Appendix 1

List of participants

Participants EFC WP15 meeting 11th September 2018 Krakow (Poland)

NAME	SURNAME	COMPANY	COUNTRY
Al Musharfy	Mohamed	ADNOC Refining Research Center	UNITED ARAB EMIRATES
Astudillo	Miguel	CEPSA	SPAIN
Baldy	Beata	Sandvik	POLAND
Bateman	Colin	IGS	USA
Bour Beucler	Valerie	Nalco Champion	FRANCE
Claesen	Chris J	Nalco Champion	BELGIUM
Dupoiron	François	Total Refining & Chemicals	FRANCE
Eidhagen	Josefin	Sandvik	SWEDEN
Escorza	Erick	Tenaris Dalmine	ITALY
Fullin	Luna	Tenaris Dalmine	ITALY
Gabetta	Giovanna	Eni	ITALY
Galliot	Ludovic	Total Refining & Chemicals	FRANCE
Genchev	Georgi	Salzgitter Mannesmann Forschung GmbH	GERMANY
Helle	Henk	CorrosionControl.Nu	NETHERLANDS
Houlle	Patrice	Patrice Houlle Corrosion Service - MTI	FRANCE
Höwing	Jonas	Sandvik	SWESEN
Kawakami	Tadashi	NSSMC Europe	GERMANY
Kraba	Lubomir	Borealis Polyolefine GmbH	AUSTRIA
Lorkin	David	Permasense Limited	UK
Lucci	Antonio	Rina Consulting	ITALY
Monnot	Martin	Industeel	FRANCE
Niemi	Raisa	Neste Jacobs Oy	FINLAND
Onodera	Yoichi	Mitsui & Co. Norway	NORWAY
Poldi	Matteo	Eni	ITALY
Ropital	François	IFP Energies nouvelles	FRANCE
Shiladitya	Paul	TWI	UK
Skolyszewska-Kühberger	Barbara	OMV Refining & Marketing GmbH	AUSTRIA
Sotoudeh	Kasra	TWI	UK
Spaghetti	Alessandra	Sandvik	ITALY
Suleiman	Mabruk	ADNOC Refining Research Center	UNITED ARAB EMIRATES
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Van Rodijnen	Fred	Oerlikon metco	GERMANY
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Vosecký	Martin	Nalco Champion	CZECH REPUBLIC
Wold	Kjell	Emerson	NORWAY
Young	aroline	TWI	UK
Zhang	Jian-Zhong	SABIC	UK
Zlatnik	Ivan	MITSUI & Co Deutschland	CZECH REPUBLIC

Appendix 2

EFC WP15 Activities

(Francois Ropital)

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 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

- Task Force on Corrosion in CO_2 Capture Storage (CCS) applications
- Task Force on atmospheric corrosion

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

http://efcweb.org/WP15.html

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 (2019 Seville-Spain, 2020 Brussels-Belgium, 2021 Budapest-Hungary)

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

Publications - Guidelines

Education – qualification – certification
List of "corrosion refinery" related courses on EFC website ?
Proposal of courses within Eurocorr ?

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)
13 April 2017	Frankfurt - Germany (EFC Head offices)
3 May 2018	Dalmine- Italy (Tenaris)

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

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

•EFC Guideline n° 46 on corrosion in amine units *A revision is in progress by a task force*

•Future publications – task forces : suggestions ?

- best practice guideline on corrosion in sea water cooling systems (joint document WP9 Marine Corrosion and WP15)
- best practice guideline to avoid and characterize stress relaxation cracking ?

Best practice guideline on corrosion in sea water heat exchangers systems

What content ?

- Main seawater heat exchangers systems
- Seawater environment: aggressivity, living organisms, deposits and scale formation
- Different forms of corrosion in sea water heat exchangers systems (galvanic, crevice,…)
- Biocide treatments (chlorination) – how they can affect the corrosion resistance
- Corrosion tests
- Materials used
  - Carbon steels and coating
  - Stainless steels
  - Nickel base alloy
  - Copper alloys
  - Aluminium, Titanium alloys
  - Plastics and composites
- Others ?

WP15 Corrosion Atlas Web page

http://efcweb.org/Working+Parties_Task+Forces/WP+Corrosion+in+Refinery+and+Petrochemistry+Industry/WP+15+Refinery+Corrosion+Atlas.html

Information :
Future conferences related to refinery corrosion

24-29 March 2019
CORROSION 2019 NACE Conf Nashville Tennessee

8-13 September 2019
EUROCORR 2019 Seville Spain

6-10 September 2020
EUROCORR 2020 Brussels Belgium

19-23 September 2021
EUROCORR 2021 Budapest Hungary

Look at the Website:
http://efcweb.org/Events/Congresses_+Symposia+and+Exhibitions-p-4.html

Appendix 3

New developments on a new methodology to characterize Stress Relaxation Cracking

(Martin Monnot)

Advancement of our development of a methodology to characterize Stress Relaxing Cracking on welded stainless steels

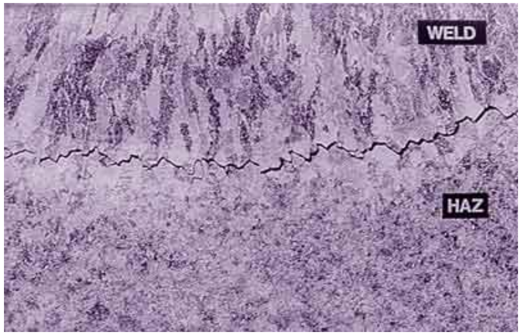
03/05/2018

Martin MONNOT

Introduction

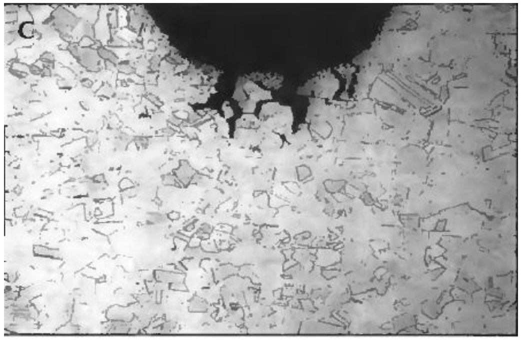
- Reheat Cracking and Stress Relaxation Cracking are damage mechanisms occurring in equipments from many industries combining both high stresses and high temperatures.

- **Reheat Cracking (RHC)** is commonly associated to Carbon & CrMo(V) steels, and is generally a problem occurring during fabrication (PWHT after welding) of the equipment



Example of a RHC Crack in a HAZ of a CrMoV low alloy steel

- **Stress Relaxation Cracking (SRC)** is commonly associated to austenitic alloys, such as 300 series and nickel base alloys occurring during service of the equipments.



Example of a SRC Crack in a HAZ of a 347H austenitic stainless steel

Introduction

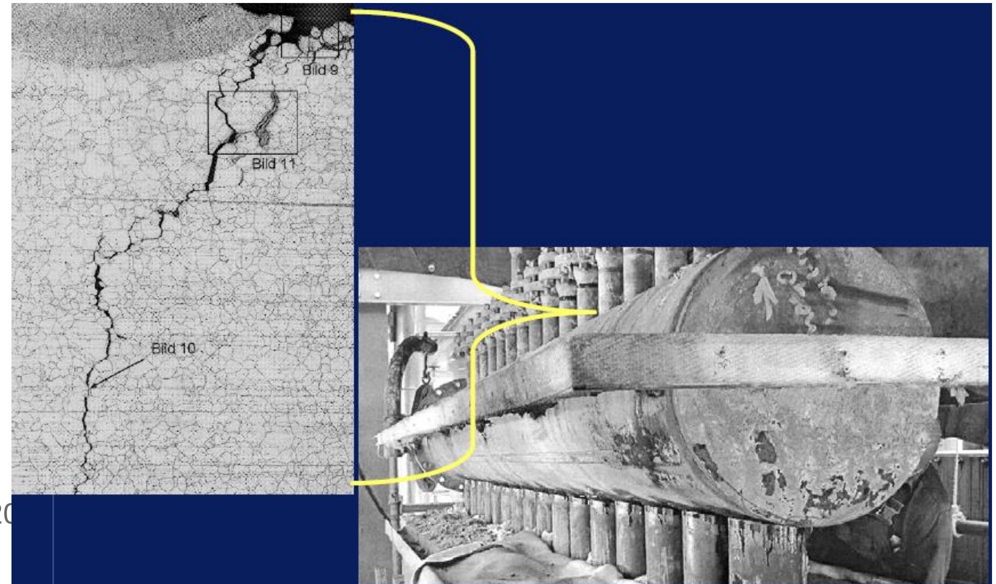
- **SRC is complex to mitigate:**
  - Almost all austenitic microstructures with improved creep resistance are susceptible, but with variations in the intensity,

    Ex : 3xxH stainless steels

    AISI 347H > AISI 321H > AISI 304H > AISI 316H

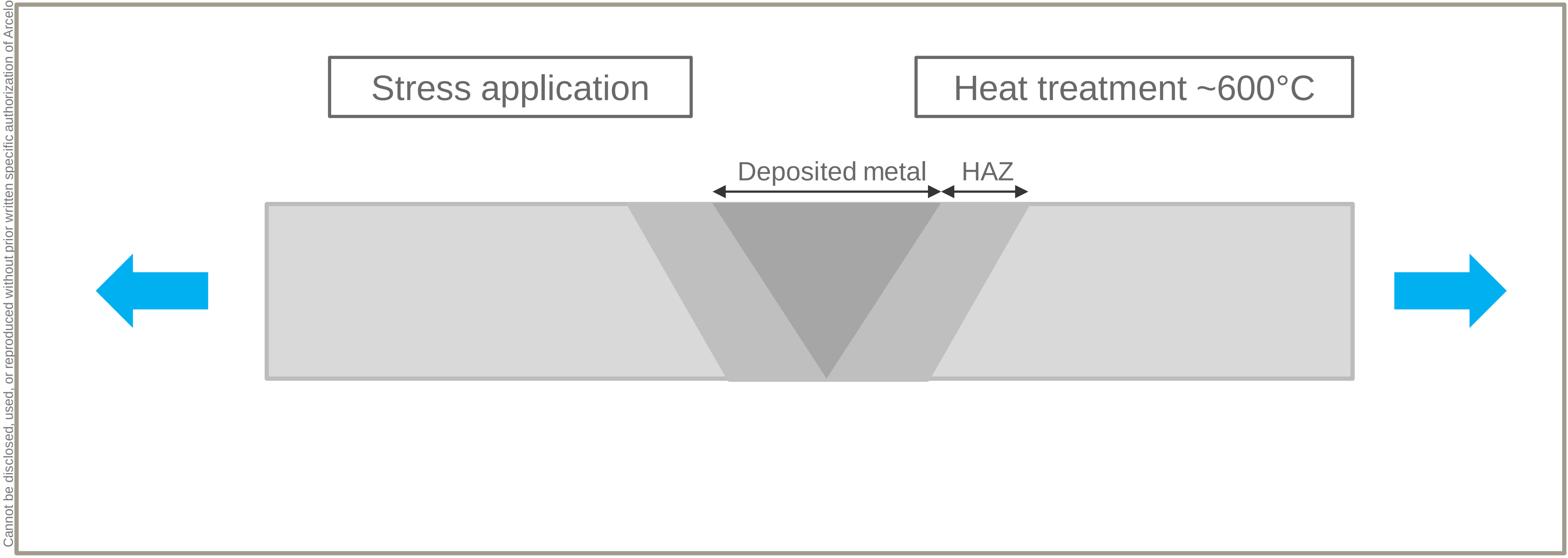
    +Nb +Ti

Grade	Cr	Ni	Nb	N	C
347H	18	9	0.3	0.07	<0.08
304H	18	8	-	-	<0.07



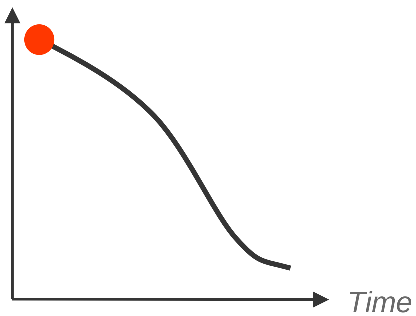
Example of a SRC failure of a 800H header (2005)

