Appendix 1

List of participants

Participants EFC WP15 meeting 13th September 2016 Montpellier (France)

NAME	SURNAME	COMPANY
Akvan	Farzaneh	Consultant
Al Ghafri	Asas	ORPIC
Al Musharfy	Mohamed	Takreer
Dupoiron	François	Total Refining & Chemicals
Eidhagen	Josefin	Sandvik
El Kamel	Meriem	Technip
Goti	Raphael	Total Refining & Chemicals
Groysman	Alec	Technion; Assoc.Chem. Eng
Hindrum	Maria	Sandvik
Hofmeister	Martin	Bayernoil Raffineriegesellschaft mbH
Holmes	Tracey	Special Metals
Houlle	Patrice	Patrice Houlle Corrosion Service - MTI
Knudsen	Ole	SINTEF
Kus	Slawomir	Honeywell
Le Manchet	Sandra	Arcelor Mittal
Lorkin	David	Permasense Limited
Loyan	Sophie	Total
Lyublinski	Efim	NACE
Marcolin	Giacomo	Tenaris Dalmine
Martinez	Sanja	University of Zagreb
Meissner	Andreas	Salzgitter Mannesmann Precision GmbH
Ortolani	Matteo	Tenaris Dalmine
Peet	Matthew	Intertek
Ropital	François	IFP Energies nouvelles
Schempp	Philipp	Shell Deutschland Oil GmbH
Shown	Biswajit	Reliance
Skolyszewska-Kühberger	Barbara	OMV Refining & Marketing GmbH
Suleiman	Mabruk	Takreer
Surbled	Antoine	Consultant
Van Rodijnen	Fred	Oerlikon metco
van Roij	Johan	Shell Global Solutions International B.V.
Wood	Paul	WG Intetech Ltd

Appendix 2

EFC WP15 Activities

(Francois Ropital)

AGENDA EFC Working Party 15
Corrosion Refinery Industry Meeting

14h00-14h20 Welcome - WP15 Activities (F. Ropital)

Eurocorr 2017 and 20th International Corrosion Congress (Prague – Czech republic) sessions and workshops,

Eurocorr 2018 (Krakow – Poland) sessions and workshops

publications,

next meeting: next spring 2017

other points

14h20-15h00 Corrosion failures – Topics from the audience

Corrosion in the Residue Fluid Catalytic Cracking Unit (Reactor & Regenerator) - Ntsikelelo Ngonyoza (ORPIC)

Sensitation and cracking of reactor vessel made of 1.4910 (Follow up to presentation at spring meeting 2015) - Martin Hofmeister (Bayernoil)

Discussion on cases and questions from the participants

15h00-15h25 Sour water corrosion

Prediction Model for Alkaline Sour Water Corrosion: New Insights and Improved Accuracy - Slawomir Kus (Honeywell)

AGENDA EFC Working Party 15
Corrosion Refinery Industry Meeting

15h25-15h50- Monitoring

Recent Advances in Online Integrity Monitoring including Case Studies - David Lorkin (Permasense Ltd)

15h50-16h10 Coffee Break

16h10-16h30 Protection technologies

New corrosion protection technologies for Oil&Gas Industries - .Efim Lyublinski (COR/SCI)

16h30-16h50 Corrosion in sour gas amine units treatment

Report on the advancement of Task Force work on the revision of the EFC 46 guideline (a meeting of the task force will take place just after this meeting

16h50 Other topics and points – End of the annual business meeting

Meeting of the Task Force on corrosion in sour gas units treatment

Excuses from :

NAME	SURNAME	COMPANY	COUNTRY
Astudillo	Miguel	CEPSA	SPAIN
Bonilla	Fernando	V&M France	FRANCE
Bour Beucler	Valerie	Nalco Champion	FRANCE
Brandl	Ramona	OMV	GERMANY
Carroll	Richard	BG Group	UK
Ciccomascolo	Francesco	Böhler Welding Holding GmbH	GERMANY
Claus	Claus	GE Betz	BEGIUM
Corradini	Raffaele	Techint Engineering	ITALY
Cypriano	Daniel	Petrobras	BRAZIL
de Heus	Rob	Sitech services	NETHERLANDS
Delage	Jean Michel	AXENS - IFP Technology Group	FRANCE
Demma	Alessandro	A3 Monitoring Ltd	UK
Doublet	Sebastien	Air Liquide	FRANCE
Gabetta	Giovanna	Eni	ITALY
Kamionka	Marc	Technip	FRANCE
Kawano	Koji	Idemitsu Engineering	JAPAN
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Legait	Pierre Alexandre	Bohler welding group	FRANCE
Rangel	Pedro	CEPSA	SPAIN
Rehberg	Thomas	KAEFER Isoliertechnik GmbH & Co. KG	GERMANY
Reinders	Arjen	CB&I Lummus B.V.	NETHERLANDS
Saarinen	Kari	Zerust Oy	FINLAND
Scanlan	Rob	BP	UK
Shapcott	Stefen	Johnson Matthey Process Technologies	UK
Siegmund	Gerit	ExxonMobil Germany GfKorr	GERMANY
Tabaud	Frederic	BP R&LT (Refining and Logistic Technology)	NETHERLANDS
Van Dooren	Piet	Borealis	BELGIUM
Verstijnen	Wim	Shell Global Solutions International B.V.	NETHERLANDS
Volden	Lars	Statoil ASA	NORWAY
Vosecký	Martin	Nalco	CZECH REPUBLIC
Wolfs	Bert	Sitech	NETHERLANDS
Zakeri	Hadi	Petroineos	UK

Presentation of the activities of WP15

European Federation of Corrosion (EFC)

- Federation of 29 National Associations
- 21 Working Parties (WP) and 1 Task Force
- 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 » Activities

Who is an EFC member

To be an EFC member you (individually or your company, university) has to be member of one of 29 national EFC "member societies". Your company or university can now also an affiliate member.

For example:
in Norway: Norsk Korrojonstekniske Forening
in France: Cefracor
in Germany: Dechema or GfKORR
in UK: Institute of Corrosion or IOM or NACE Europe
in The Netherlands: Bond voor Materialenkennis
in Poland: Polish Corrosion Society
....
You will find all these information on www.efcweb.org or in the EFC Newsletter

Benefits to be an EFC member:
- 20% discount on EFC Publications and NACE Publications
- reduction at the Eurocorr conference
- Access the new EFC web restricted pages (papers of the previous Eurocorr Conference) via your national corrosion society web pages

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 12: Computer based information systems
- WP 13: Corrosion in oil and gas production
- WP 14: Coatings
- WP 15: Corrosion in the refinery 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
- Task Force on Corrosion in CO_2 Capture Storage (CCS) applications
- Task Force on Corrosion reliability of Electronics

EFC Working Party 15 « Corrosion in Refinery » Activities

http://www.efcweb.org/Working+Parties-p-104085/WP%2B15-p-104111.html

Chairman: Francois Ropital Deputy Chairman: Johan Van Roij

The following are the main areas being pursued by the Working Party:

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

Forum for Technology
Sharing materials/ corrosion/ protection/ monitoring information by providers

Eurocorr Conferences

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

Publications - Guidelines

EFC Working Party 15 « Corrosion in Refinery »

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)

Publications from WP15

• EFC Guideline n°40 « Prevention of corrosion by cooling waters » available from
http://www.oxbowbooks.com/oxbow/working-party-report-on-control-of-corrosion-in-cooling-waters.html

•Update in relation with Nace document 11106 "Monitoring and adjustment of cooling water treatment operating parameters" Task Group 152 on cooling water systems

• EFC Guideline n° 46 on corrosion in amine units
http://store.elsevier.com/product.jsp?locale=en_US&isbn=9781845692377

•EFC Guideline n° 42 Collection of selected papers
http://store.elsevier.com/product.jsp?locale=en_US&isbn=9781845692339

•EFC Guideline n° 55 Corrosion Under Insulation *New edition nov. 2015*
http://store.elsevier.com/product.jsp?isbn=9780081007143&pagename=search

•Future publications : suggestions ?

- best practice guideline to avoid and characterize stress relaxation cracking ?

WP15 Corrosion Atlas Web page

http://www.efcweb.org/Working+Parties/WP+Corrosion+in+the+Refinery+Industry/WP+15+Refinery+Corrosion+Atlas.html

EFC Working Party 15 plan work 2015-2017

. Joint sessions with other EFC WP at Eurocorr (2017 Prague-Czech Republic, 2018 Krakow-Poland) on which topics?

Eurocorr 2017 (3-7 September) will be coupled with the 20th International Corrosion Council (ICC) congress (that takes place every 3 years in different parts of the world)

- Update – New EFC guidelines
  - – Corrosion in amine treatment units
  - –best practice guideline to avoid and characterize stress relaxation cracking ?

- Education – qualification – certification

  List of "corrosion refinery" related courses on EFC website ?

  Proposal of courses within Eurocorr ?

Information :
Future conferences related to refinery corrosion

•26-30 March 2017
CORROSION 2017 NACE Conf New Orleans

3-7 September 2017
EUROCORR 2017 Prague Czech Repunlic

Look at the Website: www.efcweb.org/Events

Appendix 3

Corrosion in the Residue Fluid Catalytic Cracking Unit (Reactor & Regenerator)

(Ntsikelelo Ngonyoza)

Corrosion in RFCC Main Fractionation Column

Ntsikelelo Ngonyoza
Senior Materials and Corrosion Engineer
n.ngonyoza@gmail.com

Background

- The Orpic Sohar Refinery had a major planned maintenance turnaround (TA) from the 23 February 2016 to the 23rd April 2016.
- Severe Corrosion was observed in the heavy gasoline section of the main column
- Severe corrosion of piping and equipment was observed in the heavy gasoline corrosion loop
- Corrosion in the main column overhead corrosion was also observed but not to the extent of the heavy gasoline corrosion loop.

Figure 1: NH_4Cl accumulation in heavy gasoline pump strainer

NH4Cl Corrosion

- Solid NH4Cl salts form from NH3 and HCl vapour in the process stream.
- Solid NH4Cl salts desublimate (direct gas to solid transformation)
- To prevent salt formation, the operating temperature should be above the Desublimation temperature.
- NH4Cl salts are highly hygroscopic and are very corrosive to most metallurgies when wet.
- The graph in Figure 2 shows the desublimation temperature for a given process NH3 and HCl partial pressures.

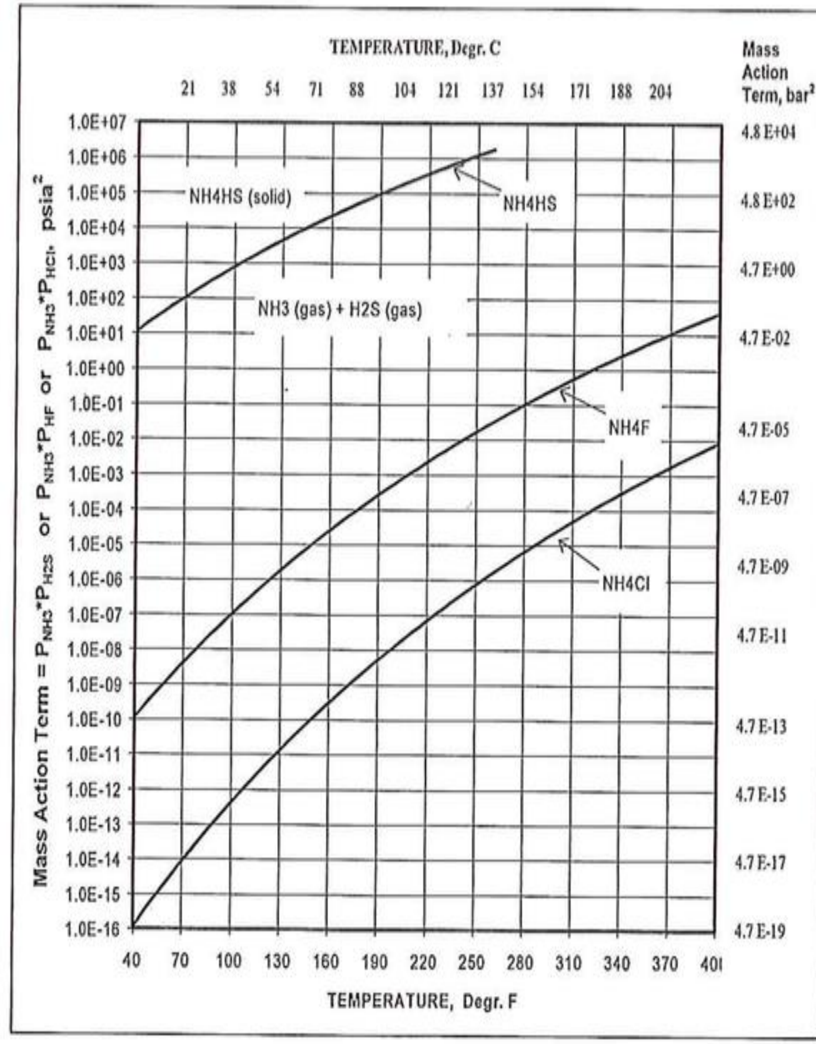


Figure 2: NH4Cl desublimation/deposition graph

The Ideal Scenario

- The top of the column operates above the Nh4Cl desublimation temperature and in the "dry" condition i.e. +- 25°C above the dew point temperature.
- Formation of NH4Cl salts occurs in overhead condenser
- Wash water is injected upstream the column overhead condenser in order to wash away the NH4Cl salts in the condenser.

