Appendix 1

Welcome and introduction

F. Dupoiron (Total)

CONTENTS

1 OVERVIEW
2 MARKETS
3 STRATEGY
4 REFINING & PETROCHEMICALS OPERATIONS
5 SPECIALTY CHEMICALS
6 ADDITIONAL INFORMATION

1 OVERVIEW

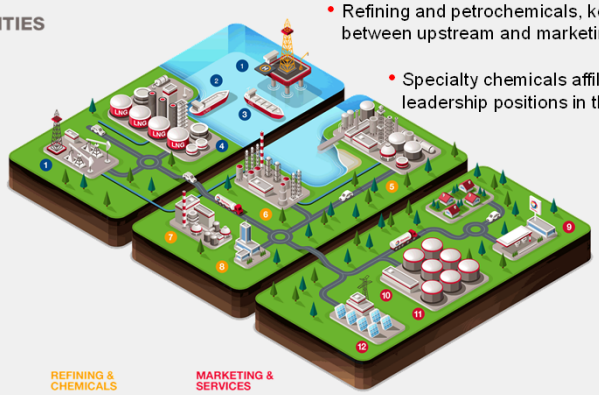
Contents

POSITION WITHIN TOTAL

Contents

OUR ACTIVITIES

- Refining and petrochemicals, key activities between upstream and marketing.
- Specialty chemicals affiliates that hold leadership positions in their segments.



UPSTREAM

1. OIL AND/OR GAS PRODUCTION
2. LNG CARRIER
3. OIL TANKER
4. LIQUEFACTION/ REGASIFICATION

REFINING & CHEMICALS

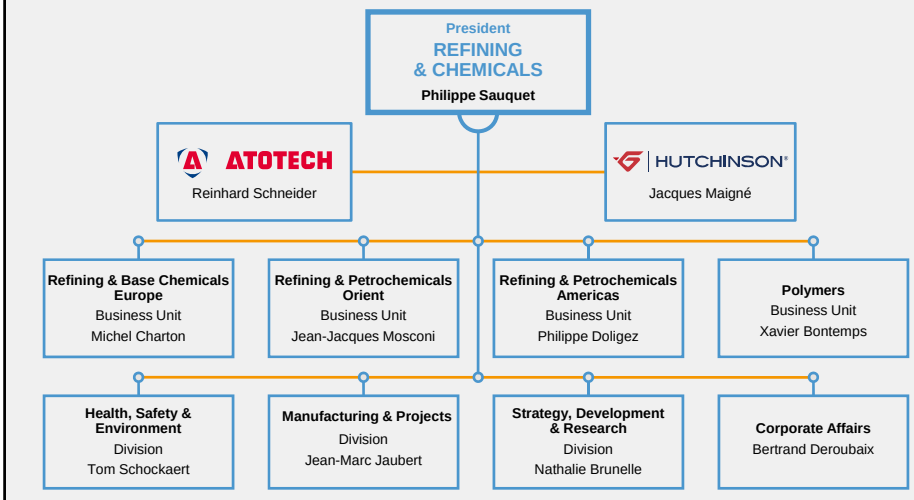
5. REFINERY
6. BLENDING PLANT
7. SPECIALTY CHEMICALS
8. TRADING OFFICE

MARKETING & SERVICES

9. SERVICE STATION
10. LUBRICANTS PLANT
11. OIL DEPOT
12. SOLAR PANELS

REFINING & CHEMICALS ORGANIZATION CHART

Contents



WORKFORCE

Contents

45,000 employees at January 1, 2015

Refining & Petrochemicals: 30% of the workforce

Specialty Chemicals: 70% of the workforce

Americas	Europe	Asia and the Middle East
United States 9%	France 32%	China 10%
South America 14%	Belgium 7%	Other countries 1%
	Rest of Europe 26%	
	Africa 1%	

KEY FIGURES

Contents

Refining

14 refineries worldwide*
including **5** in France

No. 1 refiner in Europe
12% of Europe's refining capacity,
or 1.7 million b/d

No. 10 refiner worldwide
2% of global refining capacity,
or 2.2 million b/d

* Marketing & Services (M&S) operates seven other refineries.

Petrochemicals

26 petrochemical facilities

No. 2 in petrochemicals in Europe
No. 10 in petrochemicals worldwide
> 20 million tons per year

Specialty Chemicals

Revenue
$5.9 bn

HUTCHINSON

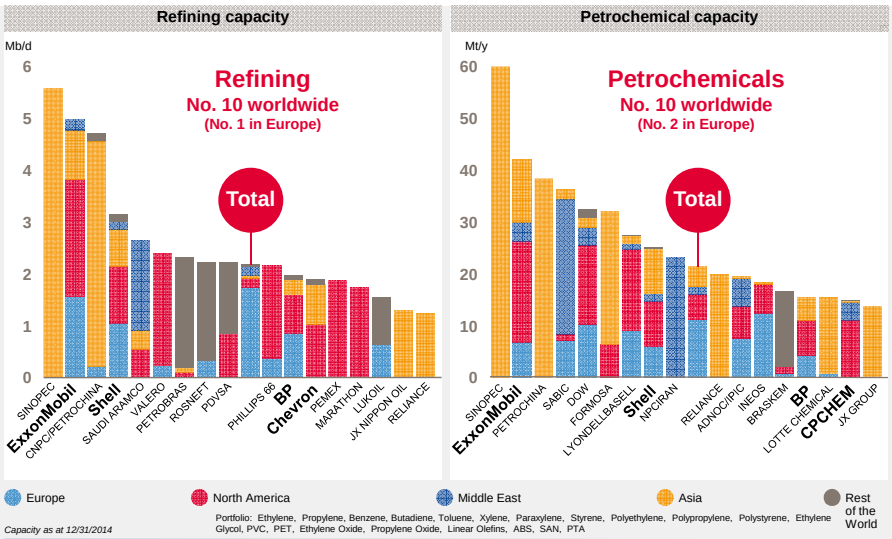
World leader in rubber products
96 sites, **28,600** employees

ATOTECH

No. 1 worldwide in metal and surface finishing
17 sites, **4,000** employees

A WORLD-CLASS REFINING & PETROCHEMICALS PLAYER

Contents



3 STRATEGY

Contents

© Michel Labelle

OBJECTIVE 1

PUTTING SAFETY FIRST

Contents

RESPONSIBLE CARE®
OUR COMMITMENT TO SUSTAINABILITY

TOTAL COMMITMENT SAFETY FOR ME, FOR YOU FOR ALL

"SAFETY IS OUR NO. 1 PRIORITY AND A KEY FACTOR IN OUR INDUSTRIAL PERFORMANCE"

Philippe Sauquet
President, Refining & Chemicals

© Total

Safety Targets

ZERO FATALITIES

TRIR:
<1.6 in 2015
<1 in 2020

© Michel Labelle

SIX KEY STRATEGIC OBJECTIVES

Contents

BECOME AN INTEGRATED, MORE COMPETITIVE PRODUCER

1. **Make safety and preventing major environmental risks an absolute priority**.
2. **Adapt and optimize the production base in Europe:** Cut costs and lower break-even points, develop operational excellence, position our most efficient sites as industry leaders and focus investments on large integrated complexes.
3. **Develop petrochemicals in the Middle East and our supply to fast-growing Asian markets:** Secure access to cost-advantaged resources and establish a selective local presence in Asia.
4. **Americas:** Leverage the U.S.'s competitive advantage in energy to consolidate and grow our production base.
5. Differentiate through **innovative processes, products and solutions** for our customers.
6. Support **Hutchinson's and Atotech's** profitable growth, in line with Total's strategy.

A SAFE AND COMPETITIVE REFINING & CHEMICALS FOCUSED ON EMERGING MARKETS

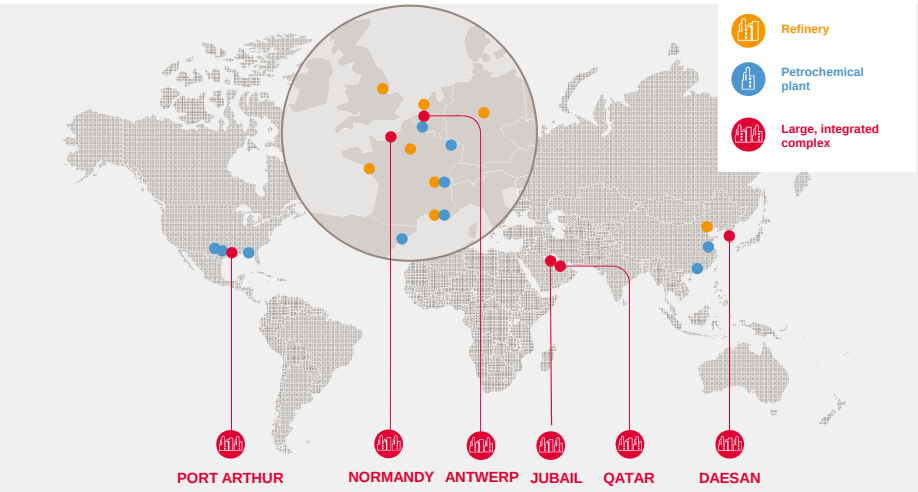
4 REFINING & PETROCHEMICALS OPERATIONS

Contents

© Michel Labelle

FACILITIES

Contents



NORMANDY COMPLEX

Contents

- Upgraded facilities
- New configuration operational in early 2014
- Optimized product mix:
  ➔ Less gasoline
  ➔ More diesel
- Enhanced energy efficiency and lower carbon emissions
- Integrated refining and petrochemicals operations

NORMANDY, FRANCE

Refining capacity:
247,000 b/d

Special products: Lubricants and special fluids

Ethylene	Butadiene	Benzene	SM*	Paraxylene
515 kt/y	75 kt/y	370 kt/y	650 kt/y	130 kt/y

HDPE	EVA**	PP	PS
280 kt/y	45 kt/y	240 kt/y	85 kt/y

*Styrene Monomer – ** Ethylene vinyl acetate copolymer*

© Michel Labelle

ANTWERP COMPLEX

Contents

- Three integrated facilities:
  Third-largest refinery in Europe, an olefins plant and a polymer plant
- Located in the center of the Amsterdam/Rotterdam/Antwerp (ARA) hub
- €1 billion invested to align output with demand by increasing production of distillates (diesel)
- New conversion unit

ANTWERP, BELGIUM

Refining capacity:
338,000 b/d

Special products: MTBE & ETBE

Ethylene	Benzene	Toluene
1,075 kt/y	240 kt/y	215 kt/y

HDPE*
480 kt/y
(4 lines)
Line A + B closed at the end of 2014 (70 kt/y)

** High-density polyethylene*

© Michel Labelle

SATORP COMPLEX

Contents

- Complex refinery
- Access to advantaged feedstock
- Units operational since mid-2014
- Integrated with petrochemical units producing paraxylene, propylene and benzene
- Joint venture between Saudi Aramco (62.5%) and Total (37.5%)

JUBAIL, SAUDI ARABIA

Refining capacity:
386,000 b/d

Special products: coke

Propylene	Benzene	Paraxylene
200 kt/y	140 kt/y	700 kt/y

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PORT ARTHUR COMPLEX

Contents

- Deep conversion refinery
- BTP*, a world-class steam cracker in partnership with BASF
- Improved cracker flexibility:
  - ➔ 40% ethane
  - ➔ 40% butane and propane
  - ➔ 20% naphtha

* *BASF Total Petrochemicals LLC*

PORT ARTHUR, TEXAS, UNITED STATES

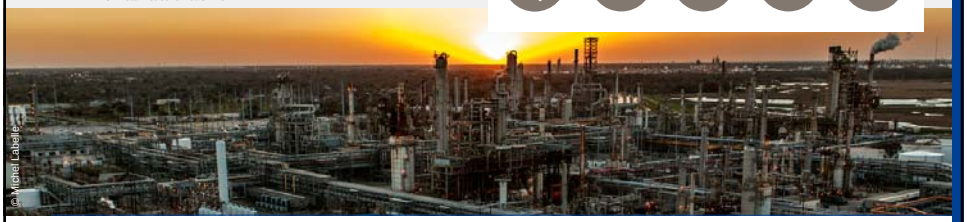
Refining capacity:
169,000 b/d

Special products: special fluids and coke

C3 splitter
1,200 kt/y — at Mont Belvieu *(Total: 33%)*

BTP steam cracker:

Ethylene	Benzene	Toluene	C3 metathesis process	Butadiene
1,090 kt/y	150 kt/y	80 kt/y	300 kt/y	300 kt/y


© Michel Labelle

HTC – DAESAN COMPLEX

HTC: HANWHA TOTAL PETROCHEMICALS CO. (50/50 JOINT VENTURE)

Contents

- Large complex producing a wide range of monomers and polyolefins
- Vast expansion project completed in July 2014: new aromatics unit, new condensate splitter and a 240-kt/y EVA line
- Perfectly positioned to access the Chinese market

DAESAN, SOUTH KOREA

Refining capacity (condensate refinery):
225,000 b/d

Ethylene	C3 metathesis process	Butadiene	Benzene	SM	Paraxylene
1,000 kt/y	230 kt/y	120 kt/y	1,170 kt/y	1,040 kt/y	1,800 kt/y

LLDPE*	HDPE	LDPE**/EVA	EVA	PP
125 kt/y	170 kt/y	150 kt/y	240 kt/y	700 kt/y

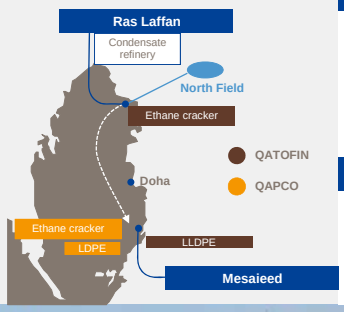
* *Linear low-density polyethylene* ** *Low-density polyethylene*


