF_{CUI}, CoF)$$

Dynamic PoF Probability of failure for CUI

From CR sensor signal readings and inputs coming from the characteristics of the asset



= **Dynamic CUI risk**

CoF from exiting RBI

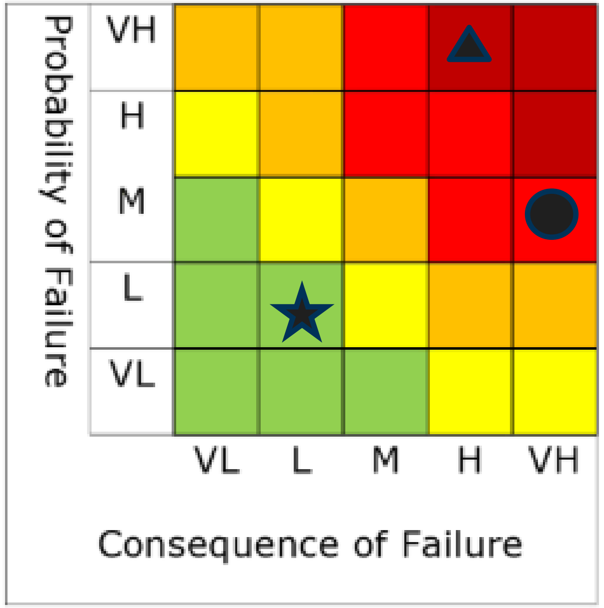
Existing data should be used to assign a consequence of failure (CoF) to obtain the CUI risk. Advice on this can be found in DNVGLRPG101.

CoF					
	VL	L	M	H	VH
SAFETY	Negligible impact	Minor imp. personnel	Medical treatment	Serious injury	Fatalities
FINANCIAL	Negligible business impact	<100 00 eur business impact	100 000 to 1 M eur	1 to 10 M eur	> 10 M eur

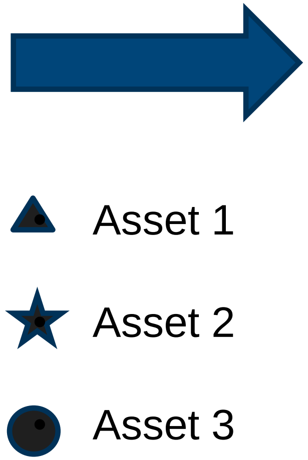
Enabling Dynamic RBI for CUI

Optimizing inspections and safety with field inputs

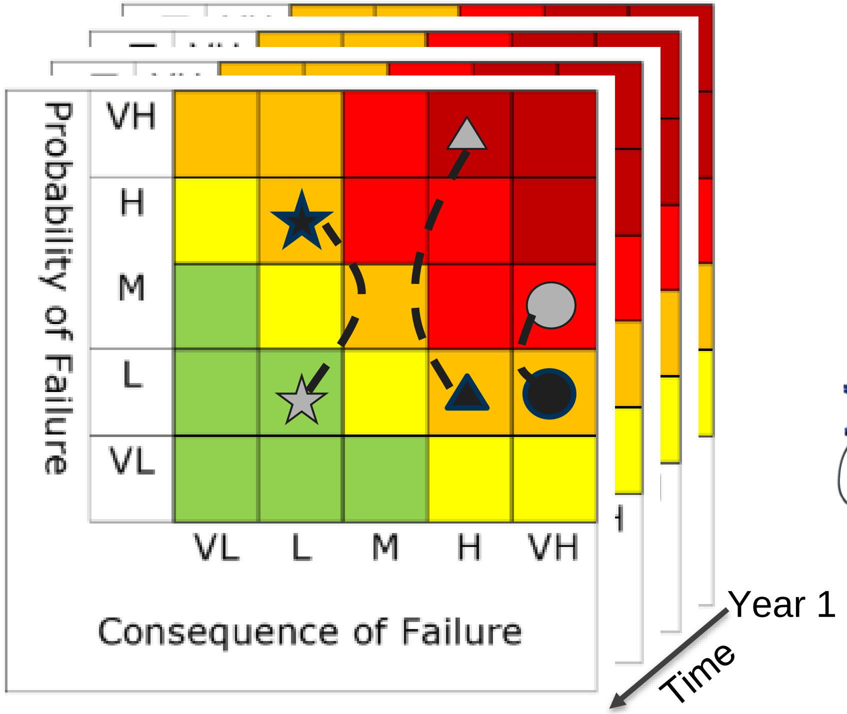
Static RBI



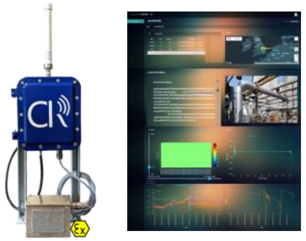
Year 1 ~ Year 5



Dynamic RBI



Enabled by CorrosionRADAR monitoring system



- Is not periodically updated
- Does not reflect field conditions
- Scope for optimisation

- Periodic updates (manual or automated)
- Incorporates field conditions (moisture)
- Optimised inspection cycles

Higher resolution of RBI - Scenario

Static CUI risk

Probability of failure due to CUI dependent on:

- ✔ Material barrier
- ✔ Coating barrier
- ✔ Water wetting barrier
- ✔ Design barrier

} Input data from the characteristics of the asset

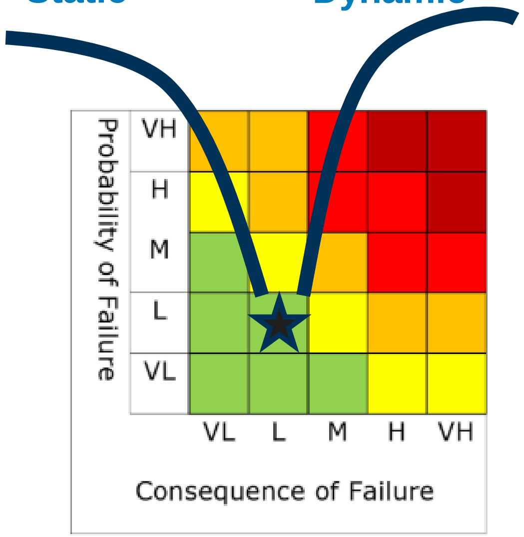
Assessing the CUI risk year 1 — Risk assessment update year 4 — Risk assessment update year 7 — TODAY

	1 year		2 year		3 year		4 year		5 year		6 year		7 year	TODAY
	TOTAL PoF CUI RISK													
Pipe length	**6 month**	**12 month**	**18 month**	**24 month**	**30 month**	**36 month**	**42 month**	**48 month**	**54 month**	**60 month**	**66 month**	**72 month**	**78 month**	**84 month**
0	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
0.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
1	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
1.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
2	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
2.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
3	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
3.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
4	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
4.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
5.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
6	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
6.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
7	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
7.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
8	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
8.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
9	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
9.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
10	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH
10.5	VL	VL	VL	VL	VL	VL	VL	L	L	L	L	L	VH	VH

Conclusion:
Today there is Very High probability of failure due to CUI along the 10.5 m pipe.

Higher Resolution (location and time)

Static — Dynamic



Dynamic CUI risk with CR sensors

Probability of failure due to CUI:

- ✔ Material barrier
- ✔ Coating barrier
- ✔ Water wetting barrier
- ✔ Design barrier

Continuously monitored • • • — TODAY

	1 year		2 year		3 year		4 year		5 year		6 year		7 year	TODAY
	TOTAL PoF dynamic CUI RISK													
Pipe length	**6 month**	**12 month**	**18 month**	**24 month**	**30 month**	**36 month**	**42 month**	**48 month**	**54 month**	**60 month**	**66 month**	**72 month**	**78 month**	**84 month**
0	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
0.5	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
1	M	M	H	M	M	M	M	M	M	M	M	VL	VL	VL
1.5	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
2	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
2.5	VL	VL	VL	L	VL	VL	VL	VL	L	VL	M	M	H	H
3	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	M	M	H	H
3.5	VL	VL	VL	VL	L	VL	L	VL	VL	VL	VL	VL	VL	VL
4	VL	VL	VL	VL	L	VL	VL	L	L	VL	VL	VL	VL	VL
4.5	VL	VL	L	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL
5	M	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
5.5	M	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
6	VL	VL	VL	VL	VL	L	L	M	M	L	VL	VL	VL	VL
6.5	VL	VL	VL	VL	VL	L	VL	VL	L	VL	VL	VL	VL	VL
7	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
7.5	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
8	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL
8.5	VL	VL	L	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL
9	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
9.5	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
10	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
10.5	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL

Conclusion:
Today there is very low probability of failure due to CUI from 0 to 2.5 m pipe and from 3.5 and 10.5 m. And low PoF between 2.5 and 3.5 m.

Dynamic CUI risk assessment with CR sensors

DNVGL-RP-G109

Assessing the Probability of Failure for CUI based in 4 CUI barriers

$$PoF_{CUI} = f\left(PoF_{material}, PoF_{coating}, PoF_{water\ wetting}, PoF_{design}\right)$$

— A. Material barrier:

- — material type
- — material surface temperature
- — temperature fluctuations
- — contaminants

— B. Coating barrier:

- — coating age
- — coating type
- — quality control and workmanship
- — wetting conditions
- — temperature

— C. Water wetting barrier:

- — location
- — dewpoint temperature
- — insulation system
- — workmanship
- — maintenance routines

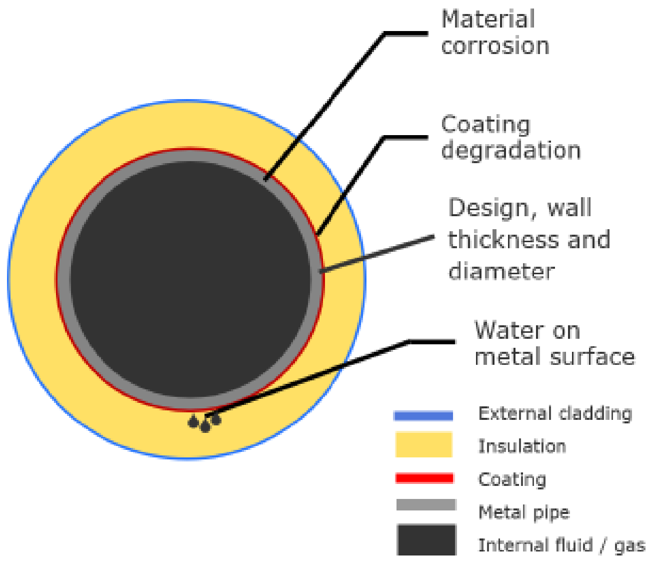
— D. Design barrier:

- — wall thickness
- — pipe dimensions
- — inspection method, extent, timing and results.

CR moisture sensor signal

CR temperature sensor signal

Dynamic CUI Probability of failure

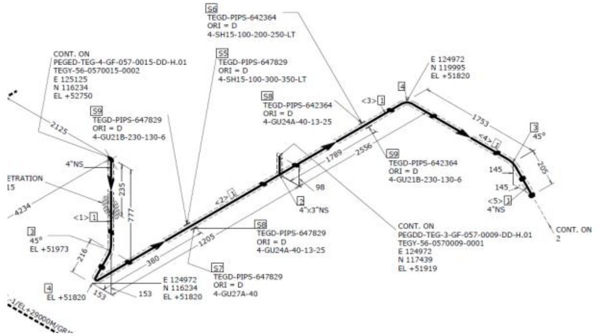


4. HOW – ROI

Target Use cases – Pipes and Equipments

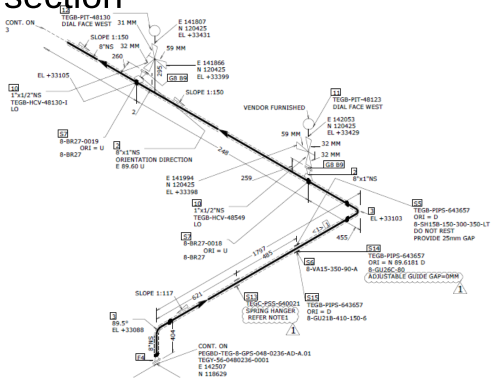
Asset 1 – Pipeline xxxxxx

<4" NS
<80 DegC
<100m section



Asset 2 – Pipeline xxxxxxx

>8" NS
>80 DegC
<100m section



Typical Weighting:

Economics

Type of equipment:

Vessel; Column; Heat Exchanger; Storage tank;Pipeline

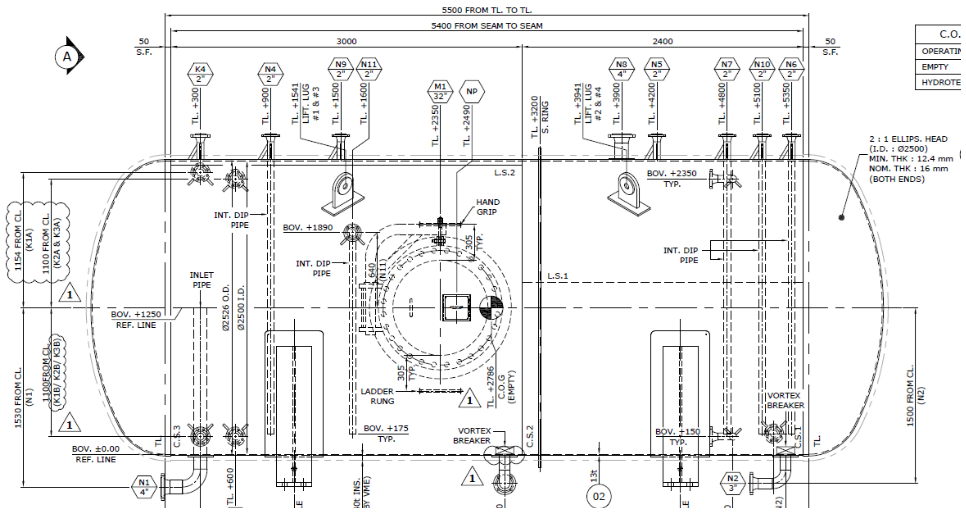
Size of equipment:

Length; Diameter; Height

Conditions:

Temperature; Humidity; Fluctuations; Age

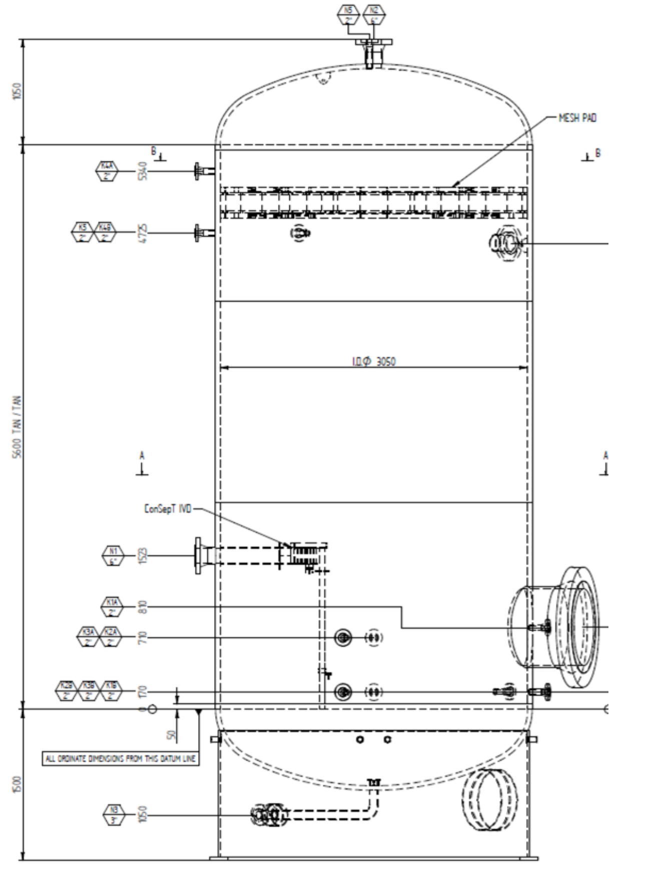
Asset 3 – Vessel xxxxx



Surface area = xxxx Sq Meter

Asset 4 – Vessel xxxx

Surface area = xxxx
Sq Meter



Template of Cost Benefit Analysis per asset

Input

Manual inspection cost per meter (or square meter) of asset

Input

Length of pipeline to be considered for analysis

Input

Inspection cycles (4 years in this case)

Input

Total % of length of pipeline manually inspected (Status quo)

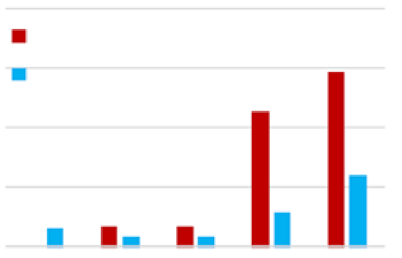
Input

Total % of length inspected when with CorrosioRADAR

[redacted]

Asset 1 - Pipeline 057-0015, Op Temp 30DegC, 4"Dia, wall thickness 2" Sch80 (5.54mm), 100m

All costs in GBP			Year	Inspection%	Manual Inspection	CR+Inspection%	With CorrosionRADAR	Net savings
Cost per unit (GB	2280		0	0	£0	0%	£30,000	-£30,000
Length or area (n	100		4	15%	£34,200	2%	£16,560	£17,640
			8	15%	£34,200	2%	£16,560	£17,640
			12	100%	£228,000	20%	£57,600	£170,400
			Total		£296,400		£120,720	£175,680



Manual cost of inspection (status quo)

Output

Reduced cost of inspection with CorrosionRADAR

Output

Net Savings

Output

Manual inspection cost vs Reduced cost with CorrosionRADAR

Output

Other benefits:

- *Loss of containment*
- *Quality assurance*
- *Reduced maintenance repair scope*
- *Increased interval*
- *Zero unplanned shutdown / disaster*
- *Modernisation & Transformation alignment*

Benefits of CR CUI Monitoring System

COST

ESTIMATED MAINTENANCE COST SAVINGS: 30-45%

RISK

Key Takeaways

- Predictive CUI monitoring System – Corrosion and Moisture sensors
- Cost Benefit Analysis and ROI calculations are attractive
- Pilots - From Pilot to scale up
- Consultancy - Digitalisation and predictive corrosion management
- Organising a dedicated seminar for your company
- Business Model - CAPEX or OPEX whichever suits you (e.g. Data as a Service)

Please contact us at **info@corrosionradar.com**

Appendix 5

Asset Integrity Management : Digital solutions from PPG

(Chris Magel and Michael Kuhn)



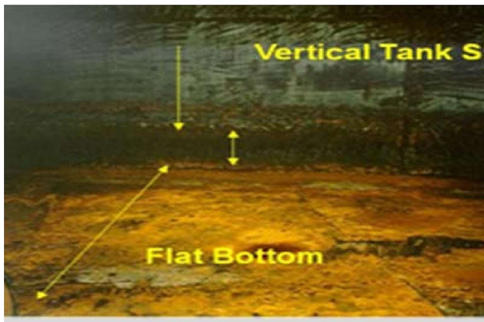

AIM, Asset Integrity Management

Digital Solutions From PPG

Chris Magel Business Development Manager
Michael Kuehn Director Global Strategic Accounts

September 2020

Corrosion did not stop during Lockdown – the importance of monitoring



Crude Oil Tank

Corrosion under HC PFP

CUI

Corrosion during Transport/ Storage

NACE recently published a report citing the total global cost impact of corrosion to be US$2.5 trillion dollars annually

Asset Integrity Management (AIM)

Why Asset Integrity Management (with changes in the industry)

- Owners expected lifetime of their assets are increasing – ISO 12944 C 5 Very high category
- Construction methods are changing – more modular construction where coating systems were already exposed to Atmospheric conditions for up to 3 years – different baseline / mechanical damages
- Pressure on OPEX – proper corrosion management system will result in significant cost savings
- Public Image – no Oil and Gas company or Chemical company can effort an accident to happen (Branding)
- Asset Integrity should be seen as a constant monitoring system for safety
- Downturn in industry – budgeting of asset maintenance is more critical for the future

Therefore PPG decided to develop their own system as a coating specialist and provider.