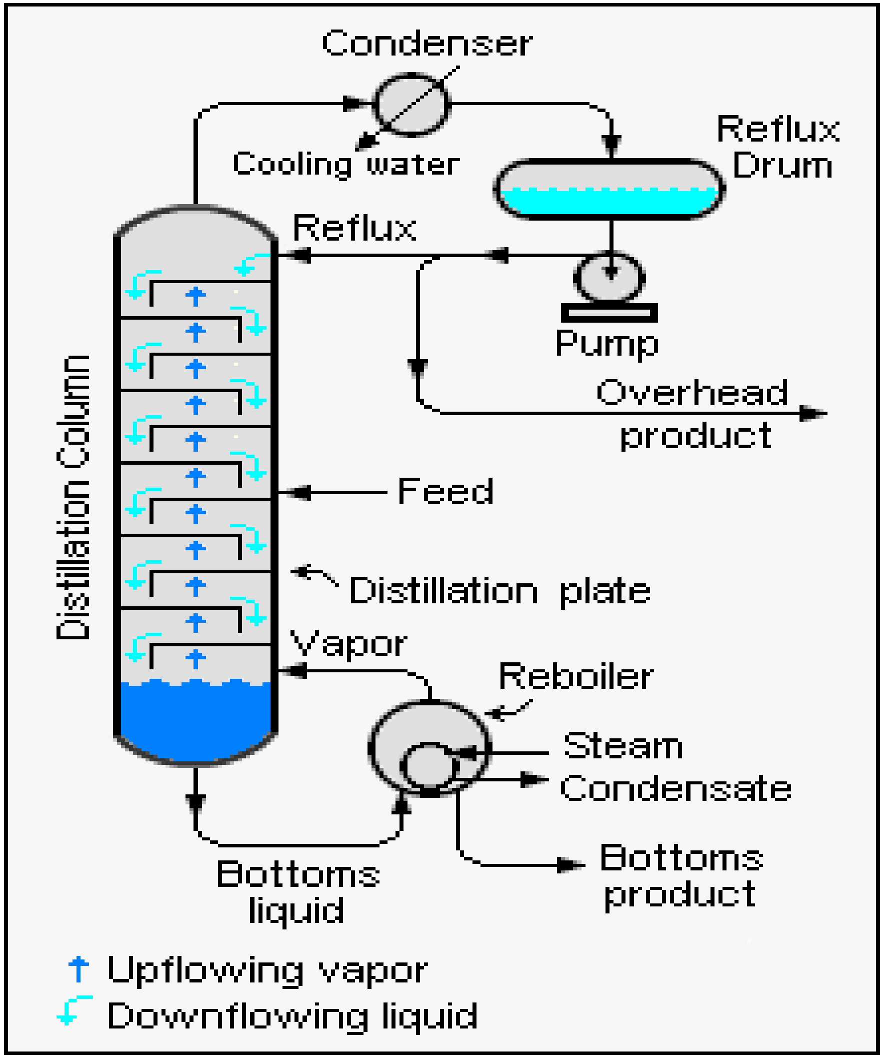


Figure 3: Schematic of distillation process

The Reality

- Calculated NH4Cl Desublimation for the column was 135°C
- Column top temperature was 115°C, therefore most NH4Cl formation occurred inside the column at the Heavy Gasoline section where operating temperature is 130°C.
- High corrosion rates experience in heavy gasoline draw-off accumulator tray of column and downstream heavy gasoline corrosion loop piping and equipment.
- Figure shows the extensive assets replacements (piping and equipment) that were executed in Feb 2016.

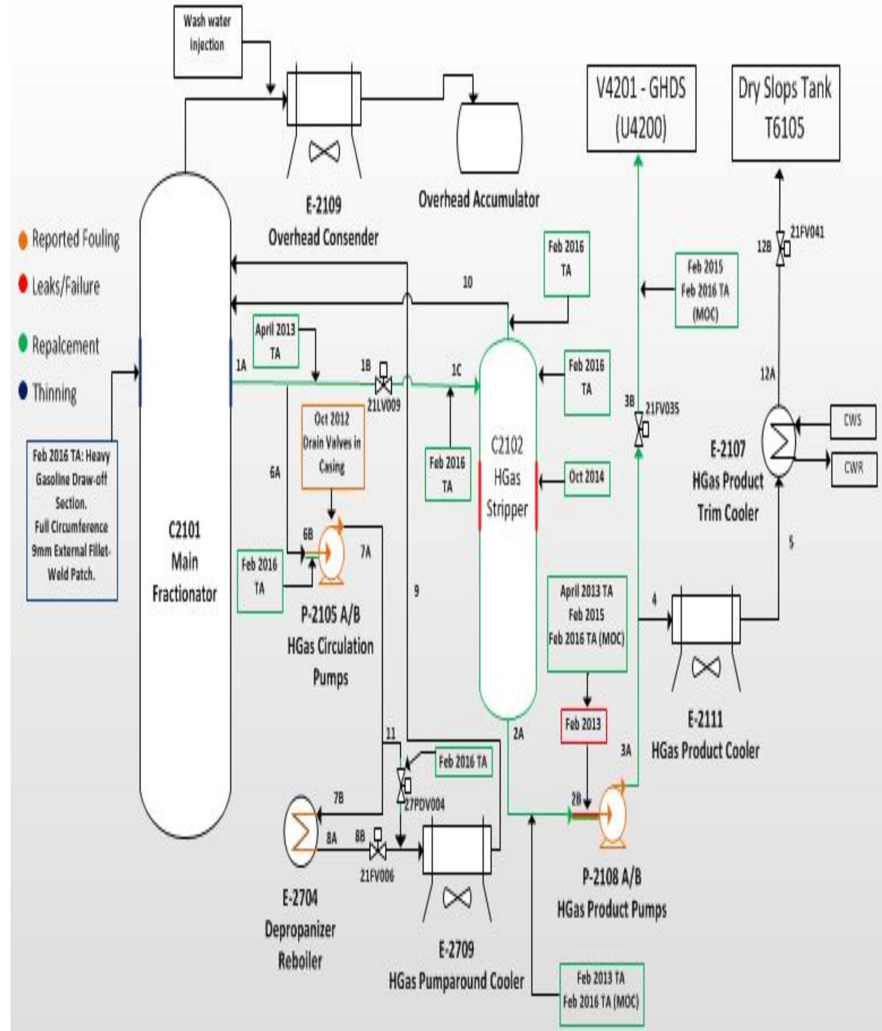


Figure 4: Heavy Gasoline Corrosion Loop

Heavy Gasoline Draw-off Accumulator Tray & Overhead Condenser Tubes

- Heavy Gasoline accumulator try inside column.
- Liquid-vapour Phase most affected of accumulator tray was most affected (1mm/yr corrosion rate).
- Even though the overhead condenser experienced pitting, the column overhead corrosion loop was less affected by NH4Cl corrosion when compared to the heavy gasoline corrosion loop.

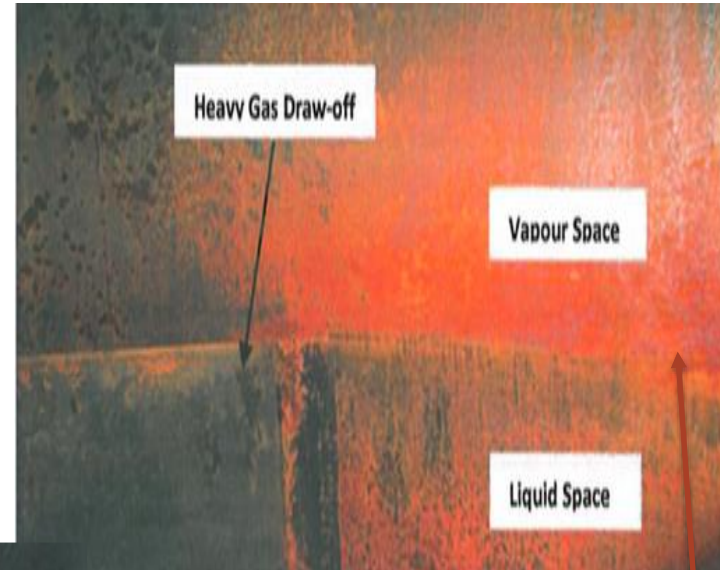


Figure 5: Column Heavy Gasoline draw-off

Heavy Gasoline Accumulator Tray and Draw-off Liquid-Vapour Interface

Figure 6: Column Overhead Condenser Tube

Column Overhead Condenser Outlet Pits

Heavy Gasoline Piping Circuit

- Table 1 shows the corrosion monitoring location (CML) corrosion rates and the projected remaining life assessment for the heavy gasoline piping circuit.
- The grey columns in the table represents the sections of the piping circuit that were replaced in early 2016.

Table 1: Shows the projected retirements dates for CMLs in SR-2100-HGA (end dates for retirement thickness).

Figure 1 Sketch Number	CML on Isometric Drawing	Nominal Thickness (mm)	Measure Min Thickness (mm) - December 2015	Max CR* (mm/yr) (Meridum - December 2015)	Max CR* CML Location	Remant Life to Retirement (yrs)	Projected End Date to 2.38mm Retirement Thickness (As of May 2016)
1a	1 & 2 (C2101 Outlet)	7.11	6.00 - CML 1	0.4	CML 2 - Bend		2024 (CML 1 - Outlet Pipe)
1b	3 to 10 (Control 21LV009 + Bypass)		4.99 - CML 5	0.58	CML 8 - Tee		2020 (CML 5 - Bend)
1c	11 & 12 (C2102 Inlet)	7.11	7.70 - CML 12	1.19	CML 12 - Inlet Pipe	4.5 - CML 12	2020 (CML 12 - Inlet Pipe)
6	13 to 20 (P-2105 A/B Inlet)	6.35	6.30 - CML 15	0.77	CML 15 - Bend	6.3 - CML 15	2021 (CML 15 - Bend)
7a	21 to 30 (P-2105 A/B Outlet)	6.35	6.50 - CML 21 7.20 - CML - 28	1.58 1.80	CML 21 - P2105 A Outlet CML 28 - Pipe	6.5 - CML 21 7.2 - CML 28	2018 (CML 21 & 28)
7b	77 to 80 (E-2704 Inlet)	6.35	6.19 - CML 77	0.58	CML 80 - Bend		2023 (CML 77 - Pipe)
2a	31 to 33 (C2102 Bottom Outlet)	6.02 (MOC - 4")	6.02 (Nominal)	0.25	CML 31 - Bend		2030 (CML 33 - Bend)
2b	34 to 41 (P-2108 A/B Suction)	7.11 (MOC - 6")	6.9 - CML 41	4.3	CML 41 - P-2108B Suction Pipe	1 - CML 41	2017 (CML 41 - P-2108B Suction Pipe)
3a	42 to 53 (P-2108 A/B Outlet)	5.49 (MOC - 3")	8.1 - CML 53	1.16	CML 53 - Pipe DS Valve	3.5 - CML 53	2018 (CML 53 - DS Valve)
3b	103 to 113 (Control Valve 21FV 035 & Bypass)	5.49	5.50 mm - CML 107 4.70 mm - CML 108	1.19 - CML 107 1.26 - CML 108	CML 107 - 3"x2" Reducer - 21FV035 CML 108 - 2"x3" Expander) - 21FV035	2.6 - CML 107 1.8 - CML 108	2018 (CML 107) - DS Reducer - 21FV035 2018 (CML 108) - DS Expander - 21FV035
4	54 & 55 (E-2111 Inlet)	5.49	5.39 - CML 54	0.87	CML 54 - Pipe		2019 (CML 54 - Pipe)
5	56 & 57 (E-2111 Outlet)	5.49	5.9 - CML 57	0.12	CML 57 - Pipe		2043 (CML 57 - Pipe)
9	58 to 76 (E-2709 Outlet to C2101 Inlet)	6.35	6.8 - CML 58 11.2 - CML 67	0.60 0.72	CML 58 - E2709 Outlet Pipe CML 67 - Expander DS 35FV022		2021 (CML 58 - Pipe) 2026 (CML 67 - 10"x12" Expander DS 35FV022)
8a	89 to 99 (Control Valve 24 FV 006 & Bypass)	6.35	6.5 - CML 96	0.58	CML 96 - Pipe		2023 (CML 96 - Pipe)
8b	100 to 102 (Outlet of E-2704)	6.35	9.2 - CML 100	0.33	CML 100 - Bend		2036 (CML 100 - Bend)
10	None (C2102 Vapour Line to C2101)	8.18	8.18 (Nominal)	None	None		None
11	81 to 88 (Control Valve 27 PDV 004 & Bypass	7.11	5.80 - CML 83 8.00 - CML 85	1.59 1.17	CML 85 - Pipe DS 27 PDV 004 CML 83 - Bend	3.5 - CML 85 2.9 - CML 83	2019 (CML 85 - Pipe DS 27 PDV 004) 2019 (CML 83 - Bend)
12a	117 - 123 (Outlet of E2107)	6.02	5.60 - CML 117 6.40 - CML 121 5.79 - CML 123	0.67 0.62 0.50	CML 117 - Bend CML 121 - Bend CML 123 - Pipe		2020 (CML 117 - Bend) 2022 (CML 121 - Bend) 2022 (CML 123 Pipe)
12b	124 - 132 (Control Valve 21FV 041 + Bypass)	6.02	9.30 - CML 130 6.00 - CML 129	0.41 0.33	CML 130 - Tee CML 129 - Pipe		2032 (CML 130 - Tee) 2026 (CML 129 Pipe)

Actual wall thickness data of the lines replaced in 2016 TA (rows highlighted in grey) was used to calculate remnant life and end dates for Table 1.

Solutions

- Install isolation valves for the main fractionation column condenser, E-2109/1-34, in 2019 TA to allow on the run (OTR) replacement of condenser tubes.
- Repair Main Fractionation Column C2101 – Internal Nickel Alloy (C276, Alloy 625) HVOF thermal spray/strip lining/weld cladding in 2019 TA.
- Sectional replacement of heavy gasoline piping circuit in higher nickel alloy metallurgy.

Appendix 4

Sensitisation and cracking of reactor vessel made of 1.4910

(Martin Hofmeister)

Cracking in material 1.4910

Relaxation cracking
or other embrittlement phenomena?

EFC WP15

Design data

- Material 1.4910 (X3CrNiMoN17-13-3)

C max. 0,04	**Cr** 16,00 – 18,00	**Ni** 12,00 – 14,00	**Mo** 2,00 – 3,00	**N** 0,10 – 0,18	**B** 0,0015 – 0,0050

- PWHT of vessel head: 1030°C, cooled in still air ?