Stress Relaxation Cracking phenomena

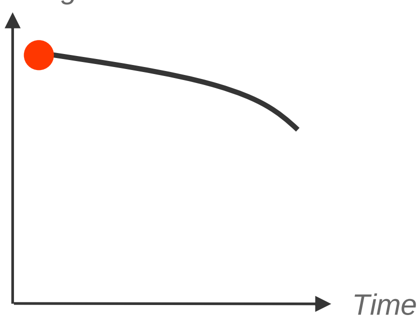


Stress Relaxation Cracking phenomena

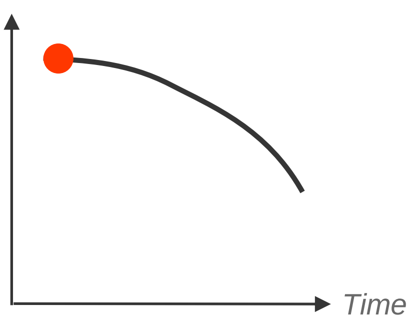
Intergranular hardness

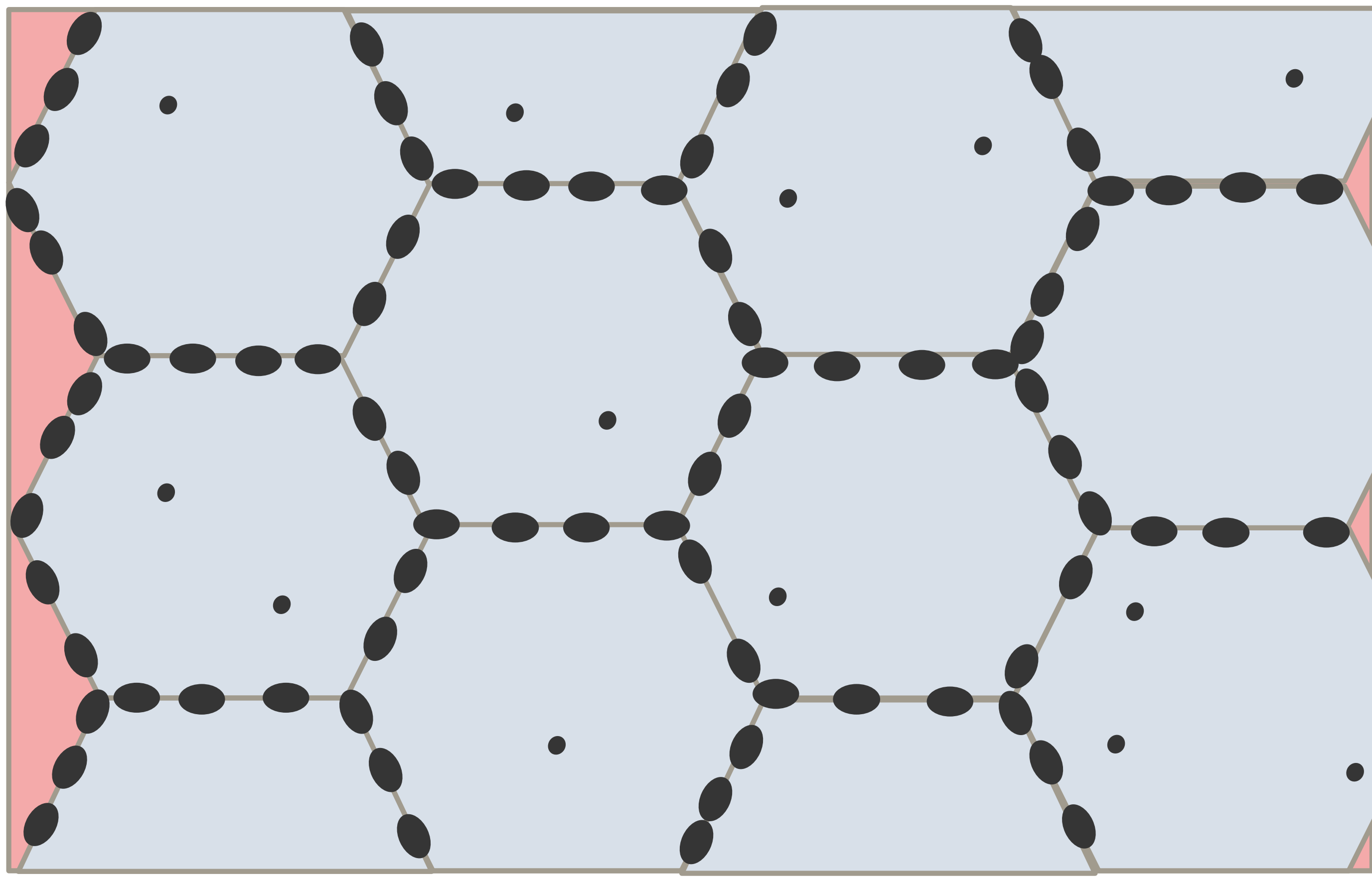


Intragranular hardness



Stress





Difficulties to simulate SRC

- SRC comes from difference of hardness between grains and grain boundaries
  - Difference of precipitation kinetics between grains and grain boundaries
- Cracks is initiated by stress relaxation present in the HAZ

➢ Crack initiation is the combination of two metallurgical state occurring with two different kinetics

- SRC cases is service are observed for applications at 600°C-725°C after two years
  - Increase of testing temperature may change cracking mechanism (*creep*)
  - Duration should not exceed one month

Loading on U-bend set-up

ArcelorMittal

- The stress level in plastic domain is assumed sufficient to initiate SRC
- Sensitization have been performed before bending to begin ageing with advanced precipitation state

Transversal weld

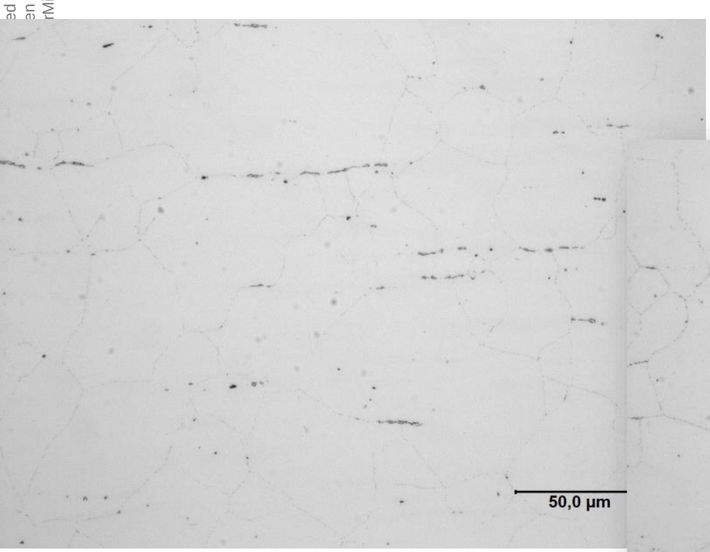
- ✓ U-bend set-up : strain around 10%
- ✓ Specimen 15 mm thick
- ✓ Welding process : SAW and GMAW through all thickness
- ✓ Sensitization before straining
- ✓ Test duration of 720 hours

Determination of sensitization conditions

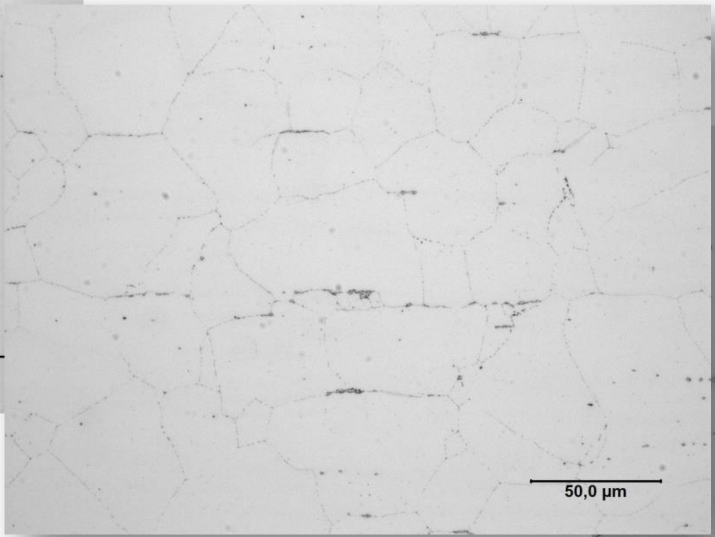
- The purpose of sensitization is to begin carbides precipitation in order to match precipitation state with stress relaxation kinetics to initiate cracks

- Sensitized state should present precipitation in grain boundaries only : difference of hardness between grains and grain boundaries.

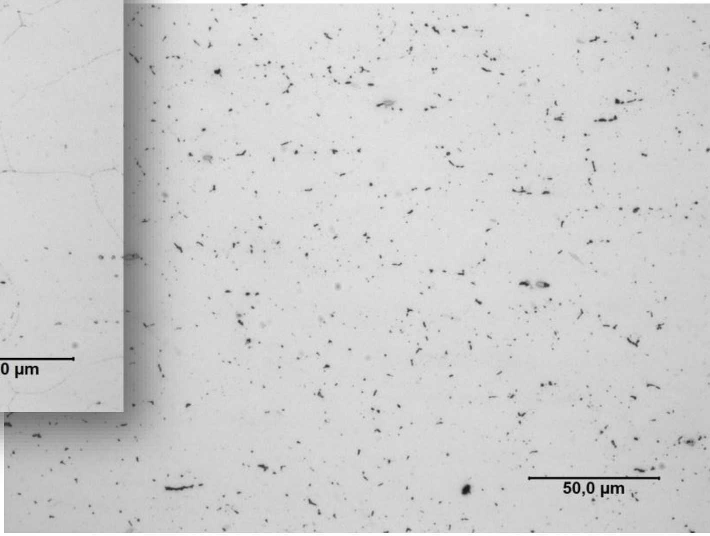
600ºC/500h



650ºC/500h



700ºC/500h

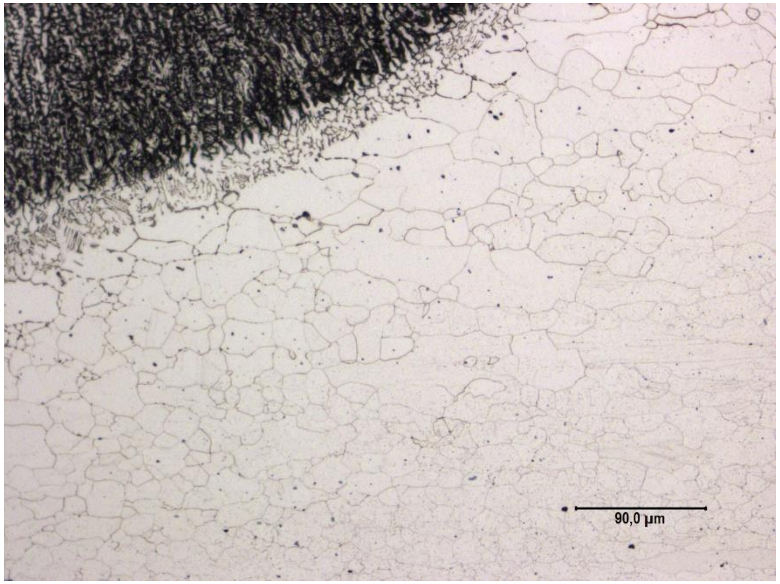


Precipitation state after ageing

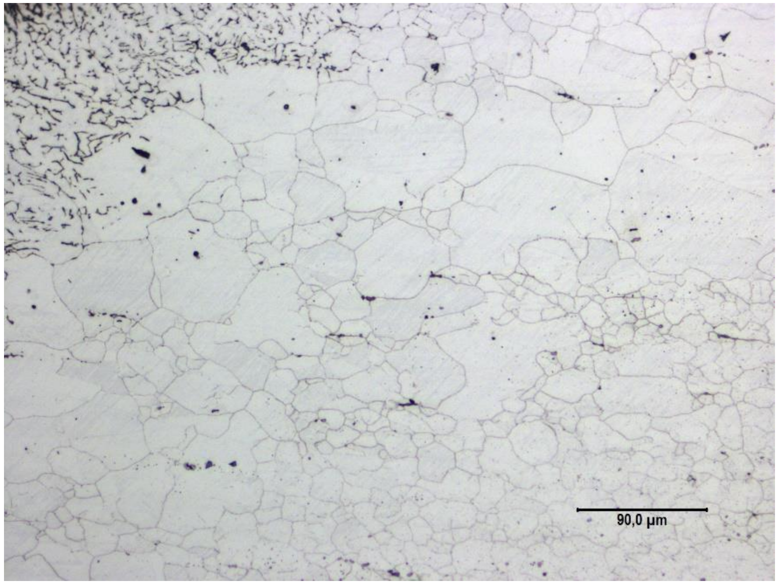
HAZ microstructure after testing

ArcelorMittal

- The precipitation state increase during the ageing on U-bend



Sensitized state
(600ºC/250h)