Asset Integrity Management (AIM)

How Do I Implement a Corrosion Management System

- The first step in implementing or restarting a corrosion maintenance program is to establish the baseline condition of the facility and record the quantities of each asset type. The condition assessments (CA) and quantity survey's (QS) are typically based on some pre-determined physical boundaries or "blocks" for each asset location in a hierarchal structure.
- Once the physical boundaries of the section are defined, a condition analysis is performed to establish a baseline condition based on several condition attributes and environmental factors such as;
  - Corrosion Type (general rust, pinpoint rust, or heavy pitting)
  - Degree of degradation (SSPC-Vis 2)
  - Coating thickness (DFT Gauge)
  - Coating Adhesion (ASTM D3359)
  - Atmospheric Environment (mild, moderate, or severe)/ CUI/ High temperature in Atmospheric

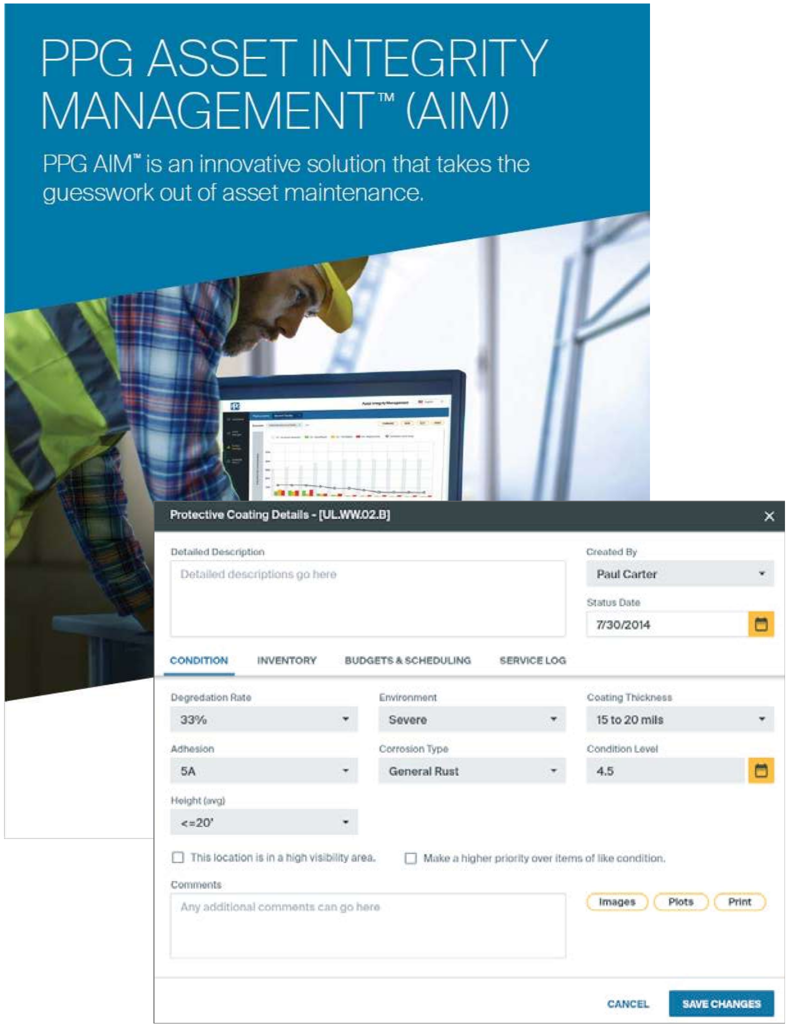
  Once complete, scheduling of work based on priorities can be implemented.

AIM Overview

Digital Solutions From PPG

Asset Integrity Management (AIM)

- AIM is a corrosion management system (CMS) designed to enable asset owners to track coatings maintenance requirements across their facilities.
- Competitive offerings exist, but AIM is the only system with predictive modeling and the most advance budgeting tool available.



AIM…

- Optimizes maintenance budgets
- Provides a complete understanding of your facility
- Allows you to fast forward the age of assets to see likely outcomes and plan accordingly

Asset Integrity Management (AIM)

- PPG AIM was developed as an ROI tool with over a decade of input and feedback from asset owners and applicators.
- PPG AIM is completely owned and developed by PPG's in-house IT team ensuring your data is secure and accessible.
- PPG can help you digitize your corrosion management

lyondellbasell

Stolt-Nielsen Limited

VALE

OXY

covestro

LBC

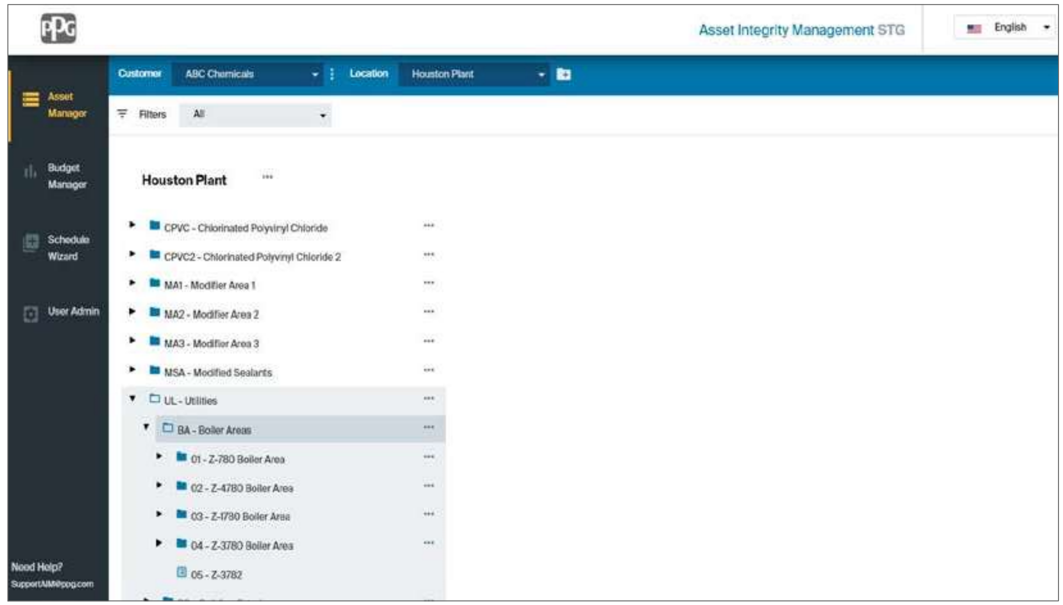
TANK TERMINALS

Asset Integrity Management (AIM)

How it works…

Asset Manager

- Master catalog of all assets within your facility grouped by location, unit, and section detail.
- Assets mapped by defined boundaries using your naming conventions.
- Single interface to view all details concerning the assets including; plots, pictures, condition analysis, inspection reports, etc.

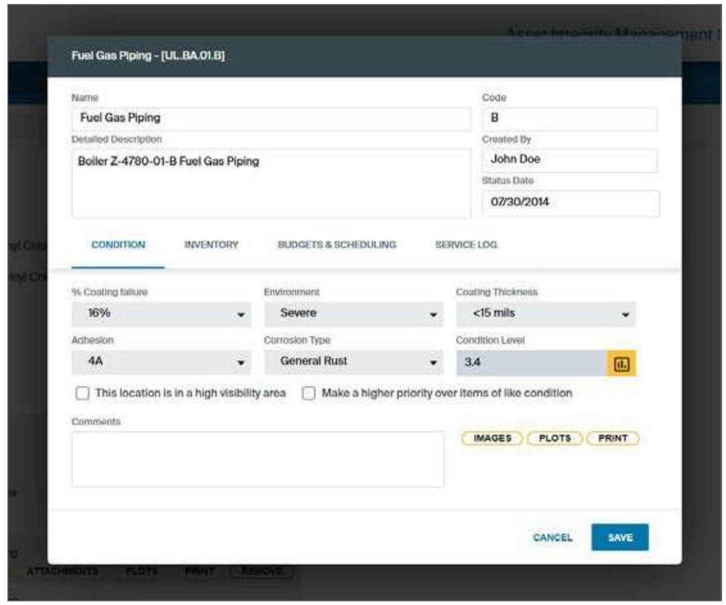


Asset Integrity Management (AIM)

How it works…

Condition Assessment

- Based on criteria established in NACE 509, includes inventory of items for precise budgeting.
- Assessment is date stamped to allow for predictive modeling of future condition of the asset.
- When maintenance work is performed, condition is "reset" to allow for constant rebalancing of priorities.



Asset Integrity Management (AIM)

How it works…

Budget Manager

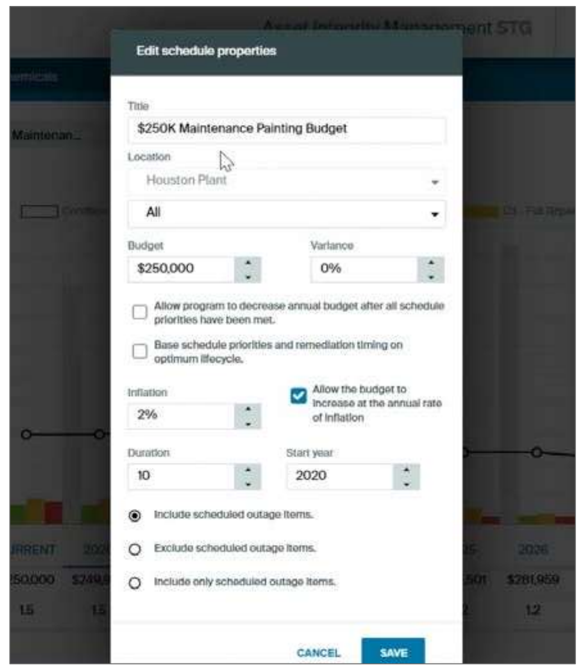
- Provides a graphical display of the current condition and a forecast of the condition for each year of the maintenance program.
- Asset location details are listed for each year of the maintenance program.

Asset Integrity Management (AIM)

How it works…

Budget Manager

- Allows facility owners to run multiple “what if” scenarios with varied budgets and time horizons.
- Evaluate these outcomes to plan and optimize your corrosion management program.



Asset Integrity Management (AIM)

How it works…

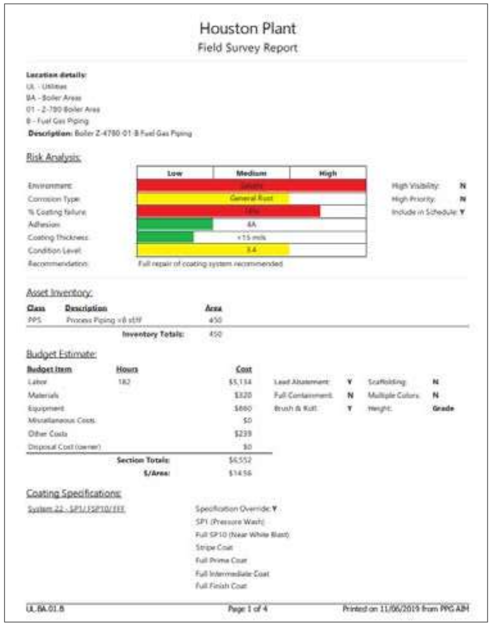
Reports / Scheduling

Asset Location	Location Description/Comments	Year	P/L	Area	%	Labor Hrs	Budget	Budget/Area
CPVC.OBL.03	T-C102-A PVC Hopper Silo	2025	1.0	50	0.01 %	6	$256	$5.12
CPVC.PB.02.H	Bldg. Structure Over & Around Agitators A-C301 A & B & Mist Separators S-C301 A & B	2025	2.1	2,240	0.44 %	341	$13,523	$6.04
MA3.PR.01	N-S Pipe Rack on West Side of MA3 From Pipe Crossing to MA3 Control Room	2025	2.1	3,600	0.70 %	445	$17,962	$4.99
MA3.WSRB.06	B3702 and Air Receiver	2025	2.1	450	0.09 %	60	$2,405	$5.34
CPVC2.PB.01.I	B-C2605, H-C2605, F-C2507, F-C2506 and other structure , handrails and pipe	2025	2.1	1,700	0.33 %	227	$9,086	$5.34
CPVC2.PB.02.F	Boiler (Insulated)	2025	2.1	4,805	0.94 %	567	$22,993	$4.79
CPVC2.PB.02.I	Production Building Structure, Columns and Beams	2025	2.1	10,460	2.04 %	1,113	$45,667	$4.37
CPVC2.PB.03.A	C-2501 A/B, C-2103 A/B, Handrails,OH Lift, Deck Structure	2025	2.1	3,180	0.62 %	375	$15,217	$4.79
MSA.PB.05	Level 3 including R-S410, T-S420, T-S415, T-S209, T-S201, R-S721	2025	2.1	1,875	0.37 %	250	$10,021	$5.34
MSA.PB.06	Level 4 including P-S303A/B, P-S411A/B, P-S203A/B, P-S273A/B, R-S721, T-S301, P-S307	2025	2.1	3,215	0.63 %	379	$15,385	$4.79
MA2.BD.02	KO House 2	2025	2.2	2,700	0.53 %	407	$16,619	$6.16
MA1.KO.05	V-490 KO Tower	2025	3.4	9,850	1.92 %	2,682	$107,367	$10.90
	Annual Totals:		1.2	44,125	8.62 %	6,852	$276,501	$6.27

Asset Integrity Management (AIM)

How it works…

Reports / Scheduling



Houston Plant

Field Survey Report

Location details:
UL - Utilities
BA - Boiler Areas
01 - Z-780 Boiler Area
B - Fuel Gas Piping
Description: Boiler Z-4780-01-B Fuel Gas Piping

Risk Analysis:

	Low	Medium	High
Environment:			
Corrosion Type:		General Rust	
% Coating failure:			
Adhesion:		4A	
Coating Thickness:		<15 mils	
Condition Level:		3.4	
Recommendation:	Full repair of coating system recommended		

High Visibility: N
High Priority: N
Include in Schedule: Y

Asset Inventory:

Class	Description	Area
PPS	Process Piping <6 stff	450
	Inventory Totals:	450

Budget Estimate:

Budget Item	Hours	Cost
Labor	182	$5,134
Materials		$320
Equipment		$860
Miscellaneous Costs		$0
Other Costs		$239
Disposal Cost (owner)		$0
	Section Totals:	$6,552
	$/Area:	$14.56

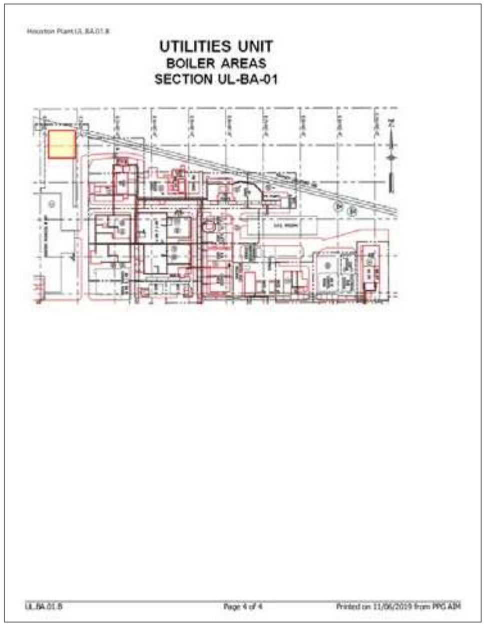
Lead Abatement: Y
Full Containment: N
Brush & Roll: Y
Scaffolding: N
Multiple Colors: N
Height: Grade

Coating Specifications:

System 22 - SP1/ FSP10/ FFF

Specification Override: Y
SP1 (Pressure Wash)
Full SP10 (Near White Blast)
Stripe Coat
Full Prime Coat
Full Intermediate Coat
Full Finish Coat

UL.BA.01.B Page 1 of 4 Printed on 11/06/2019 from PPG AIM



Software system generic overview

- More than 1 system available on the market
- Generally fee required on annual basis
- Functionality differs
- Level of detail differs
- Corrosion protection in general tackled as “ad hoc maintenance
- Predictive modeling allows improved and more accurate budgeting
- Can be integrated in full asset integrity management programs

Features	PPG	C1	C2	C3	C4	C5	C6
	AIM						
Fees	✔	✔	✔	✔		✔	
Rebate	✔		✔				
Facilitator	Trained Coating Specialist	Trained Coating Specialist		Contractor	Trained Coating Specialist	Contractor	Trained Coating Specialist
Coating Assessment	✔	✔	✔		✔	✔	
Corrosion Assessment	✔	✔	✔		✔	✔	
PFP Assessment	✔	✔					
Photo Mapping	✔	✔	✔		✔		
Surface Area Measurements	✔	✔	✔		✔		
Online Planning and Reporting	Phase II	✔	✔				
Customizable PDF Reports	✔	✔					
Predictive Model	✔						
Project Specific Coating Specification	✔	✔	✔		✔		
Secure Document Storage	✔	✔					
Access for Owners	✔ Tiered	✔	✔	✔ Limited			
Customized Risk/Condition Matrix	✔	✔					
Uploaded Drawings/GA	✔	✔					
Access to Inspection Reports	✔	✔					
Budget Management Tool	✔	✔					
Project Scheduling Tool	✔	✔					
Compatible with Existing Systems	✔						
Data Storage & Management	✔	✔					
Reports to Assist with Bid Documents	✔	✔					
Online/Mobile Reporting Tool (QA/QC)	✔	✔		✔			
Project Document Library	✔	✔		✔			
3rd Party Inspection Capability	✔	✔		✔			
Supplier QA Services	✔	✔		✔			

Flow

Identify
- Owners
- Asset integrity providers

Check
- Interested to step in the program
- Seek commitment from customer

Online Intro
- Skype intro
- Training of customer

Contract
- Prepare contract
- Seek alignment on conditions
- Fee and survey cost
- Tablet

Survey
- Technical survey on site by FTS
- Implement full plant scheme in program (by us)

Discuss
- Evaluate and set base status of plant
- Agreement

Handover
- Full handover of license to customer
- Follow up as sourcing of coating materials should be PPG

Available information • Brochure • Draft contract

We partner with customers to create mutual value.

PPG AIM®

The Future of Corrosion Management

AIM for predictability

Forecast the future condition of your protective coatings using our dynamic, data-driven model.

AIM for greater precision

Plan and schedule your corrosion management precisely.

AIM for better budgeting

Prioritize and rank your maintenance spending, so you can budget more effectively.

AIM for optimization

Optimize your asset maintenance process.

Please contact Chris.Magel@ppg.com or Kuhn@ppg.com for any questions.

Appendix 6

Non-intrusive corrosion-erosion monitoring solutions to enhance operational profitability in the alkykation units

(Peter Fischbacher)

EMERSON

Emerson Corrosion & Erosion
Permasense

Non-Intrusive Corrosion/Erosion Monitoring Solutions to Enhance Operational Profitability in the Alkylation Unit

---

Peter Fischbacher - BDM Europe
Office - Seregno / Italy

Peter.Fischbacher@emerson.com

Corrosion Monitoring – **Why?**

Philadelphia refinery (PES) fire in 2019

- Old, corroded pipe led to Philadelphia refinery fire
- Highly toxic chemical hydrofluoric acid (HF) that escaped into the atmosphere via a leak caused by corrosion

Link: https://uk.reuters.com/article/us-pes-bankruptcy-investigation/old-corroded-pipe-led-to-philadelphia-refinery-fire-chemical-safety-board-idUKKBN1WV1TW

Permanent corrosion monitoring reports corrosion events in real time, so that remedial actions can be taken before unplanned incidents occur!

Avoid Corrosion & Erosion Process and Personal Safety Consequences

Process Safety (PSM)

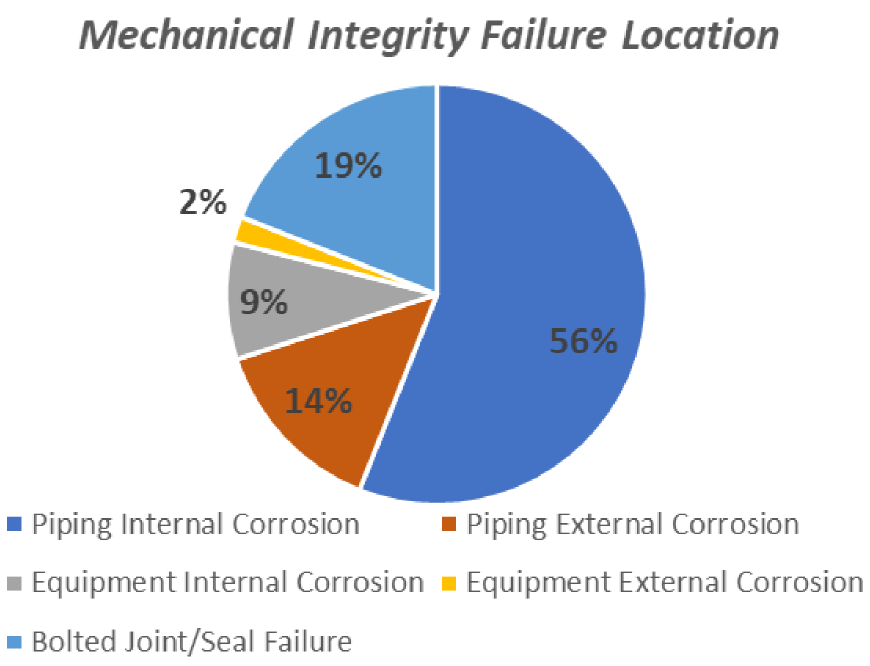
- ***Pipe*** Ruptures
- ***Equipment*** Failures
- ***Loss of Containment***