- Working temperature 500°-530°C, design 590°C
- Temperature excursions possible up to design temperature
- Working pressure 2,5 barg (→low stress)

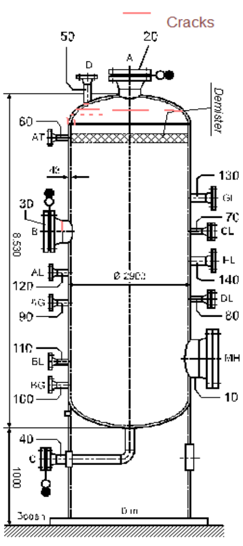
- Hydrocarbon vapours

- Vessel life until first cracks (detected) 11 years

Stress

- Low stress factor from internal pressure
- Historical external loads not known, „reserves“ from internal pressure
- Residual stresses from head forming, welding
- Secondary stresses from start-up procedures (high dT/dt) possible

Cracks – Location



Typical crack depth: 2-20mm, outer surface

Cracks evoluting during process

bayernoil

Folie 5
12.10.2016
M. Hofmeister

Datei:

bayernoil

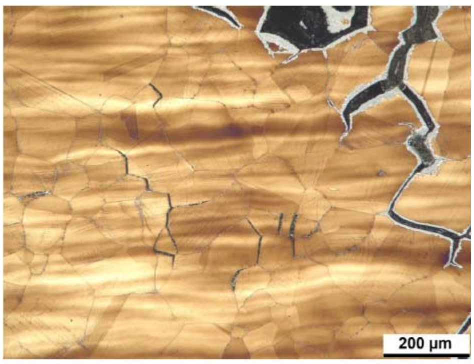


Abb. 8 600015591-M_064
S 1.1 - Ätzung: Lichtenegger & Bloech I
interkristalline Risse - mit Karbiden belegte Korngrenzen

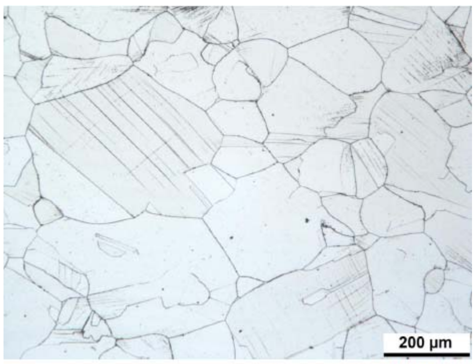
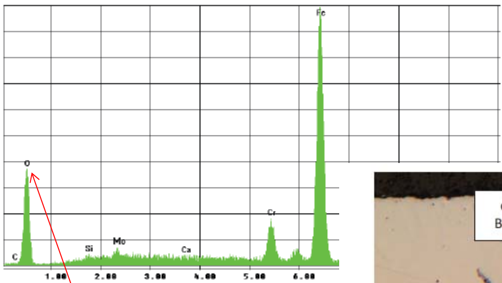


Abb. 9 600015591-M_077
S 1.1- Ätzung: V2A-Beize
Austenit mit Rekristallisationszwillingen und vielen Verformungslinien mit einer Korngröße nach ASTM E 112 von 1,5

Folie 6
12.10.2016
M. Hofmeister

Datei:

Crack in Knuckle Area of Vessel Head



Scale: Oxides

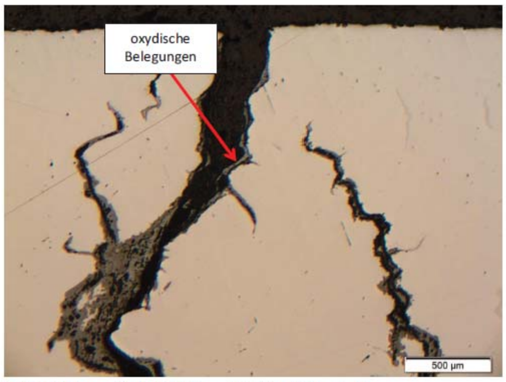


Bild 15: Metallographischer Schliff (ungeätzt): Riss Außenseite 50x

Secondary cracks

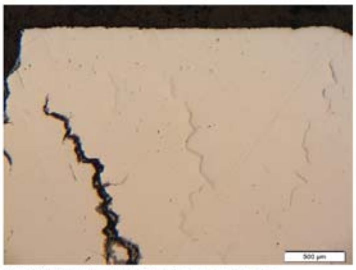


Bild 17: Metallographischer Schliff (ungeätzt): Nebenrisse Stelle 1, 50x

Bild 21: Metallographischer Schliff (präparativ geätzt): Gefüge Außenseite, 100x

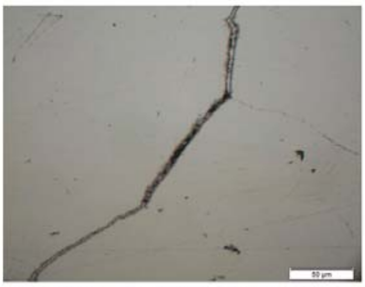


Bild 25: Metallographischer Schliff (präparativ geätzt): Belegungen der Korngrenzen, 500x

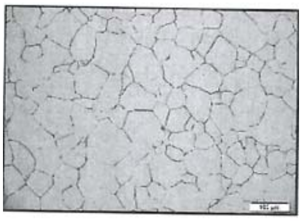
Stress relaxation cracking

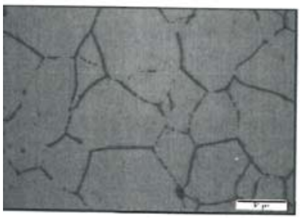
- ?

- 1.4910 largely free of precipitations and immune to stress relaxation cracking according to TNO report, typical time period until damage is 1-2 years
- solution annealing recommended if cold working exceeds 15% (relevant at knuckle area)
- working temperature to low for this damage mechanism (according to experience)
- carbide precipitation at grain boundaries, no signs of fine distribution of carbides inside grains giving extra hardness of grains and low strength at boundaries

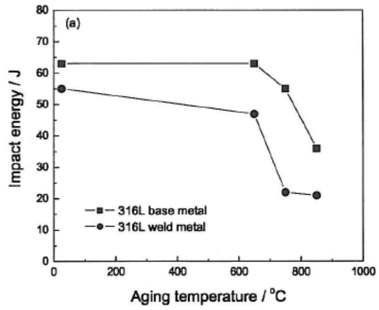
- Control of Relaxation Cracking in Austenitic High Temperature Components, H. van Wortel, NACE 07423

Sensitization





C-content 0,02-0,04%
Replicas 2011
Influence of coarse grain?



Effect of Aging on the Toughness of Austenitic and Duplex Stainless Steel Weldments

Omyma Hassan Ibrahim[1)†], Ibrahim Soliman Ibrahim[2)] and Tarek Ahmed Fouad Khalifa[3)]
1) Metallurgy Dept., Nuclear Research Centre, Atomic Energy Authority, Egypt
2) Nuclear Safety Centre, Atomic Energy Authority, Egypt
3) Shoubra Faculty of Engineering, Benha University, Egypt
[Manuscript received August 31, 2009, in revised form February 26, 2010]

CVN and Elongation (transvers)

- Head
  - Material certification 294 J 51%
  - After service 56-68 J 33%
- Shell
  - Material certification 294 J 51%
  - After service 213-232 J 41%
- Repair weld (HAZ in old shell)
  - After service und repair 136-164 J 43,5% (new plate)

- VdTÜV (1987): Minimum 80 J
- DIN EN 10028-7: Minimum 100 J (longitudinal) 60 J (transvers)
- Manufacturer: Typical > 300J

- Elongation: Minimum VdTÜV 1987: 35%; DIN EN 10028-7 40%

Appendix 5

Sour Water Corrosion

(Slawomir Kus)

Dr. Slawomir Kus
Sept-2016

SOUR WATER CORROSION - PREDICTION MODEL FOR ALKALINE SOUR WATER CORROSION: NEW INSIGHTS AND IMPROVED ACCURACY

EFC Working Party 15 - Corrosion in Refinery Industry

Honeywell

Agenda

- Ammonium bisulfide corrosion – general info
- Sour Water prediction model development – historical recap
  - Experimental setup
  - Phase I, II and III – main findings
- Sour Water Prediction Model
  - How does it work?
  - Calculation steps and generic prediction boundaries
  - References
- Next step – Prediction and IOW
- How properly set IOW limits using SW prediction model
- Multi-parametric prediction and IOW determination
- Summary and Q&A

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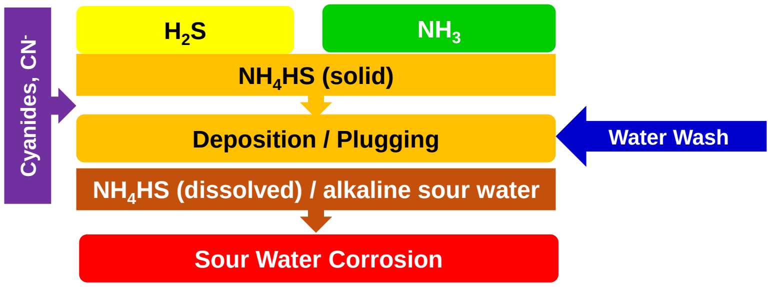
Ammonium bisulfide corrosion (NH_4HS)



- Affected areas:
  - REAC coolers
  - HP/LP separators
  - Coolers/heat exchangers and associated piping

Major parameters influencing on NH_4HS corrosion are:

- NH_4HS concentration
- Wall shear stress **(not velocity)**
- H_2S partial pressure
- NH_3 partial pressure
- Presence of cyanides (CN^-)

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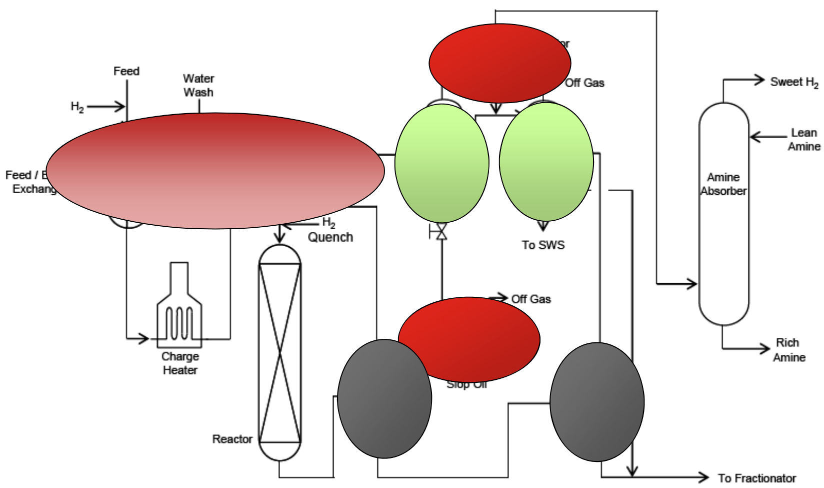
Problem Areas in Refinery Sour Water Handling



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SW Corrosion Model Development – Historical recap

- Absence of quantified data made SW corrosion prediction / prevention of failure difficult
- In 2000, Shell Global Solutions and other large operating companies commissioned Honeywell to run a Joint Industry Project designed to generate data for ammonium bisulfide corrosion
- Purpose: To create a definitive, engineering basis for dealing with sour water corrosion
  - Phase I (H_2S Dominated Regime): was completed in June 2003
  - Phase II (NH_3 Dominated Regime): was completed in March 2007
  - Phase III (Completing the picture - Cyanide corrosion): Program testing completed in Dec 2011 – Final report will be released in Feb 2012

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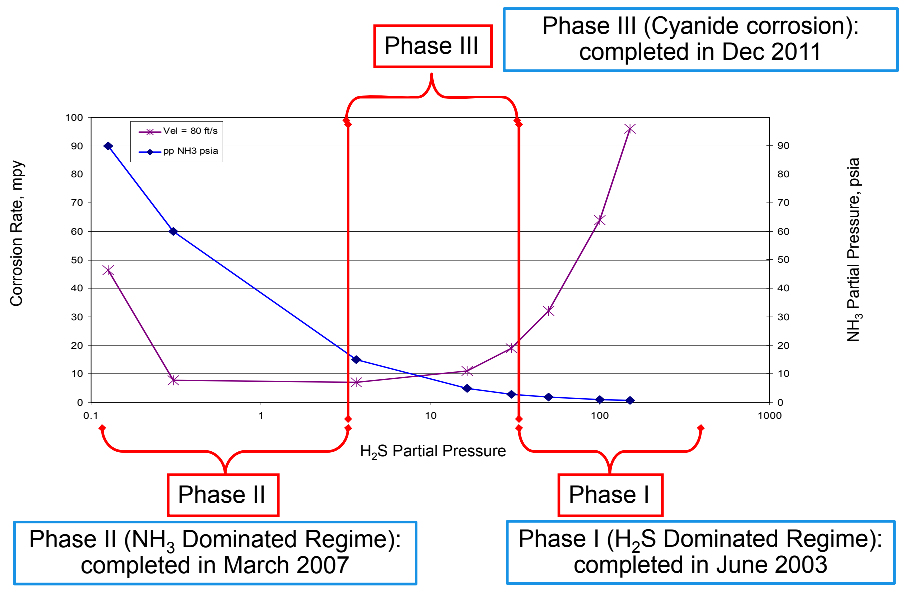
Sour Water Corrosion – "Tie-in plots"



316L SS, T = 130 F, NH_4HS Conc = 25 wt%

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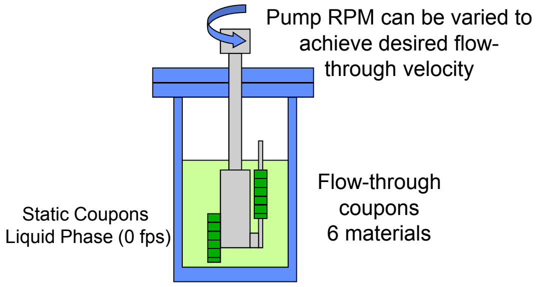
Sour Water corrosion tests – standard experimental setup