Sensitized state +
600ºC/500h under stress

No SRC initiate with U-bend stress loading

Loading in uniaxial direction

- The loading method could be one reason of difficulties to obtain SRC
- Dead weight is known to be more severe, but the load should not be to high to prevent creep failure

✓ Dead weight device : 180 MPa
✓ Specimen sampled from 15 mm thick weld plate
✓ Welding process : SAW and GMAW through all thickness
✓ Test duration of 720 hours

➢ Failure in deposited metal after around 300 hours
➢ Fracture surface is no SRC

Loading in uniaxial direction

- The failure is in deposited metal, the failure mechanism is not SRC as expected

Conclusion

ArcelorMittal

- Stress Relaxation Cracking is a very complex mechanism to reproduce
- Cracks should be initiate by the difference of hardness between grains and grain boundaries at high temperature combined with stress relaxation
- Sensitization before straining has not permitted to highlight SRC
- No cracks characteristic of SRC has been obtained with Four-point bending, U-bend and uniaxial traction set-up.

➢ New tests will be performed with 347 grade with higher content of carbon

Appendix 4

MTI pending project

(Patrice Houlle)

Materials Technology Institute

MTI Project 291 :
Stress Relaxation Mitigation Strategy

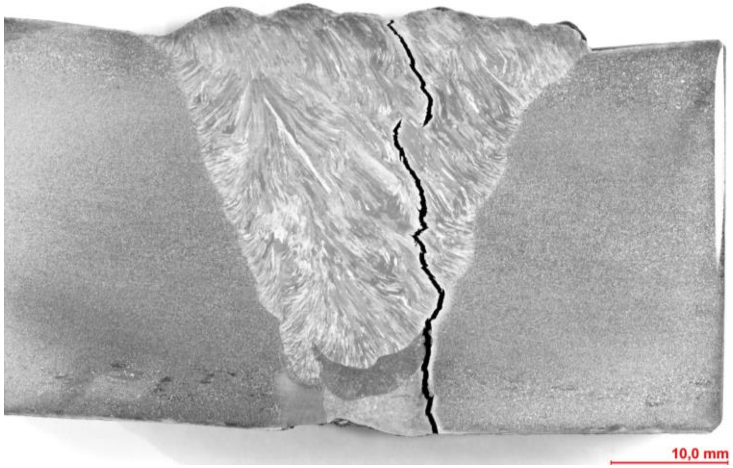
P.Houlle

September 11, 2018
WP 15 Meeting
EuroCorr 2018 , Krakov

Project 291 Phase 0

Introduction

– This MTI-Project is intended to identify pre-conditions under which stress relaxation cracking (SRC) occurs for specific alloys and subsequently develop a mitigation strategy including but also beyond the well-known heat treatment around 900°C. In particular, it shall be defined under which preconditions this heat treatment can be skipped while assuring a safe operation of the equipment.



Project 291 Phase 0

Objectives

- **Literature review** and evaluate significance and feasibility of possible test methods for SRC and compare to the proposed 4-point-bend test method.
- **Verify proposed 4-point-bend** test method by comparison with available 3-point-bend test results from first TNO Joint-Industry-Project.
- **Optimize 4-point-bend test method**, in regard of its significance, e.g. for different levels of SRC susceptibility and the actual occurrence of SRC in real application.

Project 291 Phase 0

Scope

The proposed test method shall be applied to the following samples under the specified test conditions. Moreover, sample fabrication and preparation shall comply with the stated requirements and shall be included in the proposal:

- **AISI 347H**: 12 samples of welded and 3 sample of un-welded base metal
- **Alloy 800H**: 12 samples of welded and 3 sample of un-welded base metal

Project 291
Status

- Contractor : Jülich FZ
- Date : March 2018
- Deadline: May 2019

- Status
  - 800H sourcing
    - 800H: Plate and Consumables : done
  - 800H samples preparation done
  - 347H sourcing
    - Consumables : done
    - Plates : GZ being checked

Project 291

- Who can participate in this MTI project
  - Obviously all the MTI members (for free)
  - But MTI will consider about partnering with interested company
  - Please contact :
    - Heather Stine hstine@mti-global.org (US)
    - Patrice Houlle phoulle@mti-global.org (Europe , Middle East)

Appendix 5

Effectiveness of water scrubbing instead of water washing on crude unit overhead corrosivity

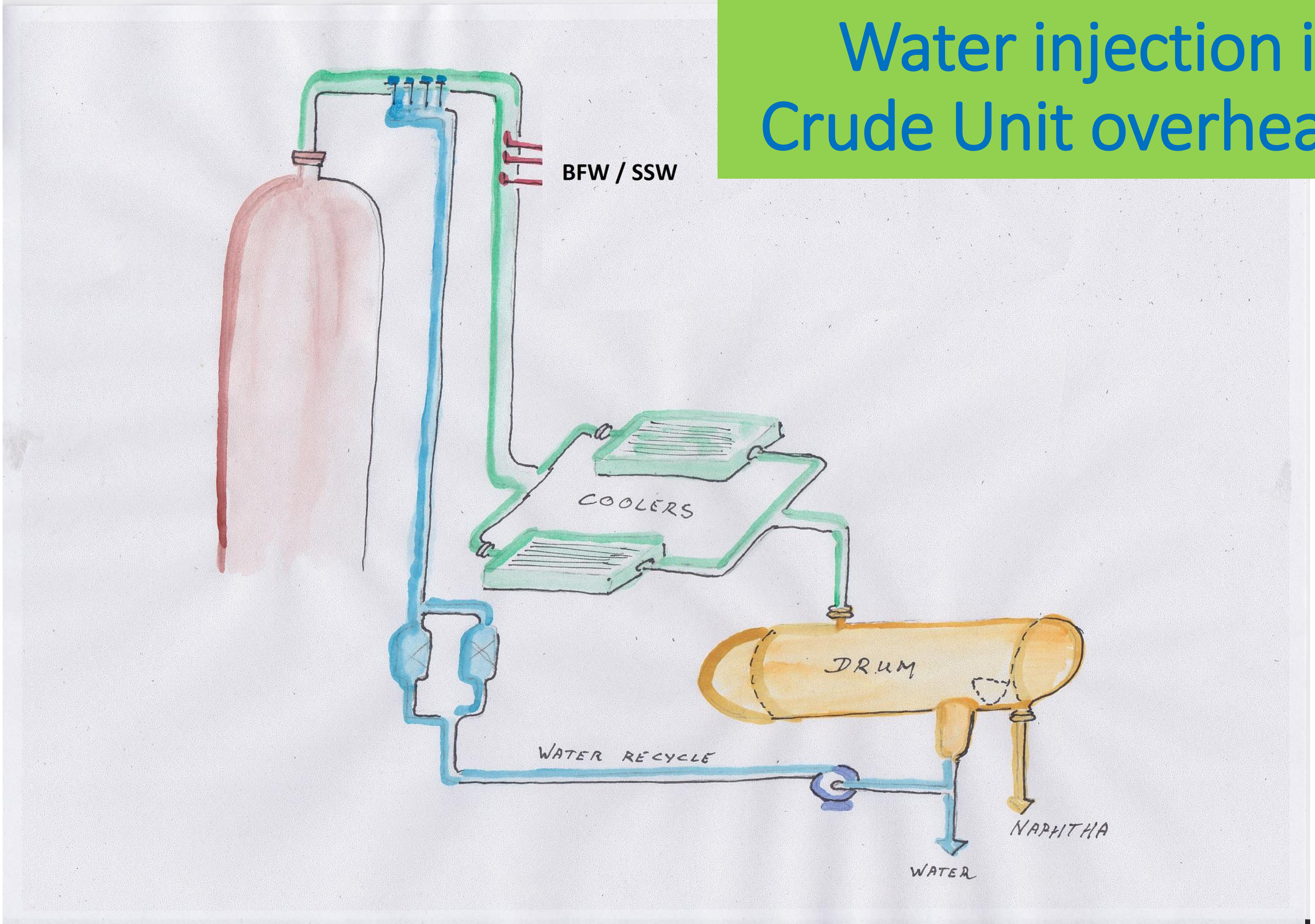
(Henk Helle)

Limitations on the effectiveness of water injection in CDU overhead line

Henk Helle

CorrosionControl.Nu

Water injection in the Crude Unit overhead vapor



Water spray and its effect

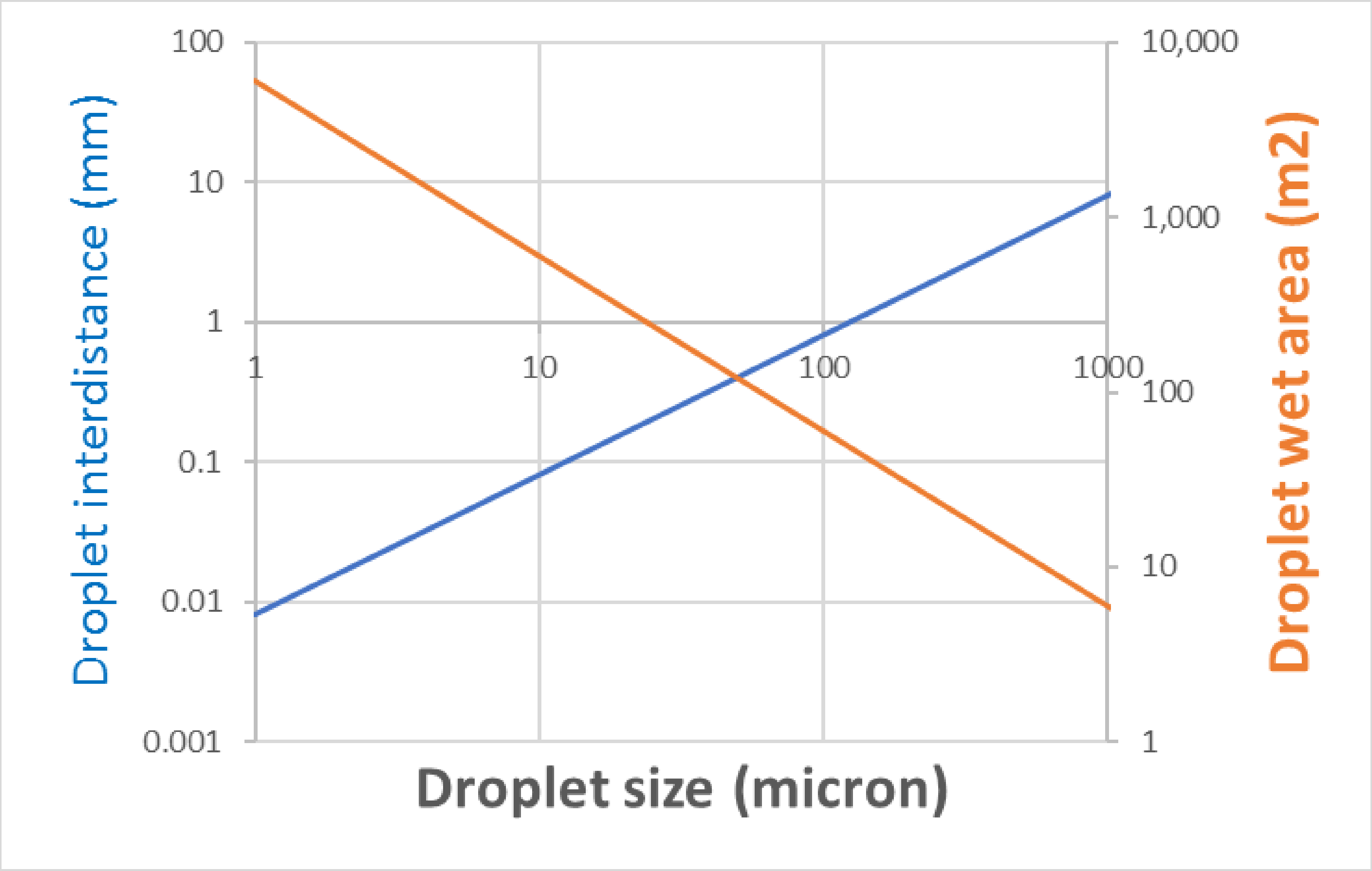
Effect	Useful characteristics of the spray	
Saturation of the vapor with water	A large wet surface area	
Water washing of salt deposits	Very small droplets that are carried along with the vapor deep into the bundles	
Scrubbing, absorption of HCl from the vapor	Small distance between the droplets	