© Michel Labelle

INTEGRATING OUR ASSETS IN QATAR

Contents

- Two ethane crackers and large polyethylene units
- Rated capacity of 1.15 million tons a year of polymers
- Condensate refinery: capacity to double in 2016 to 292 kb/d
- Partner: Qatar Petroleum



RAS LAFFAN

Refining capacity:
146,000 b/d

Condensate refinery
(Total: 10%)

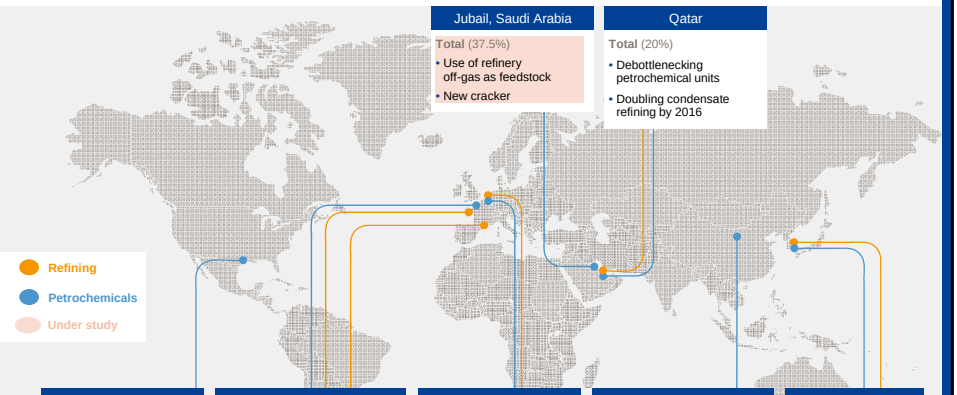
Ethylene
1,300 kt/y RLOC
(Total: 22.2%)

MESAIEED

Ethylene	LDPE	LLDPE
800 kt/y QAPCO	**700** kt/y	**550** kt/y
	(Total: 20%)	*(Total: 48.6%)*

PROJECTS UNDER WAY

Contents



Jubail, Saudi Arabia
Total (37.5%)
- Use of refinery off-gas as feedstock
- New cracker

Qatar
Total (20%)
- Debottlenecking petrochemical units
- Doubling condensate refining by 2016

Port Arthur, United States
Total (100%)
- Ethane side cracker project

France
Total (100%)
- **Normandy** – Capitalizing on improvements at key units and increased feedstock flexibility
- **La Mède** – Biorefinery
- **Donges** – Hydrodesulfurization

Antwerp, Belgium
Total (100%)
- Aligning production with future demand
- Using off-gas to produce olefins

Inner Mongolia, China
Total and China Power Investment
- Coal-to-Olefins (CTO) project: Producing polymers by first converting coal into methanol (MTO-OCP process)

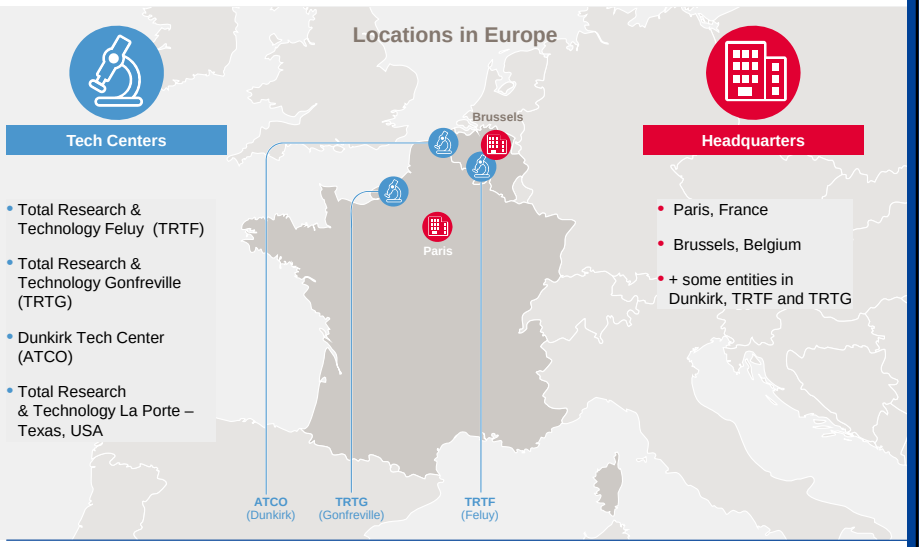
Daesan, South Korea
Total (50%)
Continued expansion

TECH CENTERS AND HEADQUARTERS

Contents

Tech Centers

- Total Research & Technology Feluy (TRTF)
- Total Research & Technology Gonfreville (TRTG)
- Dunkirk Tech Center (ATCO)
- Total Research & Technology La Porte – Texas, USA



Headquarters

- Paris, France
- Brussels, Belgium
- + some entities in Dunkirk, TRTF and TRTG

5 SPECIALTY CHEMICALS

Contents

© Michel Labelle

TWO SPECIALTY CHEMICALS AFFILIATES THAT HOLD LEADERSHIP POSITIONS IN THEIR SEGMENTS

Contents

→ Technological expertise in chemicals and materials science

Elastomers

HUTCHINSON®

2014 revenue: $4.6 billion

Metal and Surface Finishing

ATOTECH

2014 revenue: $1.3 billion

HUTCHINSON®

A WORLD LEADER IN RUBBER AND THERMOPLASTIC ELASTOMER PRODUCTS

Contents

2014 revenue: $4.6 billion

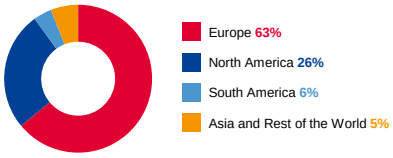
Automotive

2 major markets
70/30

- Sealing systems
- Fluid transfer systems
- Vibration, acoustic and thermal insulation
- Transmission and mobility

Aerospace & Other Industries

Breakdown of 2014 sales by region



Strategy

- Growth in target markets:
  → Aerospace in the United States and Asia
  → Automotive in growth regions
- Innovation and product differentiation
- Excellence

6 ENJOY THIS FRUITFUL MEETING

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6 ADDITIONAL INFORMATION

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GENERIC REFINERY PROCESS SCHEME

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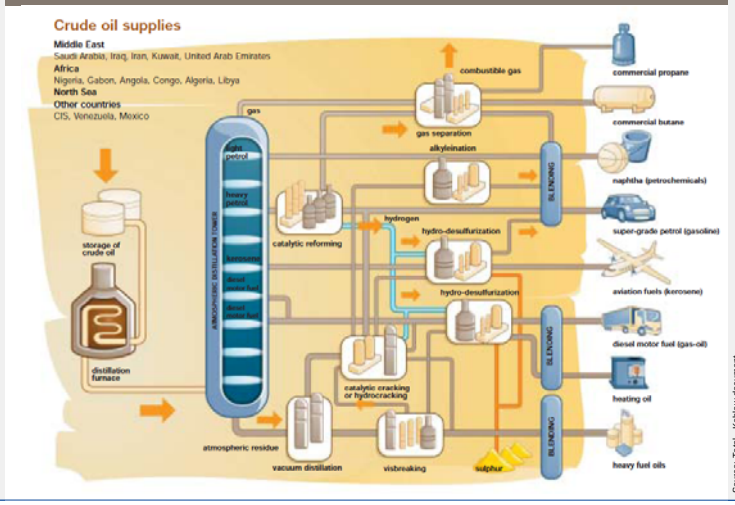
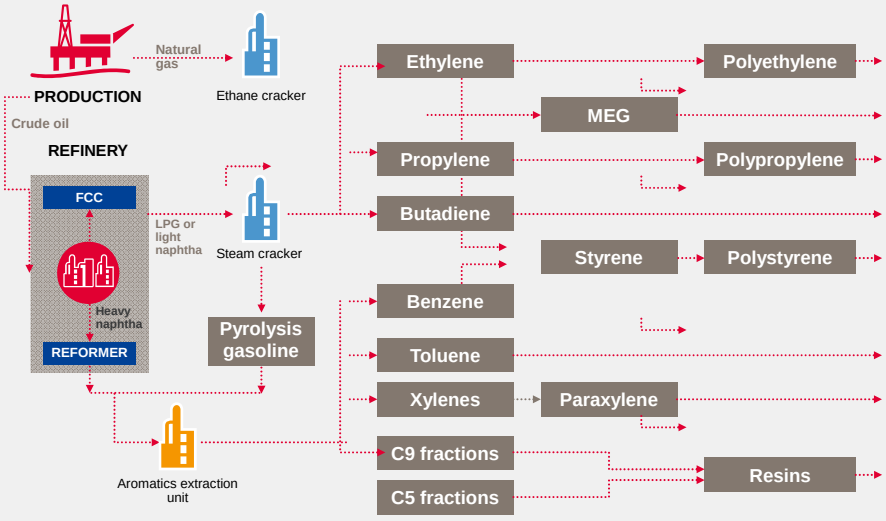
Crude oil supplies



Source: Total - Keblow document

FROM OIL & GAS TO POLYMERS, AN INTEGRATED PROCESS

Contents



OUR COMMITMENT TO SUSTAINABLE DEVELOPMENT

Contents

Feedstock
Renewable
Alternative source of monomers

Processes
Environmentally responsible

Energy efficiency
1% per year reduction in energy use

Use Phase
More environmentally responsible thanks to innovative products

End-of-Life
Effective and environmentally responsible management

Mechanical or energy recycling

Disposal

RESPONSIBLE CARE®
OUR COMMITMENT TO SUSTAINABILITY

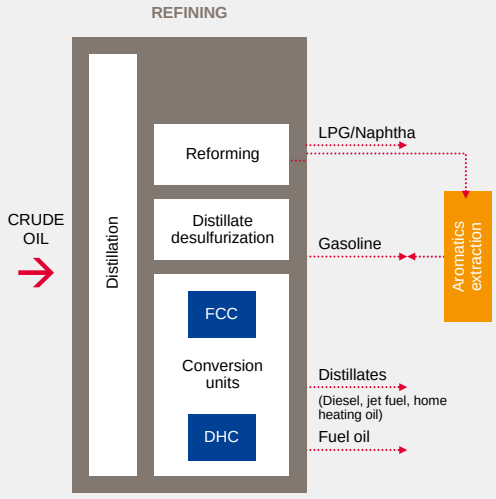
- Axens — Bio-ethylene from ethanol
- UOP A Honeywell Company — Methanol-to-Olefins (MTO)
- futerro — Polylactic acid (PLA)
- coskata — Biotechnology Syngas-to-ethanol
- agilyx — Waste plastics

TOTAL lumicene®

TOTAL ECOSOLUTIONS

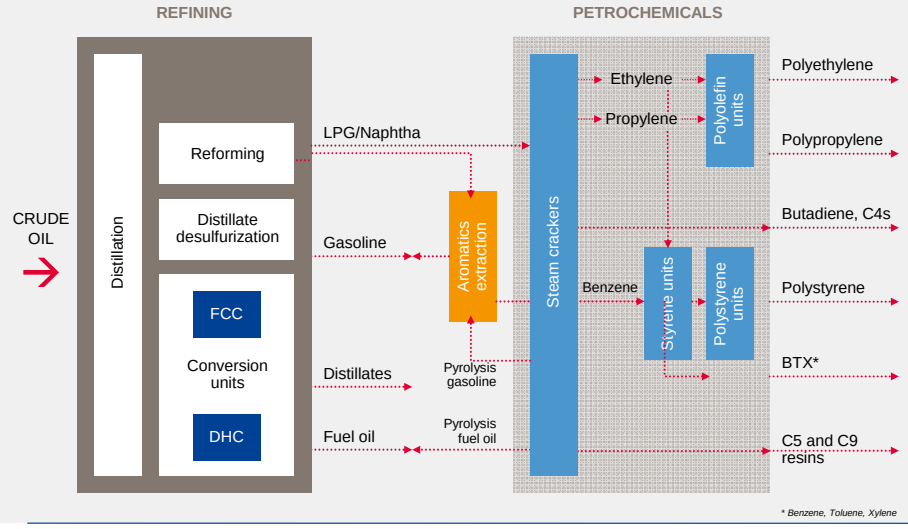
INTEGRATED REFINING & PETROCHEMICALS OPERATIONS: SYNERGIES TO BE DEVELOPED

Contents



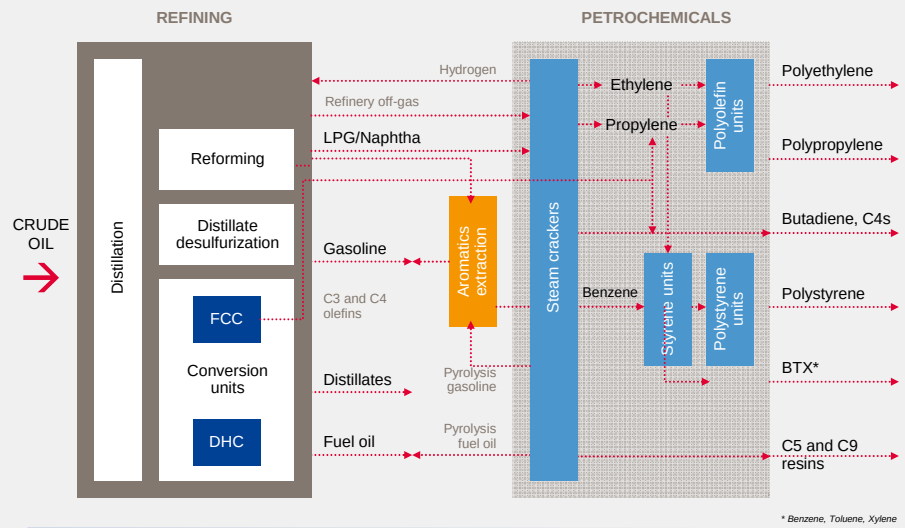
INTEGRATED REFINING & PETROCHEMICALS OPERATIONS: SYNERGIES TO BE DEVELOPED

Contents



INTEGRATED REFINING & PETROCHEMICALS OPERATIONS: SYNERGIES TO BE DEVELOPED

Contents



Appendix 2

List of participants

Participants EFC WP15 meeting 26th April 2016 Paris (France)