Sour water solution maintained at desired temperature and pressure

Tested materials

- Carbon steel
- 410 SS
- 304 SS
- 316 SS
- Alloy 2205
- Alloy 2507
- Alloy 400
- Alloy 600
- Alloy 625
- Alloy 20Cb-3
- Alloy 800
- Alloy 825
- Alloy C-276
- AL6XN (6% Mo)

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Sour Water Prediction Development – Phase I key findings

- Introduction of a new key parameter (H_2S partial pressure) for prediction of SW corrosion (not previously utilized)
- For the first time fluid dynamics (represented in terms of a WSS parameter) was identified as critical element in determination of SW corrosion:
  - Corrosion rate measured at any test velocity in the laboratory flow loop **does not** directly equate to the corrosion rate at the same velocity in a pipe or tube of different size.
  - WSS was chosen as the scalable parameter in order to make the appropriate comparison and to establish a linkage between the laboratory flow loop and actual service conditions.
- Defined the effect of hydrocarbons on the corrosivity of sour water
- Determined the impact of SW corrosion inhibitors (ammonium polysulfide and imidazoline-based compounds)

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Sour Water Prediction Development – Phase II key findings

- Determined behavior of materials in NH_3-dominated sour water environments — primarily high NH_3 partial pressure (in combination with very low H_2S partial pressure), temperature and free cyanide concentration
- Temperature was found to be a major factor in corrosion determination for many of the materials examined
  - effect of temperature on the thermodynamic equilibrium involving the solubility of H_2S and NH_3 resulting in higher H_2S partial pressures at the higher temperature
- First observation of the impact of cyanide additions
  - Corrosion rate increased on all materials, but varied in their extent depending on alloy and the conditions of NH_4HS concentration, WSS and NH_3 pp
- Determination of new iso-corrosion diagrams for different NH_3pp versus NH_4HS concentration and velocity

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Sour Water Prediction Development – Phase III key findings

- Phase III results were key to addressing the data gap and identifying a new corrosion regime in the intermediate H_2S pp region between the H_2S- and NH_3-dominated regions.
- Determined of new iso-corrosion diagrams for intermediate H_2Spp region.
- NH_4HS concentration, WSS, H_2S pp and free cyanide are the most significant parameters in predicting sour water corrosion.

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Sour Water Prediction Model: How does it work?

1. Calculate effective shear stress from process flow conditions
2. Convert the field shear stress into an equivalent lab flow loop velocity
3. Using lab velocity and NH_4HS concentration, predict corrosion rates for all materials using the respective isocorrosion diagrams developed using REAL DATA
4. Correct corrosion rates for the effect of NH_3 and H_2S partial pressure, temperature, hydrocarbon content, cyanides and chemical treatment based on REAL DATA

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Sour Water Corrosion Prediction with Predict-SW

- Papers presented at NACE Corrosion Conference
  - Paper Nos. 06576 and 06577)
    (one by Shell Global and the other by Flint Hills Resources)
  - Paper Nos. 09377 and 10349 (by Honeywell)
- These papers include case studies correlating predicted corrosion rates with measured rates
- Some case studies (BP) were presented publically at non-corrosion focused events (like Honeywell Users Group)
- Over 30 refinery operators and engineering companies are using latest SW Prediction model

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Next step in modelling – Prediction and IOW

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How Prediction Models can help establishing IOW?

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Prediction model and IOW Limit Scenarios

- **REAC Typical Operating/Design Conditions**
  - 4” Carbon Steel Pipe,
  - 0.125” Corrosion Allowance
  - Design Life: 15 Years (Max allowable CR = 8.7 mpy)
  - Vertical Flow
  - Pressure: 2000 psig
  - Temperature: 130 F
  - H_2S: 4 Mol%
  - NH_4HS: 3 Wt%
  - Sour Water Flow rate: 30 gpm
  - Vapor Flow rate 16 MMSCFD
  - Heavy HC Flow: 360 Bbls/day

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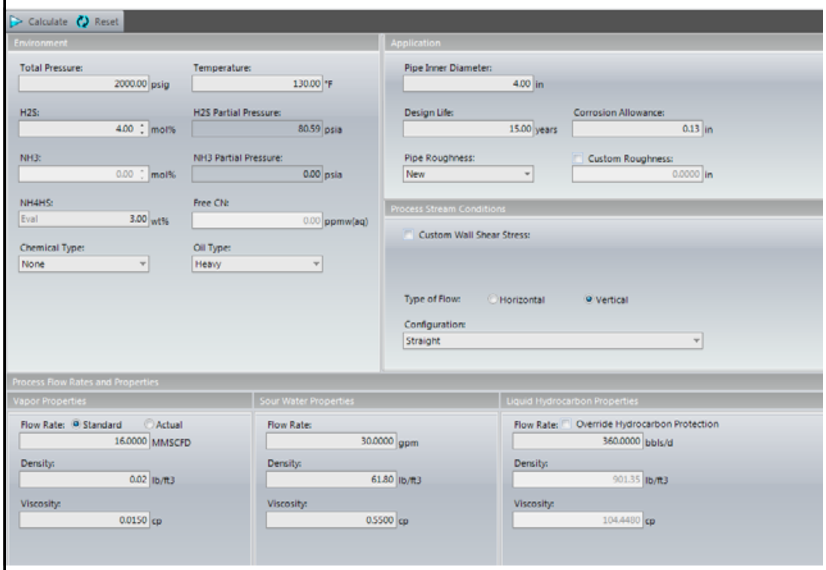
Enter Data in Predict-SW 3.0



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View Results

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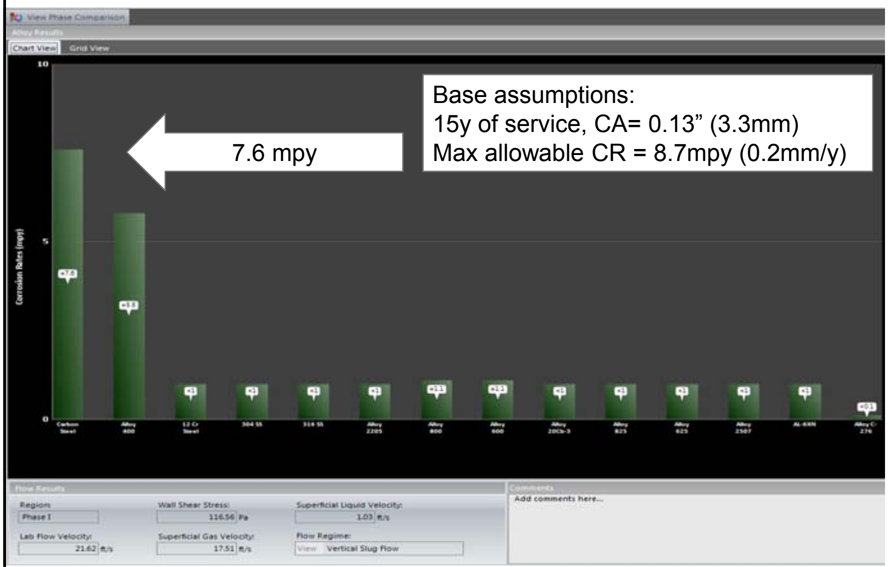

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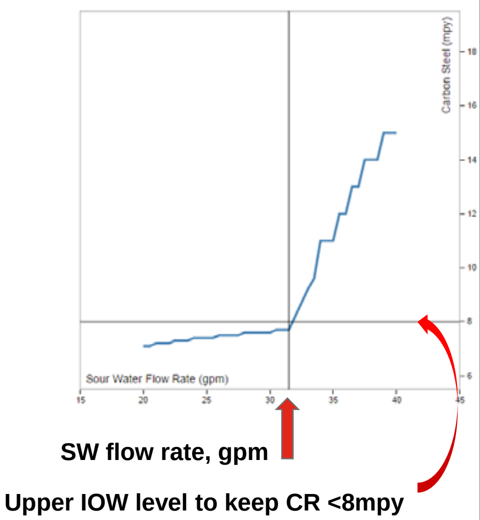
Sensitivity Analysis: Sour Water Flow Rate

Desired Maximum Allowable Corrosion Rate: 8 mpy

Maximum Allowable Sour Water Flowrate: 31.5 gpm

Based on sensitivity analysis below the SW flow of about 31gpm the corrosion will always be at safe level (<8mpy)



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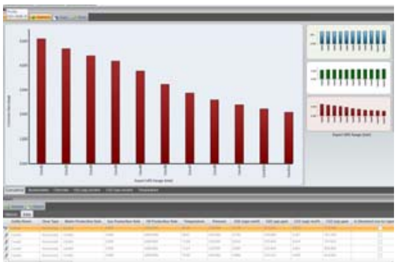
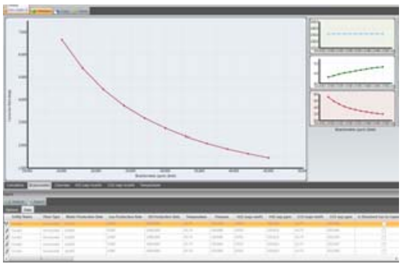
Enhancement of single point sensitivity analysis

- Multi-variable Sensitivity Analysis (Expert MPS)
  - Up to 5 variables
  - Min and Max values
  - 11 conditions per variable
  - Bar charts (6)
    - Cumulative
    - 1 per variable
  - **<u>Does not show the effects of Low/High combinations of variables</u>**





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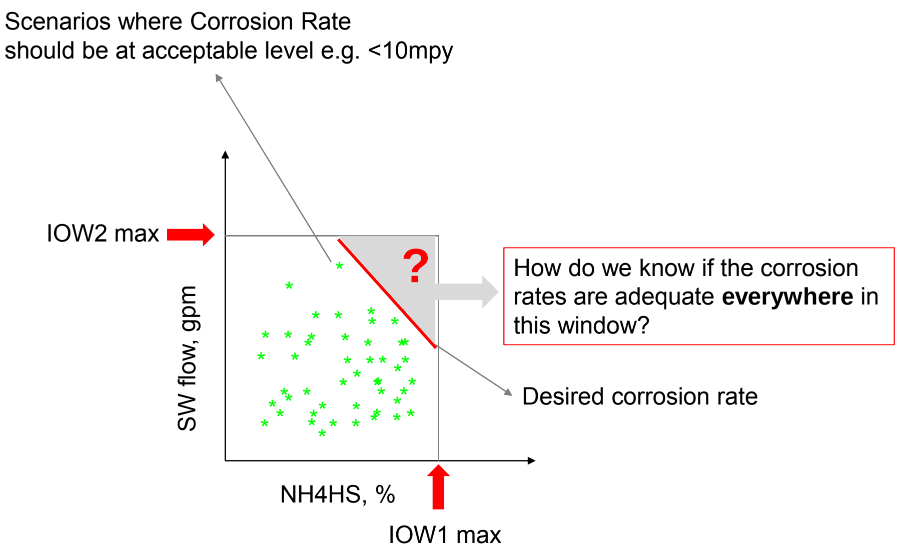
Corrosion models and IOWs



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Corrosion models and IOWs

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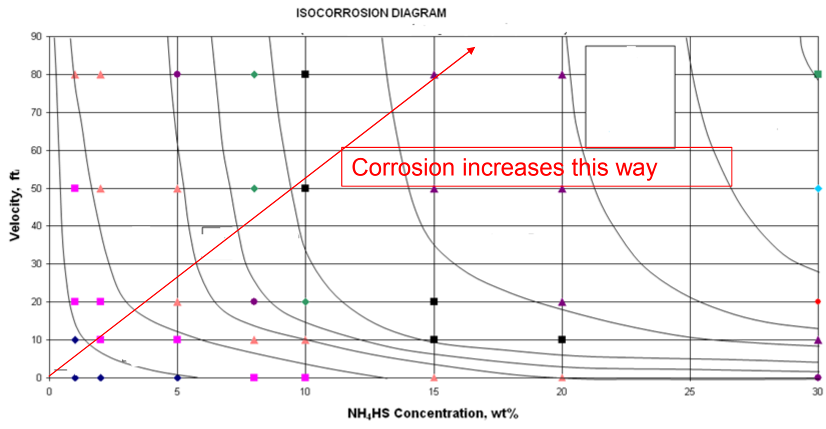

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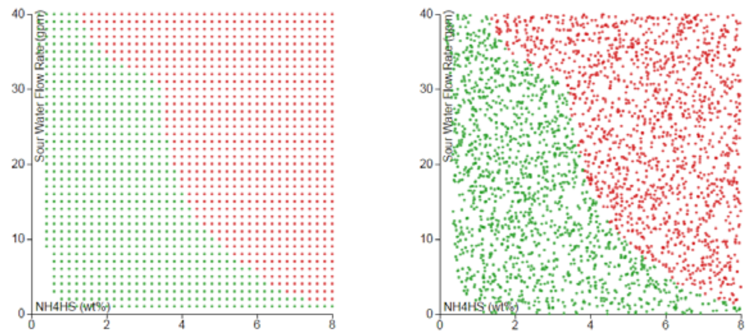
Move from a simple Grid to Uniformly Distributed Data



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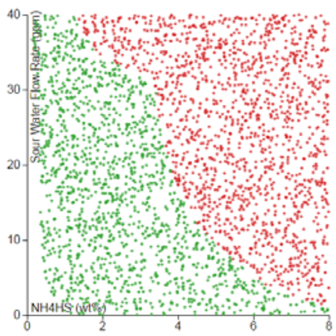
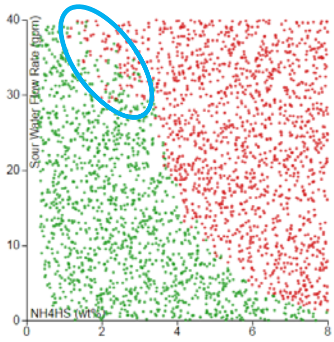
From Two to Three Uniformly Distributed Variables