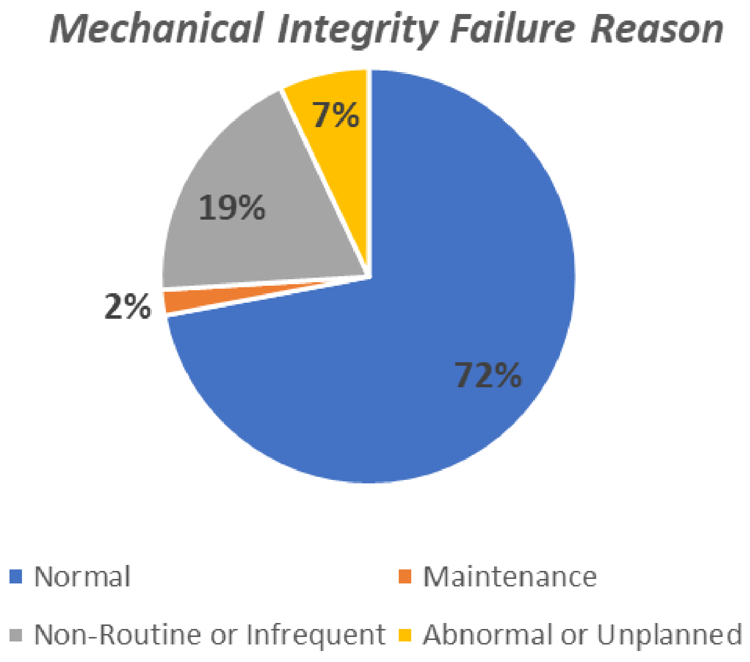
Personal & Occupational Safety

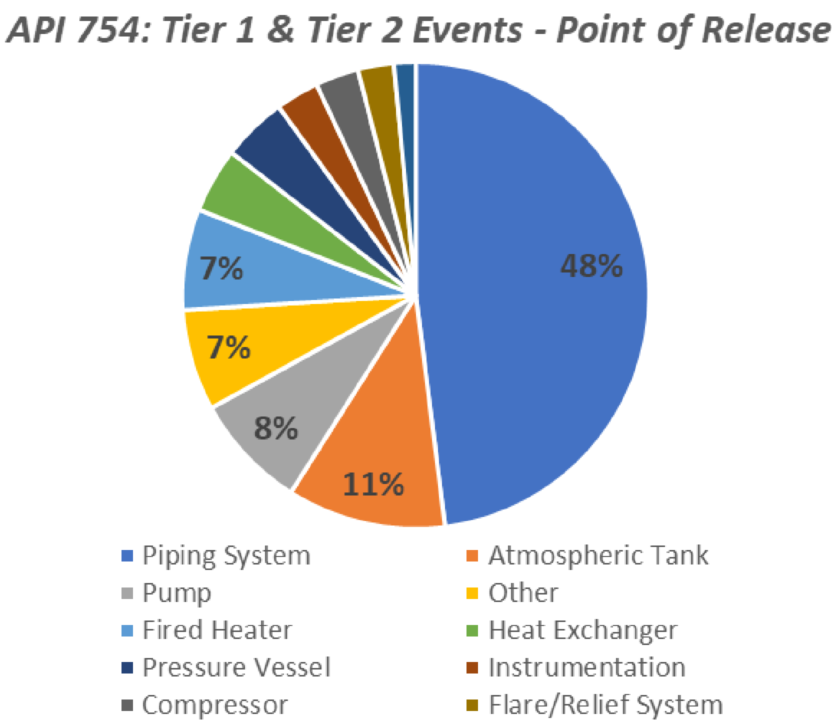
- ***Personnel*** incidents on ***scaffolding***
- ***Exposure*** to heat and potentially toxic environments

Sources: OSHA, Chemical Safety Board (CSB)

Challenges to Asset Integrity Are Impacting Safety





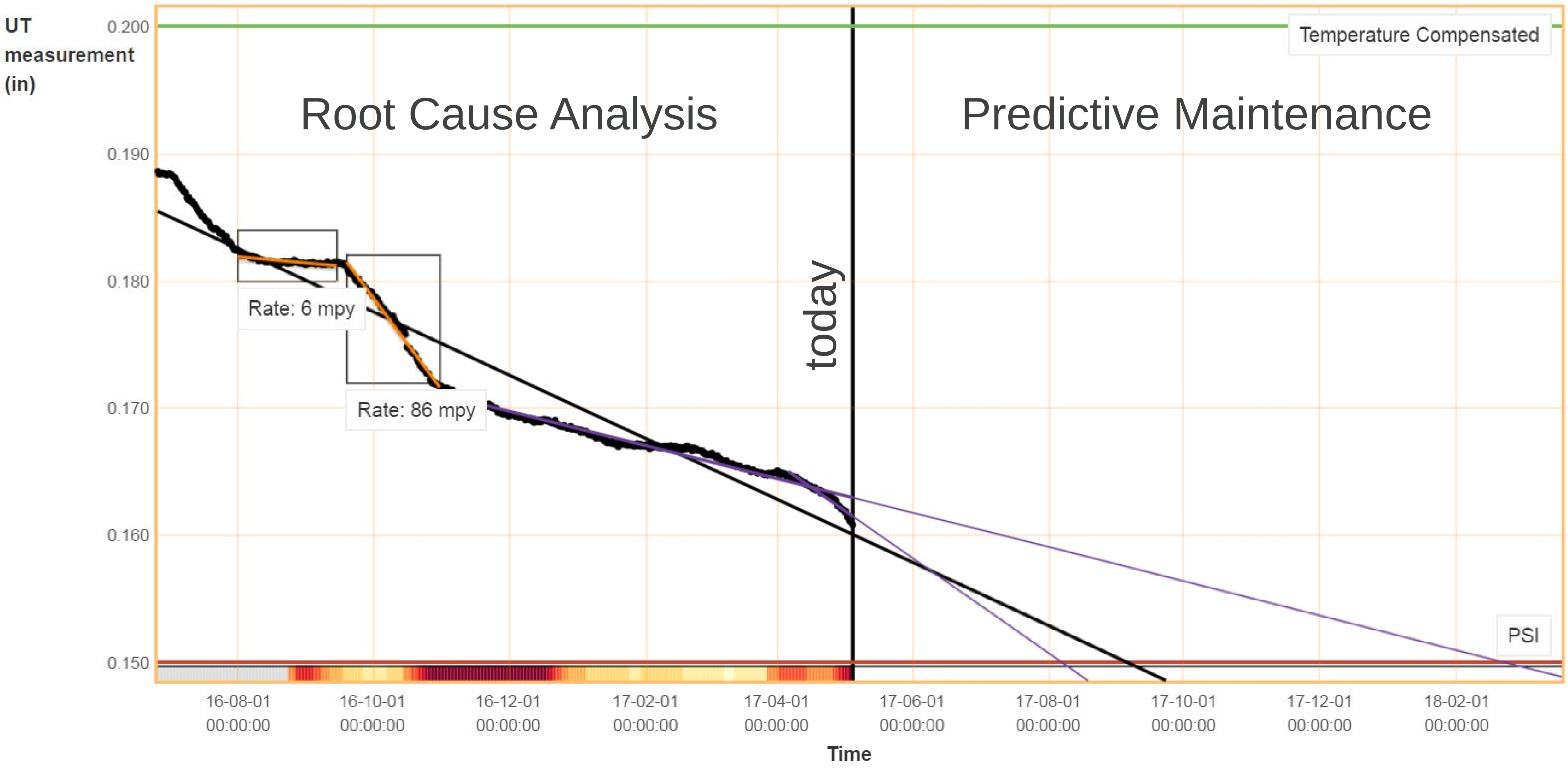


Source: LMA; Common Causes of Major Losses in the Onshore Oil, Gas & Petrochemical Industries; September 2016

API 754 Data – Tier 1 and 2 Events
Source: AFPM Quarterly Safety Webinar

Internal Piping Corrosion in Normal Operation is a Large Contributor to Process Safety

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



Alkylation Unit

HF Alkylation – Customer Case Studies

- **Main Fractionator** – proof of increased corrosion rates due to acid carry over

- **Iron Fluoride Scale** – detection of iron fluoride scale

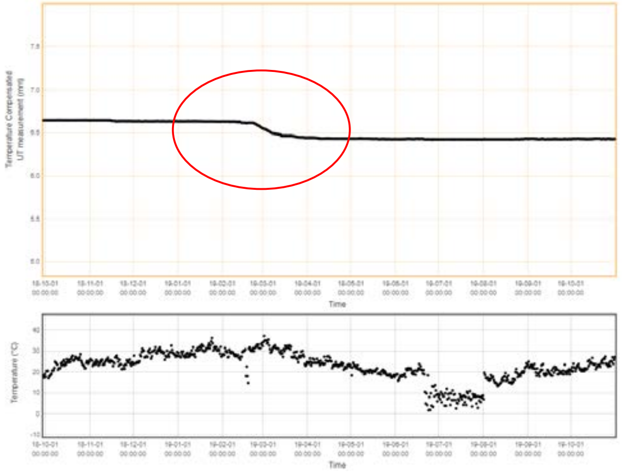
HF Alkylation – Case Study 1: Increased corrosion rates due to acid carry over

Monitoring Location: Exit Header Line

Solution: Permasense ET210

- No corrosion expected at this location
- Carbon steel selected as no HF should be present
- Corrosion monitoring used to confirm health of unit/ normal operation & turnaround planning
- High corrosion rates observed, alerting team to corrosion due to acid carry over
- Data from multiple sensors used to assess severity and spread of the corrosion caused
- Team were able to identify root cause and take corrective action before metal loss reached critical level
- Continued to monitor corrosion rate after the event to ensure that stable operation had been restored

Permasense



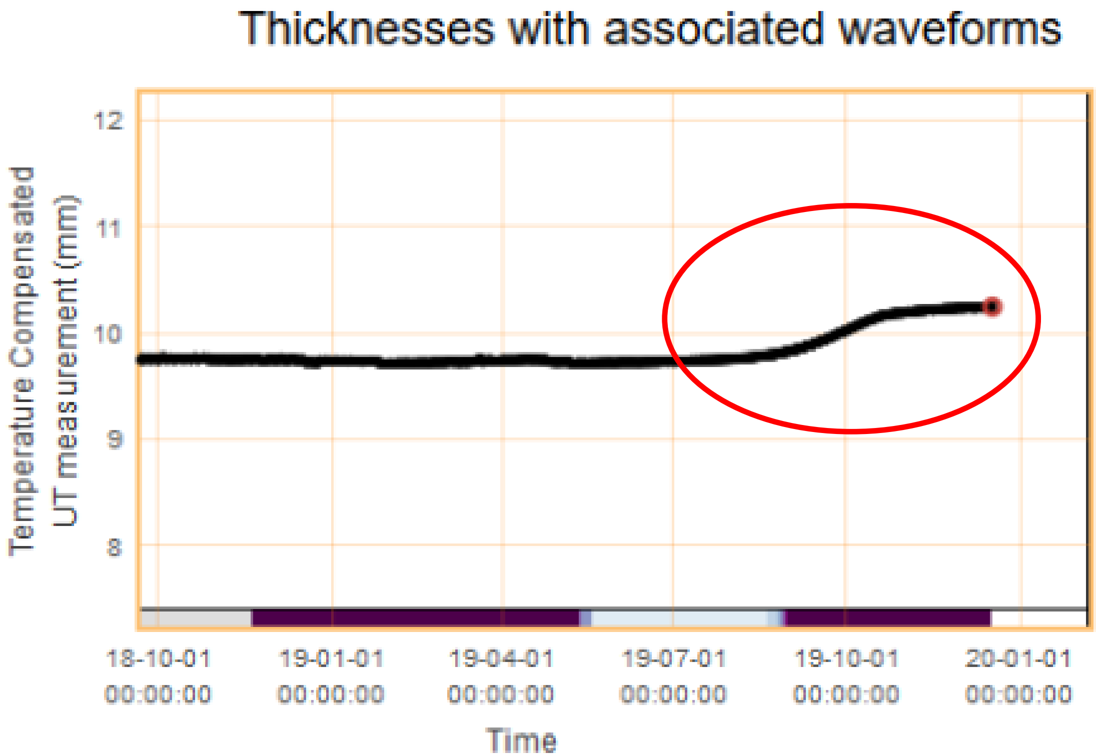
HF Alkylation – Case Study 2: Iron fluoride Scale

Iron Fluoride Scale

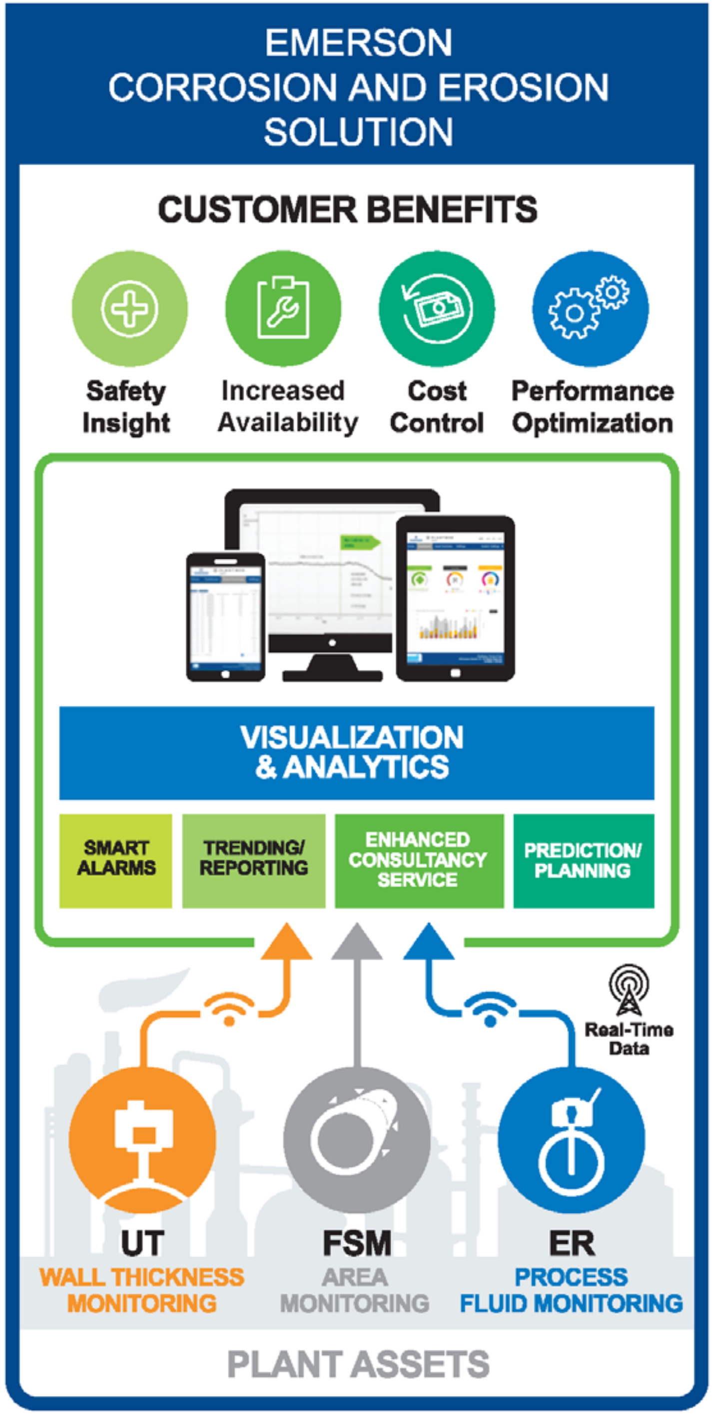
- Material & highly concentrated acid can form a stable iron fluoride layer which provides an adequate corrosion protection. Upon contact with acid/water mix, a unstable and non-protective hydrate scale is formed, which swells and gets detached from the equipment

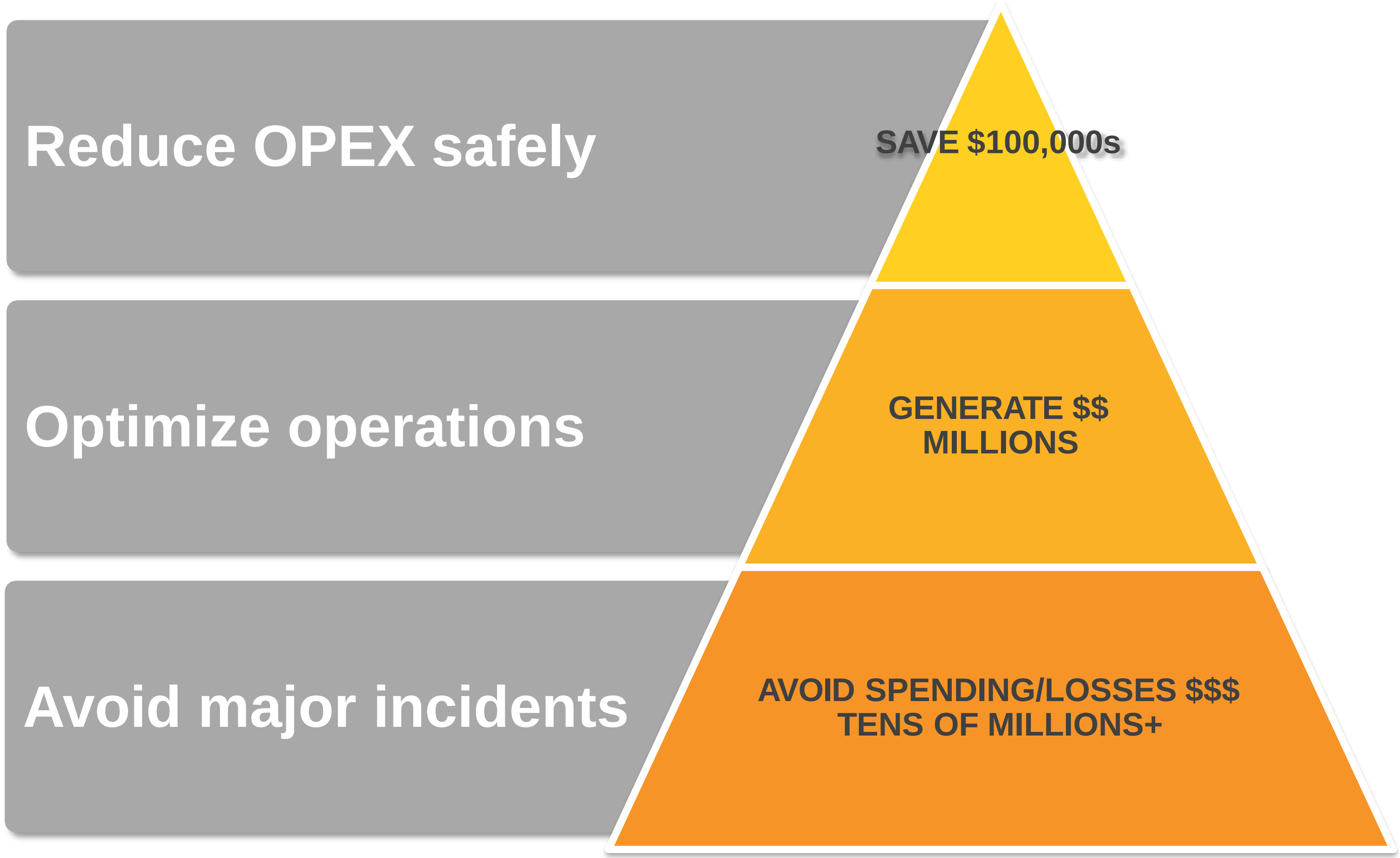
Solution: Permasense

- Permasense is used to identify the presence of iron fluoride scale inside the piping system
- Scale build-up inside in the piping distorts the ultrasonic reflection. Approximately 30% of sensors installed at HF Alkylation units are affected by this and therefore it can be also detected by ultrasonic sensors. Iron fluoride scale build-up identified by an increased wall thickness over time.