NAME		COMPANY	COUNTRY
Augustin	Christel	Total Refining & Chemicals	FRANCE
Bour Beucler	Valerie	Nalco Champion	FRANCE
Ciccomascolo	Francesco	Böhler Welding Holding GmbH	GERMANY
Claesen	Chris J	Nalco Champion	BELGIUM
de Heus	Rob	Sitech services	NETHERLANDS
Delage	Jean Michel	AXENS - IFP Technology Group	FRANCE
Dubois	Francois	AXENS - IFP Technology Group	FRANCE
Dupoiron	François	Total Refining & Chemicals	FRANCE
El Kamel	Meriem	Technip	FRANCE
Escorza	Erick	Tenaris Dalmine	ITALY
Fenton	Stephen	Steve Fenton Consultants	UK
Hofmeister	Martin	Bayernoil Raffineriegesellschaft mbH	GERMANY
Houlle	Patrice	Patrice Houlle Corrosion Service - MTI	FRANCE
Kamionka	Marc	Technip	FRANCE
Koller	Swen	Holborn Europa Raffinerie GMBH	GERMANY
Kus	Slawomir	Honeywell Control Systems Ltd	UK
Lorkin	David	Permasense Limited	UK
Loyan	Sophie	Total	FRANCE
Marcolin	Giacomo	Tenaris Dalmine	ITALY
MeLampy	Michael	PPG Protective & Marine Coatings	USA
Pothuaud	Alain	GE Water & Distributed Power	FRANCE
Rajek	Joachim	TÜV AUSTRIA HOLDING AG	AUSTRIA
Ropital	François	IFP Energies nouvelles	FRANCE
Roquencourt	Mathieu	PetroIneos	FRANCE
Rothwell	John	TWI	UK
Sager	Patrick	Total	FRANCE
Shapcott	Stefen	Johnson Matthey Process Technologies	UK
Suleiman	Mabruk	Takreer	UNITED ARAB EMIRATES
Surbled	Antoine	A.S – CORR CONSULT	FRANCE
Tabaud	Frederic	BP R&LT (Refining and Logistic Technology)	NETHERLANDS
van Rodijnen	Fred	Oerlikon metco	GERMANY
van Roij	Johan	Shell Global Solutions International B.V.	NETHERLANDS
Weisang-Hoinard	Francois	Outokumpu	FRANCE

Appendix 3

Agenda of the 27th April 2016

EFC-MTI Round table on

High Temperature Hydrogen Attack

Materials Technology Institute

"Maximizing resources through a global network of materials specialists"

EuroTAC Spring
27-28-29 April 2016
Paris, France
AGENDA

EFC EUROPEAN FEDERATION OF CORROSION

Wednesday, 27 April 2016 MTI/EFC HTHA Roundtable EFC event N°408 **Chimie ParisTech** **Ecole Nationale Supérieure de Chimie** **11, rue Pierre et Marie Curie** **75231 Paris Cedex 05**		
Welcome and Introduction Safety rules	10:00 - 10:15 am	François Ropital ,(EFC , WP15) Patrice Houlle , MTI
Key Notes : Some considerations on the thermodynamics and kinetics of carbide attack in HTHA	10:15 - 11:00 am	Michael Schutze, Dechema
Hydrogen In Refinery : HTHA and Creep	11:00 - 11:45 am	Sylvain Pillot, Arcelor
Update on API 941	11:45 - 12:30 am	John Houben, Exxon Mobil
Lunch	*12:30 - 1:30 pm*	
Company Experiences: Total	1:30 - 2:15 pm	Charles Le Neve, Total
HTHA Damages	2:15 - 2:45 pm	Karl-Friedrich Schneider, Basf
Air Liquide presentation	2:45 - 3:15 pm	Sophie Wastiaux, Air Liquide
Overview of the Pv and Pw methods and other parametric methods for HTHA rate prediction	3:15 - 3:45 pm	Brian Olsen , Stress Engineering
Break	*3:45 - 4:00 pm*	
"The Use & Misuse of NDE for the identification of HTHA."	4:00 - 4:40 pm	Peter Conlin, Sonomatic
Simulation of NDT	4:40 - 5:20pm	Philippe Dubois, Extende Sébastien Lonné, Extende
R&D project to develop a NDT to measure hydrogen charging in metal and to understand the problem before cracks appear.	5:20 -5:40pm	Joachim Radjek, Tuv Austria
Panel Discussion/ Conclusion	5:40- 6:15 pm	

Appendix 4

EFC WP15 Activities

(F. Ropital)

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
- EFC - NACE agreement (20% discount on books price)
- 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

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

Eurocorr 2016

Montpelier France 11-15 September 2016

Authors will be informed by the end of April

Refinery corrosion session on Tuesday 13th September

Annual WP15 working party meeting during Eurocorr on Tuesday 13th September

On Monday 12th September afternoon the second part of the "Polymer session" will be dedicated to corrosion of polymers in the refinery, petrochemical and chemical industries

http://eurocorr2016.org/

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

•15-20 May 2016
High Temperature Corrosion and Protection of Materials – Les Embiez France
http://www.htcpm2016.com/

•11-15 September 2016
EUROCORR 2016 Montpellier France

•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 5

Advancement of the task force on amine corrosion – Minutes of the 25th April 2016 meeting

(J. Van Roij)

Minutes of the “Amine unit corrosion” Taskforce; 25 April 2016,

With thanks to Cefracor (and Francois Ropital & Jean Kittel) the first Taskforce “Amine plant corrosion” was held at Cefracor, Paris, 25 April 2016.

Present:

Jean Kittel (IFPEN)
Slawomir Kus (Honeywell)
Sophie Loyan (Total)
Mabruk Suleiman (Takreer)
Johan van Roij (Shell)

Michel Bonis informed that he could not be present.

1. Fix the objectives of the work.
    - Extend the scope to gas plants (as proposed during the joined EFC WP13+WP15 meeting Sep 2015); as the current title of the publication 46 indicates the Refinery as the scope of the publication it was decided to change the title into: “Corrosion in Amine Units”. The publication needs to become a more practical guideline on corrosion and corrosion mitigation in amine units.

2. Conduct industry survey to obtain corrosion experience (observed corrosion / corrosion rates, solvent type, operating conditions, etc). Target to have the questionnaire available at Eurocorr and distribute it to EFC13 and EFC15 participants.
   Action for everybody: Think of questions for the questionnaire and format; to be discussed during next meeting.

3. Literature survey: SK, MS & JK already performed an extensive literature survey. Later it needs to be discussed whether this is sufficient and how to include this in the publication.

4. Extend the general section of the Publication 46 to in more detail describe the gastreating process and the corrosion mechanisms in amine units. Incorporate new aspects: e.g. materials selection, practical aspects, integrity operating windows (in combination with parameter limits), corrosion monitoring, inspection, corrosion modeling.
    - Mabruk Suleiman already has written a process description for a publication. With a little rework this looks very suitable for our Publication 46. Target to have draft ready in Sep 2016?
    - Johan van Roij already has written corrosion descriptions for a publication (and Shell internal corrosion courses). With some rework this can be made suitable for our Publication 46 (obviously on basis of the obtained experience mitigation measures, IOWs, etc. need to be added later). Target to have a draft basic description ready in Sep 2016?
    - It was decided to have the corrosion and corrosion mitigation descriptions (including inspection and corrosion monitoring) described and structured per corrosion loop. Jean Kittel and Johan van Roij showed examples of corrosion loops. JK already forwarded his corrosion loops to JvR. Action: Johan van Roij will look at the available corrosion loop

descriptions and extract a proposal for corrosion loop descriptions. Target to have draft ready in Sep 2016?

5. Next meeting (teleconference): May 19th, 9:00 AM

6. New members task force.
   During the EFC WP15 spring meeting two new people volunteered for the Taskforce: Steve Fenton (Protective Polymers Ltd) and Chris Claesen (NALCO Champion). They are welcomed and receive an invitation for the teleconference May 19.

Appendix 6

Continuous corrosion monitoring in amine acid gas units – a European refinery case study

(D. Lorkin)

permasense®

Experts in remote monitoring solutions

Continuous Corrosion Monitoring in Amine Units – A European Refinery Case Study

David Lorkin, European Sales Manager

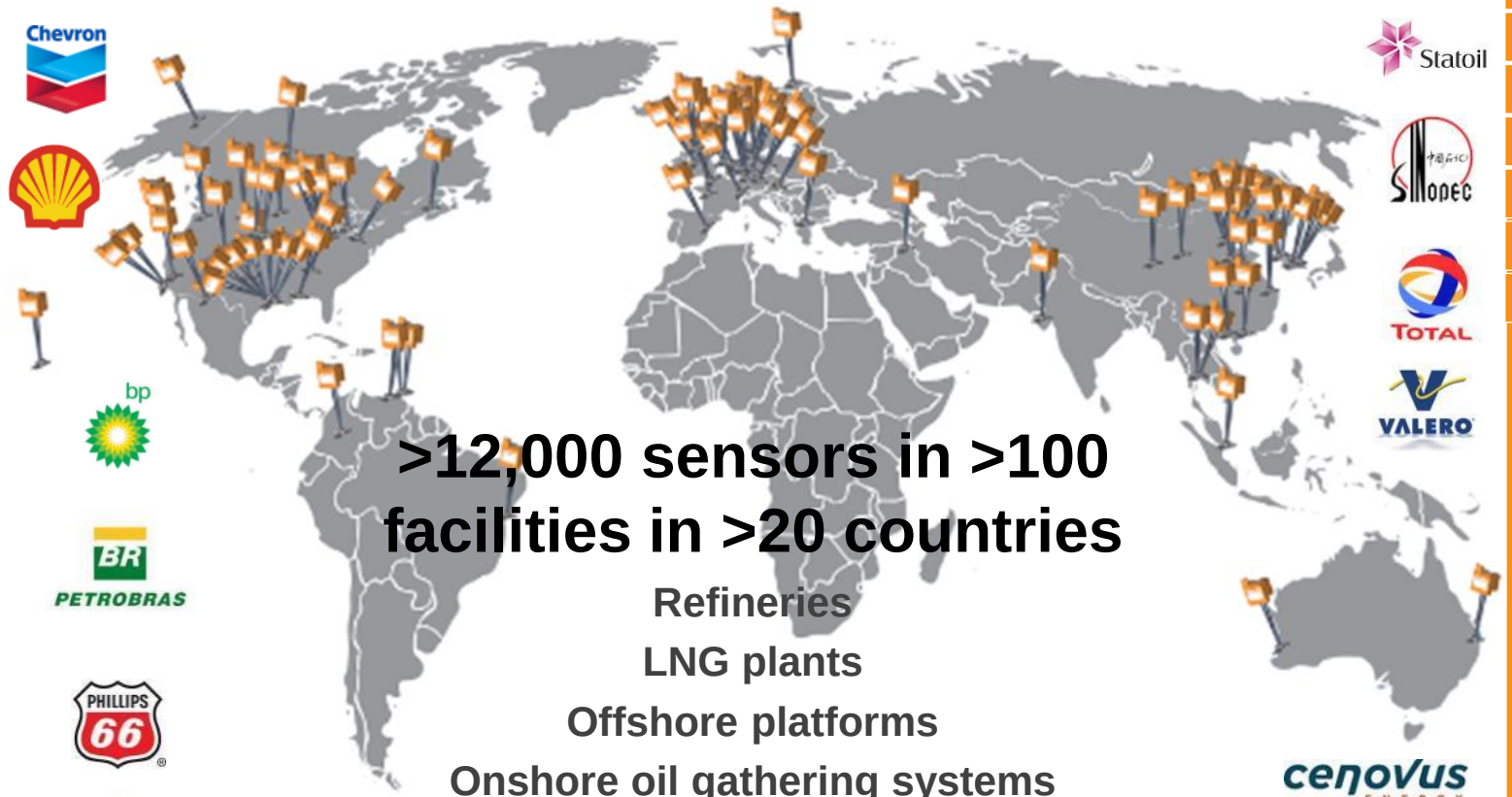
EFC Working Party 15 Corrosion Refinery Industry Meeting – Paris, 26th April 2016

Industry challenges: corrosion and erosion issues

- Well understood:
  - Process conditions
  - Crude constituents
  - Abrasive solids
  - Inhibitors
  - Metallurgy
- Not well understood:
  - Rate of damage
  - Variability of rate of damage from above factors
- Leading to:
  - Conservative operations, and/or feedstocks
  - Unplanned outages, and/or loss of containment

Industry challenges
Company >
Solutions >
System outputs >
System benefits
Business case
Technology
Deployment >
Applications >
Summary

Deployed worldwide, extensive references



>12,000 sensors in >100 facilities in >20 countries

Refineries

LNG plants

Offshore platforms

Onshore oil gathering systems

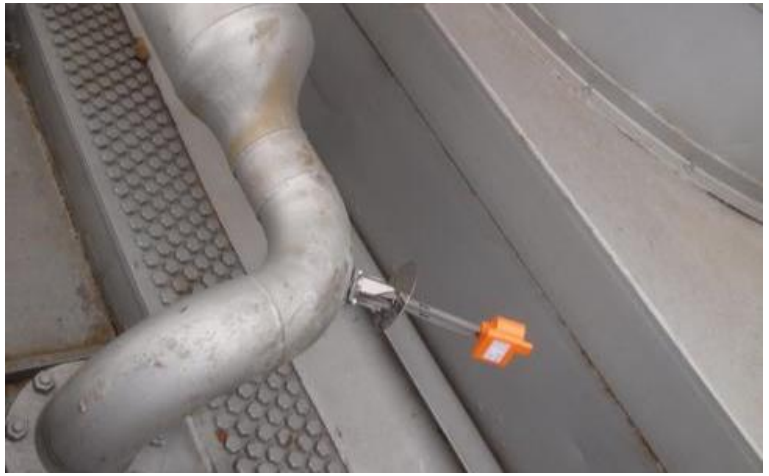
Pipelines

FPSOs

Power plants (gas and geothermal)