Assumed data for CDU overhead with washing or scrubbing facilities

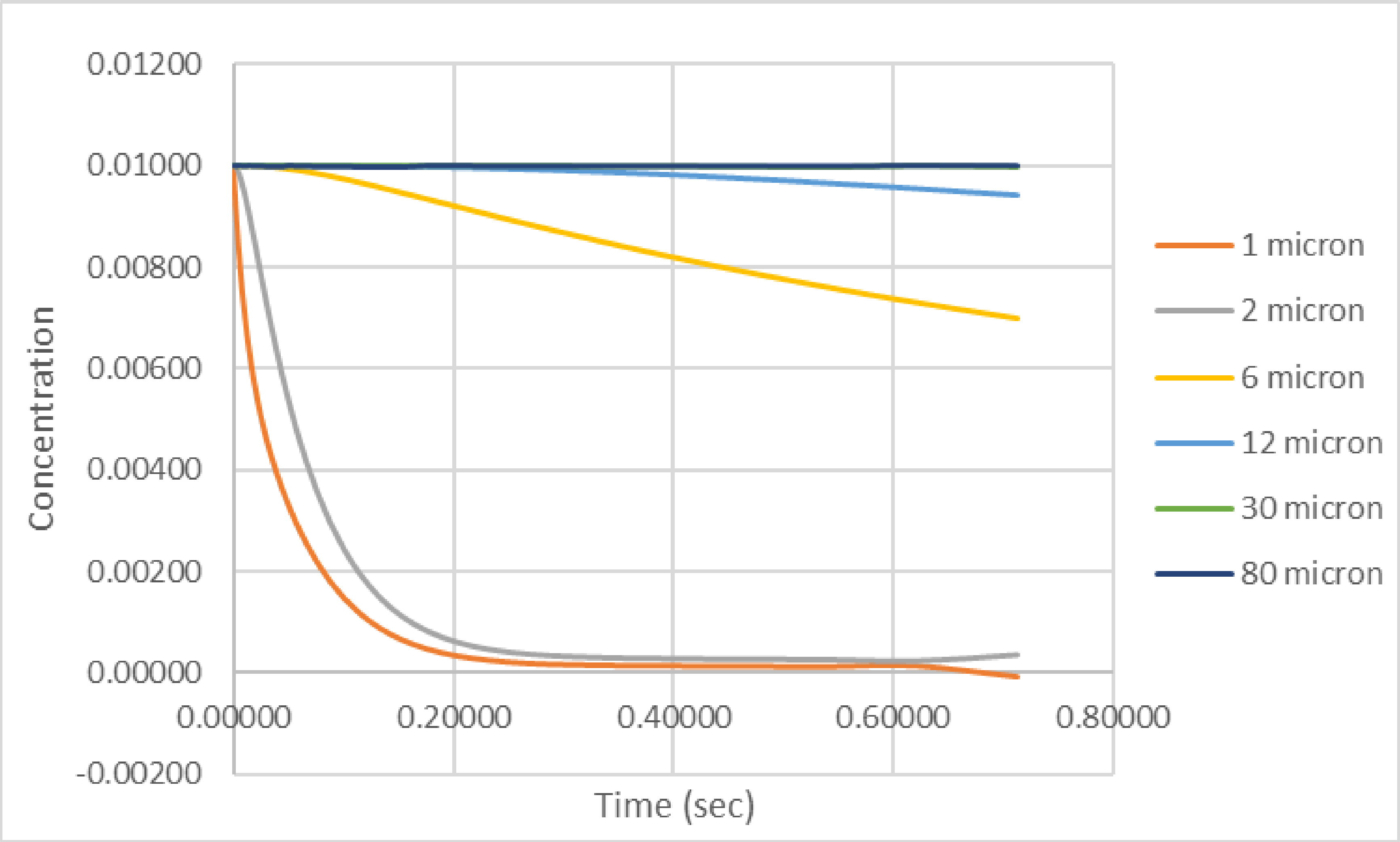
- 0.01 Mol HCl per m^3 hydrocarbon vapor
- 1 liter injected water per m^3 hydrocarbon vapor (15 w%)
- Uniform droplet size with Sauter diameters ranging from 1 μ to 1000 μ
- Residence time in overhead line is 1 second
- Diffusion coefficient HCl in HC-vapor: $4*10^{-5}$ m^2/s

- *How fine a spray is needed ?*
- What is the average distance between droplets ?
- What is the total wet area?
- What is the diffusion distance and what percentage of HCl will be absorbed?

Spray characteristics at 1 l/m3



Diffusion Distance and HCl-absorption



Conclusion

- Water washing requires a very fine, non-impinging spray, preferably <100 μ
- Co-current water scrubbing of overhead CDU-vapor, even with an ultrafine mist, cannot be effective enough to be useful.
- See: https://www.linkedin.com/pulse/corrosion-control-crude-units-16-henk-helle/

Appendix 6

Hyper-Duplex stainless steel a a viable alternative to Cu-Ni alloys in seawater coolers

(Jonas Höwing)

HYPER-DUPLEX STAINLESS STEEL AS A VIABLE ALTERNATIVE TO CUNI ALLOYS IN SEAWATER COOLERS

OUTLINE

- CuNi alloys and seawater
- Hyper duplex UNS S32707 in seawater
- Long term cost comparison CuNi vs. S32707

CUNI ALLOYS AND SEAWATER

CUNI ALLOYS IN SEAWATER - ADVANTAGES

- Excellent corrosion resistance in seawater.
  - Forms a protective scale.
- Can withstand high seawater temperatures.
- Resistant to biofouling.
  - Chlorination usually still needed to protect other parts of the system from clogging.
- Excellent thermal conductivity.
- Good fatigue properties.
- Good ductility.
- Ease of fabrication.

CUNI ALLOYS IN SEAWATER - DRAWBACKS

- Protective scale is soft and not strongly adherent to the metal surface.
  - Sensitive to erosion from solid particles.
- Sheer stresses due to high flow rates can also cause erosion of the protective scale.
  - Limitations to flow rate depends on tube inner diameter.
  - Turbulence in tube inlet can be a problem area.
- The presence of sulphides gives a non-adherent, soft scale and rapid corrosion.
  - Sulphate reducing bacteria in stagnant or polluted seawater, such as ports.

Tube inlet erosion-corrosion http://heatexchan.blogspot.com/2017/12/heat-exchangers-chemically-induced.html?_sm_au_=iPVQDQjWNrsPJJJs

HYPER DUPLEX UNS S32707 IN SEAWATER

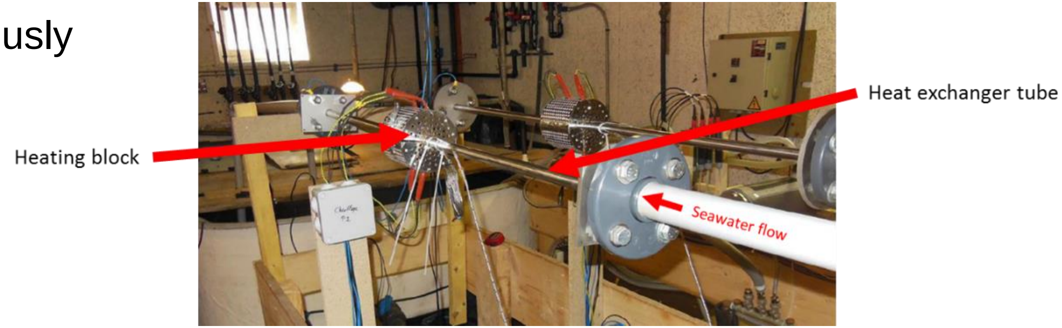
CORROSION PROPERTIES OF UNS S32707

- Hyper duplex S32707 is a high alloyed duplex stainless steel grade.
  - PRE > 48 compared to super duplex or super austenitic grades which have PRE > 40.
  - Excellent resistance towards chloride induce pitting and crevice corrosion.

UNS	Common name	ASTM G48 CPT/°C	ASTM G48 CCT/°C	Crevice corrosion in natural seawater, ambient temperature
S32750	Super duplex	80	50	No
S32707	-	>95	70	No
S31254	6Mo	80	45	-

TESTING USING MODEL HEAT EXCHANGER

- The aim of the study was to determine the limiting inner skin temperature of tubes used for seawater cooling.
  - Inlet seawater temperature 20°C or 35°C.
  - Flowrate 2 m/s.
  - Continuous chlorination at 0.5 ppm.
  - Tube inner skin temperature controlled using outer heat clamps.
  - Open circuit potential (OCP) continuously monitored to detect active corrosion.
  - Test duration up to 18 months.
- Tube materials tested:
  - Standard duplex S32205
  - Super duplex S32750
  - Hyper duplex S32707



RESULTS FROM TESTING

Material		Seawater temperature 35°C				Seawater temp. 20°C
		Tube **outside/inside** skin temperature				
Tube	PREN	65°C/50°C	105°C/70°C	135°C/85°C	155°C/95°C	170°C/95°C
S32205	36	Pitting	Pitting	-	-	-
S32750	43	No pitting	Pitting	-	-	-
S32707	49	No pitting	No pitting	No pitting	No pitting	No pitting

- Hyper duplex S32707 shows excellent corrosion resistance.
  - Outperforms super duplex.
  - Better safety margin in case of for example high seawater temperatures.