Emerson solutions help meet future business demands safely





EMERSON

Appendix 7

Enhanced surface heat transfer tubing in hard to work corrosion resistant alloys

(Mathieu Lheureux)

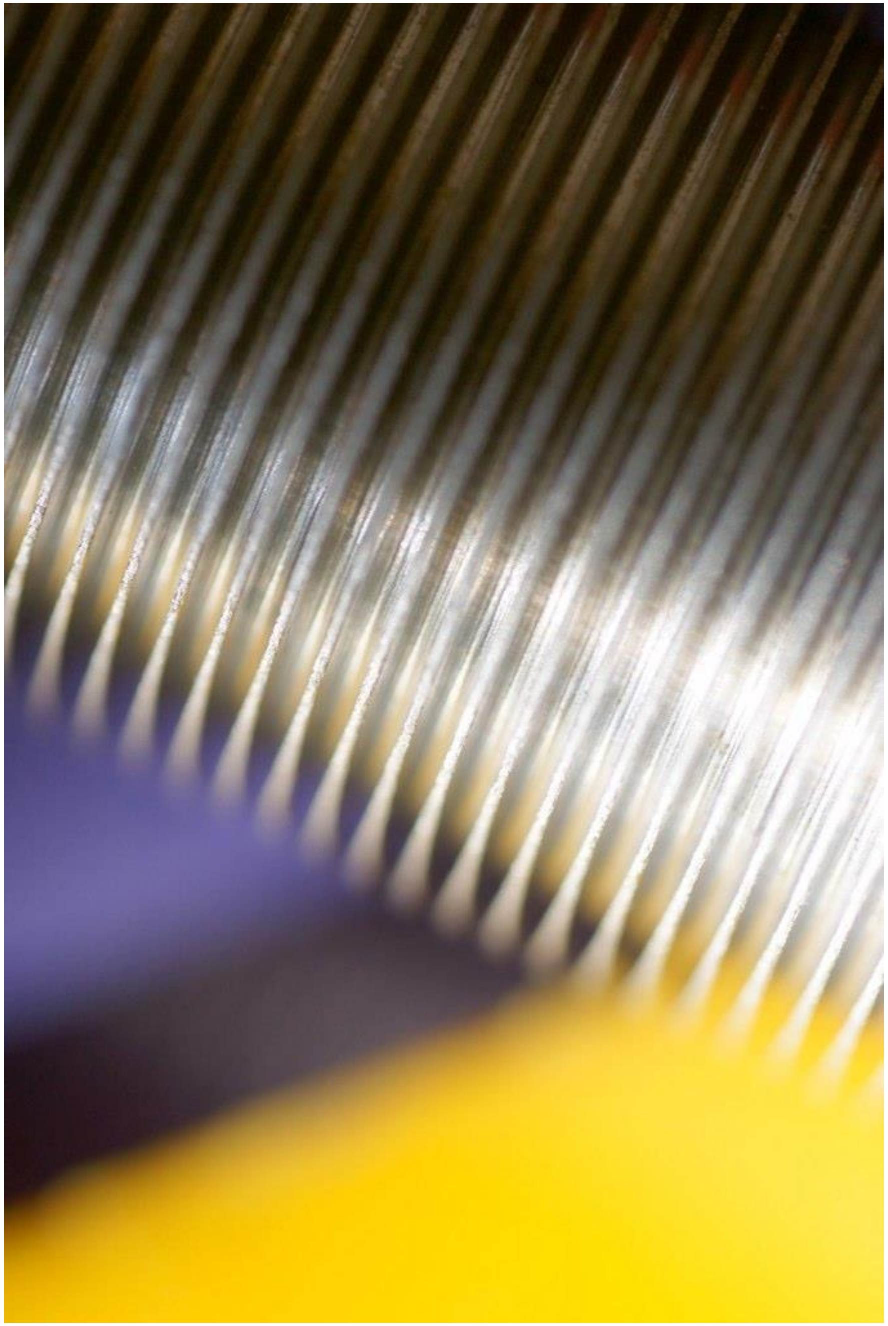
Enhanced surface heat transfer tubing in hard to work, corrosion resistant alloys

EUROCORR – WP15

09/09/2020

NEOTISS PRESENTATION OUTLINES

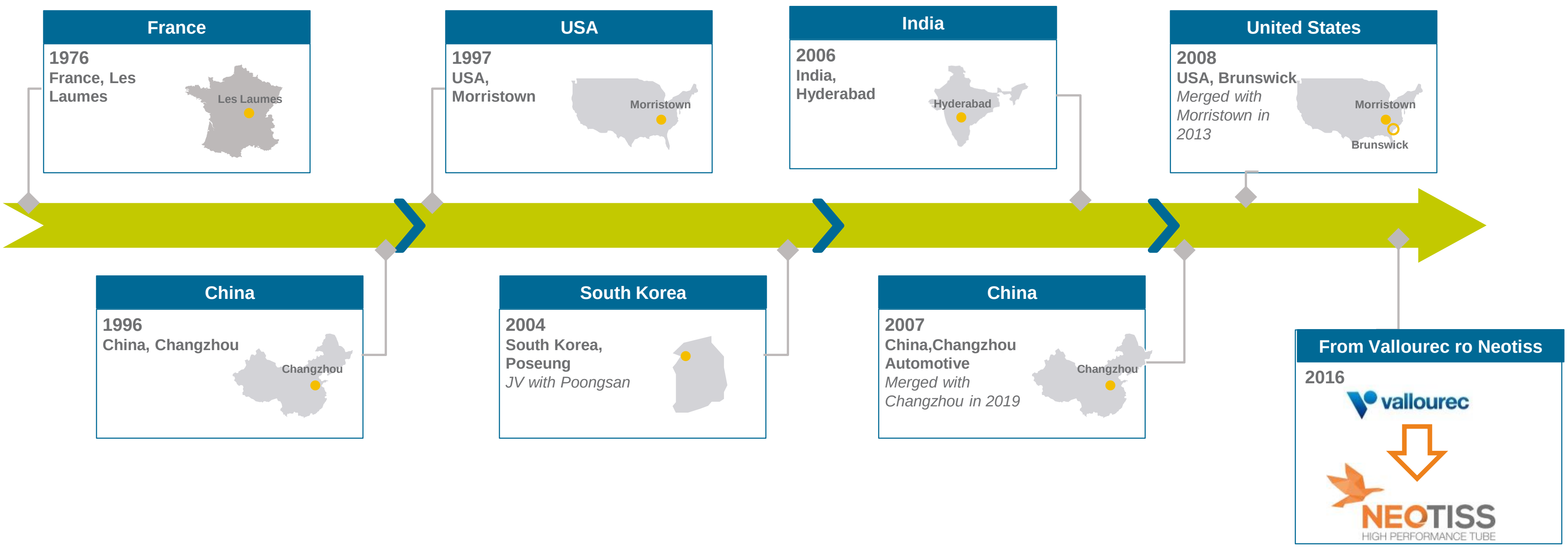
- NEOTISS general presentation
- When enhanced tube can support material selection
- When do you use enhanced tube
- Manufacturing Process
- References



1

Who is NEOTISS?

A global presence built over the years



Development close to markets with strong local partners

OUR PRODUCTS

Grade

Titanium

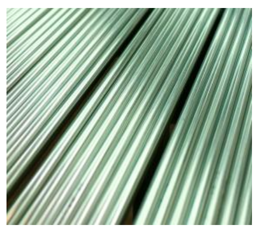
Stainless Steel

High Nickel Alloys

Brass

Shape

Straight



U-Bent

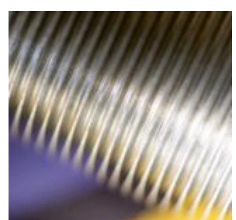
Round

Oval

Enhancement

Smooth

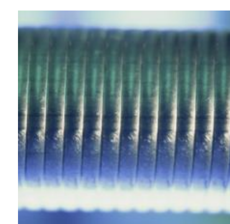
Finned



Ribbed

Dimpled

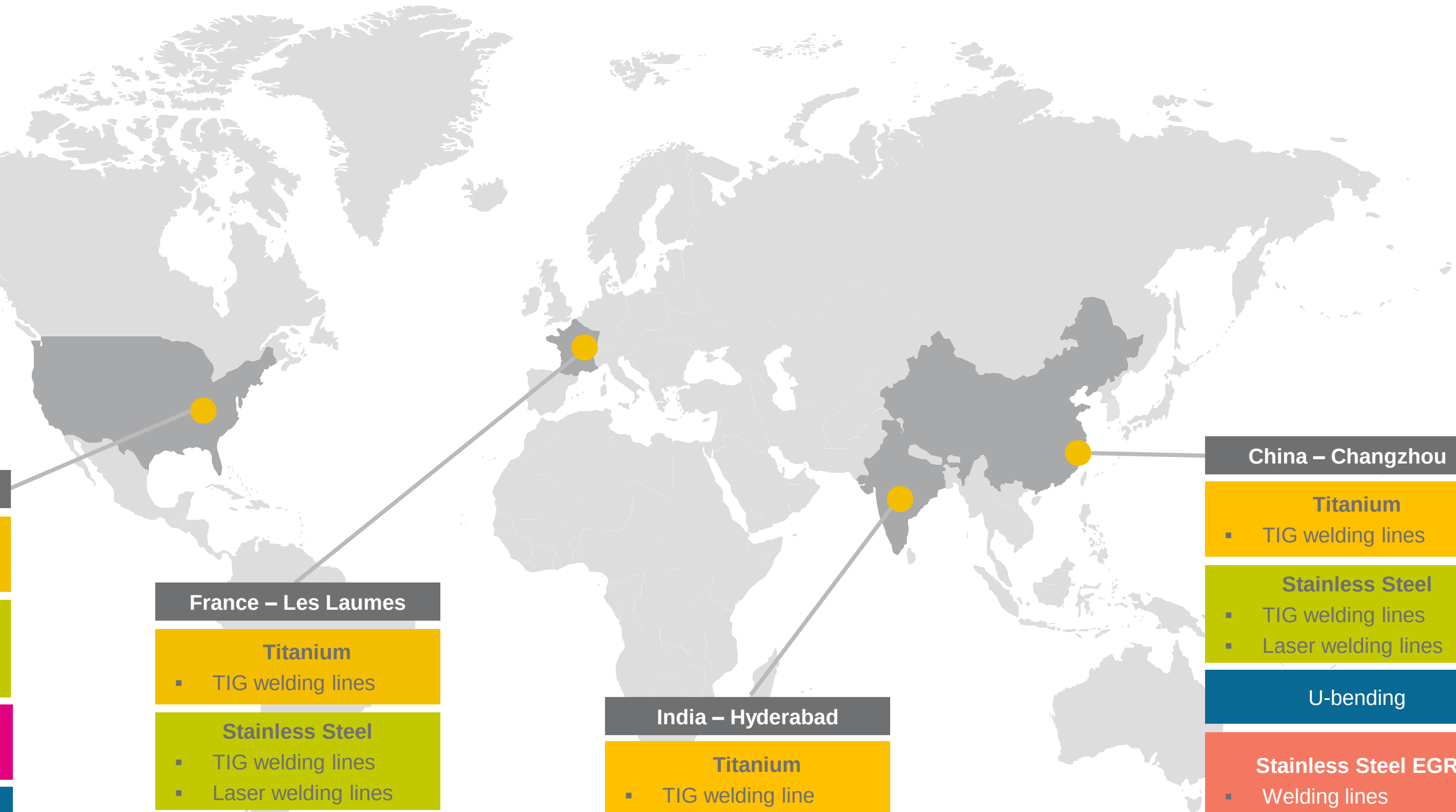
Helix



OUR LOCATIONS

Production capabilities

- *Titanium*
- *Stainless Steel*
- *Nickel Base Alloys*
- *Bending*
- *Finned tubes*
- *Auto Stainless Steel*
- *Plant (Neotiss)*



USA - Morristown

Titanium
- TIG welding lines

Stainless Steel
- TIG welding lines
- Laser welding lines

Nickel Base Alloys
- Laser welding lines

U-bending

Enhanced Tubes

France – Les Laumes

Titanium
- TIG welding lines

Stainless Steel
- TIG welding lines
- Laser welding lines

Nickel Base Alloys
- Laser welding lines

U-bending
3 Dimension bending

Enhanced Tubes

India – Hyderabad

Titanium
- TIG welding line

Stainless Steel
- TIG welding lines

U-bending

Stainless Steel EGR
- Welding lines
- Corrugation lines

China – Changzhou

Titanium
- TIG welding lines

Stainless Steel
- TIG welding lines
- Laser welding lines

U-bending

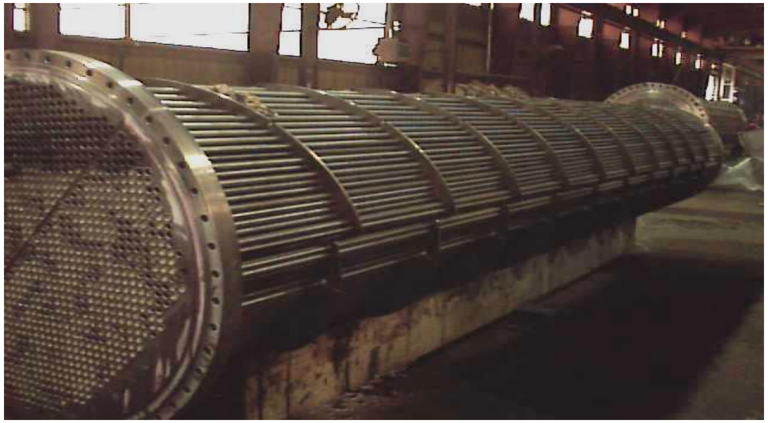
Stainless Steel EGR
- Welding lines
- Corrugation lines

2

When enhanced tubes can support material selection…

Overhead condenser refinery – Debottleneck / Retrofit

- Operational conditions of the bundle:
  - Shellside : HC Vapor Condensing
  - Tubeside: Cooling water
- Tube bundle material: CuNi 90/10
- Issues:
  - Corrosion existing on CuNi tubes
  - Limited run time (cleaning every 4 months)
- Additional challenges:
  - Need to increase the duty by 40%
  - No space to add new shells



- Solution:
  - Material: Titanium Gr 2 to address crevice corrosion
  - Technology: helix exchanger to reduce fooling
  - Technology: low finned tubes to increase the duty

- **Results:**
  - **No corrosion issue**
  - **Run time: 3 years**
  - **Duty increased by 40%**

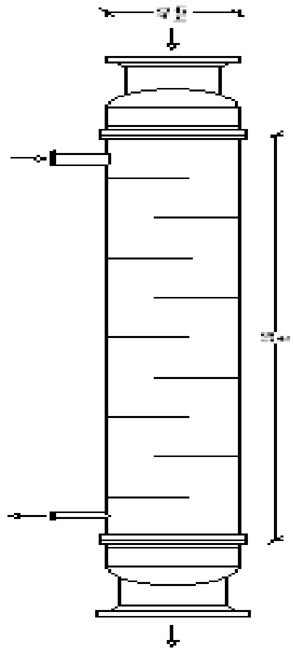
CASE STUDIES

Methanol vaporizer – Debottleneck

- Operational conditions of the bundle:
  - Shellside : Condensing steam
  - Tubeside: Methane droplet + Methanol Liquid
  - Vertical flow down
- Tube bundle material: Carbon Steel
- Issues:
  - Corrosion existing on the Carbon Steel tubes
- Additional challenge:
  - 100% vaporization mandatory

- Solution:
  - Material: stainless steel to address corrosion
  - Technology: inner ribs to compensate the loss of performance in the material choice

- **Results:**
  - **No corrosion issue**
  - **100% vaporization**

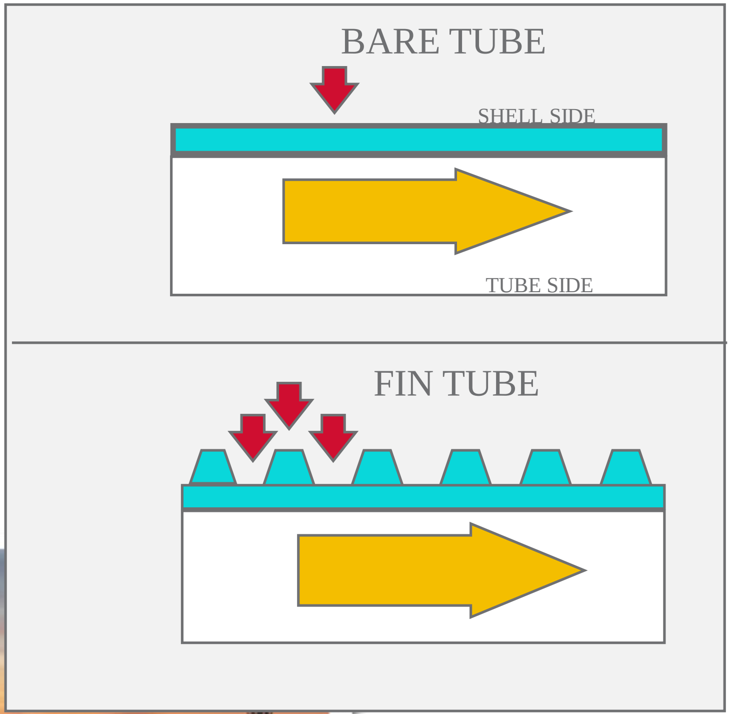


3

When do you use enhanced tubes

FINNED TUBE: A TOOL FOR PROCESS INTENSIFICATION

- Shell side controlling heat transfer
- Space is limiting
- Debottlenecking
- Close temperature approach

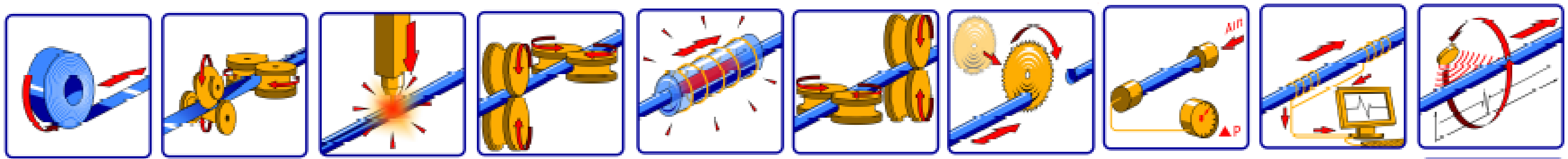


4

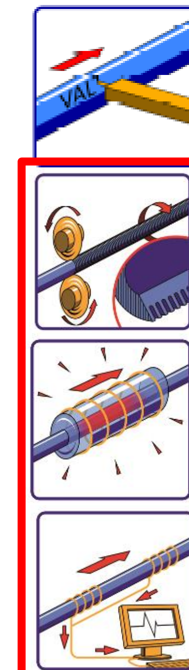
Manufacturing process

OUR MANUFACTURING PROCESS

Welded tubes manufacturing process

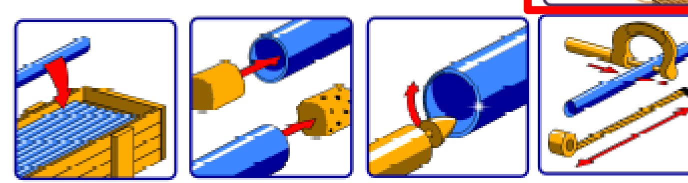


Seamless tubes

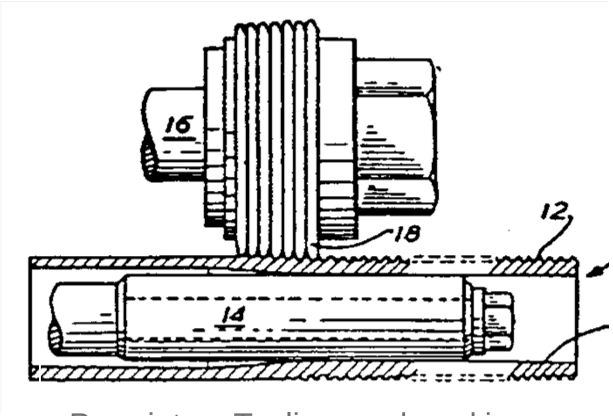


Straight enhanced surface heat transfer welded tubing

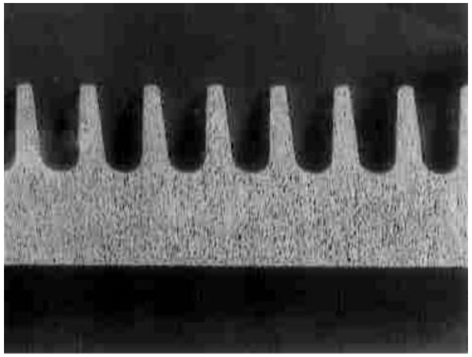
100% integrated from strip to finished tube



OUR MANUFACTURING PROCESS



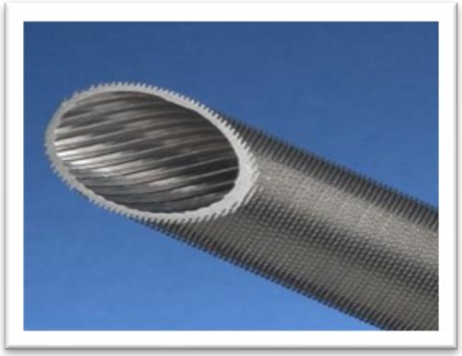
Proprietary Tooling produced in house to very tight tolerances



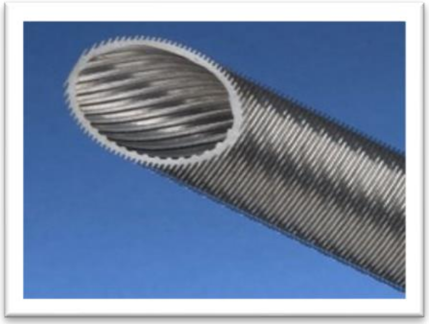
Very smooth Fin Profile with no stress risers

TYPES OF FINNED TUBES AVAILABLE

Low-fin OD Smooth Bore



THERMO-C Condensing



Low-fin OD Spiral Groove ID

THERMO-B Boiling

Smooth OD Spiral Groove ID

Finned and U-bent

- Carbon steel
- Titanium
- Zirconium
- High Nickel Alloys
- Duplex Stainless Steel
- Austenitic Stainless Steel
- Ferritic Stainless Steel
- Copper-Nickel Alloys

5 References

REFERENCES OF MAJORS USING ENHANCED TUBES

Company	Location	Neotiss Fin Tube Bundles in Service
ExxonMobil	Worldwide	300
DOW	Worldwide	130
	Worldwide	90
bp	Worldwide	42
DUPONT	USA	24
EASTMAN	Worldwide	45
PERTAMINA	Indonesia	32
PETRONAS	Maylasia	6
سابك sabic	Saudi Arabia	12
StatoilHydro	Norway	14
TEXACO	Worldwde	15
QATARGAS	Qatar	24

Appendix 8

Fitness for purpose evaluation of hydrogen production Unit centrifugally cast tubes; post exposure metallographic and mechanical test

(Marco De Marco)

ISTITUTO ITALIANO
DELLA SALDATURA
Il Gruppo

Fitness for Purpose Evaluation of Hydrogen Production Unit Centrifugally Cast Tubes: “Post Exposure” Metallographic and Mechanical Test

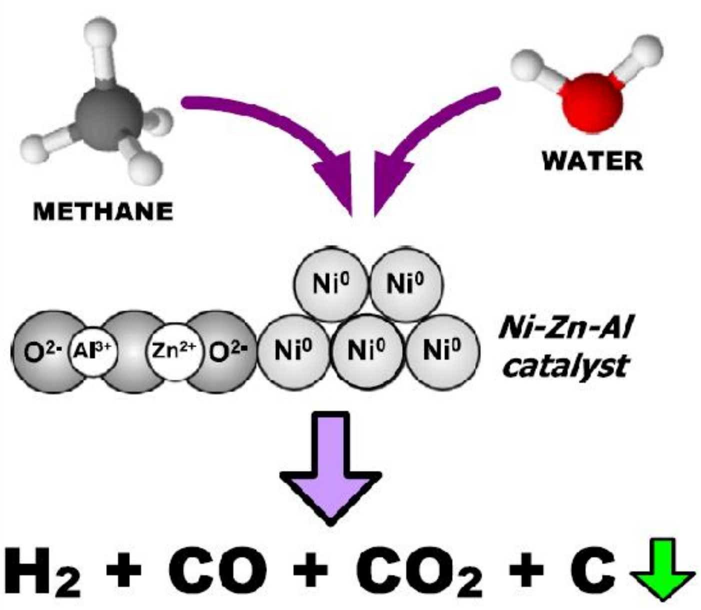
Marco Palombo, Marco De Marco, Gianluigi Cosso – IIS