Industry challenges
Company >
Solutions >
System outputs >
System benefits
Business case
Technology
Deployment >
Applications >
Summary

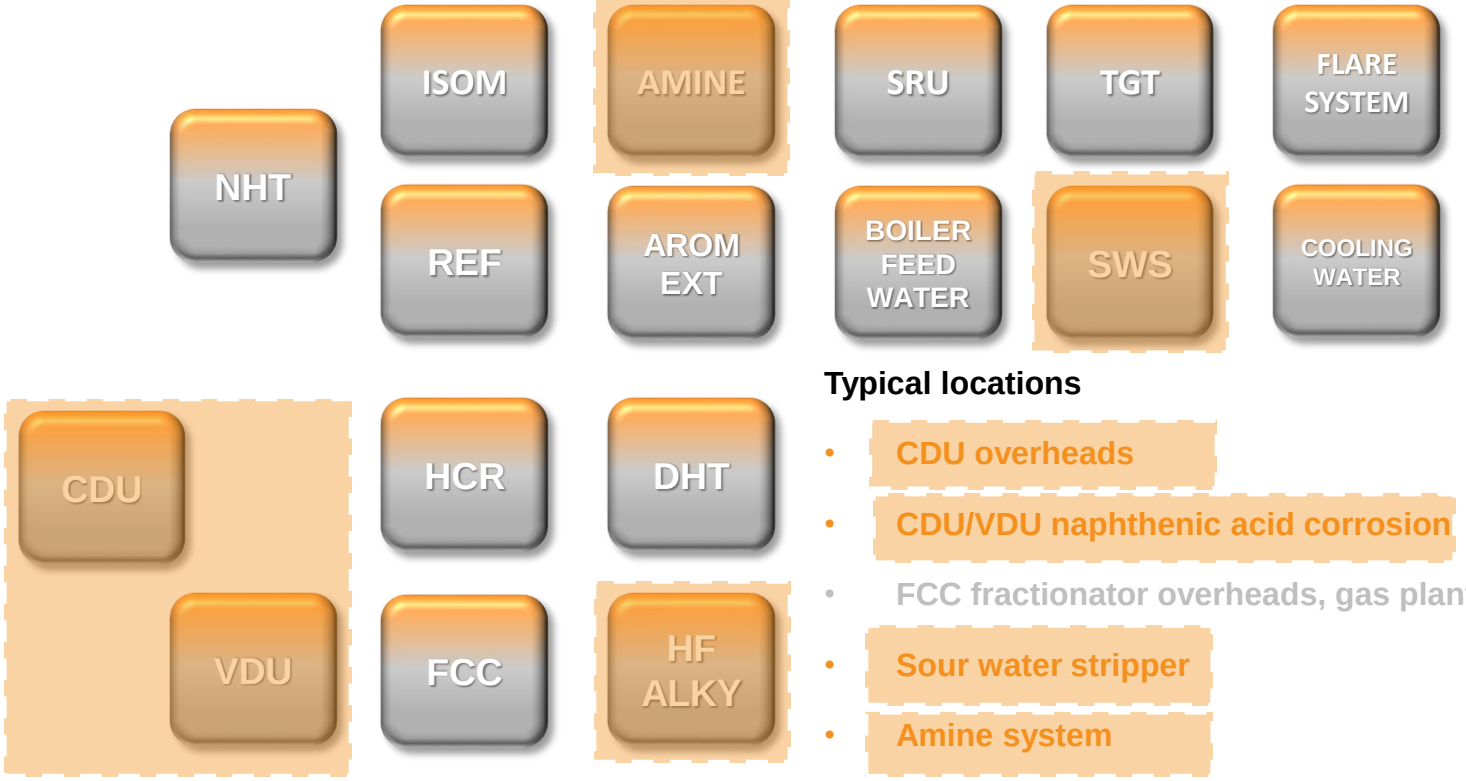
Permasense System installed on Process Units



Industry challenges
Company
Solutions
- Short-range
- Long-range
- Modular

System outputs >
System benefits
Business case
Technology
Deployment >
Applications >
Summary

Proven Applications in Refining



Typical locations

- CDU overheads
- CDU/VDU naphthenic acid corrosion
- FCC fractionator overheads, gas plant
- Sour water stripper
- Amine system
- Alky feed driers / main fractionator / depropaniser
- Hydrotreater REAC, stripper overheads
- Isomerisation, reformer stabilisers

Sensors installed on all metals found in oil & gas: from carbon and chrome steels & chrome steels to super-alloys

Challenges of Corrosion in Amine Units

- Corrosion by CO_2 and H_2S (and possibly accumulation of NH4, HCN, organic acids)
- Corrosion in vapour phase, amine solution and regenerator reflux
  - Wet acid gas corrosion of carbon steel from reaction of CO_2 and H_2S with iron through a thin liquid film
  - Amine solution corrosion of carbon steel in presence of aqueous amine
- Many variables:
  - Temperature
  - Choice of Amine-type
  - Acid Gas Loading
  - Velocity and Wall Shear Stress
  - Impurities (heat-stable amine salts)
  - CO_2 to H_2S ratio

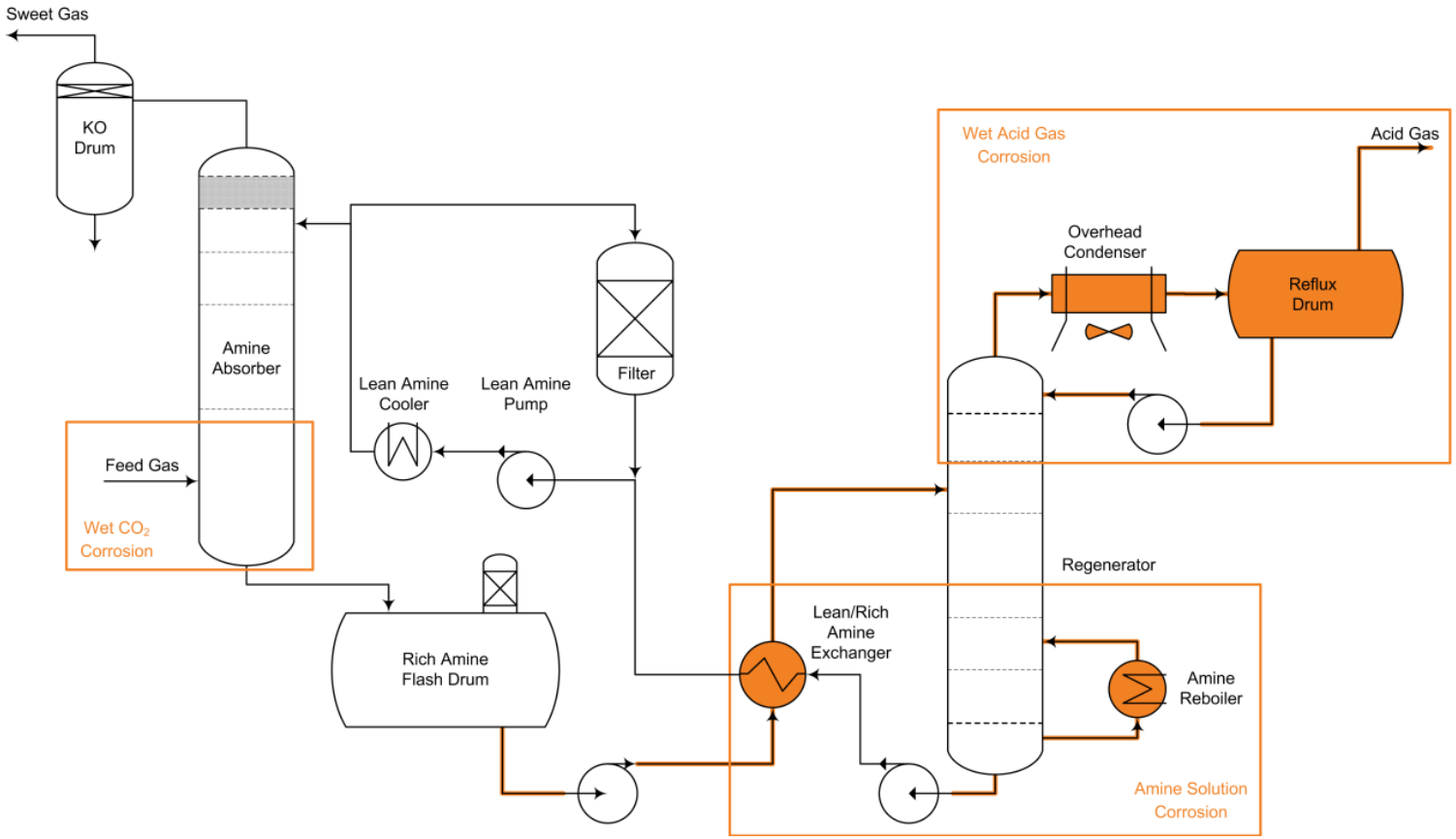
Modelled Corrosion Rates for Carbon Steel as a Function of Velocity and H2S Concentration

Averaged corrosion rates for carbon steel				
Velocity [ft/s]	H2S loading as molar ratio to MEA			
	0.2	**0.4**	**0.6**	**0.8**
0	0	0	1	1
20	8	12	12	12
40	12	14	16	20
60	13	16	20	43
80	16	18	25	66

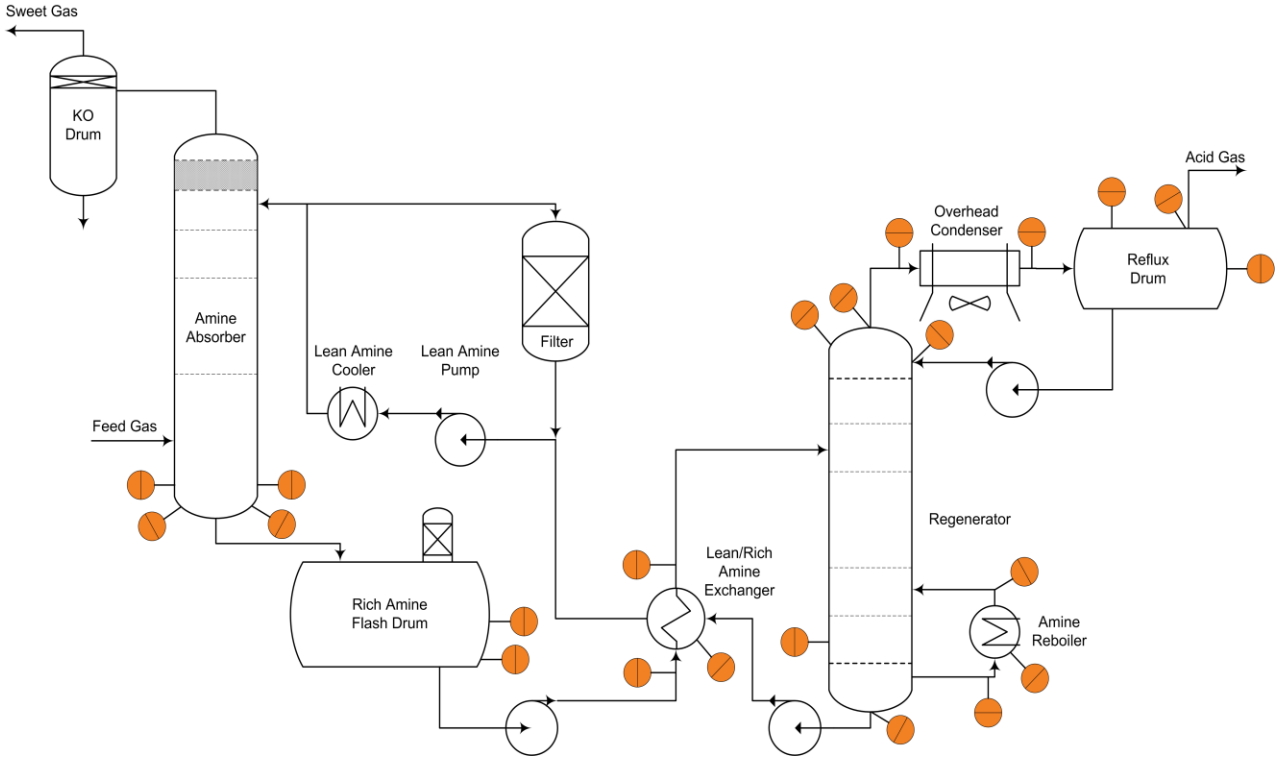
	< 5 mpy
	5 - 10 mpy
	10 - 15 mpy
	15 - 20 mpy
	20 - 50 mpy
	> 50 mpy

Variation of corrosion rates for carbon steel with amine acid gas loading and velocity. As expected, high rich amine H_2S loading, combined with high velocity, results in higher corrosion rates.