LONG TERM COST COMPARISON
CUNI VS. S32707

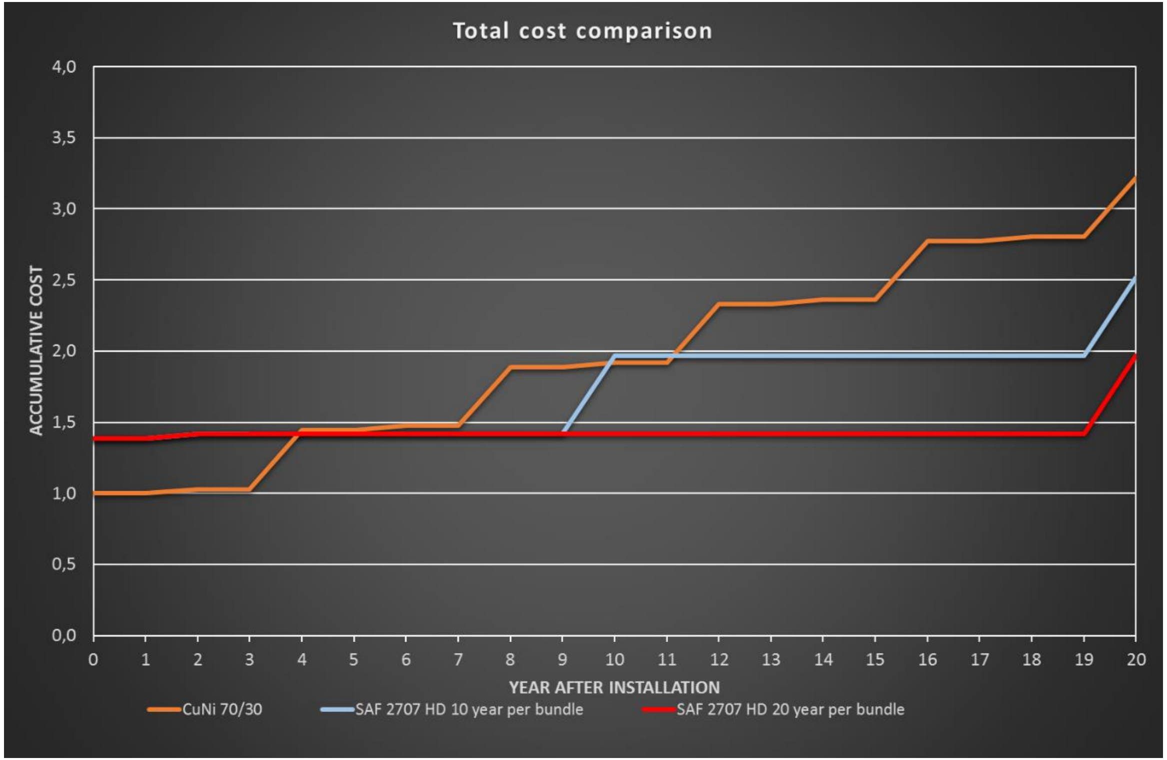
EXAMPLE COST ANALYSIS – REAL CASE STORY

- CuNi seawater coolers.
  - Material CuNi 70/30
  - Cost analysis only for ONE unit.
  - CuNi tube bundle life time 4 years (average).
  - Repair costs included.
  - Lifetime analysis 20 years.
  - Production loss during maintenance not included.
  - Capacity loss due to plugged tubes not included.

- Stainless alternative S32707.
  - S32707 expected life cycle 10 or 20 years.
  - No maintenance stops for unit expected.

- Fabrication costs for new units were acquired from highly experienced fabricator.

EXAMPLE COST ANALYSIS – TOTAL COST INDEXED



EXAMPLE COST ANALYSIS – CONCLUSIONS

- Cost analysis shows that:
  - Initial equipment cost is higher for S32707 than for CuNi 70/30.
  - In case of 10 year lifetime for S32707, cost breakeven occurs after ~10 years.
  - In case of 20 year lifetime for S32707, cost breakeven occurs after 4 years.

- Production loss not included in calculations.
  - Customer did not want to share such information.
  - Calculations quickly become very complicated.
  - Calculations favourable for CuNi solutions.

CONCLUSIONS

- CuNi alloys have been used successfully in seawater coolers for a long time.
- In cases with frequent failures though, the long term costs can be high.
- The hyper duplex grade S32707 has excellent corrosion resistance in chlorinated seawater.
- Even though initial cost is higher for S32707 than for CuNi solutions, long term savings can be expected in cases where CuNi fails.
  - In example, cost savings are achieved even if retubing of S32707 is needed after 10 years.

Appendix 7

Extension of monitoring system – application of integrity operating windows

(Barbara Skolyszewska-Kühberger)

Integrity Operating Window

Schwechat, January 2018

OMV Downstream

The energy for a better life. OMV

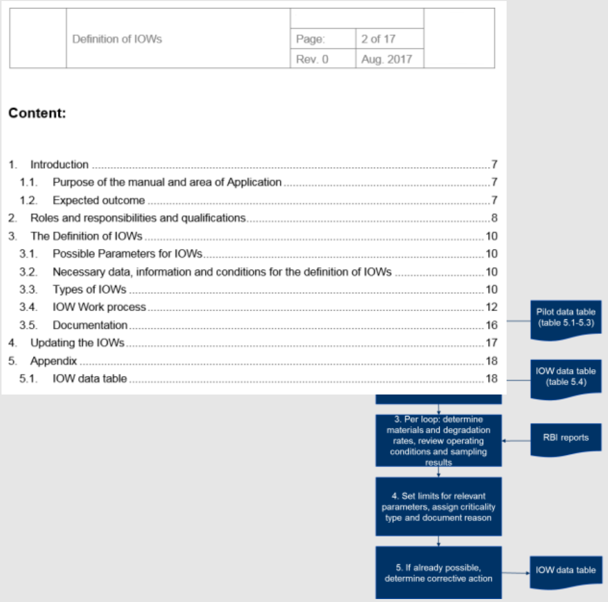
Integrity Operating Window IOW (API 584)

Integrity Operating Window

	<u>Critical</u> limit high	**Design Window DW**: Failure occurs quickly
	<u>Standard</u> level high	**Operating Window OW**: Failure occurs with sustained operations
Stable, Reliable, Profitable	Target range high Target --- Optimal Target Range low	**Integrity Operating Window IOW**: Safe to operate Indefinitely
	<u>Standard</u> level low	**Operating Window OW**: Failure occurs with sustained operations
	<u>Critical</u> limit low	**Design Window DW**: Failure occurs quickly

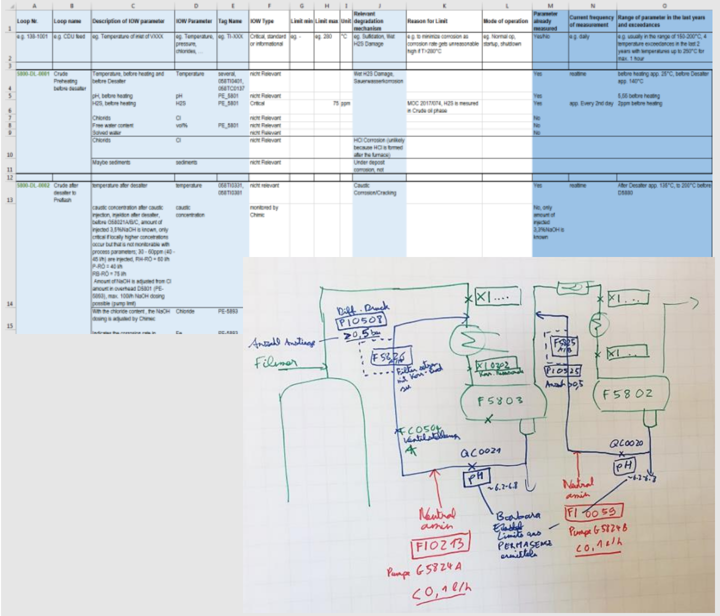
OMV IOW Methodology

1 IOW development manual



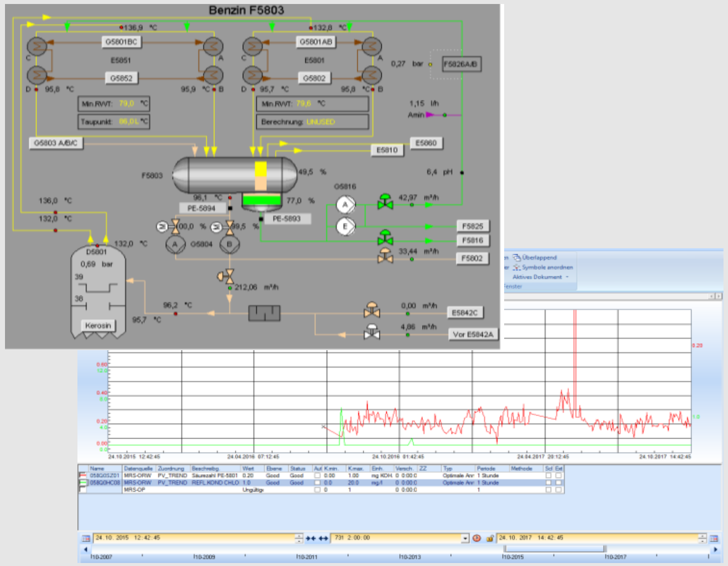
Approach defined

2 Pilot Project



Proof-of-Concept demonstrated

3 Concept for monitoring



Approach developed

Contact

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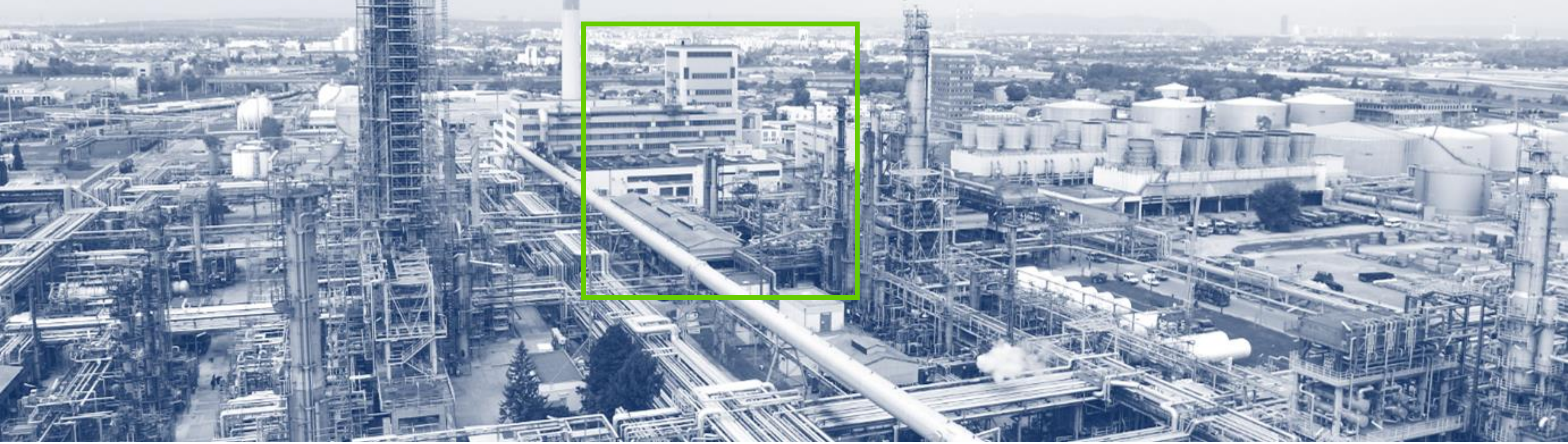

OMV Downstream

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Appendix 8

A selection of Permasense latest corrosion monitoring case studies from European refineries

(David Lorkin)

Corrosion Monitoring in European Refineries

EFC Working Party 15

11th September, 2018

Presented by: David Lorkin

Crude Flexibility Strategy

Crude Flexibility Strategy

- 15Mt/a refinery with high conversion capacity “independent” refinery
- Margin improvement project: Feeding higher TAN crudes to the refinery, taking profit from crude diversification

- Units in scope:
  - One (of three) CDU with VDU
  - Hydrotreater
  - Coker

- Two steps:
  - After TA-2018: Increase the TAN-limit from 0.3 to 0.5 with chemical injection of a phosphorous based inhibitor
  - Future after 2024: With material upgrade 2 to 3 times higher TAN

- Corrosion study identified areas with higher risk (weak spots) and lower risk. However fails to provide a reliable prediction in two sections
  - CDU: crude heater because of mist flow
  - VDU: lower circulating reflux cooler because of condensing vapors

- Corrosion study expanded to downstream units Hydrotreater and Coker

Monitoring for Crude Flexibility

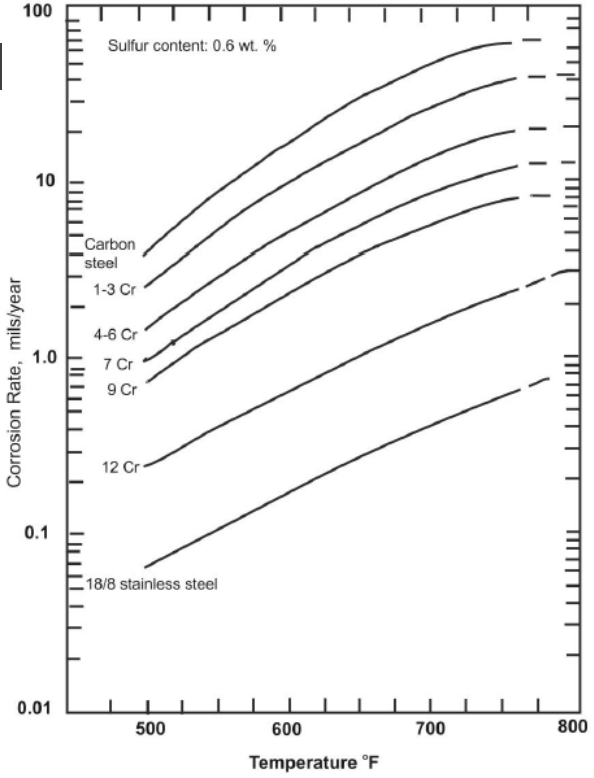
- Injection and monitoring locations selected
- 74 sensors installed in turnaround March 2018
- Monitoring started in April 2018 to plot a baseline before feeding higher TAN crudes

- It is expected that shareholders will be striving for a further margin improvement by processing high mercaptans feedstocks
- Mercaptans are known to accumulate in mid-distillates and cause severe corrosion in pump-arounds
- Planned additional monitoring.