Furnace Tubes applied in Hydrogen production plants

- ***Fe, Cr, Ni, C*** based alloys; addition of other elements as micro-alloing (e.g. Nb, Ti)
- Centrifugally ***Cast***
- ***Service T*** : 850 – 950 °C
- ***Service stresses*:** typically 10 + 15 MPa (as hoop stress)
- ***Vertical arrangement*** e filled with catalyst
- Design life ***10^5 hrs*** (≅ 11 years)
- → ***severe working conditions***

Steam reforming reactions: some chemistry

$$CH_4 + H_2O \Longleftrightarrow CO + 3H_2 \quad \Delta H^0(25\,^{\circ}C) = 2062\ \text{kJ mol}^{-1}$$



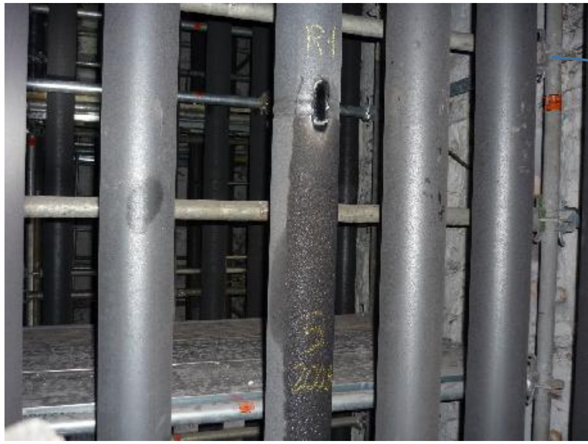
Endothermic

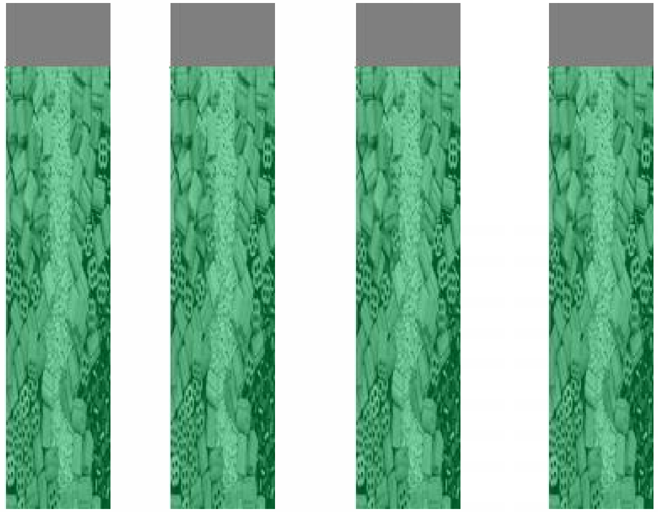
- Absorbs heat
- Controls tube Skin Temperature

Steam reforming furnace

External

Internal





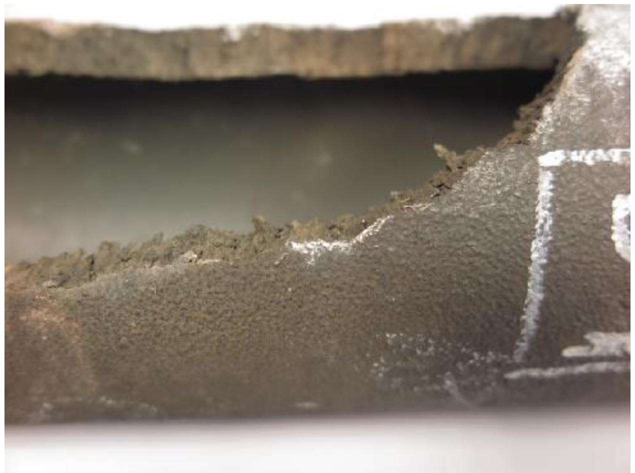
CAT
Filled

Alloys characteristics

- ***Creep*** resistance
- High temperature ***corrosion*** (Oxidation, carburization, metal dusting)
- *Acceptable* ***Ductility*** at high temperature
- Acceptable ***weldability*** (also after aging)

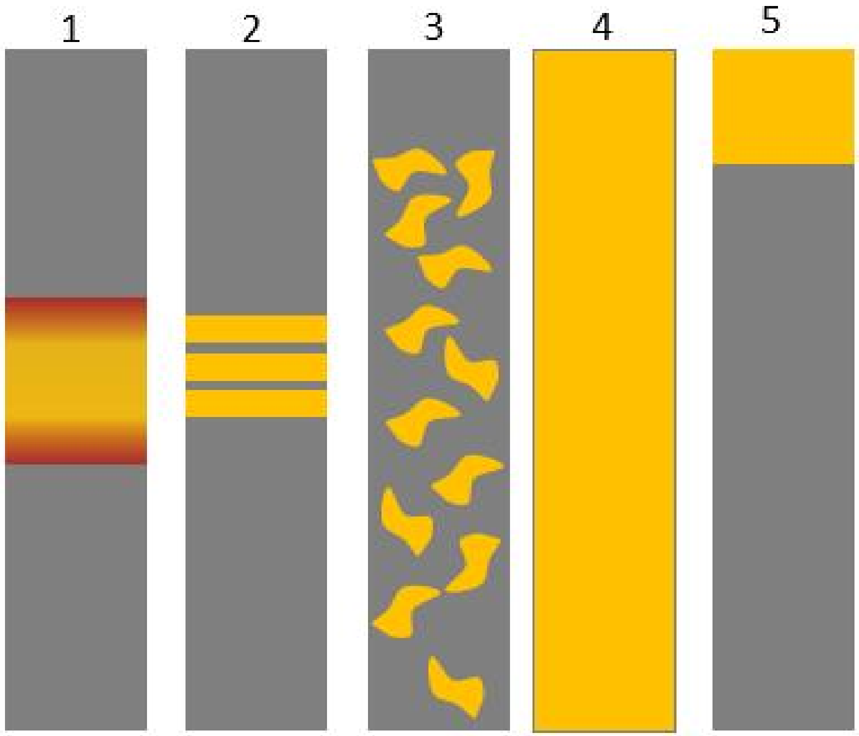
Typical damage mechanisms

- ***Creep*** failure
  - Normal End of Life (EoL)
  - Overheating (overfiring, flame impingement, CAT related problems)
- ***Thermal fatigue***
- ***Thermal shock***
- Stress Corrosion Cracking (***SCC***)
- ***Dissimilar weld*** cracking

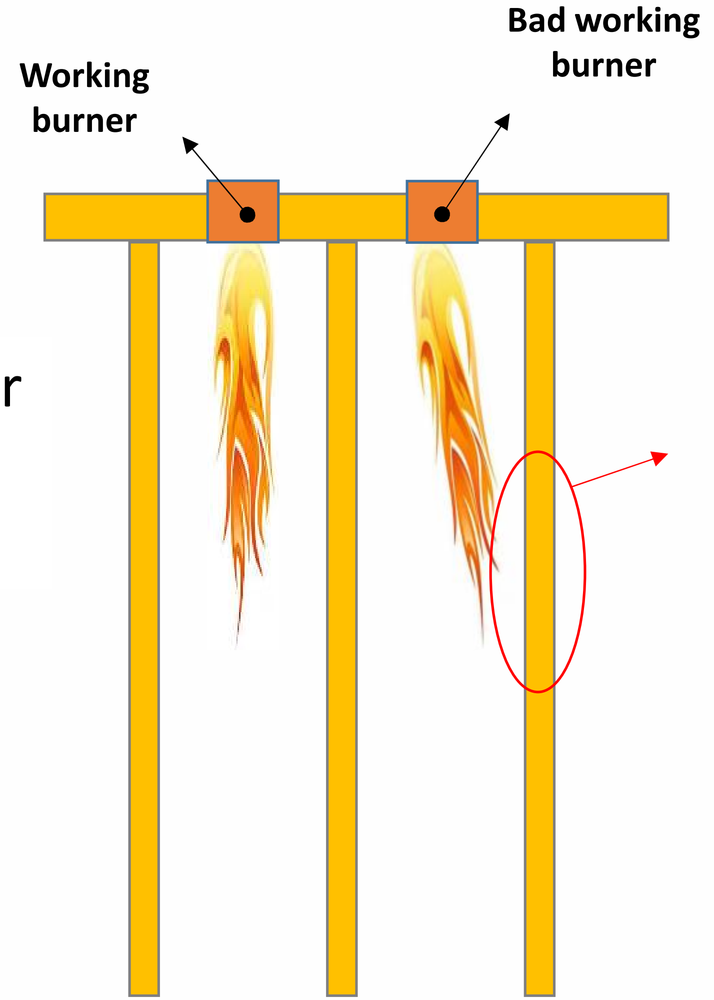


Difficult to predict EoL: overheating

1. HOT BAND
2. TIGER TAILING
3. GIRAF NECKING
4. HOT TUBE
5. CAT SETTLING



Flame impingement



- Related to burner control and maintenance

"Flame impingement"

Catalyst Tube : example of failure during service

Same furnace, different failure mechanisms (50000 hrs e 3000 hrs)

→ ***Long term and short term***

Material=	25Cr 35Ni Nb Ti
T service =	938 °C
Hoop stress =	10.5 MPa
Furnace service life =	50000 hours

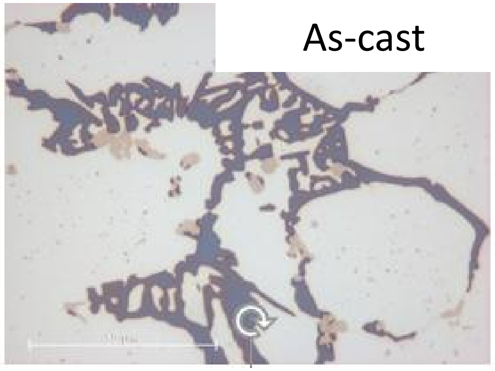
Tube service life of 50000 hours

Tube service life of 3000 hours

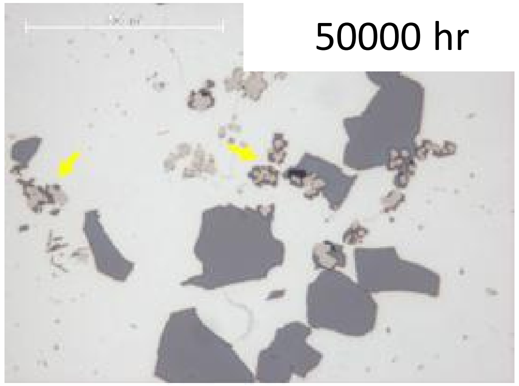
Creep Damage – Microstructural evolution

Phases evolution

As-cast

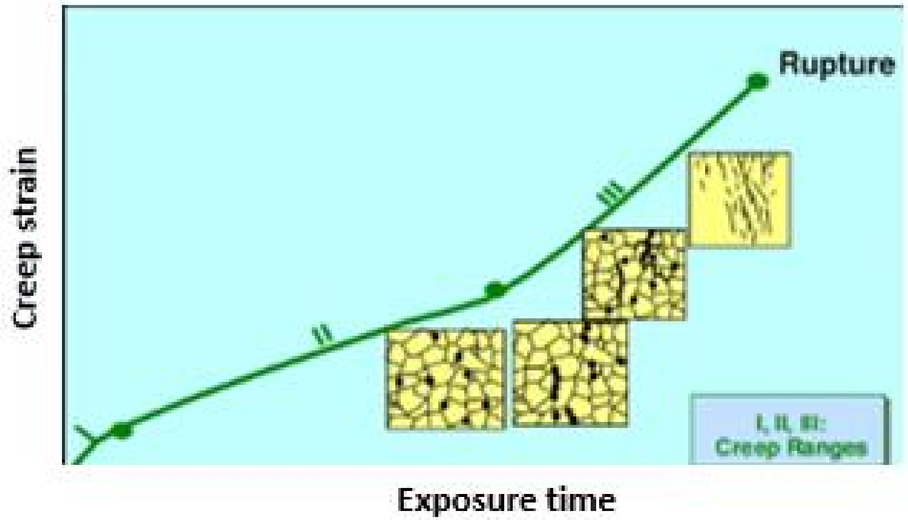


50000 hr



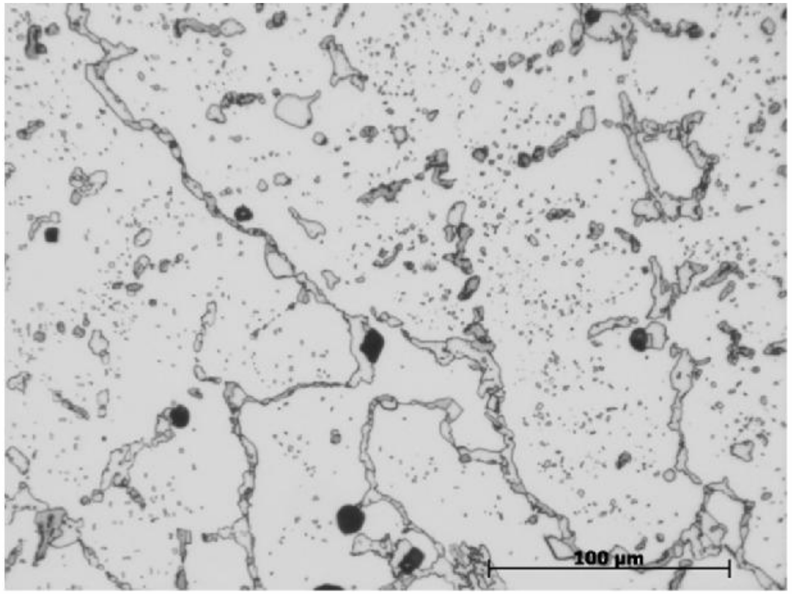
Voids- Cracks evolution

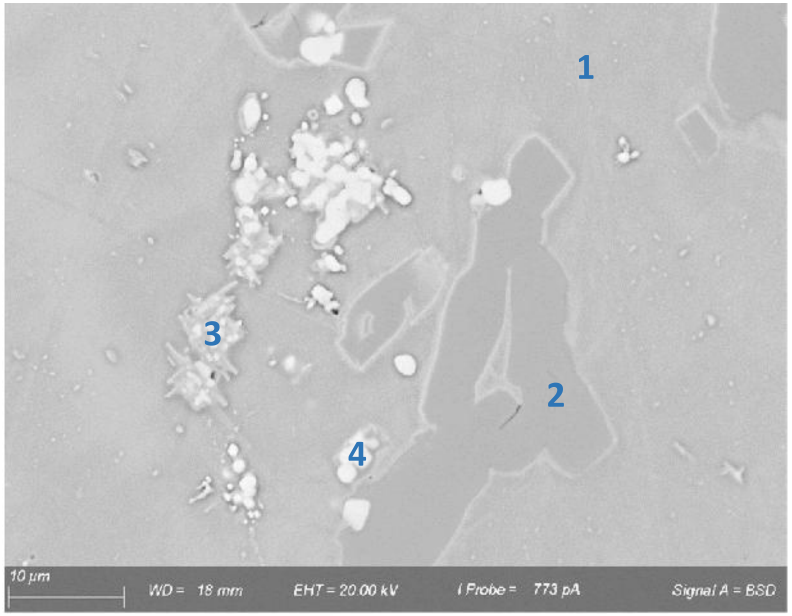
- I creep
- II creep
- III creep



Examination of aged microstructure

50000 hr service life





Coalescence of primary carbides, precipitation of secondary carbides and new phases

1: Matrix
2: Primary Chromium carbide
3: G-phase (Ni-Nb-Si)
4: Nb, Ti carbide

Hydrogen production plant: integrity assessment

- ***Inspection and NDT*** to check actual condition as best as possible
- ***Materials testing*** from samples (Cut out)
- Remaining Life Assessment - ***RLA***
- Remaining life estimation on the basis of the results
  - Service history
  - Actual material degradation
  - Future service conditions
- ***Engineering*** evaluation

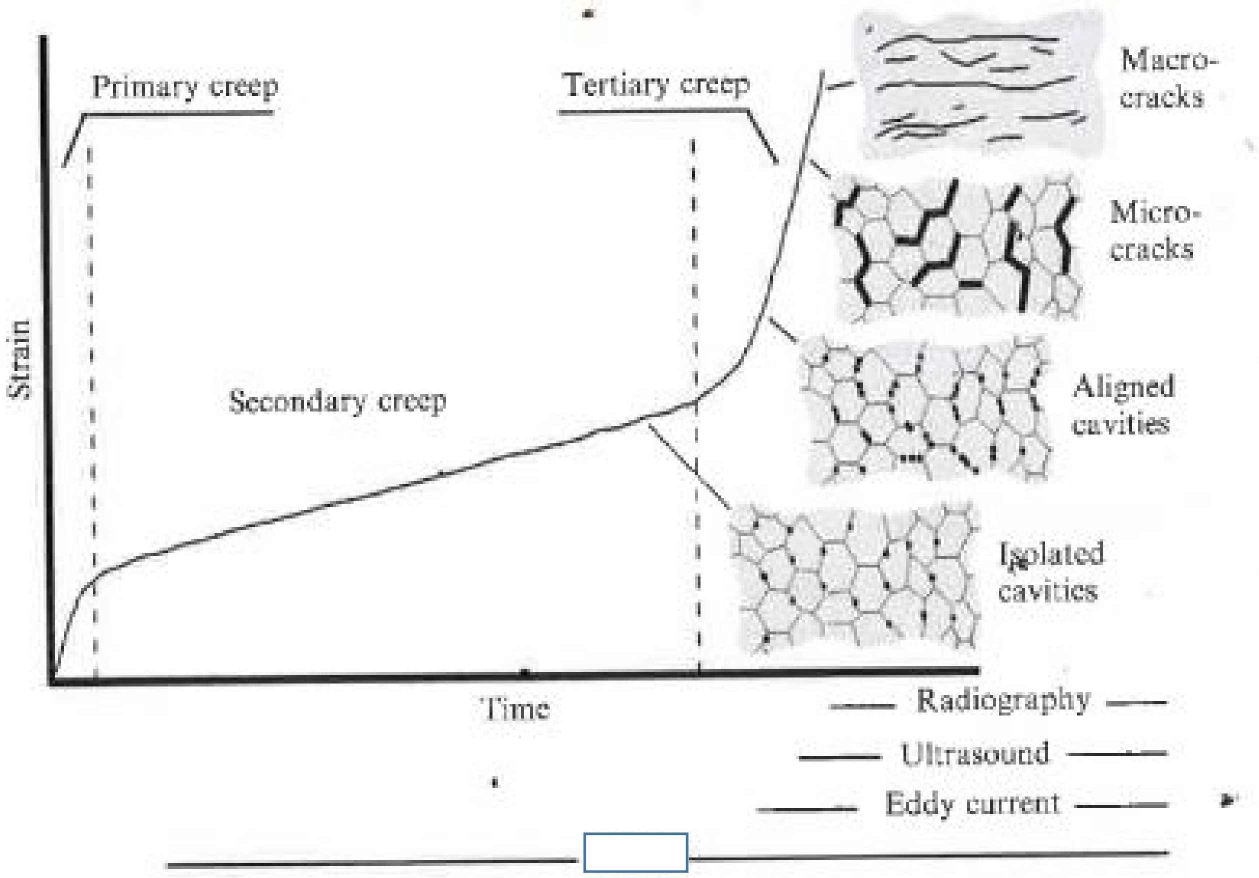
TOOLS

- ***Non Destructive Tests - NDT (PoD)***
  - Diametrical growth (expansion with creep) – Best for ***II/III creep***
  - Wall thickness measurements (deformation with creep) - Best for ***III creep***
  - Replication (advanced creep stages, aligned micro-voids, micro- and macro cracks) - Best for ***II/III creeps (external surface only !)***
  - Radiography (macro-cracking) - Best for ***III creep***
  - Eddy current - Best for ***III creep***
  - Ultrasonic test (attenuation and scattering; creep cracking) - Best for ***III creep***

- ***Destructive test on tube samples – short time test (í t, í $)***
  - Mechanical properties (short term, not time dependent)
  - Hardness
  - Microstructure

- ***Destructive test on tube samples – medium/long time test (ë t, ë $)***
  - Creep test (long term, time dependent)