Amine Unit – Simplified Process Flow Diagram showing High Risk Corrosion Areas



Proposed Location of Sensors in Amine Absorption and Regeneration Sections



- Corrosion issues
  - High gas loading
  - Heat stable salts
  - Amine degradation
  - Oxygen contamination
- Corrosion is uniform and not so localised
  - Fewer measurements needed to represent entire system
  - Elbows, bends, tees, exchanger shells
  - Lower temperature application, ET210s

Typically 10-15 measurement locations, 2-3 sensors per location

WT Sensor:

- **Standard sensor** length accommodates
  - temperatures up to 600 °C, e.g. refinery crude unit pipework
  - temperatures down to -180 °C, e.g. LNG plants
  - thick insulation or lagging

- **Compact** – short waveguide – version where extreme temperature capability not required

- Attached by Studs (full temperature range) or Clamps (up to approx. 250°C)
- Temperature and Material Compensation and AXC

Industry challenges
Company
Solutions >
System outputs >
System benefits
Business case
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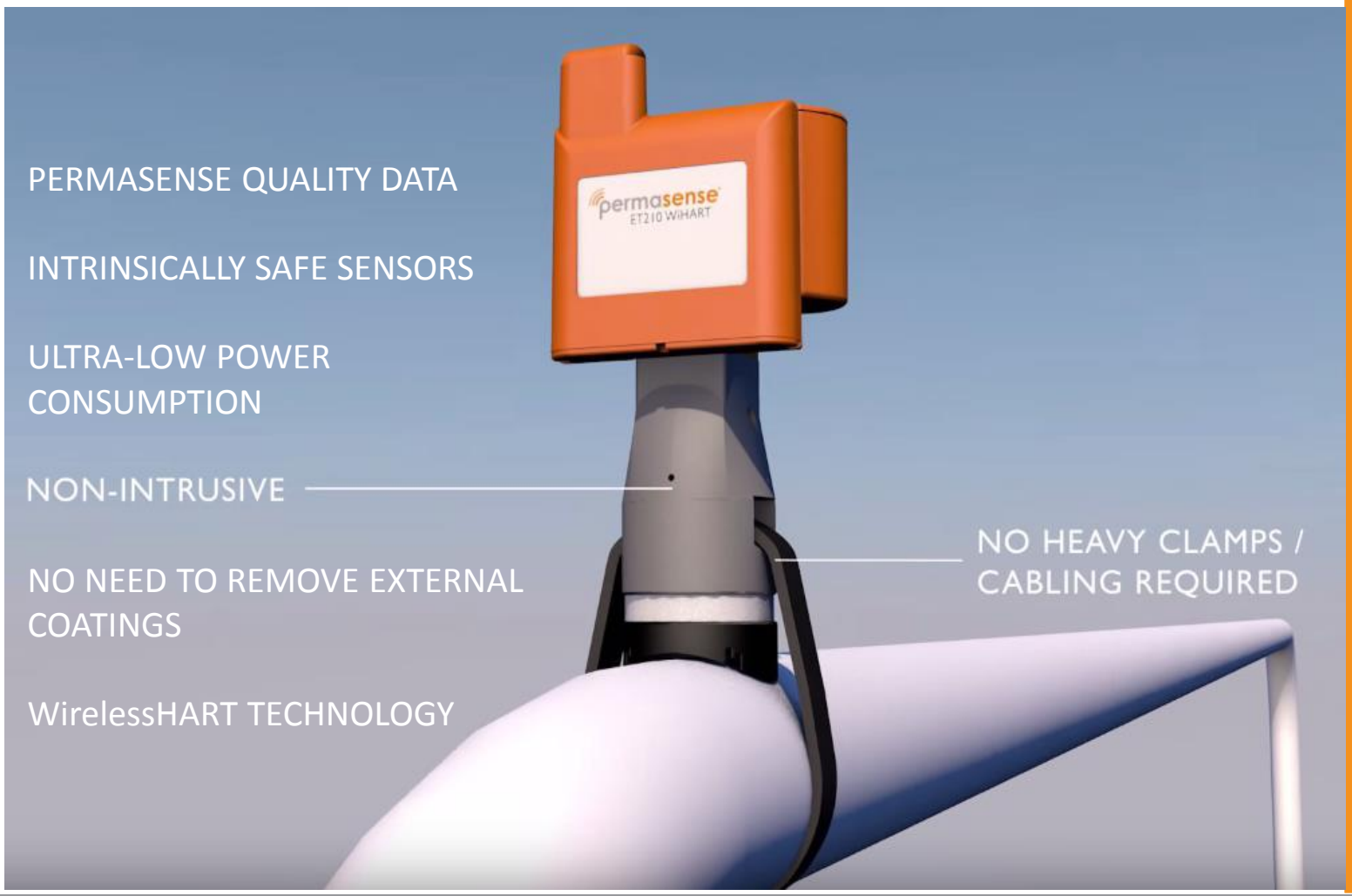
ET210 sensors for easy installation in locations operating under 120 °C (250 °F)

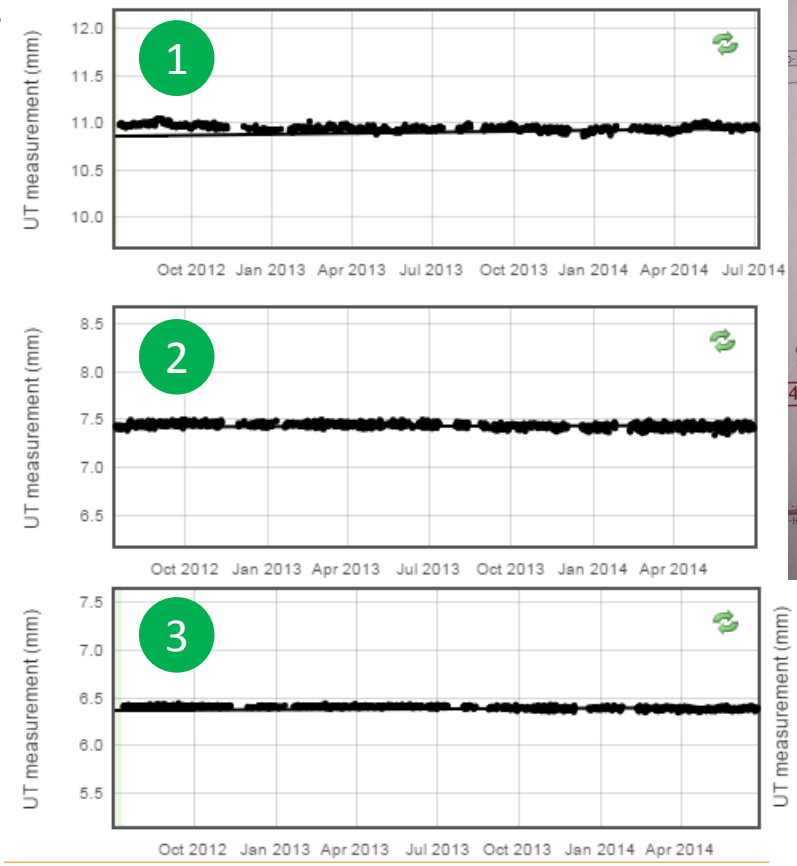


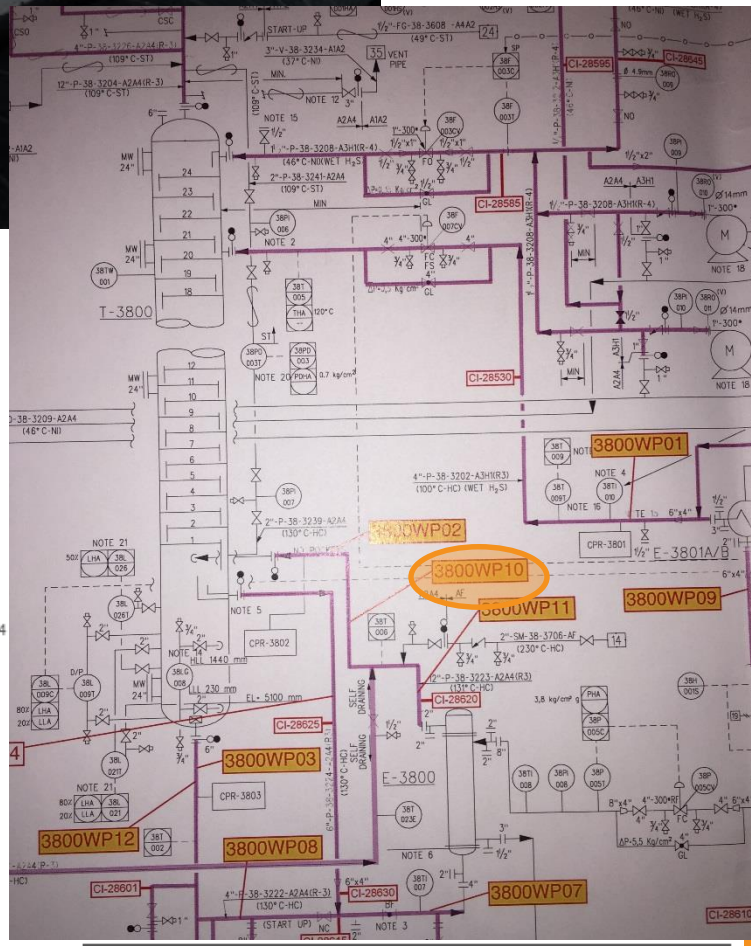
Quick and easy installation: Magnetically – heat-resistant plastic strap provides additional robustness

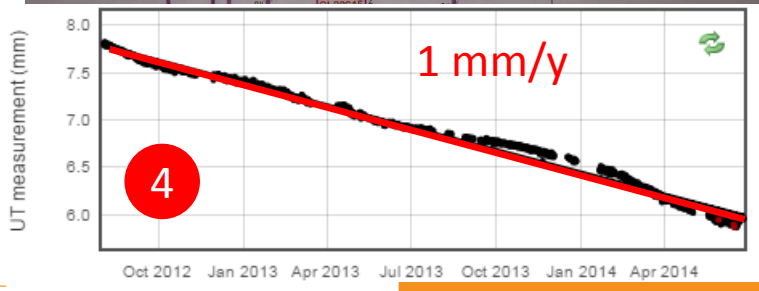
No need to remove coating:
Measures through up to 1mm of external coating

European Refinery Case Study:
Amine Absorption and Regeneration

- Customer has four amine absorber/regeneration trains
- All trains have a very similar configuration
- Markedly higher corrosion in Train 4 shown on reboiler return sensor data
- Feed showed high CO_2 content – preferential routing of FCC sour gas to this train
- Feeds were redistributed to dilute the high CO_2 gas







Continuous high-quality data enables…

- **Confidence in asset management**
  - early identification of corrosion / erosion activity
  - understanding of causes – correlation with process condition changes
  - better forecasting of attainment of retirement thickness
- **Optimisation of prevention / mitigation strategies**
  - correlation of trends with inhibition strategy
- **Insight into impact of feedstock decisions (refineries)**
  - rapid feedback with changes in crude slate
- **Cost-effective, *safe* measurement**
  - no cost of repeat measurements
  - no shutdown for measurement
  - no personnel exposure to high-risk locations

Industry challenges
Company
Solutions >
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Financial return from investment in Permasense technology

Industry challenges
Company
Solutions >
System outputs >
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Applications >
Summary

- SYSTEM PAYBACK TIME

Months to a Year

Days to Weeks

Very short

• REDUCE OPEX SAFELY
Enhance Maintenance Planning
Optimise Corrosion Control

• OPTIMISE OPERATIONS
Diversify Crude Basket
Maximise Availability
Enhance Refinery Flexibility

• AVOID MAJOR INCIDENTS
Avoid Loss of Containment
Avoid Unplanned Outages

THANK YOU FOR YOUR ATTENTION

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Appendix 7

Perforation of plates in a Sulreen reactor

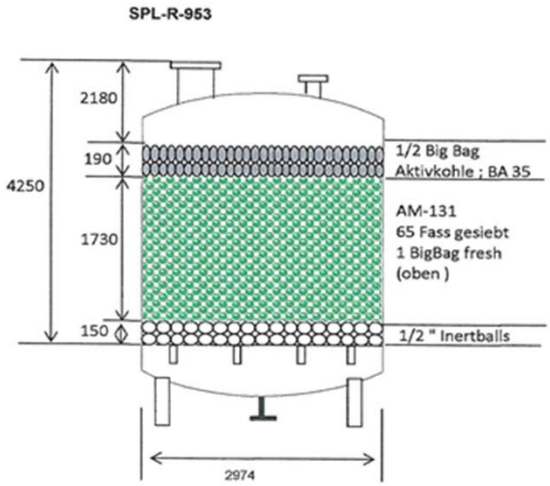
(S. Koller)

Sulfreen reactor damage

HOLBORN EUROPA RAFFINERIE GMBH

1. Overview
2. Description of the damage
3. Damage analysis
4. Conclusion / Discussion

Overview

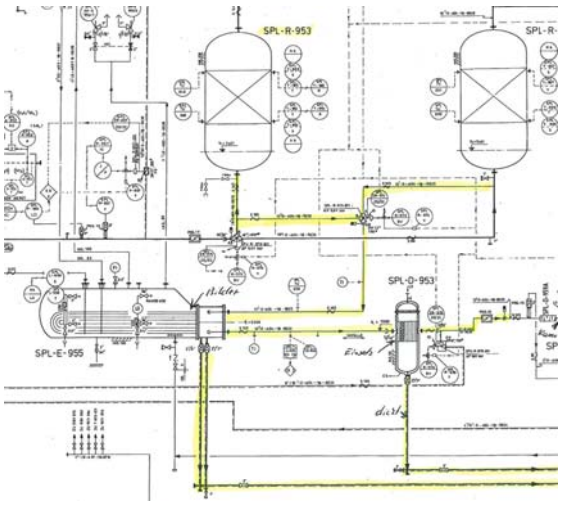


Overview

- Operation:
  - Tail gas from the Claus unit is cooled in the process gas cooler to ca. 135°C and passes through the sulphur separator before entering one of the two reactors.
  - Tail gas has usually 0,6 to 0,8 % H_2S and 0,3 to 0,4 % SO_2
- Regeneration:
  - For water and sulphur desorption a gas flow is established in the opposite direction with a temperature of ca. 320°C.
  - Regeneration gas has usually 0,2 to 0,3 % H_2S and up to 0,2 % SO_2