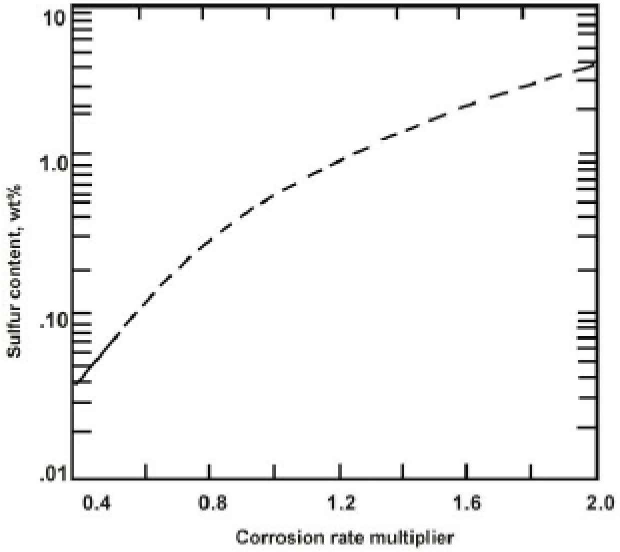
Extended Run Strategy

Corrosion Monitoring – European Oil Refinery

- Major refinery with high conversion capacity
- Corrosion monitoring was initiated as strategic decision by the former refinery manager
- Monitored areas were primarily process sections affected by high temperature sulphidation as general risk sections.
- First sensors installed in 2013
- Monitoring in the HF Alkylation unit was added in April 2018
- Currently 270 Permasense sensors installed
- Up to now no significant corrosion detected, allowing consideration of extended run strategy



Modified McConomy Curves



Turn Around Cycle Extension Strategy – European Oil Refinery

- TAR cycles are based on the requirements for in-service inspection of pressure equipment which are set to a maximum of 5 years.
- Any extension must be approved by the local authority based on expertise by the independent inspection body.
- The inspection body has to assess the risk by extended operation and the measures that are implemented to mitigate that risk.
- Mitigation measures to justify the extension of in service inspection periods are:
  - Increased corrosion allowance
  - Materials upgrade to 9Cr-steel and stainless steel
  - Corrosion monitoring
- The Permasense corrosion monitoring system is an important element of proposal to extend their turnaround (TAR) cycles to up to eight years.

TAR Cycle Extension - Benefits

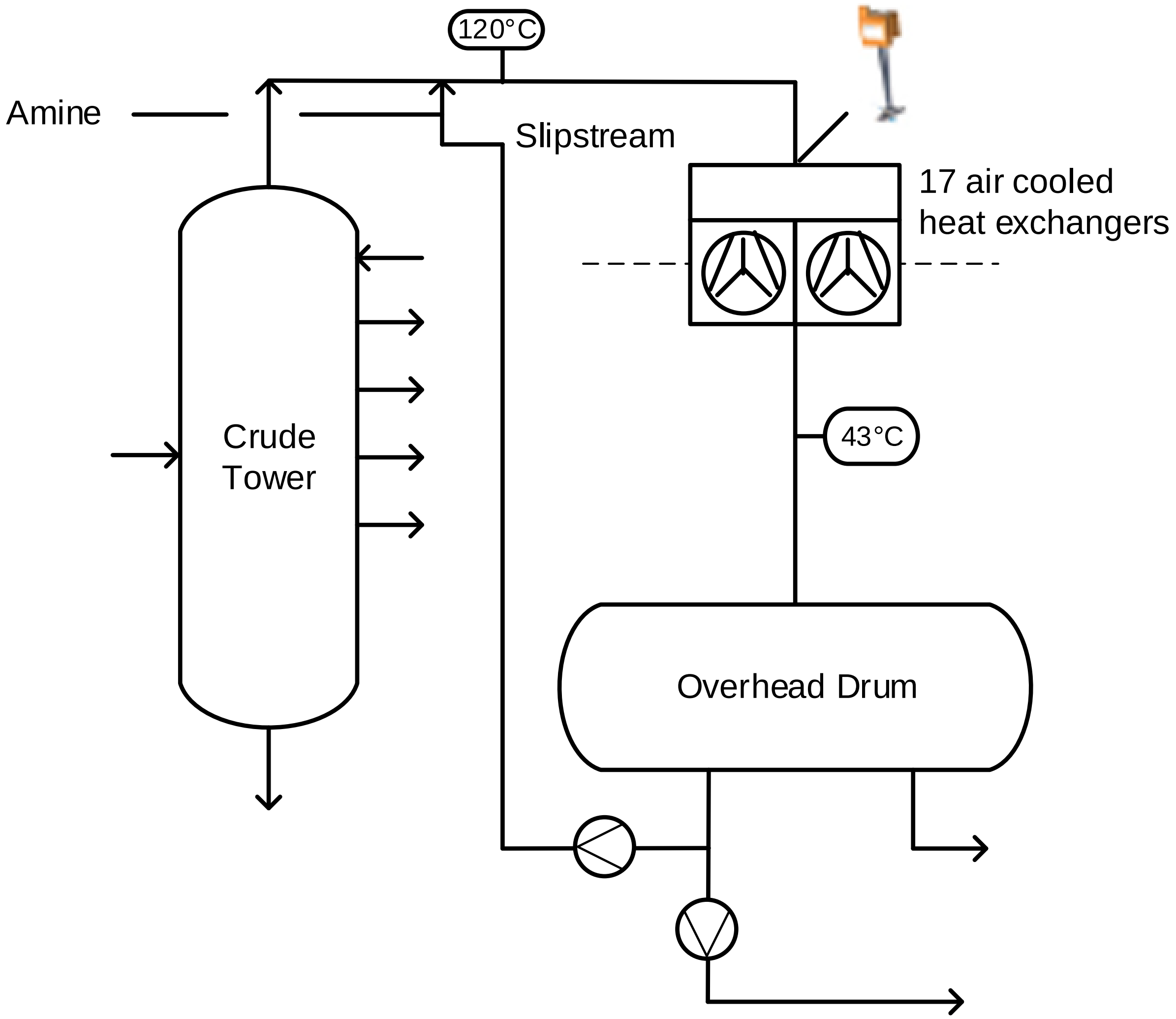
- Reduction of annualised TAR costs
- Lower production losses by reduced downtime of the units
- May amount up to some ten M€/a.

Crude Unit Overhead Corrosion Case Study at a European Refiner

EMERSON

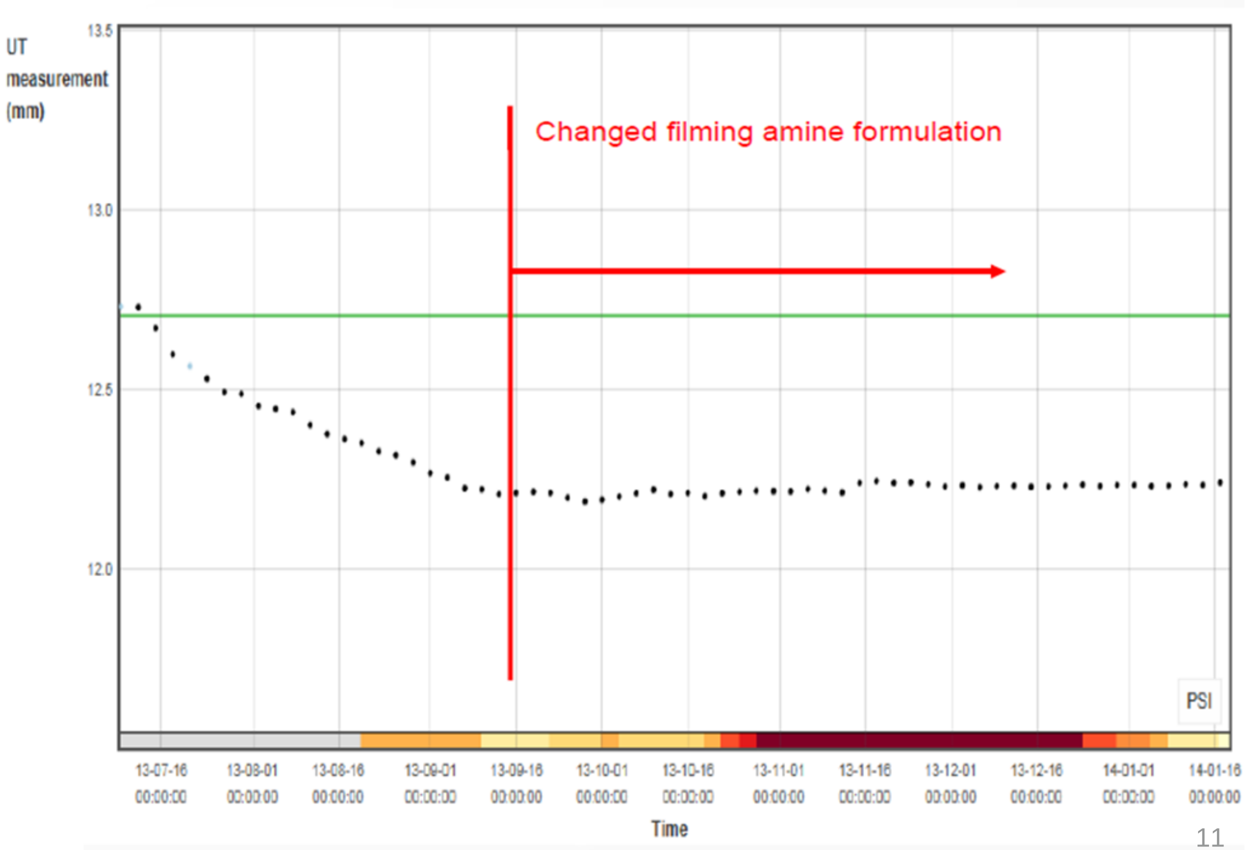
Crude Unit Overhead Corrosion Case Study

- CDU overhead system protected by chemical injection (filmer and neutralising amine).
- Severe corrosion in the overhead piping system caused leaks.
- Expensive clamps had to be installed to secure operation.
- Risk of damaging the 17 air cooled heat exchangers.



CDU Overhead: Corrosion Detection and Control

- Inspection by manual UT had identified the thinning but could not prevent the leaks.
- Dewpoint calculation tool did not predict the location of the severe thinning.
- 29 Permasense sensors were installed to continuously observe the system.
- Permasense system validated high corrosion rates.
- Trials were made to identify the cause of the corrosion:
  - Reduce flow rate.
  - Insulate piping.
  - Change filming amine formulation.
- Effects could be immediately seen in the monitoring data.
- Chemical injection issue identified as the root cause:
  - Filming amine injected with a naphtha slipstream taken from overhead drum.
  - Filming amine formulation caused emulsion formation in overhead drum.
  - Water was carried over with the slipstream causing the aggressive corrosion.
- Amine type changed, carry-over reduced, **corrosion stopped.**
  - Damage to the 17 air cooled heat exchangers prevented.



Benefits of Corrosion Monitoring

Risk: safe operation without risk of leaks within the identified remaining lifetime.