Creep stages and NDT

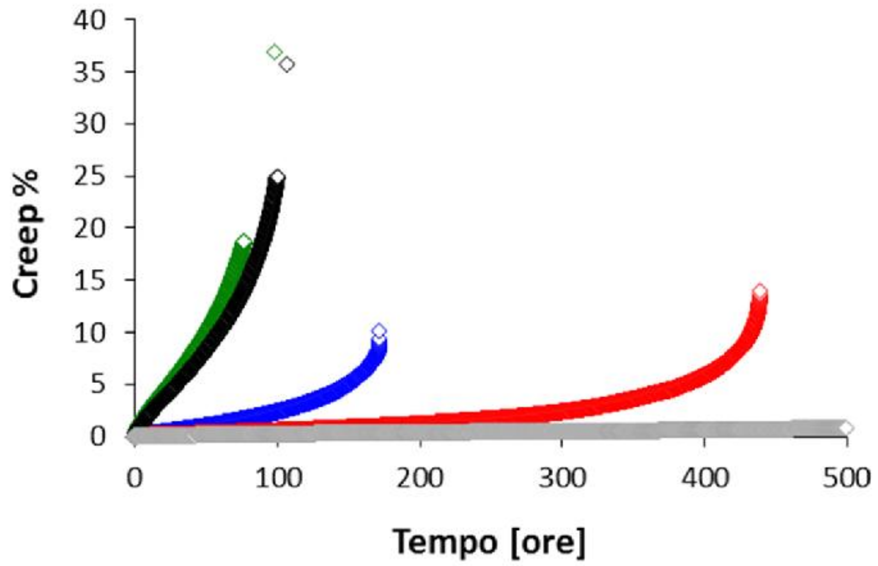


* Laser diameter measurement

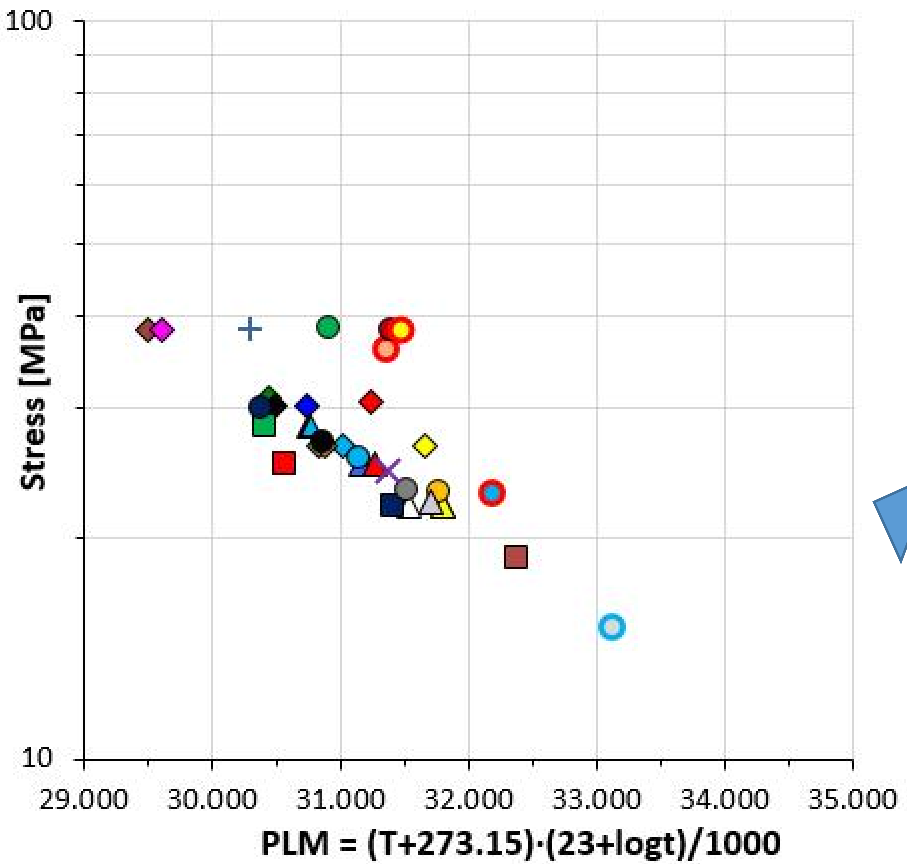
RLA BASED on creep tests

Creep tests permit to obtain details of actual creep resistance for materials (***aged***) and consumed life.

Different creep curves (with same test parameters) for different service histories of tube material



Post exposure data → analysis of results with LARSON MILLER



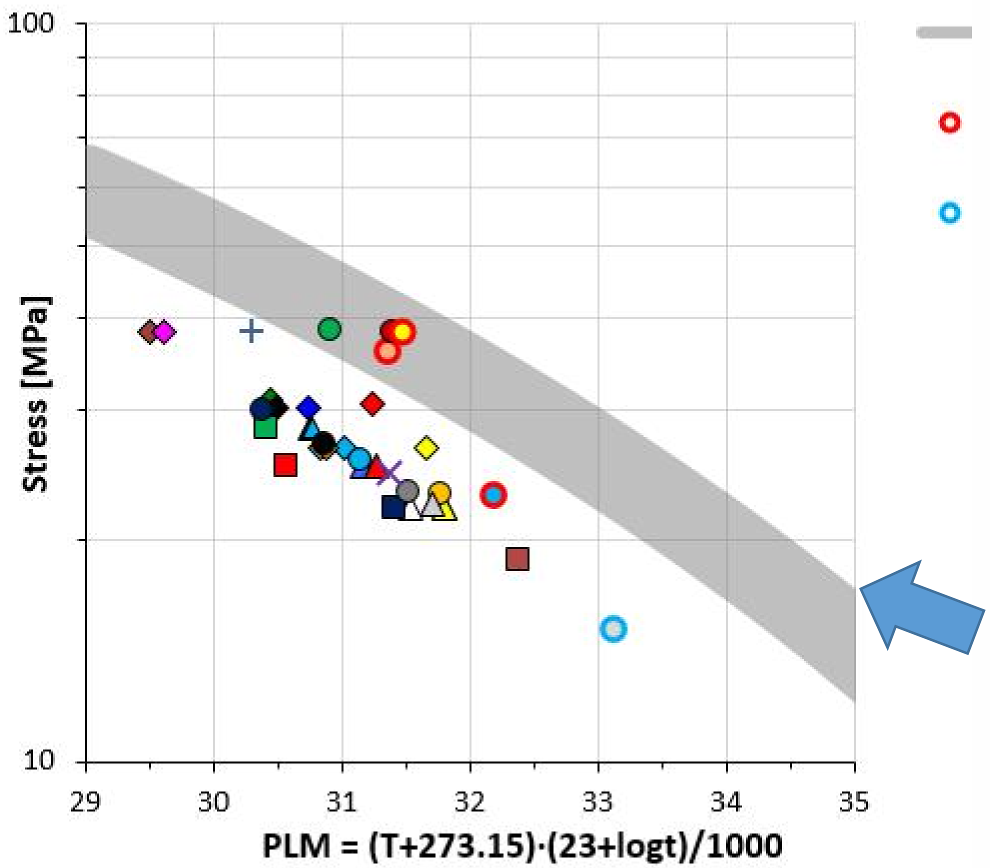
Interrupted

On-going

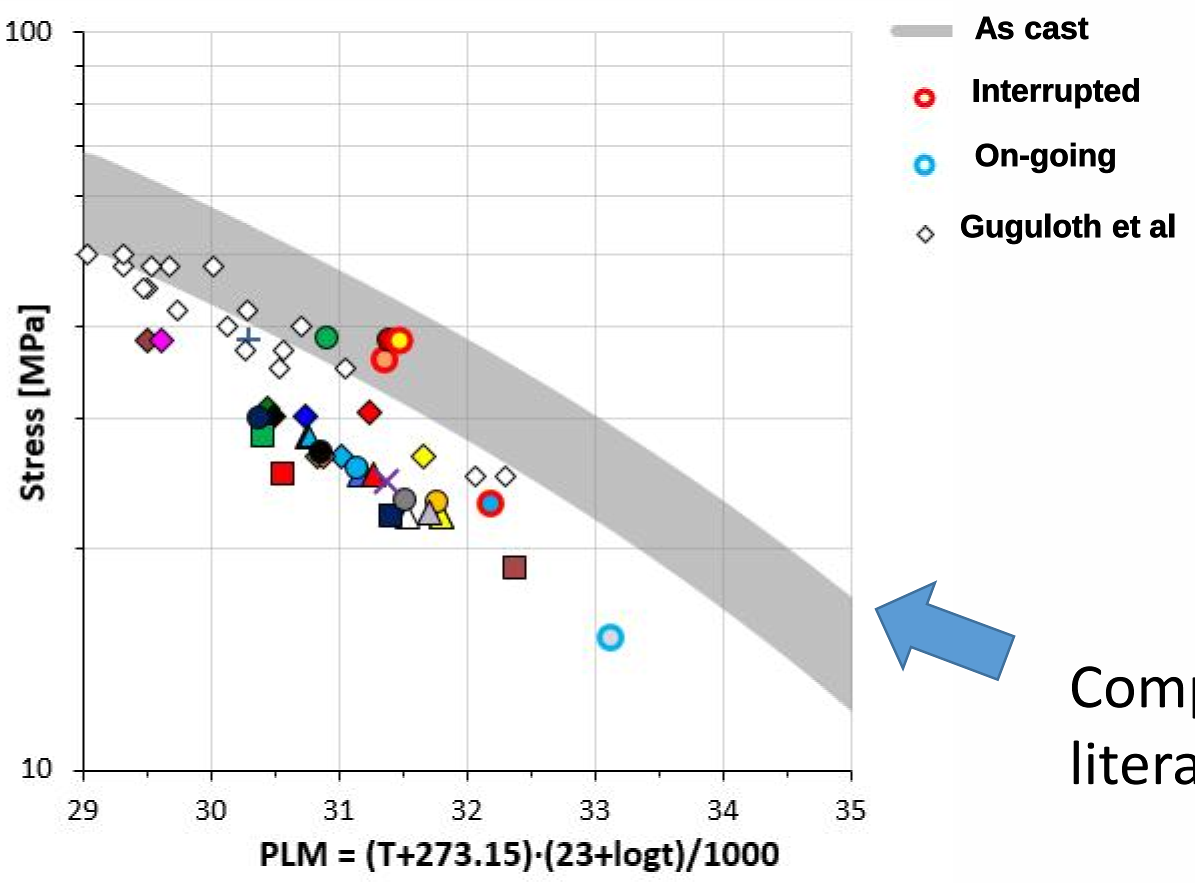
Post-exposure data of tube samples taken from service

36 tests with 5000 duration at different T and s.

Post exposure data → analysis of results with LARSON MILLER

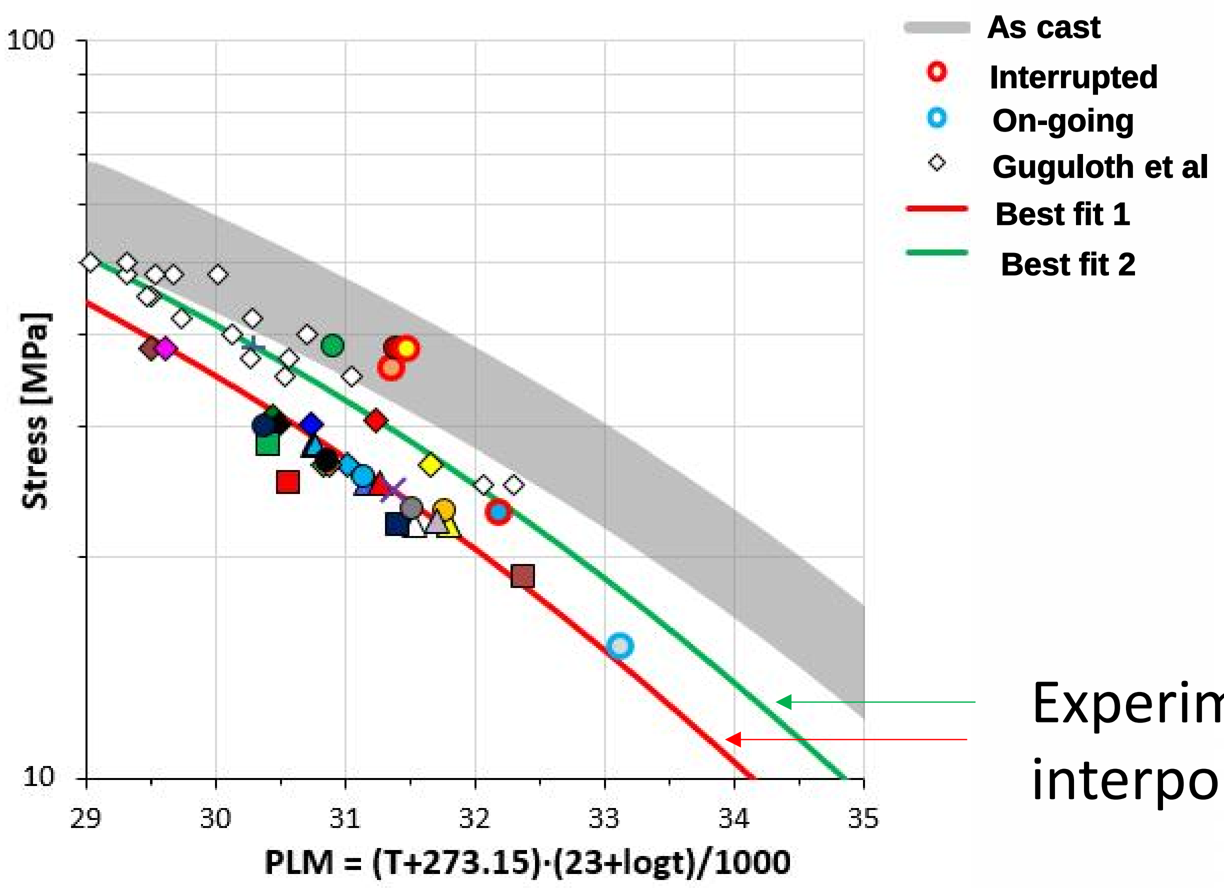


Comparison with as-cast materials (Manufacturer brochure data)



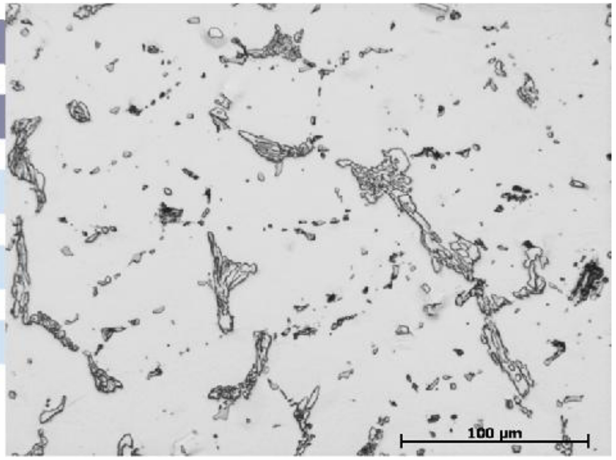
Comparison data from literature

Post exposure data → analysis of results with LARSON MILLER

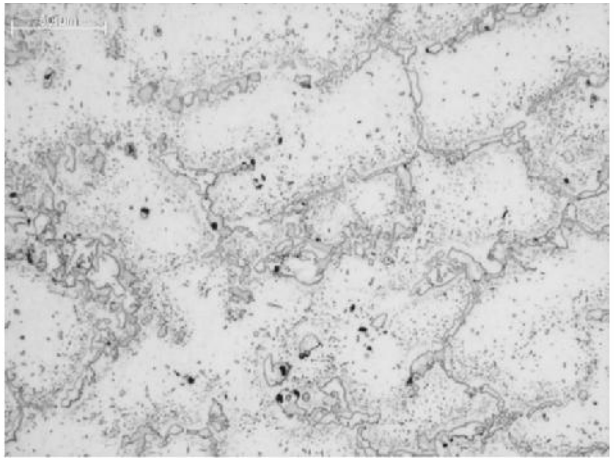


Experimental data interpolation (polynomial)

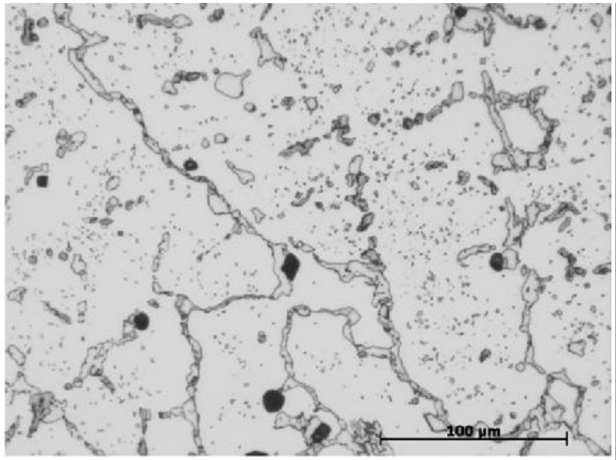
Microstructural degradation vs. Creep behavior



As-Cast



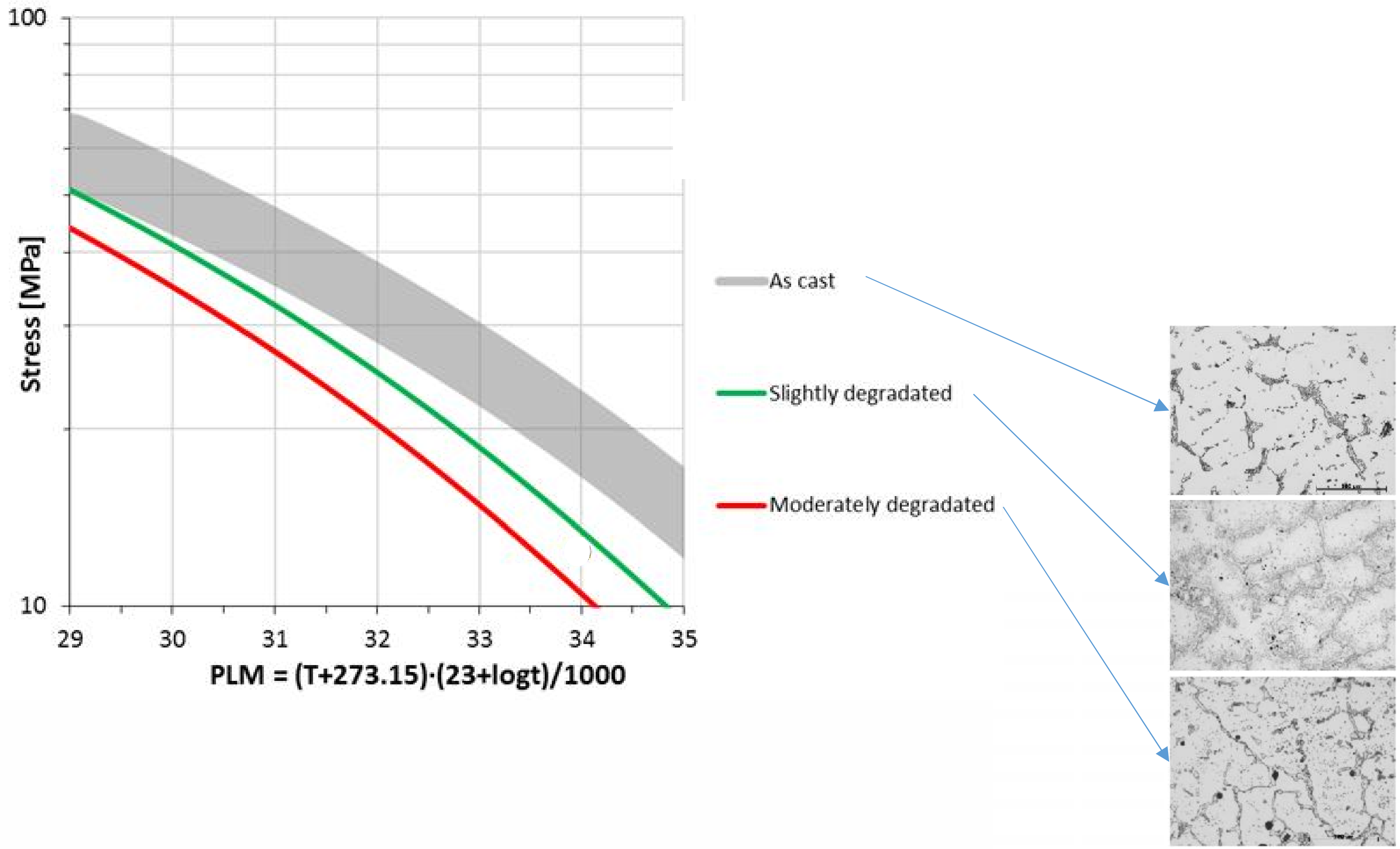
Slightly degraded



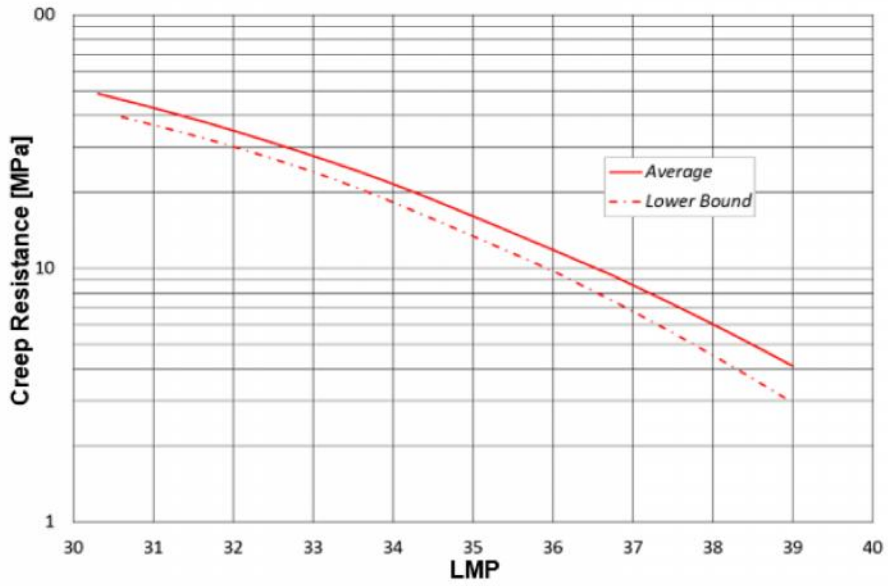
Moderately degraded

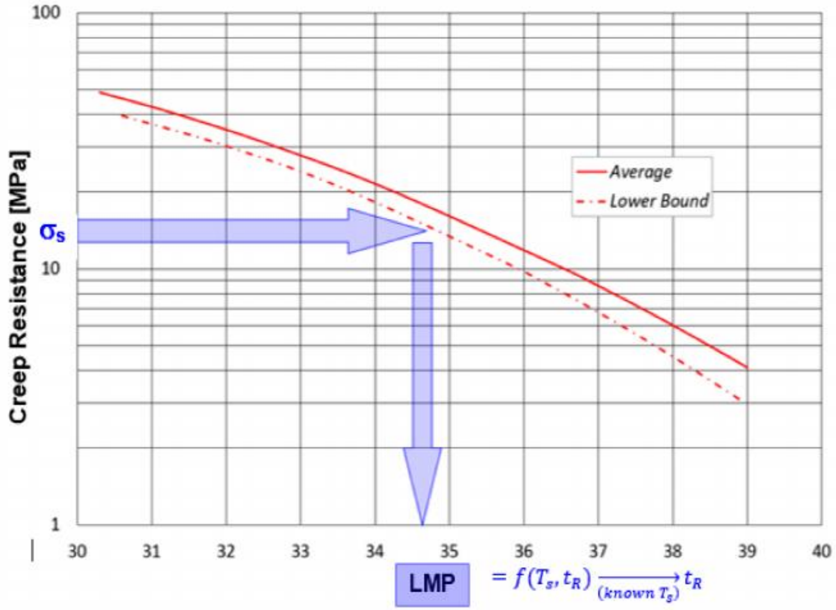
Sample	Description
As-cast	Primary eutectic carbides; HV > 200.
Slightly degraded	Slight carbide coalescence, scattered precipitation of secondary carbides; HV > 170; Creep-rupture elongation ≤ 10%; Slight diametric deformation (from NDT) < 2 %
Moderately degraded	Carbide coalescence, extensive precipitation of secondary carbides; HV < 170; Creep-rupture elongation > 30%; Diametric deformation (from NDT) >2%.