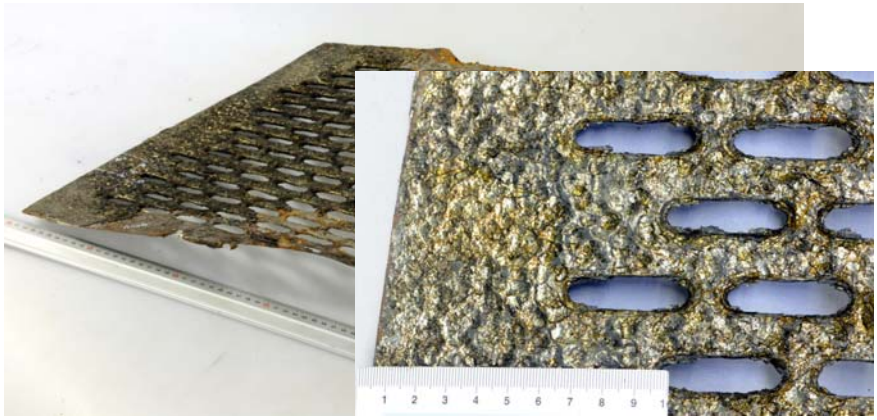
Overview - View into the reactor

Overview - Cat in the reg-gas-system



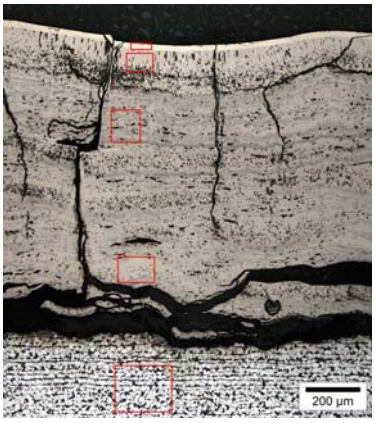
Damage analysis

Distributer (support bottom)

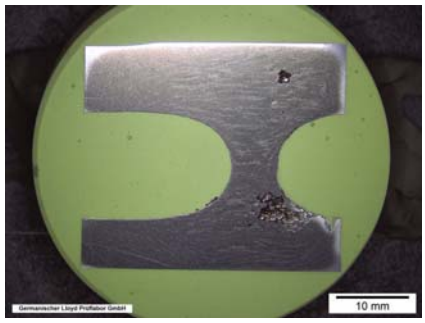


Damage analysis

Sulfidication



weak acid corrosion



Conclusion / Discussion

Material Selection:

1. **High-temperature steel with sufficient corrosion addition and replacement every 10 years**
2. **High-temperature steel with TSA-coating**
3. **Stainless steel**

Operating Parameter

1. **Increase the process temperature to 150°C**
2. **Decrease the regeneration temperature to 315°C**

Appendix 8

Sulfidation of a new ferritic stainless steel

(G. Marcolin)

Tenaris Overview

Serving the world's energy industry and other industrial applications

6.3

Million tons of steel pipes

Annual manufacturing capacity

3.7 million tons of seamless pipes

2.6 million tons of welded pipes


OCTG


Premium Connections


Offshore Line Pipe


Hydrocarbon Processing


Power Generation


Industrial & Automotive

16

Countries

Manufacturing facilities

5

R&D Centers

Worldwide

THOR™115

Demanding projects require high performing materials.
That's why Tenaris worked on the development and qualification of **a new ferritic steel product**.

THOR 115
TENARIS HIGH OXIDATION RESISTANCE STEEL

Born for Power Generation:

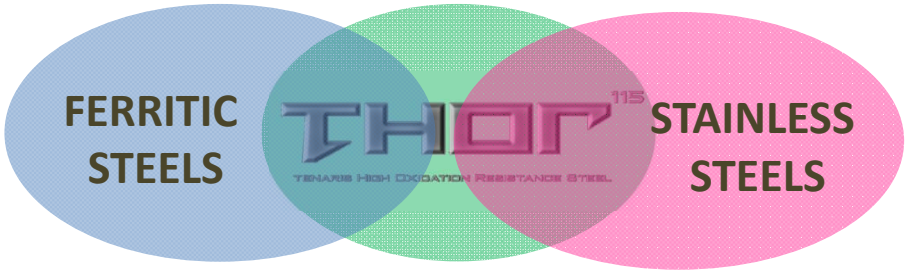
- Creep rupture strength equal and even better than T/P91
- Improved steam oxidation resistance when compared to T91/T92
- **Easy to manufacture,** put in service and weld

Nominal Cr content: 11%

THOR™115 Opportunities

Chemistry identified as suitable for Refining corrosive environment

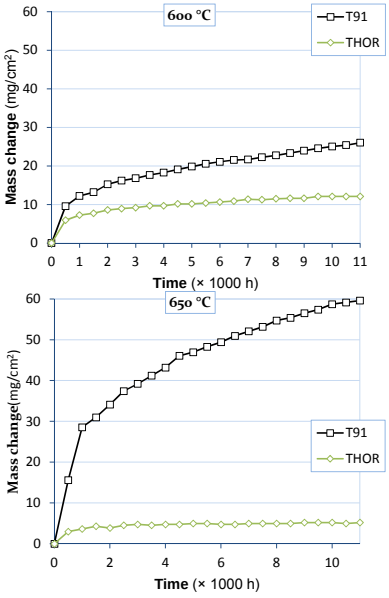
- Chemical composition in the middle of Ferritc and Stainless families
- Identification of fields of application of those materials
- Study of THOR behavior to understand strengths and weaknesses coming from Ferritic Steels and Stainless Steels

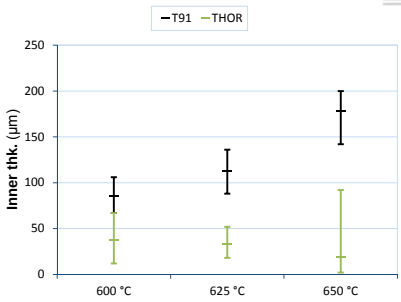


Test Plan Definition

- Loops identification
- Corrosion mechanisms
- Parameters identification
- Laboratory conditions definition
- Test equipment for dedicated trials
- Benchmarking with materials used in the identified service conditions

Steam Oxidation

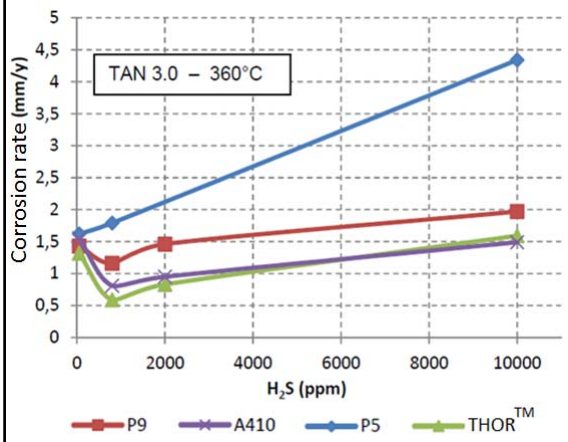




- Tests performed at Oak Ridge National Lab
- 11000 hours reached
- Benchmarking with T91

- THOR shows significantly better resistance vs P91 in terms of mass loss and oxide growth
- Mass change and scale thickness similar at 600°C and 650°C for THOR

High temperature sulfidation and naphthenic attack

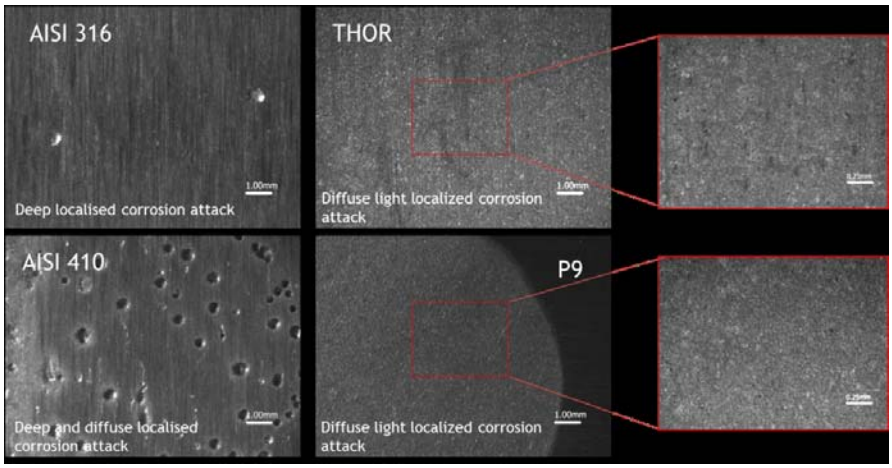


- Pilot Plant in VeneziaTeconolgie that allows to simulate operative conditions without fluid degradation
- Comparative tests
- Tests in naphthenic and sulphidic environment typical of refinery streams before desulphuration
- Expected trends confirmed after weight loss analysis at different H_2S contents

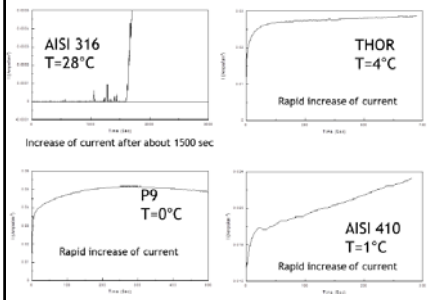
THOR SHOWS BETTER RESISTANCE vs P9, COMPARABLE TO A410

Chlorides – preliminary results

- Test Parameters as per ASTM G150
- Critical Temperatures for Pitting and Crevice
- Pitting morphology observation



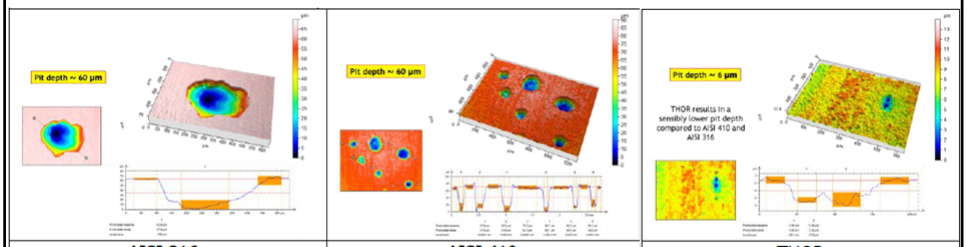
Chlorides – preliminary results



Pitting morphology observed on THOR and SS:

- Diffuse shallow pits on THOR surface (depth ≈ 6 µm)
- Deep localized pits on SS (depth ≈ 60 µm)

Possible advantage in critical-defect failure modes



AISI 316	AISI 410	THOR
Pit depth ≅ 60 µm	Pit depth ≅ 60 µm	Pit depth ≅ 6 µm

Line components - Flanges

- **Flanges** (18'' and 1'') forged at Officine Melesi
- Raw material: Dalmine steelshop billet
- Process parameters equal to the ones used for F91 flanges
- No problems during production process
- Full mechanical characterization, values well above min std requirements for F91
- Trial considered fully successful

- **Fittings**: elbows (45° and 90°) and Tees (18''x18'' and 18''x 6'') under development

THOR^{TM}115 in International Standards

- *December 2014*: **Patent** published
- *April 2016*: **VdTÜV** approval received (Materialsheet 580, March 2016)
- *August 2016*: **ASME** code will be presented (ASME insertion expected by End 2016)
- *May 2016*: **ASTM** will be presented (A213, A335 will follow)

Next steps

- New tests to reinforce available data
- Identification of new testing conditions
- Test Loops
- Chemistry fine-tuning for special application

Any advice on test condition or test equipment is more than welcome!!!

Tenaris

Tubular Technologies. Innovative Services.

Thanks for your attention

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Appendix 9

CUI: utilization of Bayesian networks for prediction of location

(J. Rajek)

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CUI

Corrosion under Insulation

& Bayesian networks

J. Rajek

S. Jain

Motivation + Status

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- ✔ **CUI is a known threat to the process industry**
- ✔ **The problem areas are “out of sight”**
- ✔ **Mitigation is time consuming and expensive**

1. **Reduce incidents due to CUI – increase process safety**
2. **Save money for mitigation – do it more clever**

Status:

Feasibility done

Cooperation partner list in development (EFC?)