Maintenance: replacement optimised in time and cost, not compromising the TAR schedule.

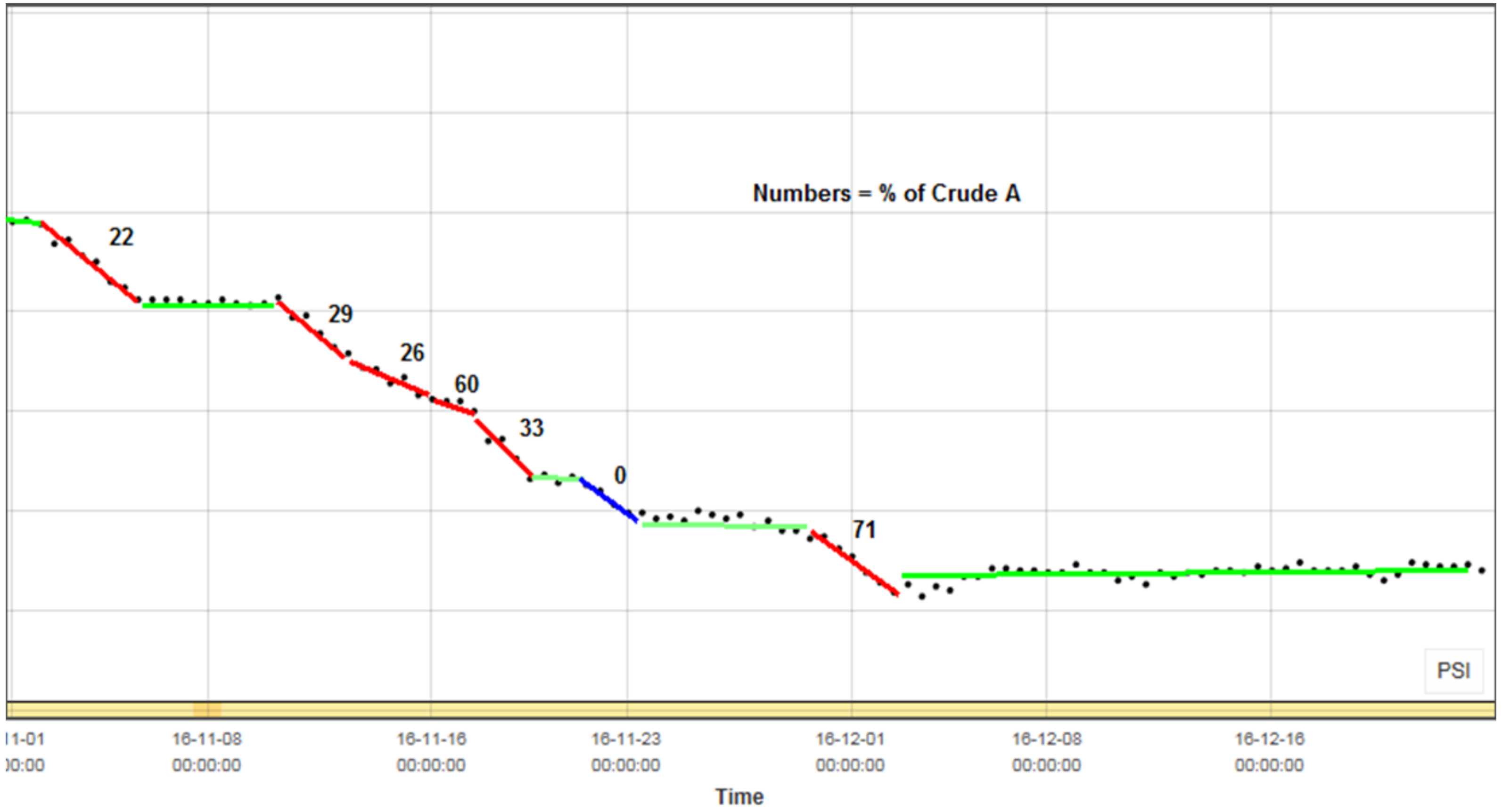
Operations: unplanned shutdown and loss of profit margin prevented.

Estimated Financial Impact of Corrosion Monitoring

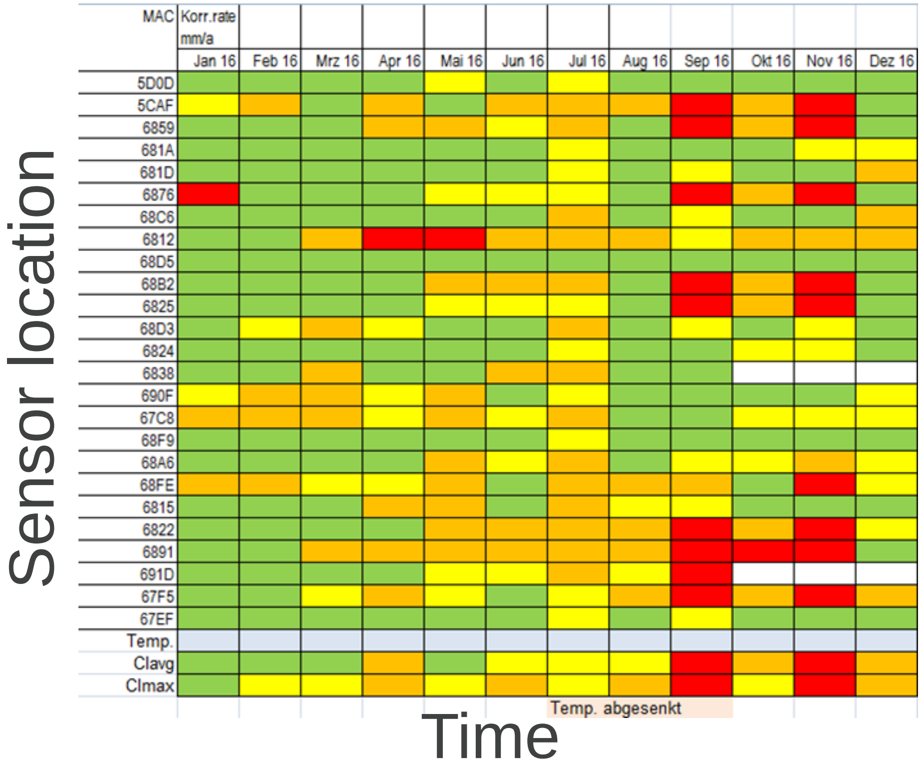
- Replacement of one air cooled heat exchanger estimated at approximately €200k avoided.
- Replacement of piping estimated at €3M avoided.
- Costs for unplanned vs. planned and well prepared replacement of piping estimated at €700k saved.
- Loss of profit margin in case of unplanned shutdown: 300k€/d*; duration depending on the necessary actions, min. 4 days. > €1M loss avoided.
- Total Impact: > €4M.

* Depending on the overall margin situation and the complexity/integration of the refinery

CDU OVHD: Corrosion Rate Correlation With Crude Blend



- A year after the corrosion rate was first stabilised, the corrosion rate increased again, immediately indicated by the monitoring sensors.
- Corrosion rate was varying with changes in the crude slate.
- Crude type “A“, high in chlorides, was identified as causing desalter issues.
- the sampling procedure in the desalter was improved to better monitor the risk.
- Other mitigations in place to control corrosion.



Benefits of Corrosion Monitoring

Risk: continuous observation assures safe operation without risk of unacceptable wall loss.

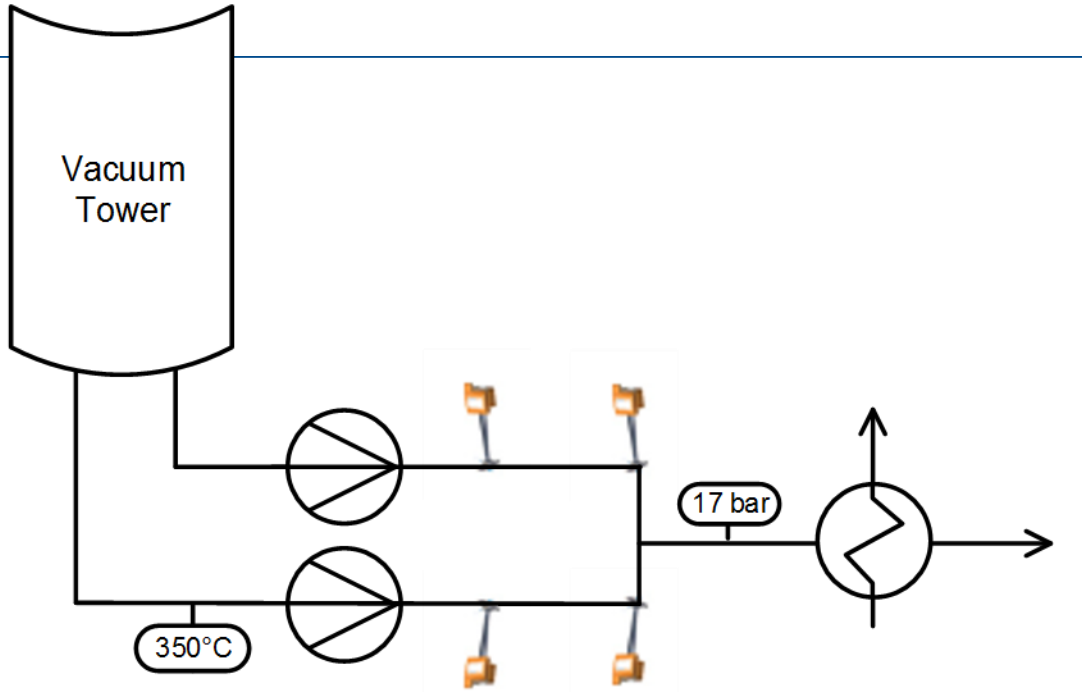
Operations: immediate response by the monitoring system provides data to select appropriate measures and optimise operation.

Equipment Life Management in VDU at a European Refinery

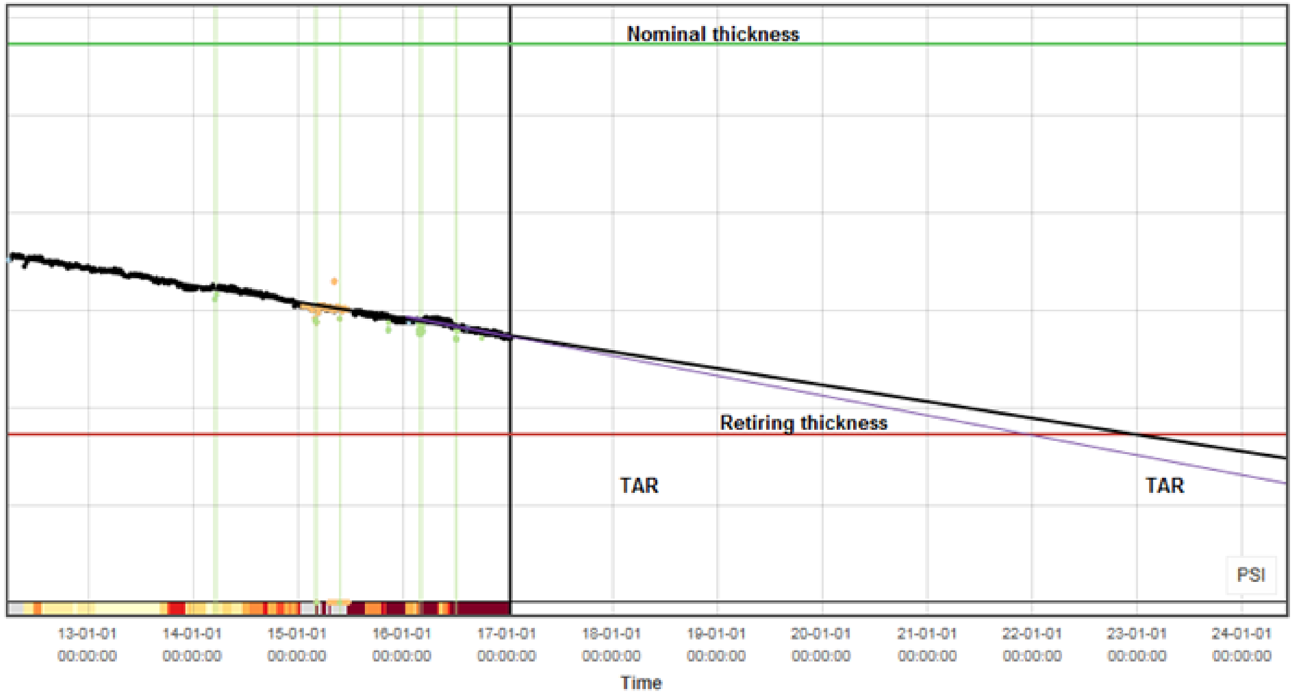
EMERSON™

High Corrosion Rates Observed in the Vacuum Residue Rundown System (Carbon Steel)

- Uncertainty about the remaining service life of the line. Can the next scheduled TAR be reached or do we run the risk of an unplanned shutdown?
  - Four sensors installed at the thinnest locations.
  - Extrapolation of the wall thickness over five years provided a reliable prediction of the remaining life, assuring that the next scheduled TAR could be reached without risk.
  - Early enough to prepare in detail the replacement of the line in P9 material (design, procurement, prefabrication).