Fitting Curves and material degradation



Remaining Life assessment approach



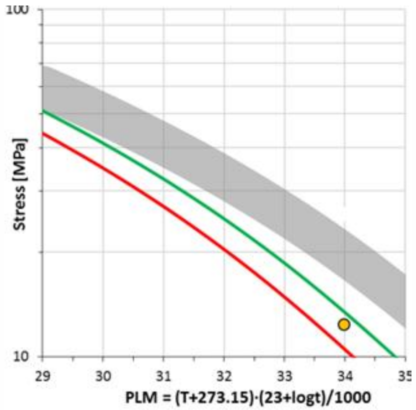


Master curve for as cast material (new)

RLA assessment

PLM = (T+273.15)·(23+logt)/1000

Remaining life assessment approach – Creep curves From metallurgical evaluation



Operating conditions: σ_{op} = 12 MPa, T_{op} = 950°C,			
"as-cast" average curve	"as-cast", lower bound curve	"Mod. degraded" curve (in red in Fig. 6)	"Slightly degraded" curve (in green in Fig. 6)
t_R (hours)	t_R (hours)	t_R (hours)	t_R (hours)
> 10^6	942,700	39,100	115,700

Conclusions

- ❑ Post exposure data analysis:
  - Metallographic examinations (macro- e micro)
  - Dimensional check
  - Short term mechanical test (hardness, tensile)

- ❑ Definition of "state od degradation":
  - Association with one of defined MASTER CURVE (as cast, slightly degraded e moderately degraded)

- ❑ RLA assessment and programming of maintenance/inspection

- ❑ More economical and less time consuming test than medium-long creep test.

- ❑ Fast answer to the plant (Coupled with NdT)

Conclusions

- ❑ As cast curve can be less conservative and not applicable to post exposure materials
- ❑ Future works $\rightarrow$ long term creep (10 ÷ 20 kh) of materials cut-out from service
  - Validation of Green and red fit "post exposure" Master curves

Appendix 9

Case studies of corrosion at oil refineries and petrochemical plants and mitigation actions

(Roman Vinogradov)

Case studies of corrosion at oil refineries and petrochemical plants and mitigation actions

Pavlodar Oil Chemistry Refinery – V. Rodionov, Zh. Bekshenov, G. Burumbaeva
JSC "D.V. Sokolskiy Institute of Fuel, Catalysis and Electrochemistry" –
A. Abilmagzhanov, A. Nefedov, N. Kenzin, D. Zhanabaev
KBR – P. Chernyavskiy, M. Arslanov, R. Vinogradov

Eurocorr 2020
WP15 meeting
September 9, 2020

The aim:

- ***Provide an overview of the current status of corrosion situation at the sites observed in FSU* and Europe***
- ***Share investigations made***
- ***Analyze few case studies and mitigation/remedy actions made***

**FSU = Former Soviet Union*

KBR's areas of expertise:

- *International experience in corrosion studies as a Consulting and Engineering company*
- *Troubleshooting integrity, reliability and corrosion problems*
- *Large engineering data base including metallurgical experience in severe applications*

Continue KBR's areas of expertise:

- *Investigations following major incidents and awareness of industrial incidents*

- *Partnering with other engineering companies, consultants and research institutes:*

  - ✓ *Collaboration with JSC "D.V. Sokolskiy Institute of Fuels, Catalysis and Electrochemistry" (Almaty, Kazakhstan) for corrosion studies in Pavlodar Oil Chemistry Refinery*

Two categories of oil refineries:

- *Sites that use the marketing scheme processing opportunity crude oils and other feedstock available on the market that can change within few days.*

- *Sites that process crude from one source with stable and predictable feed composition and qualities (provided by suppliers).*

Whichever scheme is used, each plant does require internal standard on selection of MOC (previously developed in FSU* guiding materials are out-of-date and don't consider some corrosion phenomena).*

**MOC = Materials of construction; FSU = Former Soviet Union*

- *The most frequently seen **site wide** issues:*
  - *Improper selection of materials*
  - *Various slops processed with unknown qualities and limited understanding of impact on fouling and corrosion under deposits*
  - *Limited capabilities of labs to analyze corrosion deposits*
  - *Absence of practice to avoid corrosion during units' shutdowns*
  - *Gaps in the documented procedure for coupon installation and data analysis identified at some sites*
  - *Issues with proper arrangement of insulation and CUI**

**CUI = Corrosion under insulation*

Cooling water is the most commonly seen issue at all refineries observed to date.

Typical problems with site cooling water systems:

- *insufficient biological treatment and formation of biofouling*
- *poor filtration of returned water*
- *insufficient monitoring of chemicals dosing*
- *fouling of CW* pipelines and HE* with biological sludge*
- *no inhibitor to protect some components (e.g. copper alloys)*

**CW = Cooling water; HE = Heat exchanger*

Case Study 1: Corrosion of overhead condenser at NHT*

- ***Materials***: *Tubes – Brass ЛОМш70-1-0.05 (C44300). Tube sheet - 09G2S steel (A 561 Gr70).*
- ***System:*** *NHT overhead condenser*


- ***Appearance:*** *deposits, scale and pits in headers, tube sheet and nozzles of heat exchanger.*
- ***Time from cleaning:*** *1 year*
- ***Details:*** *calculated velocity of CW in tubes is* ***0.06 m/s****. The system was dirty when chemical treatment started. No chemical cleaning or passivation at start of program. Microbe number was not defined.*

**NHT = Naphtha Hydrotreating Unit*

Continue Case 1:

Chemical treatment program: *Zn/phosphates. NaOCl as a biocide.*
Addition of water from WWTP* unit.
No inhibitor for Cu alloys.

Physicochemical analysis of deposits: *organic components (8 % wt.), which assumes the presence of microbiological part (there was no leak of hydrocarbons). Inorganics - 89 % wt.*

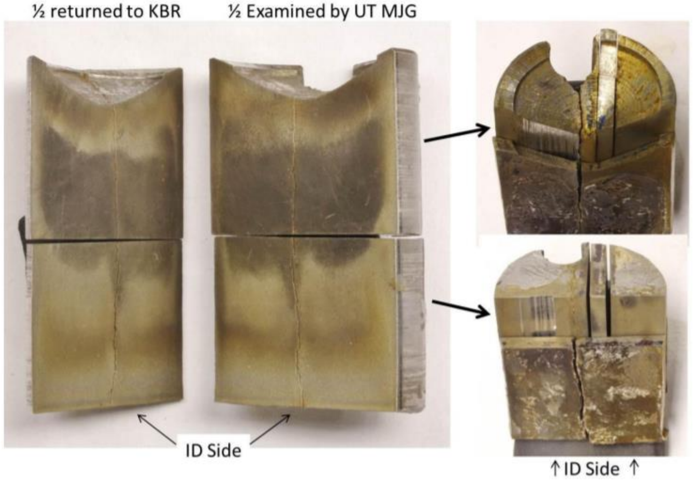
Corrosion is probably the result of iron bacteria and SRB activity.

Mitigation actions: *microbiological analyses of water and deposits, cleaning of CW pipelines, increase of CW velocities in water coolers and chemical treatment of CW system.*
Use of coating and sacrificial anodes was recommended in the header.

**WWTP = Waste Water Treatment Plant; SRB = Sulphate Reducing Bacteria*

Case Study 2: Ammonia production (ammonia synthesis loop)

- ***Material:*** *2.25Cr-1Mo-0.25V Vanadium enhanced alloy.*
- ***System:*** *Heavy Wall Ammonia Converter. 200°C, 16.68 MPa. Mixture of H_2, N_2 and NH_3.*
- ***Time to failure:*** *1.5 year.*



- ***Appearance:*** *Transverse crack in circumferential weld. The picture in the centre represents the macrograph of plane near the center of the plug sample. The cracking terminates in the base metal and is transverse to the weld direction.*

Continue Case Study 2: Ammonia Converter

- ***<u>Details:</u>*** *Twenty eight (28) start-up and shut-downs during 1.5 year of operation due to the problems with the upstream gasifier.*

- ***<u>Cause:</u>*** *the combined effects of high residual stresses remained in the weld due to improper PWHT*. This coupled with operation and hydrogen being presented in the weld, led to the fracture of the weld.*

- ***<u>Remedy action</u>*** *was to repair the weld using the recommended monitoring thermocouple locations for PWHT*.*

**Post Weld Heat Treatment*

Case Study 3. Sea water pipeline

- ***Material:*** *304 SS.*
- ***System:*** *Sea water pipeline from heat exchanger 70°C, 0.5 MPa*
- ***Time to failure****: 6 months*

- ***Appearance:*** *Holes, pits, and deep crevices*

Continue Case Study 3: Sea water pipeline

- ***Details:*** *onshore refinery with no access to sources of fresh water. Sea water is used as cooling medium. Chloride content is 35,000 ppm.*

- ***Cause:*** *wrong selection of susceptible to pitting corrosion material.*

- ***Remedy action*** *was to replace the damaged pipeline with*

  INCOLOY© 825 (40% Ni, 22% Cr, 3% Mo, 2% Cu, 1% Ti).

Conclusions

- *Some gaps with regards to best practices in the area of corrosion control and mitigation exist at FSU oil refineries*

- *Typical issues arise from chemical treatment programs, selection of materials of construction and welding control procedures*

- *Technical advisory with strong knowledge of process features, corrosion mechanisms and mitigation actions and the right metallurgy application coupled with the modern corrosion monitoring systems are required*

Appendix 10

Reliable level of corrosion inhibitor’s residual concentration in wet gas-condensate pipelines

(Askar Soltani)

VIRTUAL EUROCORR
THE EUROPEAN CORROSION CONGRESS
9th September 2020
Working Party 15, Annual Meeting of Corrosion in the Refinery and Petrochemical Industry

Reliable level of corrosion inhibitor's residual concentration in wet gas-condensate pipelines

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Abstract

Organic corrosion inhibitors have been applied for decades to mitigate corrosion in pipelines which transport multi-phase gas-condensate flow from offshore platforms to onshore facilities. There is always a minimum allowable residual concentration of corrosion inhibitors according to the recommendations of the inhibitor's manufacturer or the corrosion engineer in charge. Lack of recommended standard for the measurement of the maximum level of residual inhibitor concentration may result in operational issues in downstream equipment. In some refineries of south pars gas field, frequent loss of thermal performance was experienced in the reboiler of the condensate stabilizer column which forced frequent unplanned unit shutdowns. In internal inspection, bulky and sticky black sludge observed on the tubes of the reboiler. Analytical chemistry was carried out to analyze the different compounds of the sludge and determine their origin. Gas chromatography results on the taken field sample and simulated condensate and inhibitor's samples revealed that the main component of the sticky sludge was the active component of the imidazoline-amide based corrosion inhibitor. At elevated temperatures (i.e. in reboilers), the active component of corrosion inhibitors has significant adherence property and are able to act like a glue to bind corrosion products and salts to the high temperature surfaces and impose operational issues due to pressure drop across the system or decreasing thermal efficiency of the heat exchangers.

Key Words: Corrosion inhibitor, residual concentration, operational issues

Introduction

In oil and gas industries, the corrosion issue has always been of great importance, with consequences similar result to those of natural disaster. Corrosion normally occurs in oil and gas pipelines. Since the pipelines play the role of transporting oil and gas from the wellheads to the processing facilities, they are exposed to the continuous threat of corrosion from the date of commissioning up to the decommissioning or abandonment. Corrosion inhibitors are one of the mediums applied to minimize corrosion in petroleum industry. For an optimum inhibition to be achieved, the inhibitors must be added above a certain minimum concentration [1]. It is however important to emphasize that the inhibitor efficiency is highly dependent on its capability to be present in the water phase and reach the pipe wall. Therefore, for a given corrosion inhibitor injection rate, there is a need to quantify the amounts of the active components present in the water and oil phase [2].

In most applications where corrosion inhibitors are used to mitigate CO_2/H_2S corrosion, more than a single phase is present in the system. Therefore, when the inhibitor is applied, its components are inevitably distributed between the phases mainly the oil, the brine and the solids [3]. The film forming inhibitors are used in industries to create a molecular layer right on the surface of the steel and aliphatic tail as a second layer in hydrocarbon to prevent water from contacting the steel surface and causing corrosion [4]. The adsorption-type inhibitors reduce corrosion rate by forming layers of hydrophobic film on metal surface, which hinders transfer of substance and charges related to corrosion reactions. They are usually organic and the most widely used are the nitrogen-containing compounds, for example amines, amides, quaternary ammonium salts, imidazolines and their derivatives, salts of nitrogenous molecules with carboxylic acids, polyoxyalkylated nitrogen-containing compounds, nitrogen heterocyclic and compounds containing phosphorus, sulfur and oxygen [5-7]. Imidazoline, as a type of corrosion inhibitor, is most commonly used for protecting oil wells, gas wells or pipelines from CO_2 corrosion due to its good adsorption character and the formation of a chemical film on the surface of iron and steel. The molecular structure of imidazoline is shown in Figure 1. It consists of three parts: a five-atom ring with nitrogen element (part A), a long hydrocarbon chain (part B, R1) and a pendant side chain with an active Functional group (part C, R2). R1 is also called hydrophobic branched chain, and R2 is called hydrophilic branched chain. Hydrophobic branched chain R1 moves away from the metal surface and forms hydrophobic layers in solution, these hydrophobic layers hamper the contact of corrosive medium and the metal surface, slow down the corrosion. Hydrophilic branched chain R2 mostly contains N, O and other heteroatoms, which can achieve stable chemical adsorption on the surface of metal, so as to slow down the corrosion rate [8].

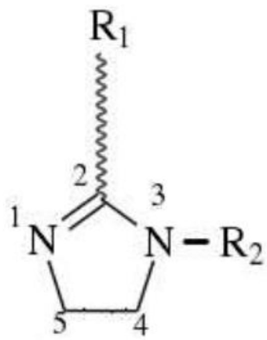

Figure 1. Scheme of an imidazoline molecule

These corrosion inhibitors are usually injected into the flow stream as a mixture of chemicals containing surfactant molecules. The so-called "active component" in this mixture is most commonly an organic surfactant compound(s) with an amphiphilic molecular structure, consisting of a polar head group and nonpolar hydrophobic tail. The polar head is often based on nitrogen-containing groups, such as amines, amides, quaternary ammonium, or imidazoline- based salts as well as other functional groups containing oxygen, phosphorus, and/or sulfur atoms. The length of a hydrocarbon tail which is attached to a polar group typically varies between 12 and 18 carbon atoms. The function of the polar head-groups is to provide a bonding between inhibitor molecules and the steel surface. Hydrophobic tails are facing the solution, are thought to be important in establishment of self-assembled layer(s) of corrosion inhibitors on the metal surface and key to the protection they offer [9]. The injected corrosion inhibitor in sea-lines of south pars gas complex was analyzed by FTIR[1] Spectroscopy in order to find out its functional groups. FTIR spectra of this inhibitor is shown in Figure 2.

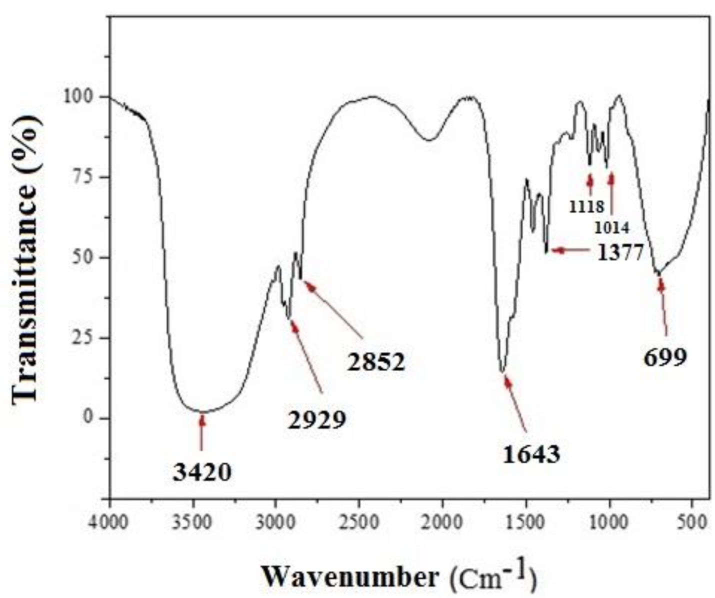

Figure 2: FTIR spectra of the fresh corrosion inhibitor

[1] Fourier Transform Infrared Spectroscopy

In Table 1, functional groups assigned to the major peaks of the FTIR spectra have been illustrated.

Table 1: Assignment of functional groups in FTIR spectra of the fresh inhibitor

Wavenumber (Cm^{-1})	3420	2929	2852	1643	1377	1118	1014	699
Functional Group	N-H	CH_2	CH_2	C=N	S=O	C-N	C-N	C=C

According to Table 1, the band at 1643 Cm^{-1} is the characteristic stretching vibration of C=N in the imidazoline ring. N-H bands detected at 3420 Cm^{-1}, can be related to the amide active component of the inhibitor. Transmittance in the region of 1118 and 1014 Cm^{-1} can be assigned to C-N stretching vibrations. The band appeared at 2929 Cm^{-1} in the spectra can be assigned to the CH_2 stretching vibrations and band at 1377 Cm^{-1} is assigned to unconjugated S=O which is able to bond their free electrons with vacant “d” orbital of iron surface atoms and reinforce inhibitor bonding to the iron surface [10].

FTIR investigations on the samples of corrosion inhibitor which was applied in the sea-lines of South Pars Gas Complex identified its composition as a mixture of amides, imidazoline ring and salts of amines. So, this corrosion inhibitor is an imidazoline-amide based inhibitor. The injection rate depends on the gas flow rate, so that it is normally injected in the rate of 20–25 lit/hr. In order to make sure that the pipeline is under the corrosion control beside the annual measurement of the weight loss corrosion coupons (i.e. installed at the end of the pipeline) and scheduled inspections by NDT[2] methods, also a daily laboratory measurement of the residual concentration of the corrosion inhibitor are done. This laboratory measurement is carried out on the samples taken from the water phase of the liquid bottles at the end of the pipelines in slug catcher. According to the recommendations of the inhibitor’s manufacturer, the minimum allowable residual of the corrosion inhibitor in the samples taken from the end of the sea-lines must be 400 – 600 ppm, however there is no allowable upper limit for this concentration.

Piping flow diagram of the sea-lines and slug catcher has been illustrated in Figure 3. As it is observed on this flow diagram, a multi-phase wet gas-condensate flow has been transported by sea-lines from offshore platforms to the onshore facilities. The first unit which receives this multi-phase flow is called a finger type slug catcher. In this unit, sour gas stream is separated from the top of the inclined pipelines in the first section of the fingers and transported to gas treating units to be sweetened and at the end of the slug catcher, water phase and hydrocarbon condensate mix together and transported to condensate stabilization unit in order to reduce the vapor pressure of the condensate by removing its lighter

[2] Non-Destructive Test

components and adjust its reid vapor pressure according to the required product specifications.