Literature research

Basic modelling in progress

Bayes' theorem

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- **Bayes' theorem describes the probability of an event, based on conditions that might be related to the event**

$$p(B/E) = \frac{p(E/B) \cdot p(B)}{p(E)}$$

We want to know

We know, have data, our hypothesis

- **In other words…**
  Initial Belief p(B) plus new Evidence = new and improved belief p(B/E)

Bayes' theorem

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- **Bayesian networks can…**
  - Make predictions under uncertainty
  - Handle unknown data via probabilistic data
  - Handle multiple inputs: Measurements, statistics, judgements

- **Bayesian networks allow…**
  - Using distributions if hard data are missing
  - Learning from small amount of information
  - To find the most probable cause - and fix it

Example – coin flip

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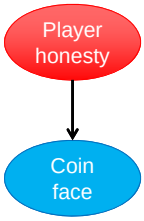
- ✔ I propose to flip a coin
- ✔ You believe by 10%, that I am cheating = use double-headed coin
- ✔ Evidence: On each flip “head” shows up

→ **How does this influence your believe that I cheat?**



✔ **We know:**

- Probability that I am a liar = 10% (assumption, hypothesis)
- If liar: Probability for “head” = 100% (model, facts)
- If honest: Probability for “head” = 50% (model, facts)
- Flip coin: Check if head or tail (test, evidence)

$$p(Liar/Head) = \frac{p(Head/Liar)\cdot p(Liar)}{p(Head)}$$

You want to know this =unknown

You use assumption and evidence =known/assumed

Example – coin flip

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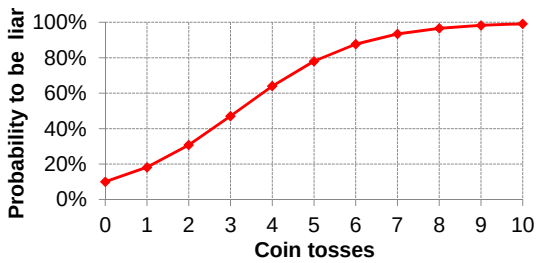
Initial assumption: p(Liar) = 10%

1. test: p(Liar if head shows up) = 18% → update assumption

$$p(\underline{L}iar/\underline{H}ead) = \frac{p(H/L)\cdot p(L)}{p(H/L)\cdot P(L) + p(H/noL)\cdot P(noL)} = \frac{100\%\cdot 10\%}{100\%\cdot 10\% + 50\%\cdot 90\%} = 18\%$$

2. test + evidence from 1. test: p(Liar if head shows up) = 31%

$$p(\underline{L}iar/\underline{H}ead) = \frac{p(H/L)\cdot p(L)}{p(H/L)\cdot P(L) + p(H/noL)\cdot P(noL)} = \frac{100\%\cdot 18\%}{100\%\cdot 18\% + 50\%\cdot 82\%} = 31\%$$



- ✔ **Falsify hypothesis**
- ✔ **Increase confidence**

Example - accident

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- ✔ **You are in the office and think about driving home**
- ✔ **Data you have:**
  - You know the time
  - You see if it is cloudy or raining
  - You could hear a siren on the highway
- ✔ **Should you drive home now?**
- ✔ **What is the chance for a traffic jam?**

Example - accident

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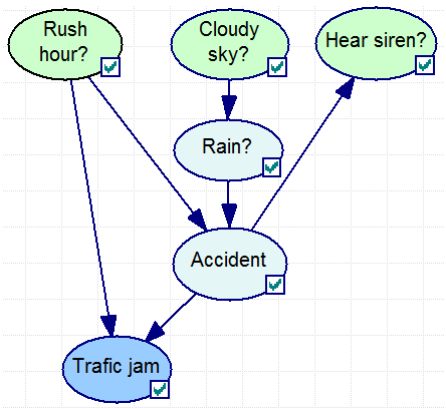
- ✔ **Possible Bayesian network**



Example - accident

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- ✔ **Prior data, example**
- ✔ **Sources: Statistics, experience, calculations, measurements**

	Cloudy sky?
clear	90%
cloudy	10%

	cloudy	clear
road wet	50%	5%
road dry	50%	95%

Rush hour	yes		no	
Rain	road wet	road dry	road wet	road dry
Accident happened	70%	40%	60%	10%
No accident	30%	60%	40%	90%

Vertical sum = 100%

Example - accident

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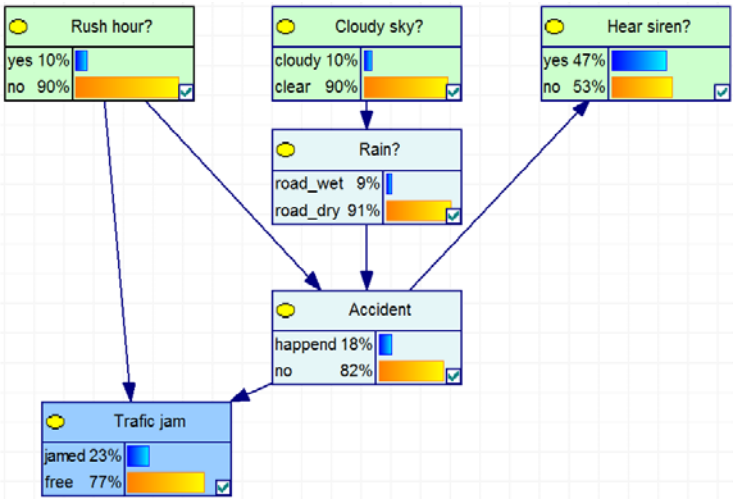
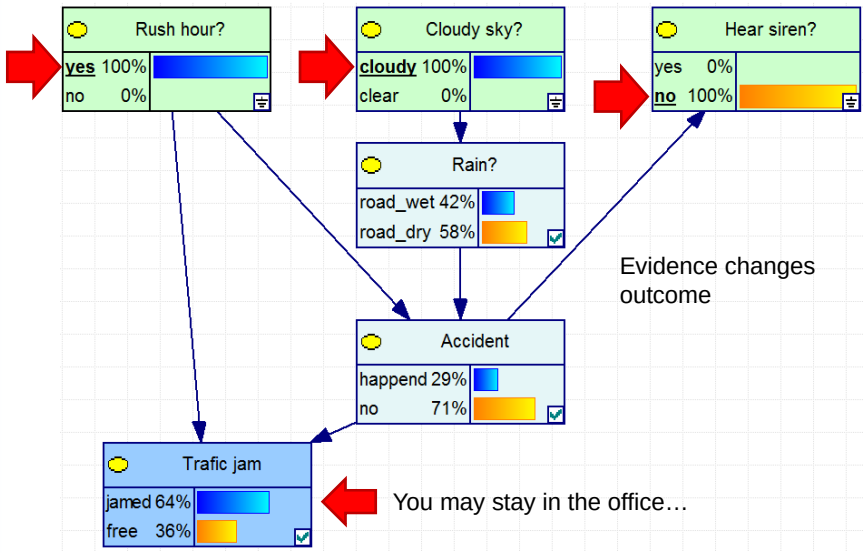
- ✔ **Prior data, no evidence**



Example - accident



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CUI score tables as Bayesian network

- ✔ **Mimic CUI score tables (example)**
  - Operating temperature influence on CUI?
    - Good (no influence): T<-5C or T>175C
    - Middle: -5C<T<50C or 110C<T<175C
    - Bad: 50C<T<110C
  - Jacketing condition
    - Good, middle, bad condition
  - Coating condition
    - Good, middle, bad condition

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CUI score Bayesian network, start

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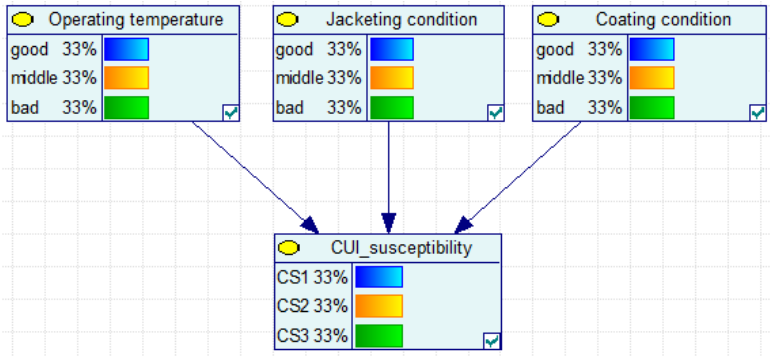
✔ **Even prior data „no knowledge”**

- All influencing parameters evenly distributed
- Model predicts even CUI susceptibility



CUI score Bayesian network, start

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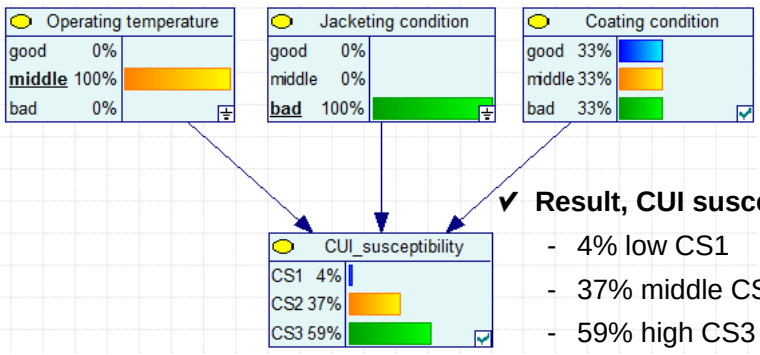
✔ **Influence of prior data**

- Operating temperature = 40C → middle
- Jacketing: Open on many places → bad
- Coating: *Unknown*



✔ **Result, CUI susceptibility**

- 4% low CS1
- 37% middle CS2
- 59% high CS3

CUI score Bayesian network, start

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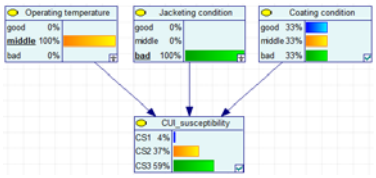
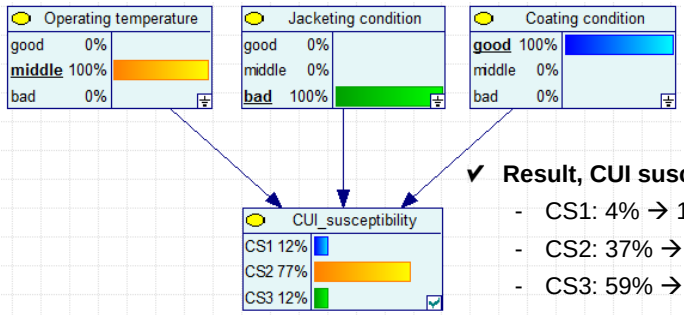
✔ **Add evidence data about coating:**

- Coating: Good condition
  → good





✔ **Result, CUI susceptibility shift**

- CS1: 4% → 12%
- CS2: 37% → 77%
- CS3: 59% → 12%

CUI score Bayesian network, start

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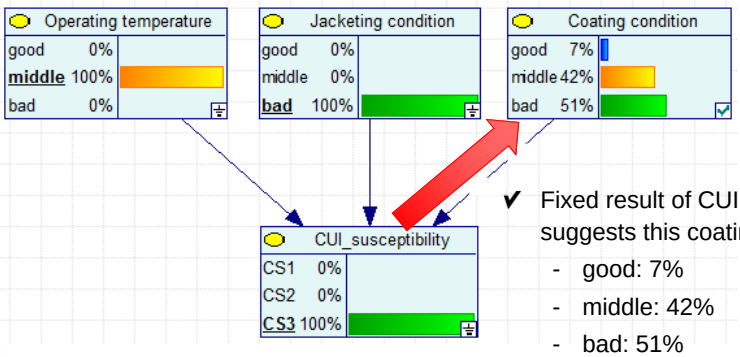
✔ **Bring in evidence, inferring**

- We found CUI condition 3 = “proof”

→ What can we learn about our coating condition?



✔ Fixed result of CUI susceptibility suggests this coating condition:

- good: 7%
- middle: 42%
- bad: 51%

Expectations

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- ✔ **Better utilization of existing data → learn**
  - Analyse data and find hidden patterns
  - Identify missing data-types
- ✔ **Better link of data**
  - Conditions, service and CUI over physical location
  - Confidence rating for prediction: Enough NDT data?
- ✔ **Outcome**
  - More precise prediction of severity AND location of CUI
  - More confidence in CUI inspection and testing program
  - Increased process safety
  - Optimised effort (safe money)

Next steps

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1. **Collection of ALL data possible**
   - Finished CUI projects
   - Published data
2. **Test & improve model**
   - Compare model results with finished projects
   - Compare model results with score table approach
3. **Discuss results with industry partners, EEPC gets:**
   - Analysis of existing data
   - Proposal how to improve CUI assessments – if possible
   - Update score tables – if necessary
4. **Pilot project?**

Thank you for your attention!

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Krugerstrasse 16, 1015 Vienna
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Joachim Rajek
joachim.rajek@tuv.at

Software: GeNIe
Decision Systems Laboratory
University of Pittsburgh

Backup

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✔ **Backup…**

Process - Results - Costs

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Initial analysis	Inspection & Risk evaluation	Risk mitigation planning	Maintenance & inspection
Output			
Prioritization Inspection plan	Risk evaluated	Mitigation plan: what, when, how?	Implementation of measures
Distribution of costs			
Engineering <3%	Scaffolding 20% Insulation 30% Inspection 10% Cleaning 5% Admin&Docu 11%	Engineering <1%	Maintenance depends… 20%

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Motivation

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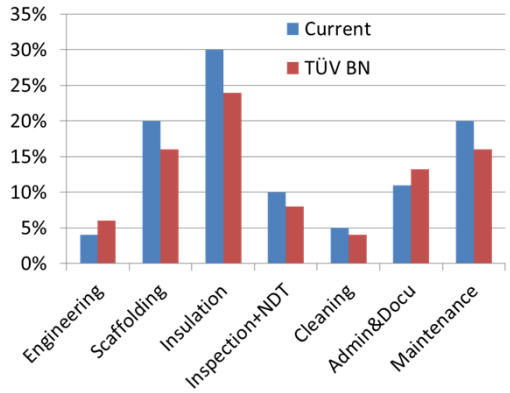

Costs

- ✔ **20% Reduction of mechanical tasks = -14% total costs**
- ✔ **10% Reduction of inspection and NDT tasks = -1% total costs**
- ✔ **10% Increased engineering, documentation = +4% total costs**
- ✔ **Potential savings = 12% of current CUI project costs**

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The team

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Joachim Rajek

Current: **TÜV Austria Services, Industry & Energy**

Previous:

OMV R&M, Head of Inspection & Integrity, Schwechat refinery

PhD, mechanical engineering & economics

Swati Jain

Current : **Senior Data Scientist/Independent consultant**

Previous :

DNV GL, oil&gas research engineer

PhD, chemical engineering

Process

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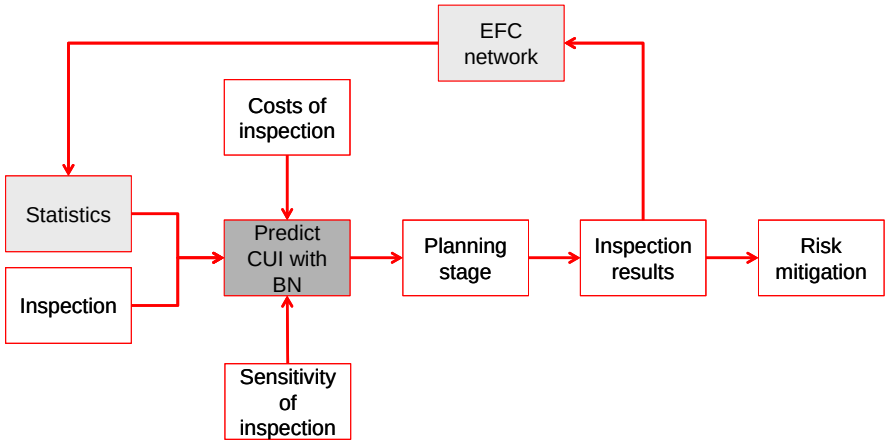