Adding Liquid HC Flow Rate: 300-400 bbls/d

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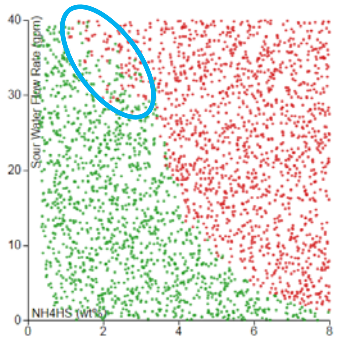
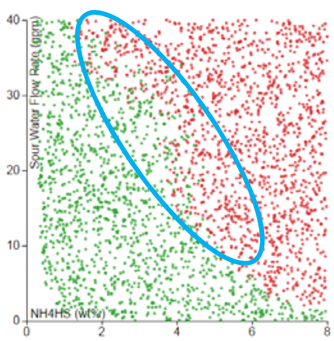
From Three to Four Uniformly Distributed Variables



Liquid HC Flow Rate: 300-400 bbls/d



Adding Vapor Flow Rate:10-20 MMSCFD

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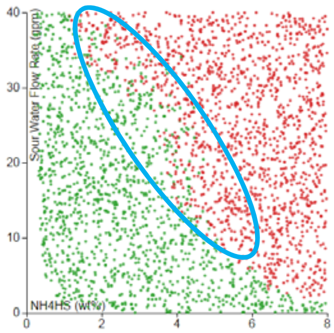
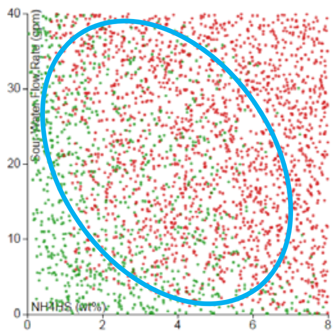
From Four to Five Uniformly Distributed Variables



Liquid HC Flow Rate: 300-400 bbls/d

Vapor Flow Rate:10-20 MMSCFD



Adding H_2S: 2-10 mol%

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Accurate Quantification of IOW Parameters

- Single IOW limits may not be enough to avoid all of the relevant high corrosion rate scenarios
- Simplified multi-variable sensitivity analyses may also not provide accurate answers on probable corrosion rates.
- In reality: essential to capture parametric interactions – see previous examples.
- Only model-based, multi parametric analysis can accurately estimate the safest limits for operating parameters

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Multi-parameters impact on IOWs

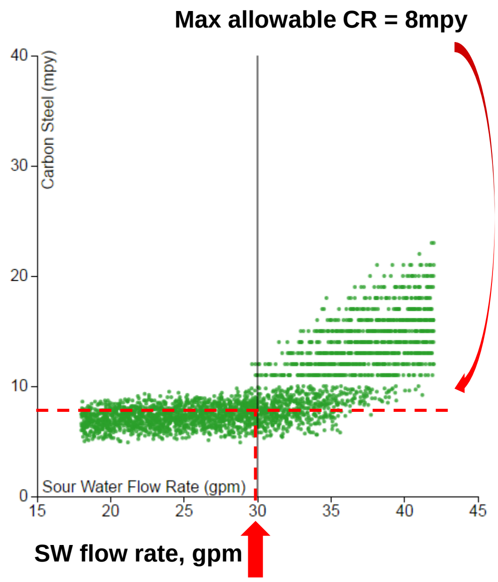
26

Sour Water Flow Rate (gpm)	Value
Minimum	15
Maximum	45
Operating Point	30
IOW Low	15
IOW High	32

Max allowable CR = 8mpy

Multi-parametric analysis includes:

- Temperature
- NH_4HS conc.
- H_2S, NH_3 conc.
- Vapour flow rate
- Liquid HC flow rate
- Total pressure



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Multi-parameters impact on IOWs

27

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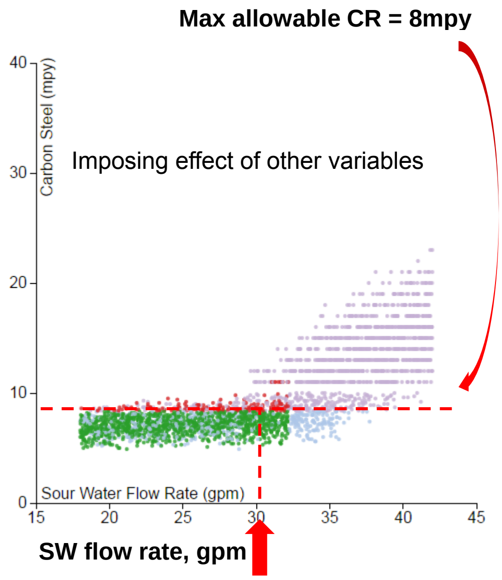
- H_2S, NH_3 conc.
- Vapour flow rate
- Liquid HC flow rate
- Total pressure



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Multi-parameters impact on IOWs

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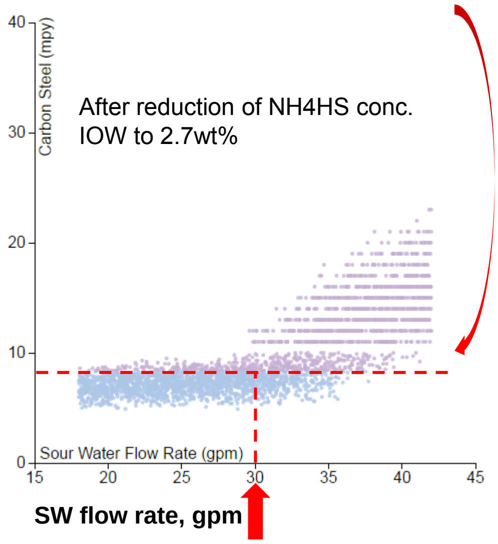

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Summary

- Available sour water prediction models provide the ability to accurately quantify corrosion, and gives refinery operators the ability to effectively mitigate failure risk and minimize cost
- Latest Sour Water Prediction Model:
  - Supports better inspection and maintenance planning, and optimal allocation of monitoring/equipment resources
  - Assists in identification of key monitoring locations for risk reduction
  - Facilitate selection of the right alloy or treatment choice: *A more expensive material is not always better*
  - Integrates with process data for better *process optimization and asset protection*
  - Helps mitigate and minimize risk of failure (as a component in any RBI program)
  - Provides tools for real-time corrosion prediction with on-line data-feedback from plant's DCS
- Accurate prediction model may reflect multi-parametric interactions of key-process parameters and allow proper determination and monitoring of respective IOWs

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Appendix 6

Monitoring

(David Lorkin)

permasense®

Experts in remote monitoring solutions

Making Integrity Monitoring Data *Valuable*: Advances in Signal Processing, Visualisation and Analysis

David Lorkin (David.Lorkin@permasense.com)

Installing permanently mounted sensors allows previously unobtainable *Quality* and *Frequency* of ultrasonic wall thickness measurements

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MEASUREMENT QUALITY

- Sensors are (semi) permanently installed allowing thickness measurements to be perfectly co-located, giving previously unobtainable repeatability and resolution to changes to the metal (corrosion or erosion) at the monitoring location

MEASUREMENT FREQUENCY

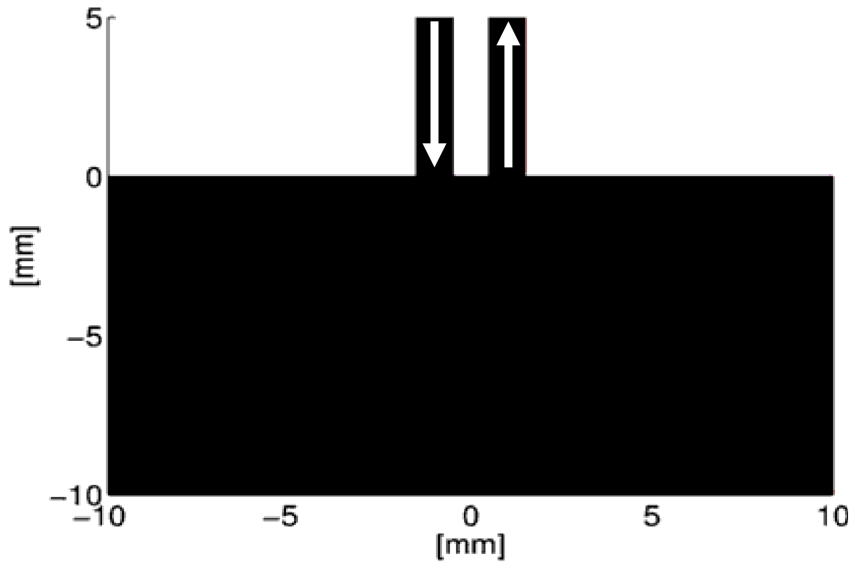
- wireless sensors deliver ~ x 1000 more data than manual inspection
- smaller changes in metal thickness are identified more quickly
- Additional data has no additional cost, once the system is installed

➢ **Corrosion and erosion events can be evaluated with unparalleled speed and resolution**

However...more data needs to be valuable!

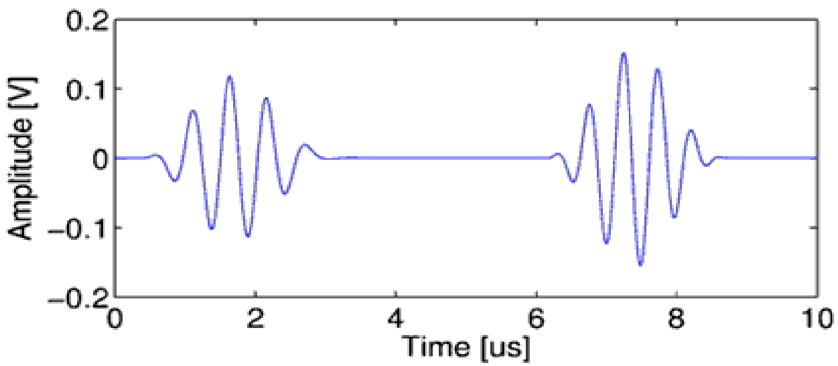
- More data doesn't necessarily mean better decisions.
- If data is not high quality, clearly displayed or easy to interpret, then the monitoring system is just an expense
- With high quality processing, visualisation and analysis – the monitoring data can transform your operations….

Ultrasonic Sensor Signal Acquisition



sensor

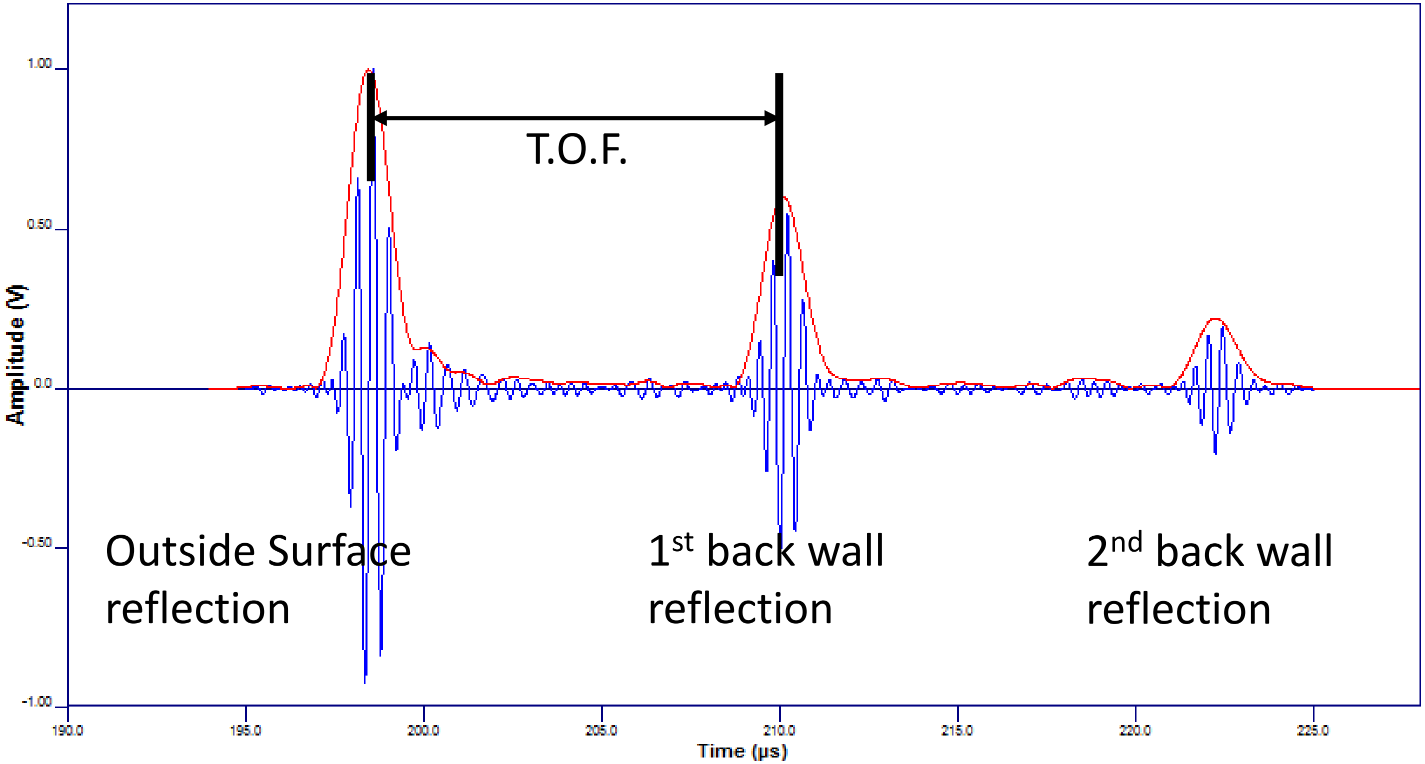
Pipe wall



Recorded ultrasonic signal

Calculating Thickness via Ultrasonic Signal

- The UT thickness measurement is calculated from finding the **time-of-flight (T.O.F.)** that it takes the sound wave to travel through the material. Knowing the velocity of the ultrasound in the material means the thickness can be accurately evaluated.