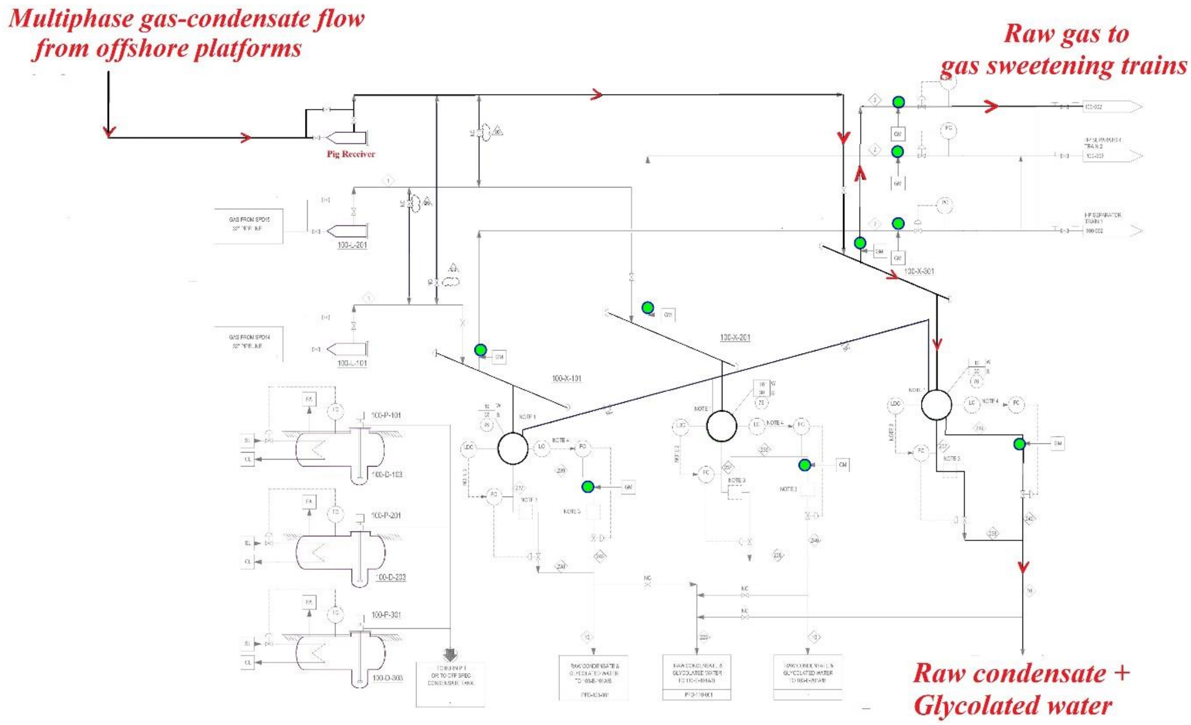

Figure 3: Piping flow diagram of platform pipelines to the slug catcher unit in onshore refinery

Piping flow diagram of the condensate stabilization unit has been illustrated in Figure 4. The raw condensate from the slug catchers is preheated, then flashed before going through a desalter. Duty of this equipment is to remove the free aqueous phase, which can be salted or not, from the hydrocarbon phase so that in downstream of the desalter the maximum allowable water content shall be 500 ppm_V and maximum 10 mg/l of the salt content. After passing the desalter, raw condensate enters into the stabilization column.

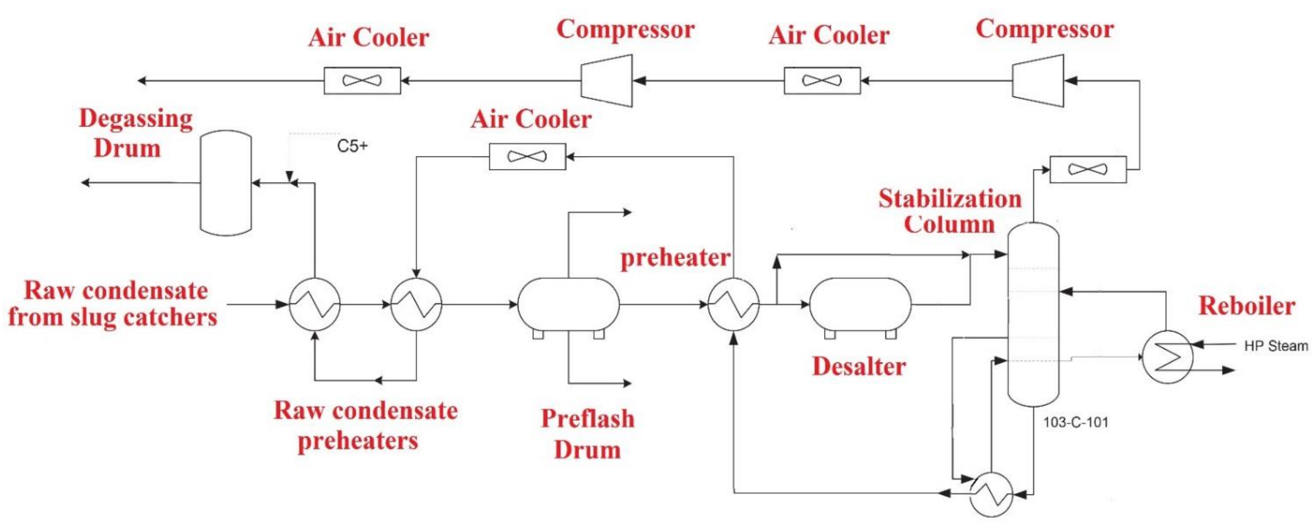

Figure 4: Piping flow diagram of condensate stabilization unit

At the bottom of this column, some of the liquid is circulated through a reboiler to add heat to the tower. As the gas goes up from tray to tray, more and more of the heavy ends get stripped out of the gas at each tray and the gas becomes richer in the light components and leaner in the heavy ends. Operating temperature of this reboiler is approximately 170^0 C. Decreasing in thermal performance of this reboiler was reported by the operator frequently which forced the operator to shutdown the unit in order to investigate the reasons of this issue. First internal inspections, revealed that all the tubes and tube spacings were accumulated by bulky and sticky sludge so that no adequate heat surface was prepared and the thermal performance of the reboiler was dropped.

Methods of investigation

In order to analyze the origin of the sludge, it was decided to use analytical chemistry method by gas chromatography in order to analyze different components of the sludge. As it is shown in Figure 5, sludge consisted of two parts: a clear aqueous phase and a sticky and gritty black phase.

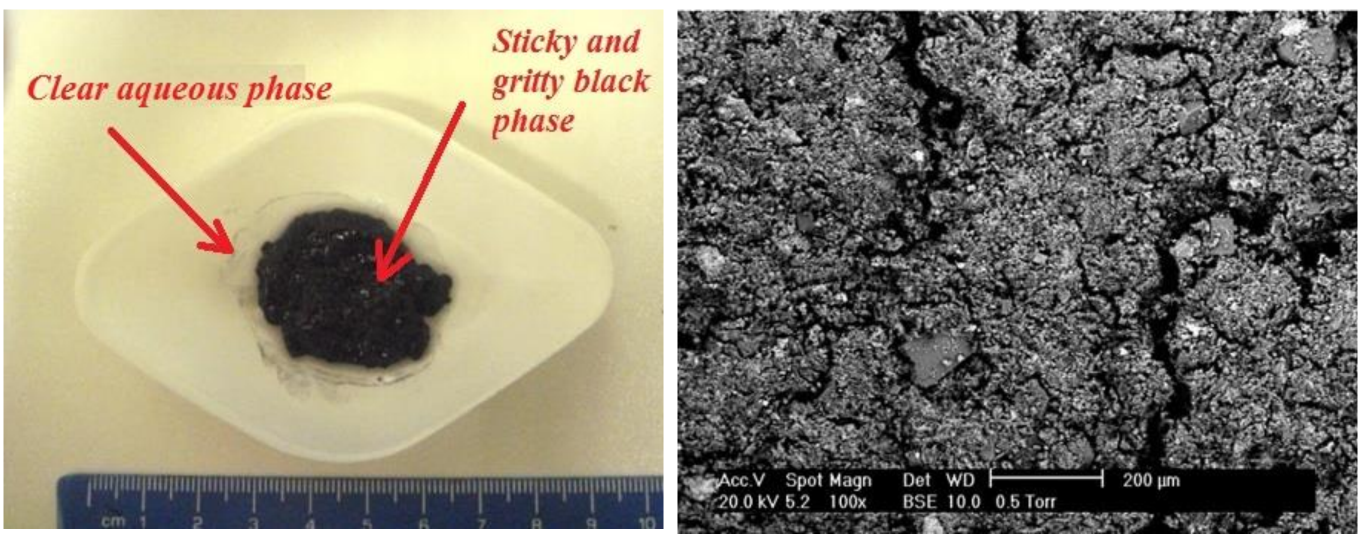

Figure 5: Sample taken from the surface of the tubes and SEM image of its black phase [11]

In order to analyze all components of the sludge, the clear aqueous phase was separated from the sticky and gritty black phase. Since the appearance of this aqueous phase was similar to the hydrocarbon condensate, so it was decided to take a sample of fresh hydrocarbon condensate and compare gas chromatograms of this sample with the clear aqueous phase of the field sample. Gas chromatograms of these two samples has been illustrated in Figure 6. As it is obvious there is an acceptable agreement in the peaks of the two samples and the clear aqueous phase could be the remained condensate on the tube bundle which was not drained completely and left on the tubes and sludges.

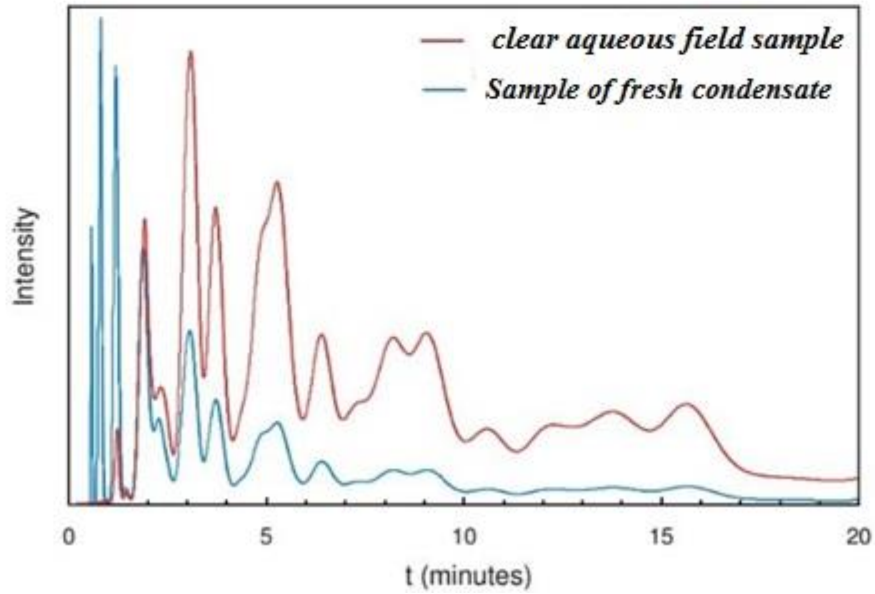

Figure 6: Gas chromatogram for the aqueous phase of field sample and condensate sample [11]

Analyzing sticky and gritty black sludge

Since the black sludge seemed to be containing solid particles like grit, so it was decided to separate the solid particles and analyze the solid part and sticky viscous parts separately. In order to do this, all the sample of gritty and sticky black sludge was dissolved in methanol as a solvent because organic corrosion inhibitors like imidazoline-amide based inhibitors are soluble in methanol and the appearance of the sticky and viscous part was like the applied corrosion inhibitor. After dissolving in the methanol, the sample was filtered to separate the solid parts and then heated in the oven to evaporate its remained volatile parts. Separated solid and viscous parts have been shown in Figure 7.

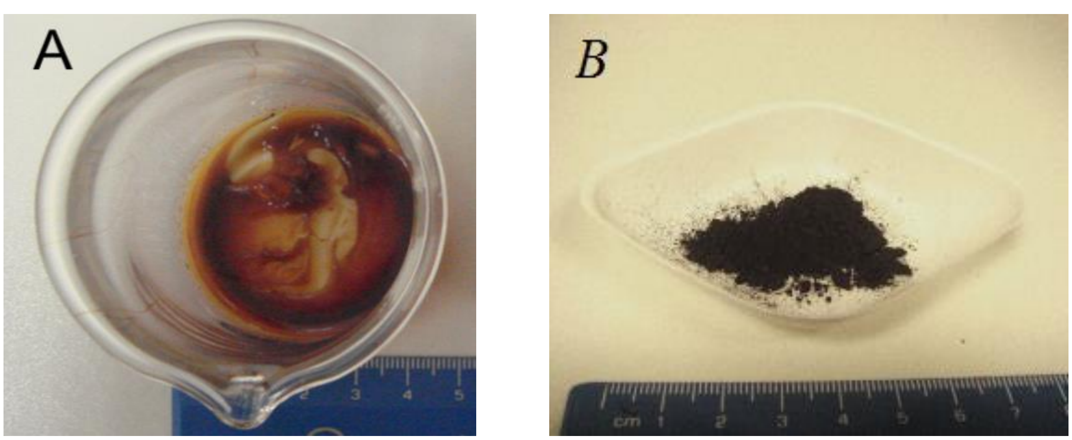

Figure 7: Separated parts of sticky and gritty sample: A: Sticky and viscous part after dissolving in methanol and heating in oven, B: Solid part after methanol dissolving, filtering and heating in oven [11]

Analyzing solid particles of the black sludge

Gravimetric measurements revealed that the solid particles made up approximately 55 wt.% of the sticky and gritty sludge. EDX[3] spectroscopy was employed for the analysis of the solid particles. Results of EDX analysis has been shown in Figure 8.

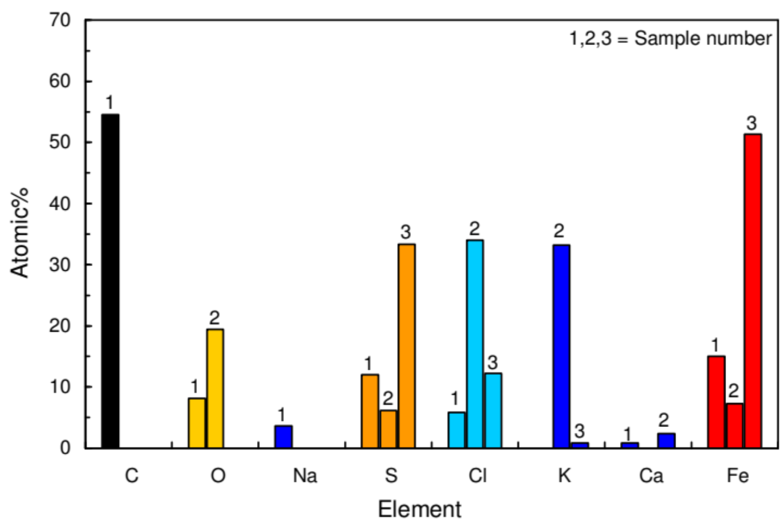

Figure 8: Results of EDX analysis on the solid sample [11]

As it is clear in Figure 8, the main elements were Fe, S, P, K, Na, O and C. The high carbon content observed for one sample likely represents crystalized heavy hydrocarbons from the condensate which were insoluble in methanol or possibly carbonized corrosion inhibitor active component which was remained on the solid particles. Fe and S elements could be the common corrosion product in sour services which form iron sulfide and sometimes are not able to form a stable film on the surface of the steel and circulate in the system. Other elements like K, P, Cl and Na are the salts of the production water which can be present in the stream when the desalter is not in service or is not working efficiently.

Analyzing sticky black sludge

As it is obvious in Figure , since the appearance of oven-dried methanol filtered viscous part was similar to the poly-amide resins used in corrosion inhibitors, therefore, a sample of the fresh corrosion inhibitor was taken and heated to elevated field temperatures (i.e. 170^0 C) to simulate solvent/volatiles loss (see Figure 9).

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[3] Energy Dispersive X-ray

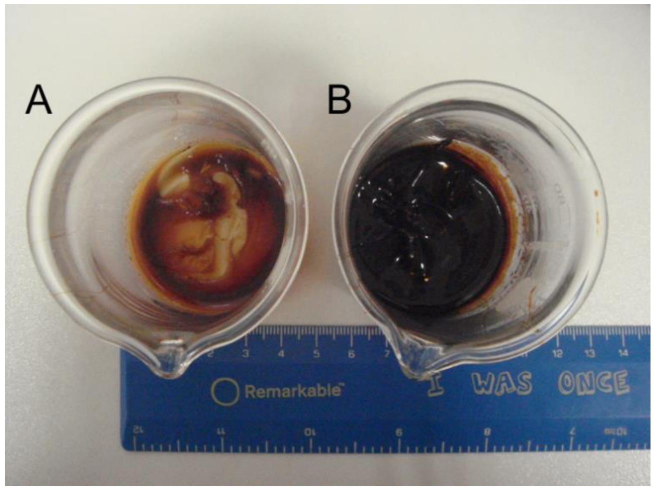

Figure 9: Viscous samples: A: sticky and viscous sample after dissolving in Methanol and heating in oven, B: Simulated fresh inhibitor's sample after heating to simulate solvent loss [11]

In Figure 10, the chromatogram of the simulated sample and field sample has been illustrated. The good agreement between the peaks confirmed that the other constituent and binder for black solid part of the reboiler could be the active poly-amide component of the corrosion inhibitor which remained when the solvent (Methanol) was evaporated.

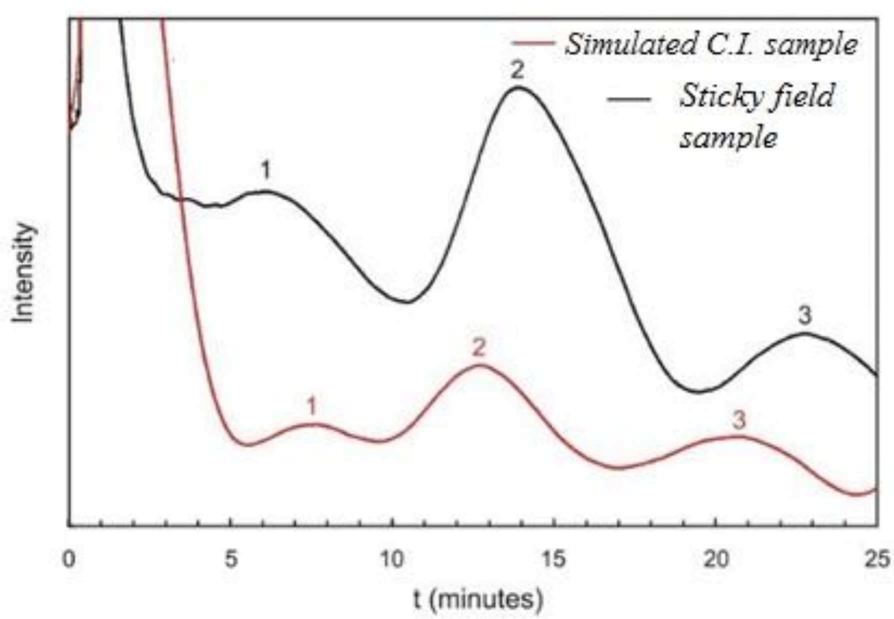

Figure 10: Gas chromatogram of simulated fresh corrosion inhibitor sample and sticky field sample after dissolving in methanol and heating in oven [11]

Results & Discussion

- Gas chromatography results identified that the clear aqueous phase of the field sample was the condensate left in the reboiler.

- Sticky sludge consisted of two parts including gritty parts and salts plus the active component of the corrosion inhibitor.
- Results of Energy Dispersive X-ray analysis revealed that the main components of the gritty part of the field sample was the iron sulfide which is a common corrosion product in sour services containing H_2S.

- Gas chromatography results revealed that the corrosion inhibitor was the main cause of sticky sludge formation on the tubes of the reboiler and decreasing its heat efficiency.

- Due to the partitioning behavior of the corrosion inhibitor in condensate phase and exposing to high temperatures in reboilers, inhibitors can be decomposed to their active component which acts as a glue to bind corrosion products and Salts on the hot surfaces and reduce thermal performance of the reboiler.

Conclusion

- Because of the partitioning behavior of the corrosion inhibitor in the condensate phase and the probability of inhibitor's decomposition at elevated temperatures and causing operational issues in the reboiler of stabilization unit it is strictly required to have a recommended standard code for getting a reliable measurement of the residual concentration of inhibitors in both aqueous and hydrocarbon phases. Lack of a standard code for residual measurement would result in erroneous or not reliable data which is able to mislead the corrosion engineer and cause operational problems and impose unplanned unit shutdowns and considerable maintenance costs.

- It is recommended to have a maximum allowable residual concentration of corrosion Inhibitors in both aqueous and condensate phase to prevent operational problems. This maximum concentration cab be specified based on the experience for a determined flow characteristic in each refinery and it would not be a constant value for all the identical refineries.

- One of the key performance factors in selecting corrosion inhibitors is their thermal stability in simulated laboratory conditions. Operating conditions at highest temperatures of the units (for example in the reboilers) shall be taken into account as key factor in evaluating and qualifying corrosion inhibitors.

- Organic corrosion inhibitors like imidazoline-amide based inhibitors at elevated temperatures decomposes to their active components which are really sticky and are able to act like a glue to bind the salts or solid particles on the hot surfaces. The critical concentration of corrosion inhibitor which may cause this problem shall be measured by field experience in order to prevent operational issues in heat exchangers.

- Desalters play a key role in condensate stabilization unit by removing free waters and salts from the condensate and in the case that it is not in service the salts carrying in the free water can be bind to the active component of inhibitor at high temperatures on the reboiler tubes and form a bulky and sticky sludge.

- This is not true to say that "the higher the concentration of the corrosion inhibitor, the better the protection", because the reliable and optimum corrosion inhibitor concentration is the concentration in which not only the corrosion rate is under the control but also no operational problem occurs.

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