Reliable prediction through manual UT inspection was not possible because of low repeatability



Benefits of Corrosion Monitoring

Risk: safe operation without risk of leaks within the identified remaining lifetime.

Maintenance: replacement optimised in time and cost, not compromising the TAR schedule.

Operations: unplanned shutdown and loss of profit margin prevented.

Estimated Economic Impact

- Costs for unplanned vs. planned and well-prepared replacement of piping estimated at €500k saving.

- Loss of profit margin in case of unplanned shutdown or extended TAR estimated at €300k/d*; duration depending on the necessary actions, min. 4 days: > €1M saving.

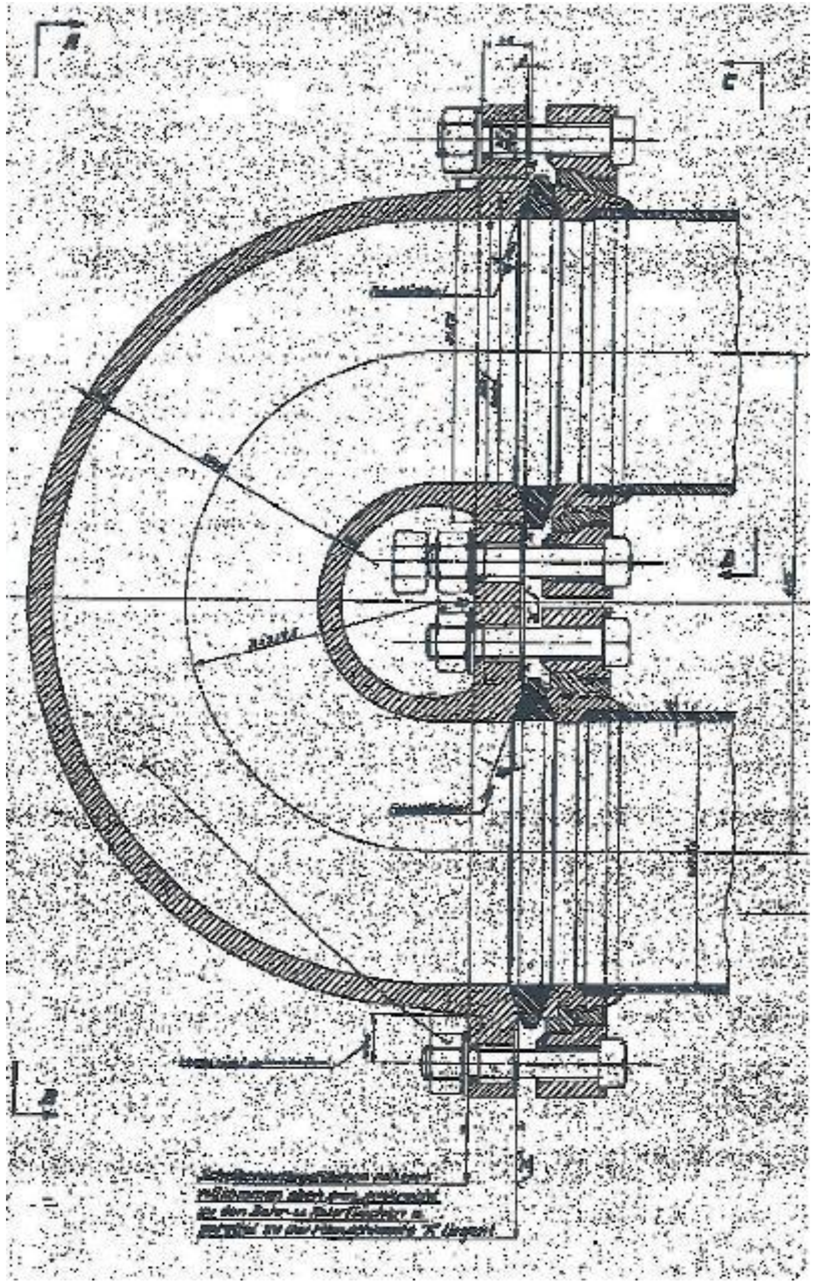
- Total Impact: > €1.5M

* Depending on the overall margin situation and the complexity of the site

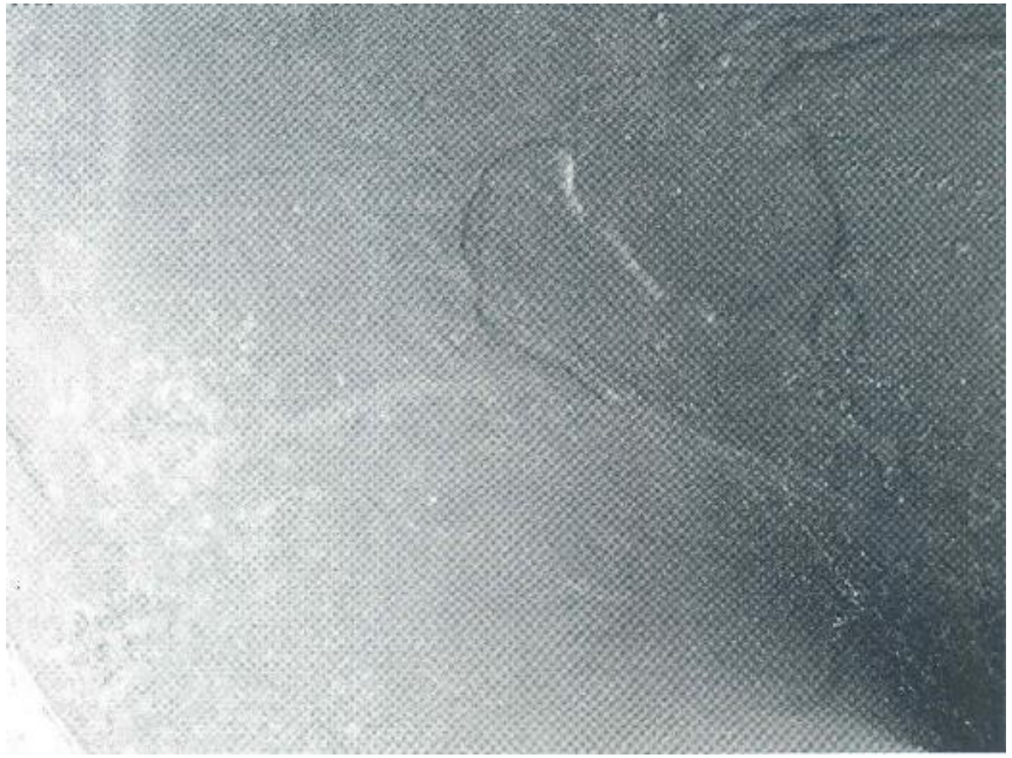
Crude Heater High Temperature Corrosion Monitoring

European 260kbbl/d Site with High Conversion Capacity

Crude Heater High Temperature Corrosion Monitoring



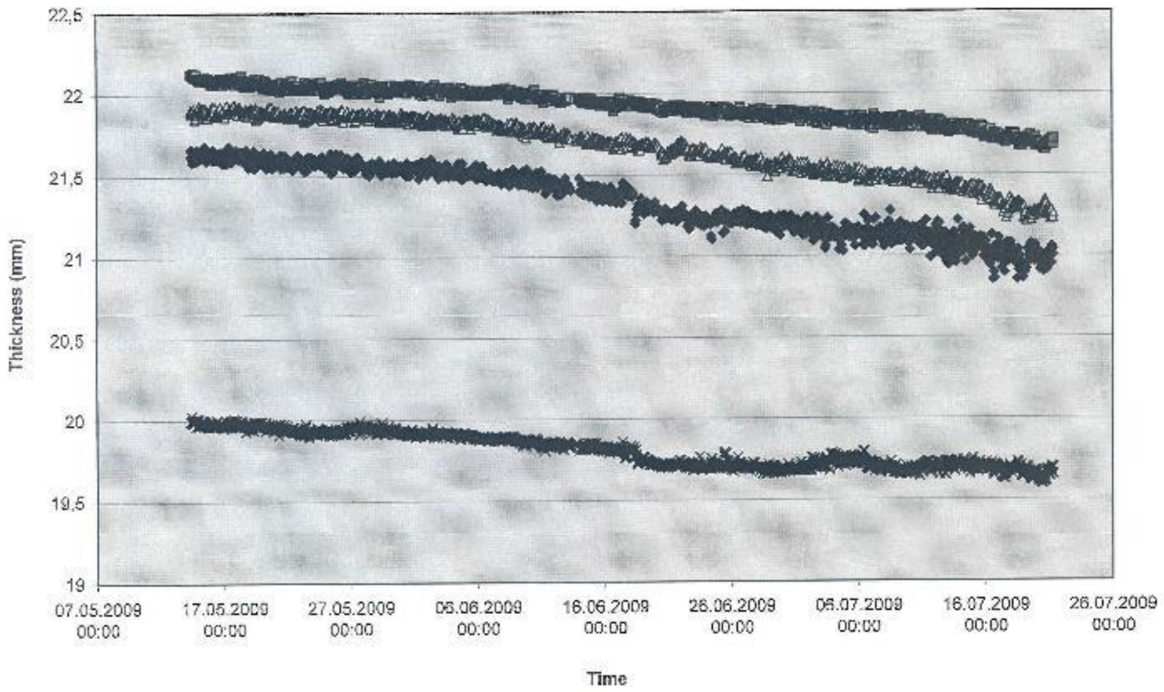
- Old crude heater with unusual design.
- Horizontal tubes in P5/P9.
- U-bends outside the firebox in cast C-steel.
- Site had expanded their operating windows to improve margin by processing higher TAN crudes, up to TAN 1.0.
- Chemical injection installed to protect against naphthenic acid corrosion (NAC). Monitoring at that time by hydrogen flux measurement, Permasense not being available at that time.
- Program worked well over three years. Critical locations were inspected in a TAR proving that chemical injection was successful.
- Only some cast C-steel u-bends showed typical NAC.
- Wall thickness not critical at that time but a leak occurred at a cast defect that was opened by progressing corrosion.



Crude Heater High Temperature Corrosion Monitoring

- Only cast carbon steel available for replacement. (No higher alloyed U-bends)
- Uncertainty about the actual corrosion rate. *Can we reach the next scheduled TAR with continued processing of high TAN crudes or do we have to stop this operation mode and lose margin?*
- Decision to add Permasense monitoring sensors. The most critical four U-bends close to the furnace outlet (i.e. at the highest temperatures) were selected for monitoring.
- Challenge to install four sensors on each bend at operating temperature 380°C successfully accomplished.
- Wall thickness curves provided a reliable prediction of the remaining life of the U-bends and that the next scheduled TAR two and a half years later could be reached without stopping the highly attractive high TAN crude processing.

Figure 1: Probes installed on cast carbon steel U-bend with M8 studs



Estimated Economic Impact

- Monitoring provided the assurance to continue processing of high TAN crudes for another two and a half years until the scheduled TAR.

- The additional profit margin at that time amounted to more than €100M.