UT phenomena with rough internal surface morphology

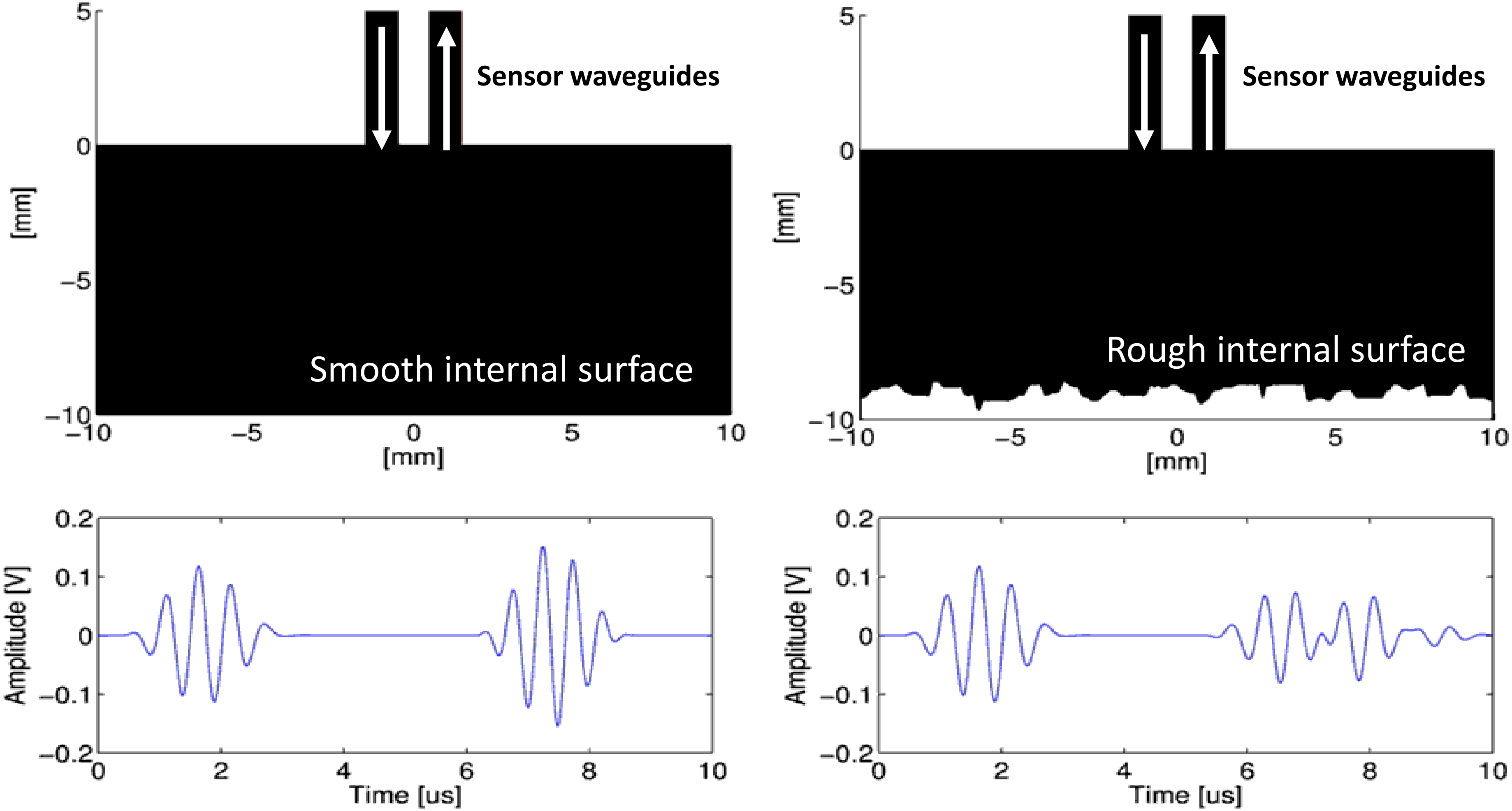
- The internal surface morphology (as seen by ultrasound) can affect the shape of the internal surface (backwall) ultrasonic reflection.

- Distortion of the backwall reflection, from rough internal surfaces, can affect the time of flight that is measured.

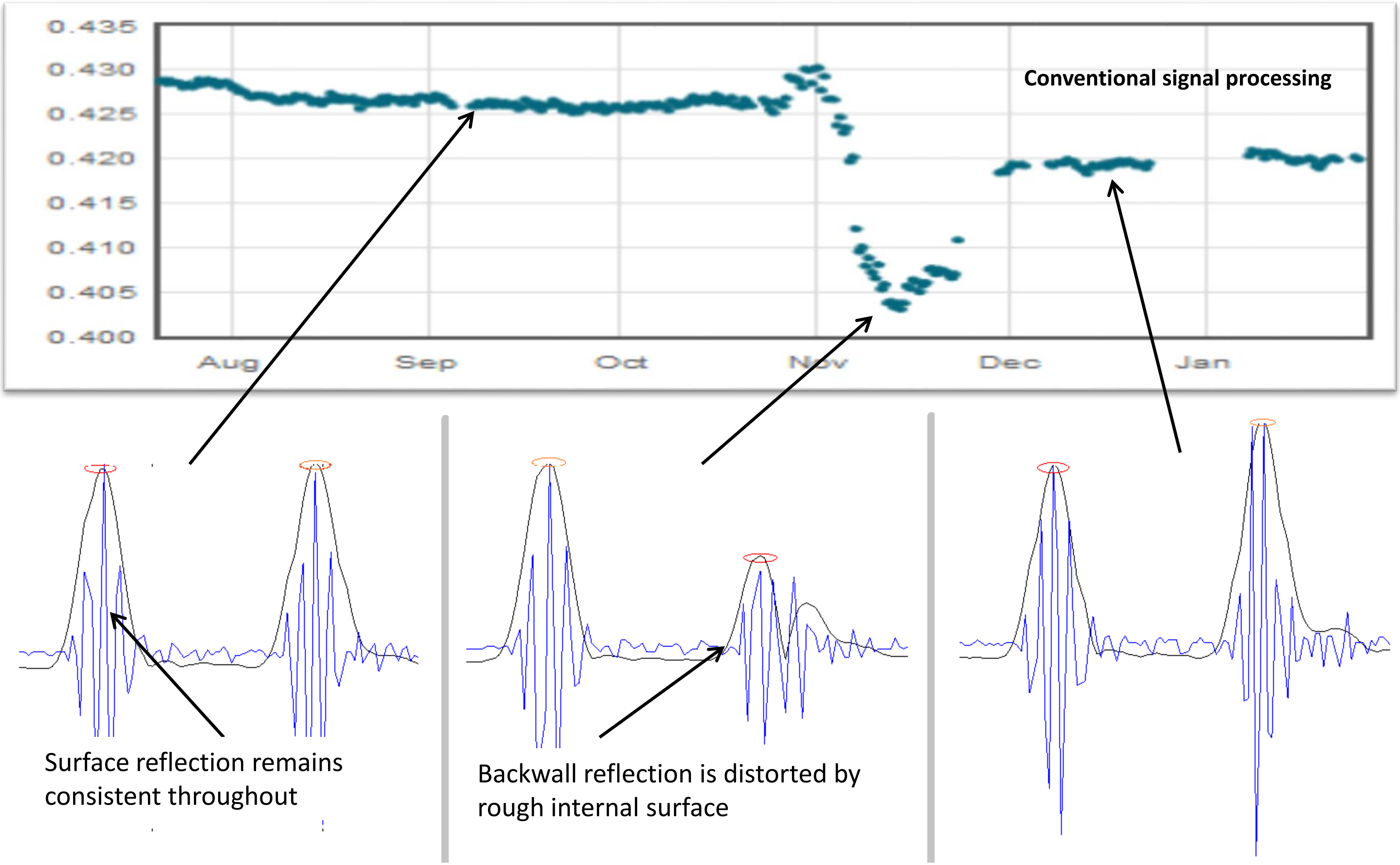
- This distortion affects the UT measurements and ultrasonic waveforms acquired by all ultrasonic wall thickness tools (including Permasense)

- **This is a physical ultrasonic effect – for any UT measurement** (BS EN 14127:2011, 8.1.1.2 states 'if the ... back-wall surface is rough the acoustic signal can be deformed, this can result in measurement error')

Rough internal surface morphology can distort the recorded ultrasonic signal



Changing internal morphology causes distortion in the recorded waveforms and creating confusing conventional UT measurements



The solution:
Adaptive Cross-Correlation (AXC) and Permasense Shape Indicator (PSI)

AXC measures wall thickness

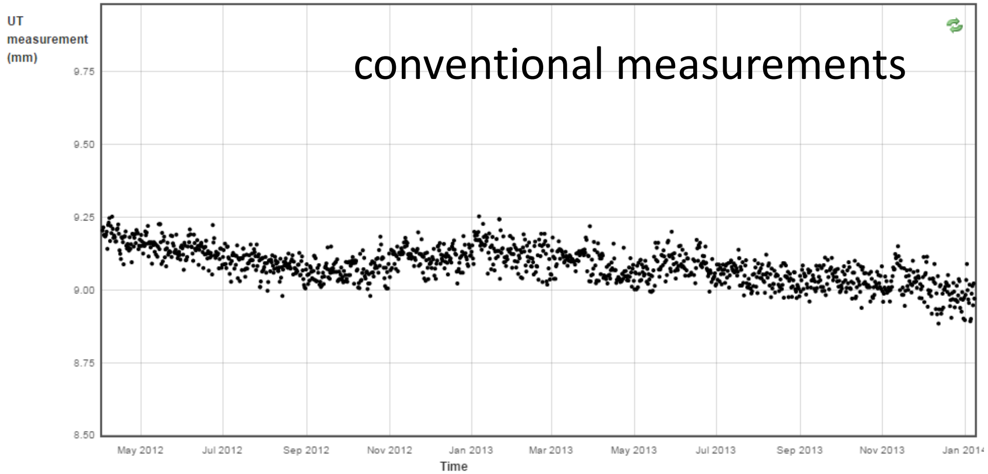
- Significantly less affected by internal surface morphology changes
  → Data interpretation resource requirement reduced
- Monitoring in many more locations will be possible with the same resources
- Reduced measurement scatter
  → Smaller corrosion rates can be detected/measured in shorter space of time

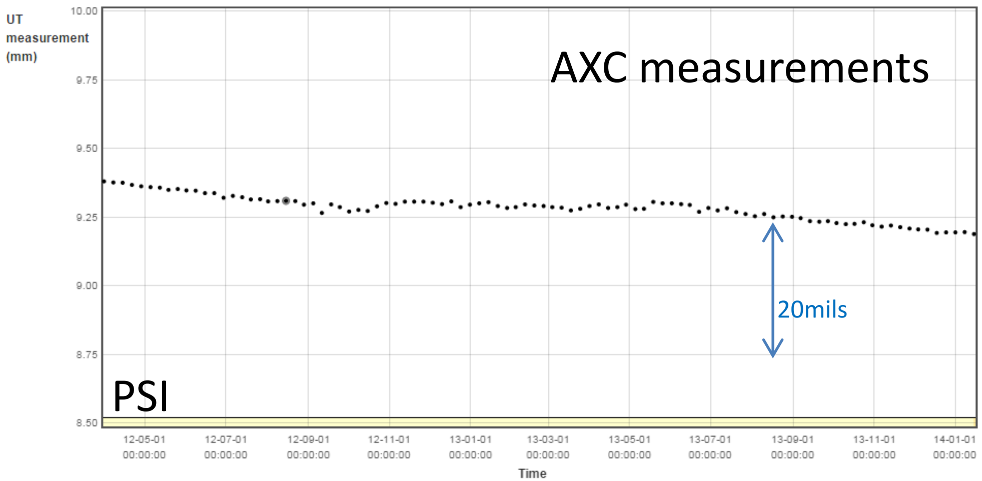
PSI detects changes in internal surface morphology

- Affords early detection of corrosion events causing internal morphology change prior to wall loss occurring
- Separates the effect of roughness and wall loss

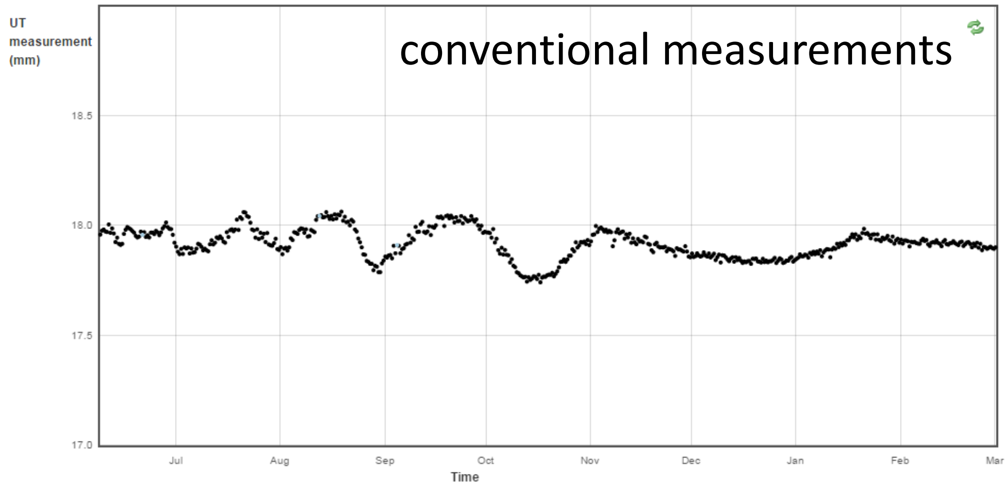
permasense

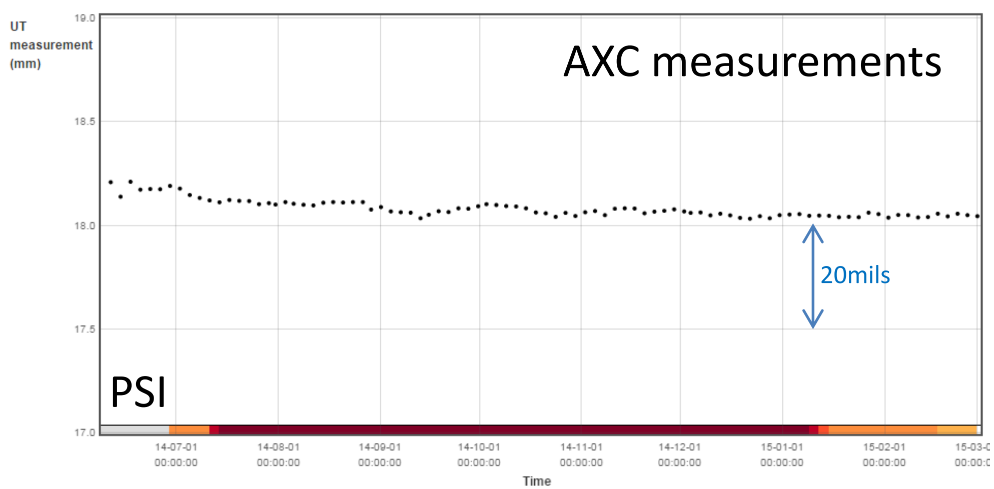
AXC has less noise than conventional processing: measure smaller rates with more confidence



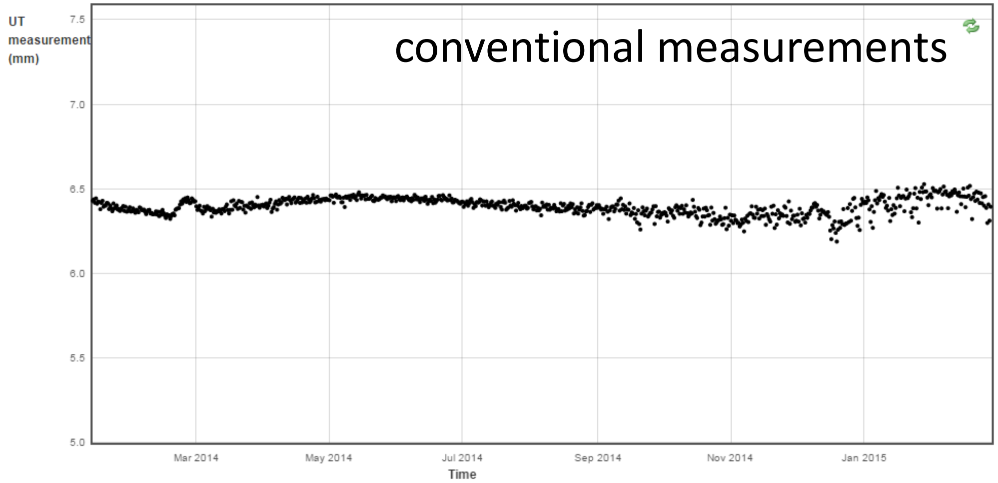


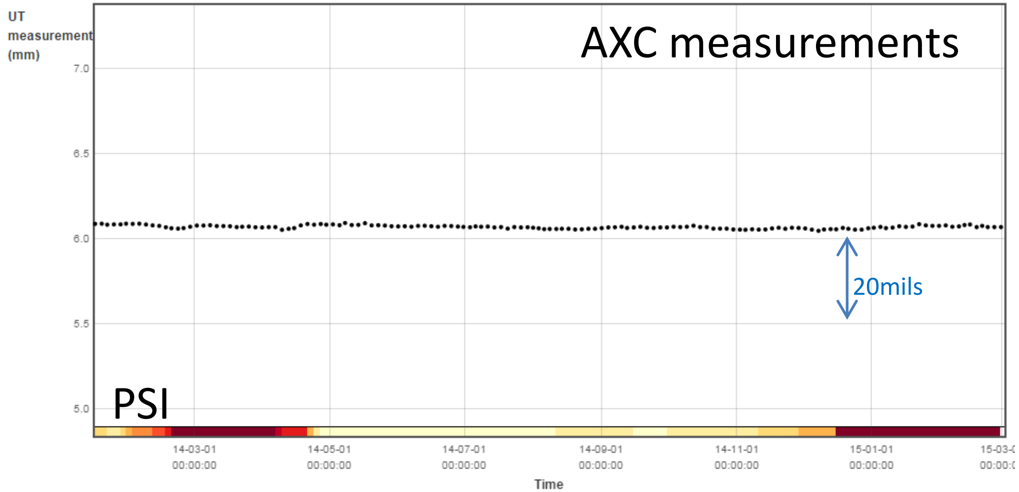
AXC is much less sensitive to internal roughness effects than conventional processing. PSI detects change in internal morphology



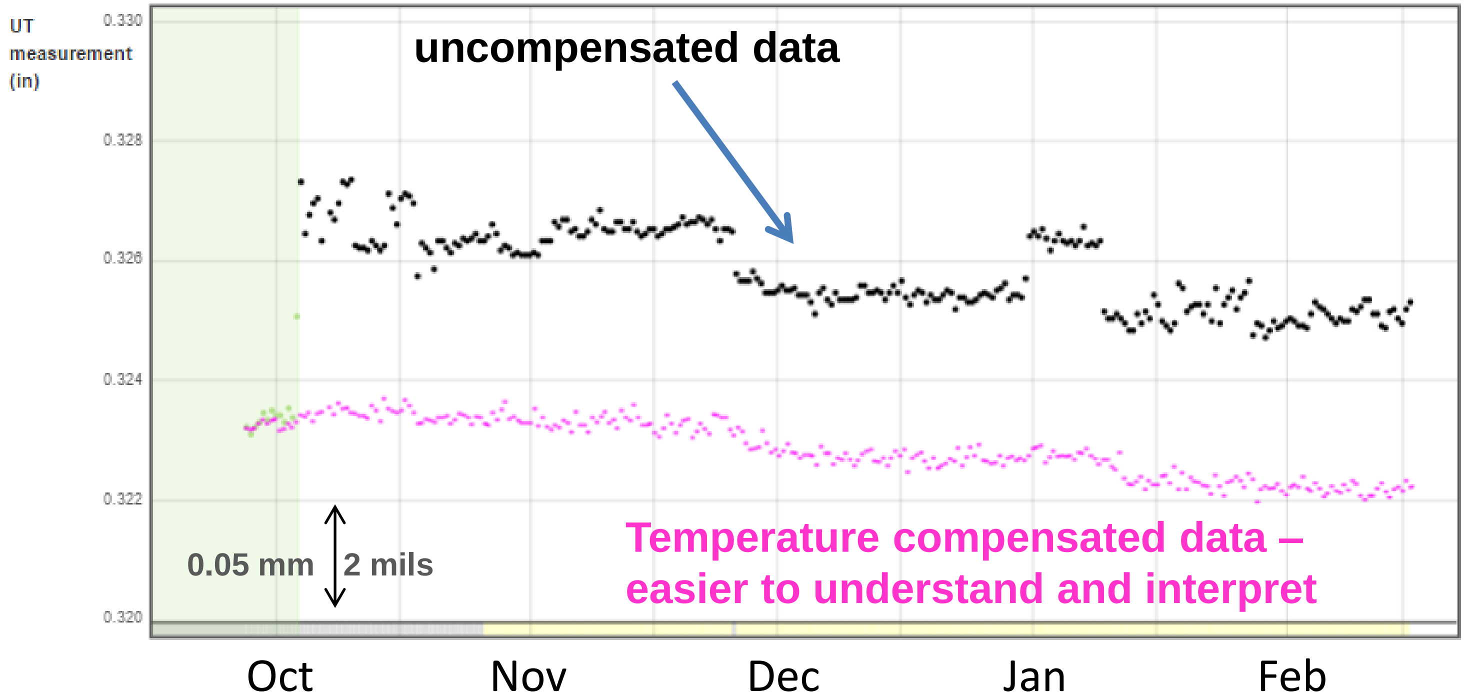


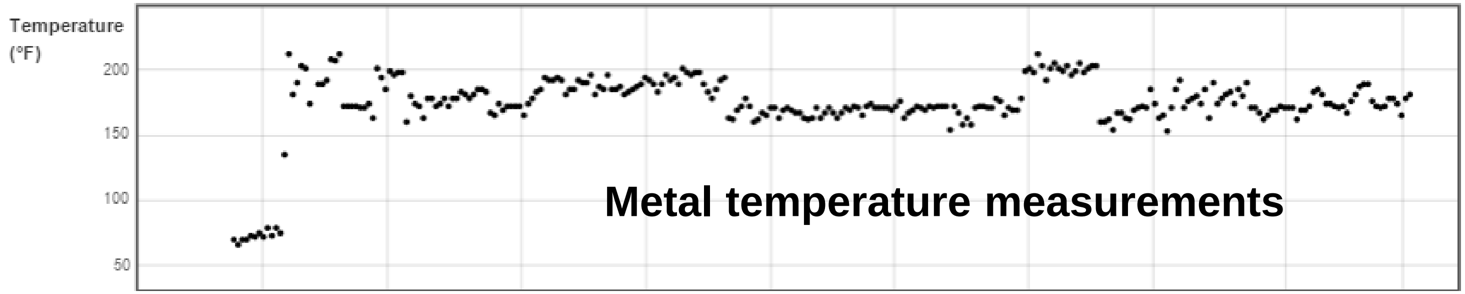
PSI detects changes in internal surface morphology



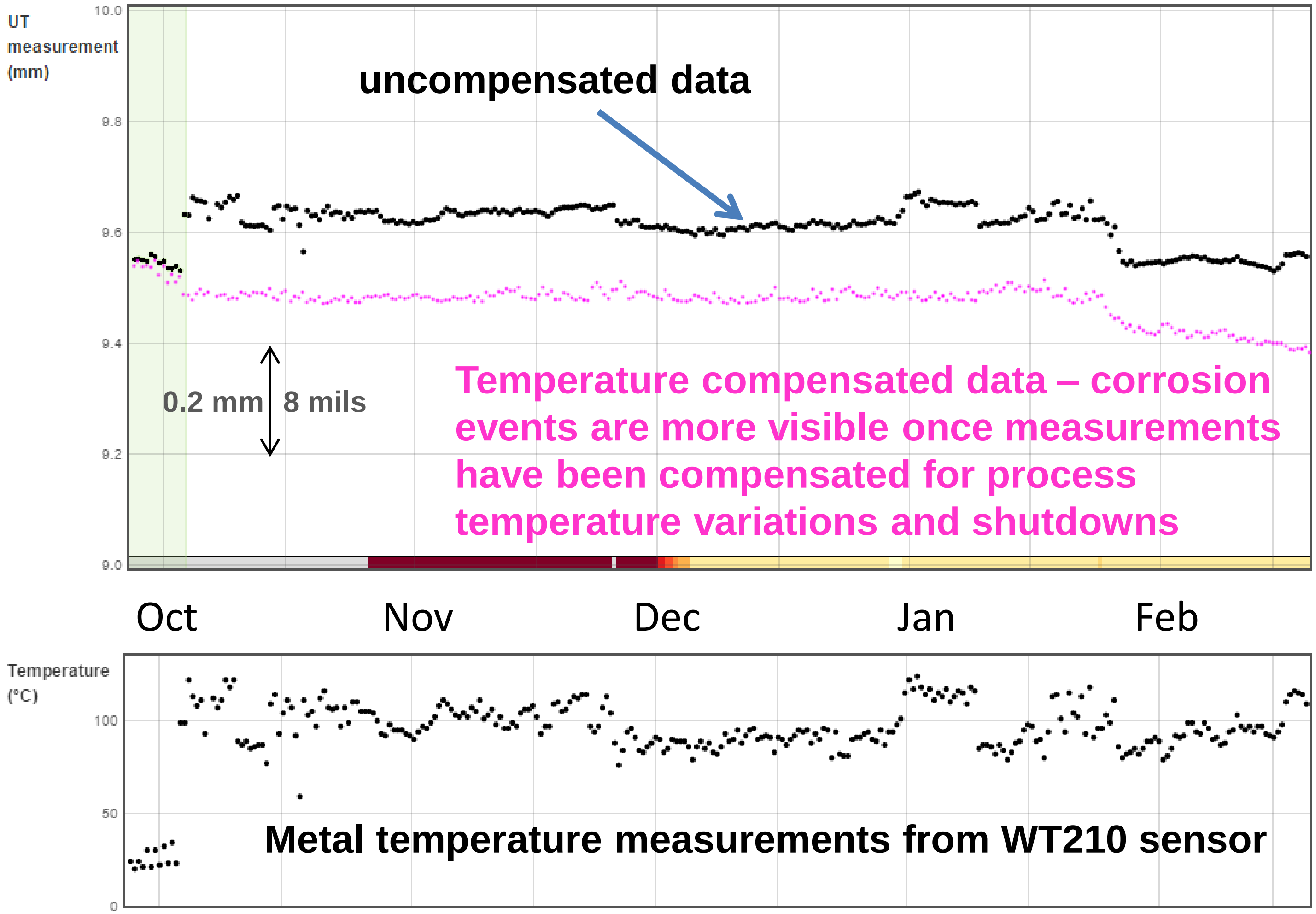


Temperature compensation further eases data interpretation



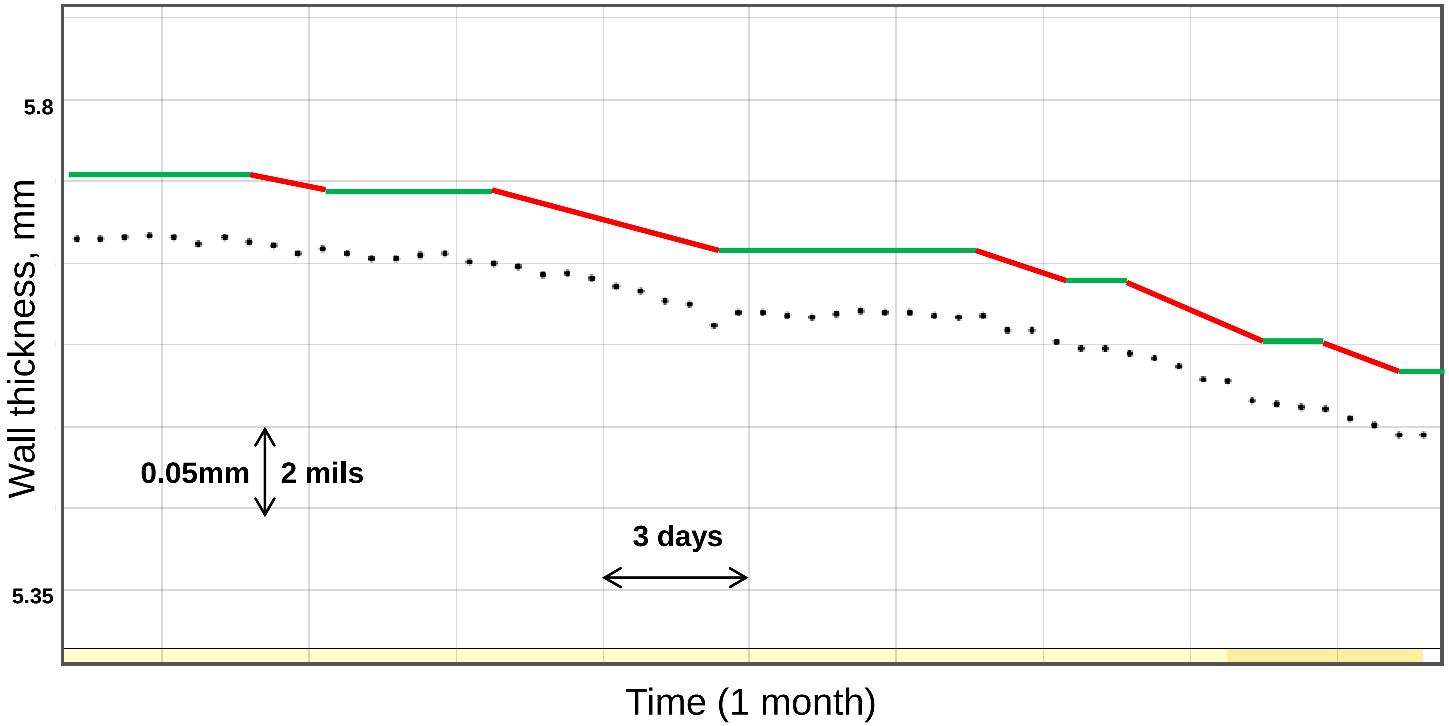


Temperature compensation - enhances event detection capability

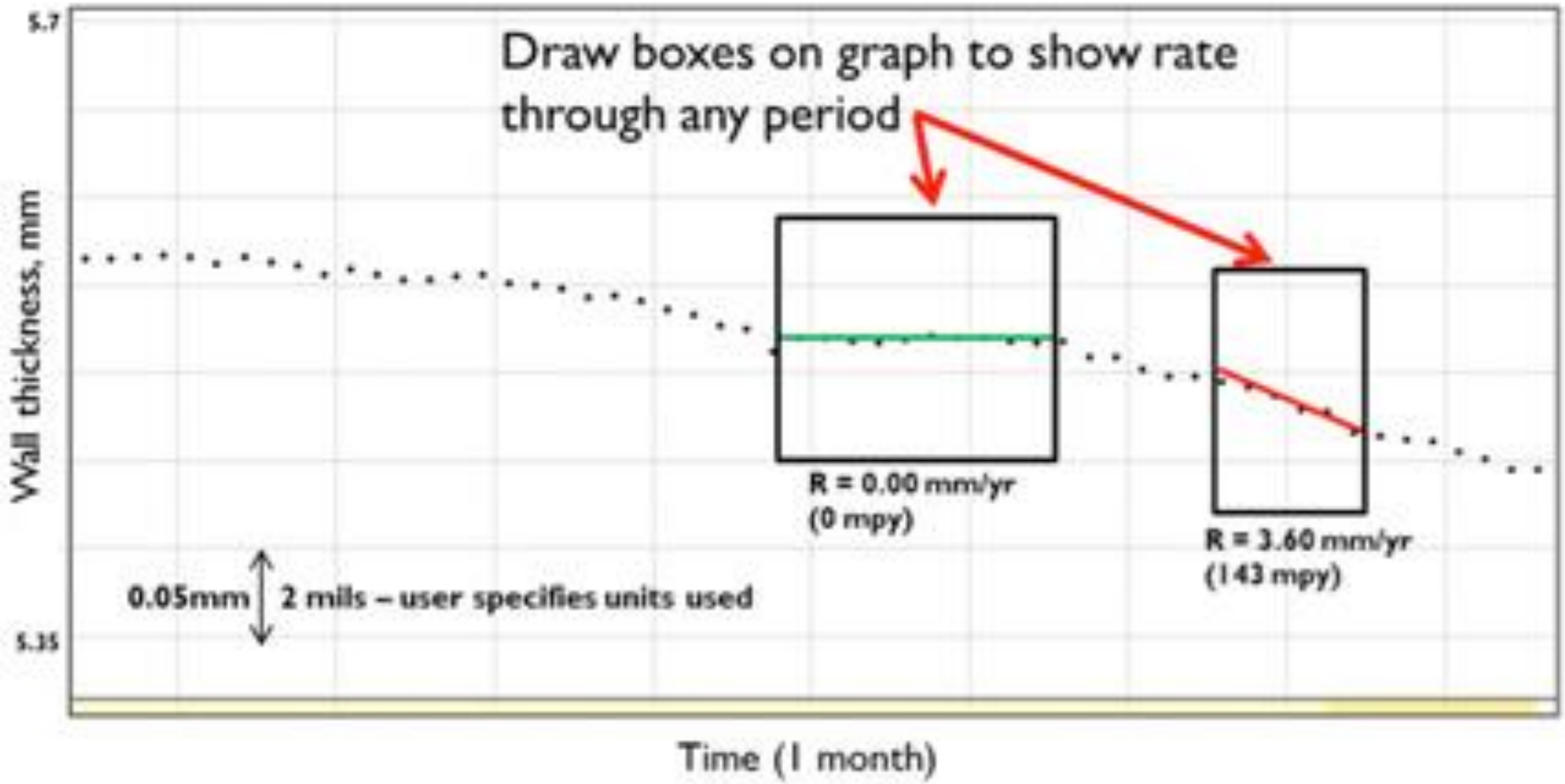


Quality and Frequency of data now affords even faster response to corrosion or erosion

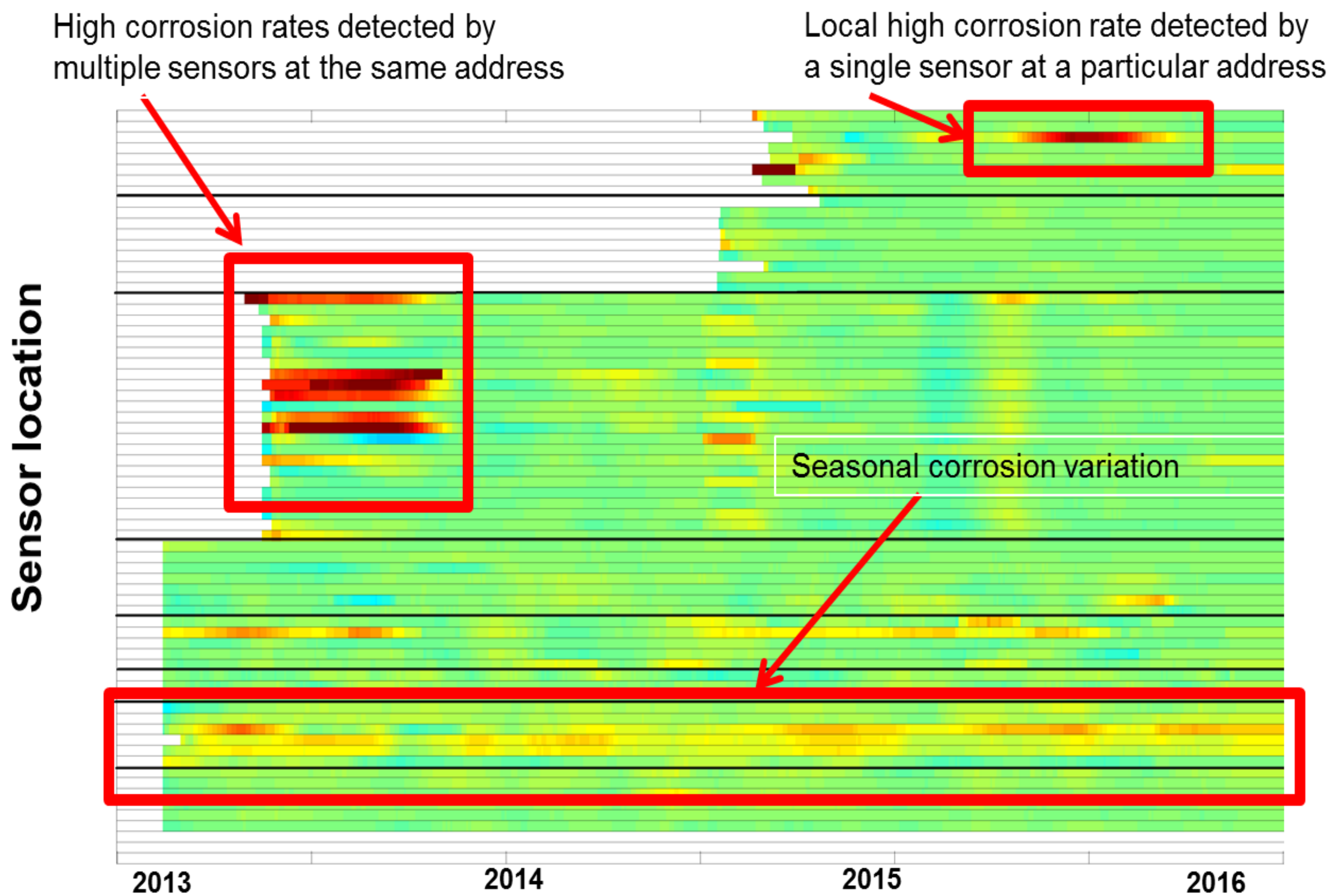
- Excellent measurement repeatability affords detection and measurement of ~10s microns / ~1 mils of metal wall loss
- This quality of data and regular data delivery (every 12 hours by default but configurable) affords detection of corrosion or erosion events within days (or quicker if loss rates are more severe)



Further Features in current software version



The future: Corrosion rate mapping for quick and easy interpretation



Summary

- Permanently installed wireless sensors can deliver a large quantity of wall thickness measurements
- This data needs signal processing and visualisation and analysis to be easy to interpret and valuable
  - AXC - to make the wall thickness measurements more accurate
  - PSI – to give an indication of when the internal surface is changing
  - Temperature compensation – to make the wall thickness measurements more accurate
- All of these features make the large quantity of data quick and easy to understand = better decisions = more value from the monitoring system
- We continue to develop better visualisation and analysis features

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Appendix 7

Report on the advancement of Task Force work on the revision of the EFC 46 guideline

(Johan van Roij)

Amine Corrosion Taskforce – Update of publication 46

Progress update & obtaining industry experience

EFC WP 13+15, Sep 2016

European Federation of Corrosion Publications
NUMBER 46

Amine unit corrosion in refineries

J. D. Harston and F. Ropital

- Taskforce amine corrosion (joined WP13, 15) founded in Sep 2015
- Main objectives to include in the update:
  - *Update the experience overview with new experience and experience from gas plants*
  - Include a literature survey
  - Restructure / format the results into "Corrosion Loops"
  - Include Integrity Operating windows
  - Include more extensive process and corrosion descriptions / backgrounds

Current amine corrosion Taskforce members:

Jean Kittel (IFPEN)
Slawomir Kus (Honeywell)
Sophie Loyan (Total)
Mabruk Suleiman (Takreer)
Michel Bonis (Total)
Steve Fenton (Protective Polymers Ltd)
Chris Claesen (NALCO Champion)
Johan van Roij (Shell)
➔ Additional members welcome

General contact address: EFC46-taskforce@efcweb.org

Or contact person: Johan van Roij (johan.vanroij@shell.com)

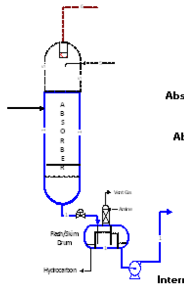
Update the experience overview with new experience and experience from gas plants:

- Questionnaire was developed (in form of Excel spreadsheet) to obtain experience.
- Questionnaire is presented (next slides) and issued today and will be send to contacts within WP13 and WP15 with request to forward it to relevant sites.
- Request is to fill in the questionnaire and send it back within 3 – 6 months time (to EFC46-taskforce@efcweb.org).
- Information can be provided **anonymously** (= without link to a company or site).
- Participants will be rewarded by receiving a summary of all the obtained experience (complete overview will be part of the updated publication 46).

Amine unit corrosion survey 2016 — EFC WP13-15 - Amine Corrosion Task Force

LOOP #1 - Absorber (1) - for multiple absorbers fill subsequent pages - up to 3 absorber units

This corrosion loop includes the lower part of the amine absorber the flash/skim drum, the cold part) of lean/rich amine exchangers and all associated piping from the absorber through the pressure letdown valve, the flash/skim drum, the absorber bottoms pump(s), to the amine lean/rich exchangers.



Absorber Out Temp, degC (OP)		(D)		Rich amine vel. (D) m/s
Absorber Pressure, barg (OP)		(D)		Rich amine vel.

lissolved acid gas composition (mol CO2 and mol H2S per mol amine)

	Absorber (bottom)	Pipe	Flash Drum	Pumps (casing)	Valves (body)
MOC:					
Other MOC (specify)					
Stress relieve and/or					
Heat tracing:					
Internal coating applied (specify					
Internal cladding or overlay welding applied (specify type):					
External coating applied (e.g. paint or thermal sprayed					
Integrity Operating Windows applied:					
Corrosion Monitoring and/or applied inspection techniques:					

Degradation history (Observed degradation mechanisms, corrosion rates, observed cracking

Other comments / remarks:

FORM TO BE FILLED SEPARATELY FOR EACH UNIT 6

Demo of the spreadsheet (Amine Unit Corrosion Survey_2016_rev7_protected)

Microsoft Excel
Worksheet

QUESTIONS?