Bayes' theorem, cancer example

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- ✔ **1% of population has this illness**
- ✔ **Test sensitivity=99% → 99% of people tested are identified correctly**

→ What is the probability to have illness given the test result is positive?

	illness	No illness
Test +	99%	1%
Test -	1%	99%

P(ill)=1% Population has illness

P(T+)=1,98% of all test results are positive

$$p(C/T+) = \frac{p(T+/C)\cdot p(C)}{p(T+)} = \frac{99\%\cdot 1\%}{1{,}98\%} = 50\%$$

→ Test says “50% probability to have illness if test is positive”

Bayes' theorem, cancer example

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- ✔ **Initial data**

P(ill)=1% Population has illness
P(T+)=1,98% of all test results are positive

- ✔ **After first test**

P(ill)=50% According test
P(T+)=50% of all test results are positive

$$p(C/T+) = \frac{p(T+/C)\cdot p(C)}{p(T+)} = \frac{99\%\cdot 50\%}{50\%} = 99\%$$

→ 2nd test says “99% probability to have cancer if test is positive”

- ✔ **Power of Bayesian theorem → Reduce uncertainty by using evidence and updating prior probability**

Power of Bayesian networks

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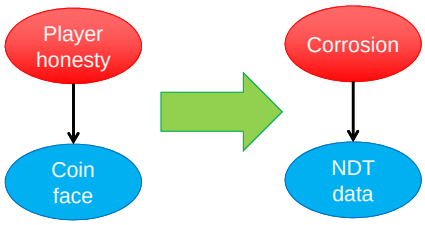

- ✔ **Conditional dependence between variables through Bayes' theorem**
- ✔ **Bayesian networks can learn from small amount of information**
- ✔ **Bayesian networks make prediction under uncertainty**
- ✔ **Bayesian networks can help determine the most probable cause and fix it**

Bayes' theorem, illness example

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- ✔ **1% of population has this illness**
- ✔ **Test sensitivity=99% → 99% of people tested are identified correctly**

	illness	No illness
Test positive	99%	1%

P(ill)=1% Population has illness

→ What is the probability to have this illness given the test result is positive?

→ **Test result: "50% probability to have illness if test is positive"**
→ **Are we happy? No!**

Mathematical reason:
Though the test is very precise (99%), the initial probability to be ill is only 1%
→ second test, we need data

Bayes' theorem, cancer example

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- ✔ **First test**
  - Initial data: P(ill)=1% Population has illness
  - First test result: P(ill/1. test positive)= 50%
- ✔ **Second test**
  - Initial data: P(ill)=50% = result of first test
  - Second test result: P(ill/2.test positive)= 99%
- ✔ **Power of Bayesian theorem → Reduce uncertainty by using evidence and updating prior probability**

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CUI score tables as Bayesian network

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- ✔ **Mimic CUI score tables (example)**
  - Operating temperature influence on CUI?
    - Good (no influence), T<-5C or T>175C
    - Middle -5C<T<50C or 110C<T<175C
    - Bad 50C<T<110C
  - Jacketing condition
    - Good, middle, bad condition
  - Coating condition
    - Good, middle, bad condition

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CUI score Bayesian network, start

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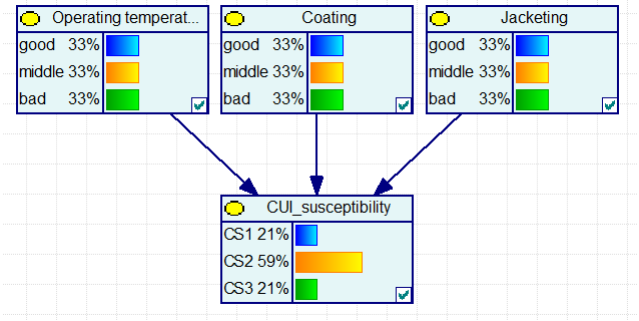
- ✔ **Even prior data „no knowledge”**
  - All influencing parameters evenly distributed
  - Model predicts 59% CS2, 21% CS1 or CS3



CUI score Bayesian network, start

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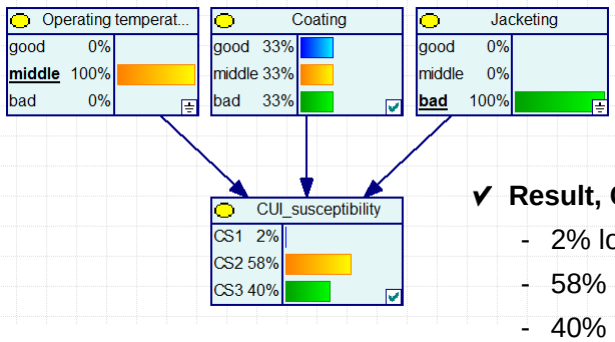
- ✔ **Prior data**
  - Operating temperature = 40C → middle
  - Jacketing: Open on many places → bad
  - Coating: *Unknown*



- ✔ **Result, CUI susceptibility**
  - 2% low
  - 58% middle
  - 40% high

CUI score Bayesian network, start

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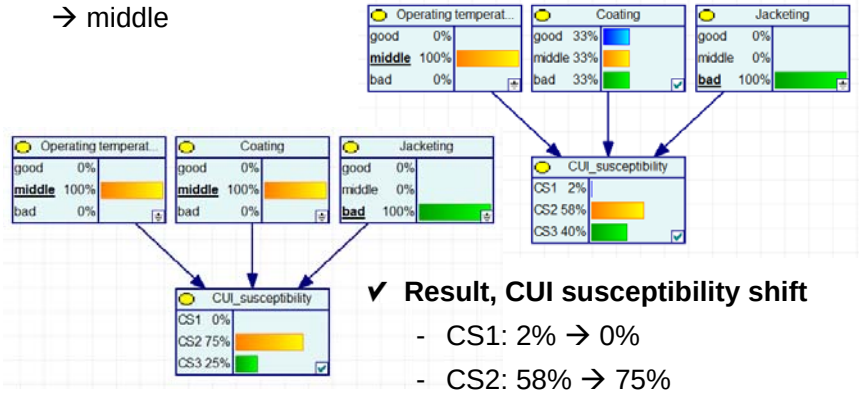
✔ **Add evidence data about coating:**

- Coating: partly damaged
  → middle



✔ **Result, CUI susceptibility shift**

- CS1: 2% → 0%
- CS2: 58% → 75%
- CS3: 40% → 25%

CUI score Bayesian network, start

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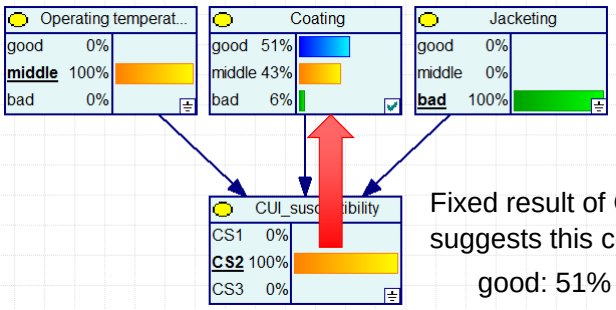
✔ **Bring in evidence, inferring**

- We found CUI condition 2 “proof”

→ What can we learn about our coating condition?



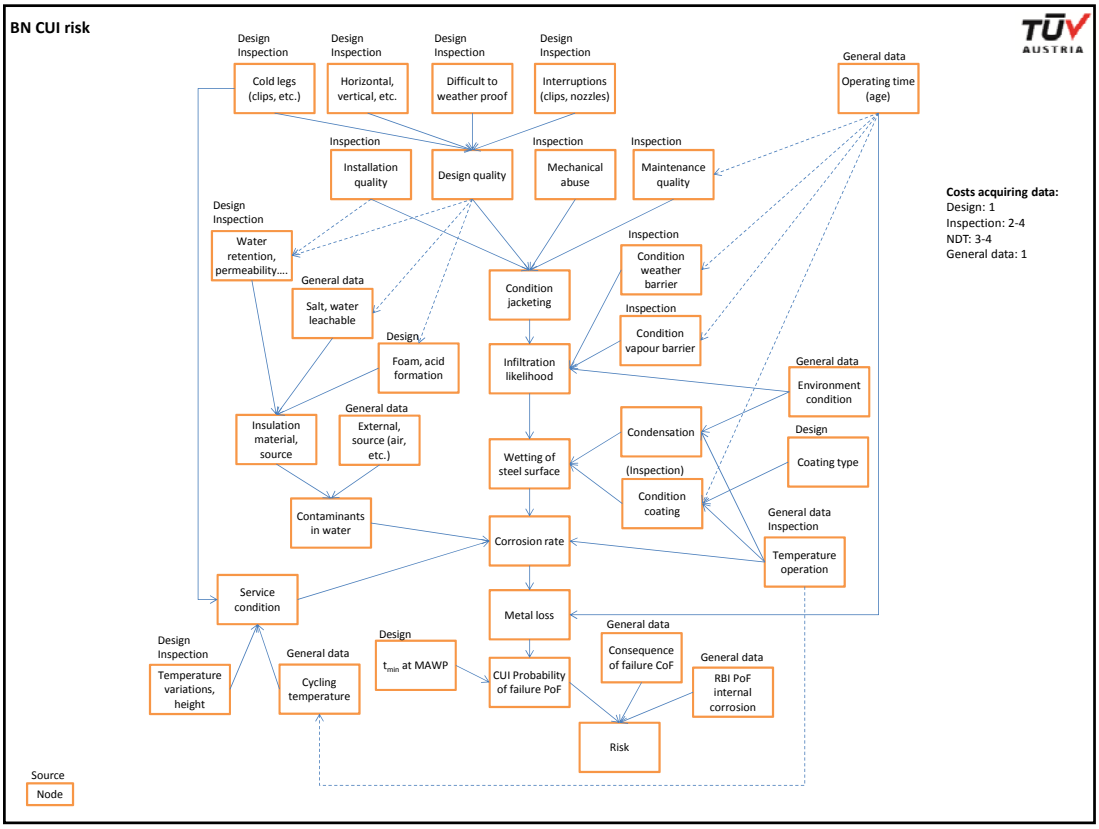
Fixed result of CUI susceptibility suggests this coating condition:

good: 51%

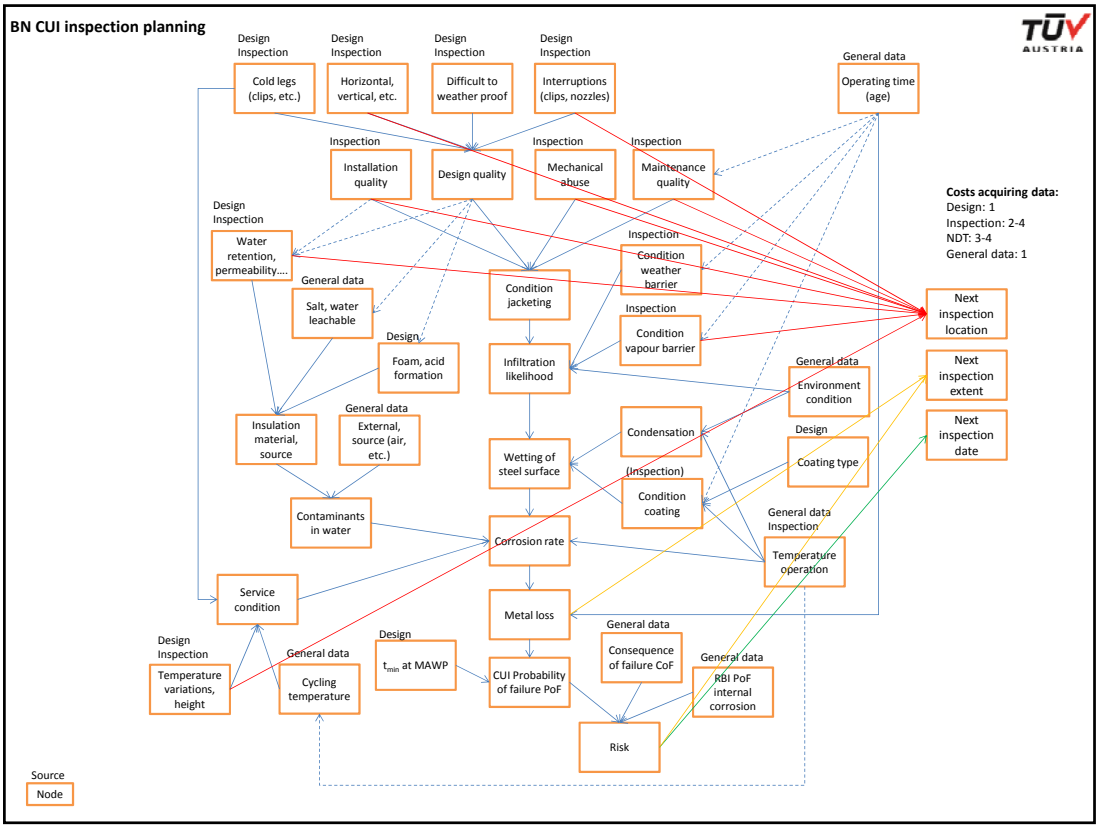
middle: 43%

bad: 6%

BN CUI risk



BN CUI inspection planning



Appendix 10

World Class Maintenance project on CUI

(R. de Heus)

Project “Corrosion under Insulation” (CUI)

World Class Maintenance

Presentation for EFC meeting April 26

WORLD CLASS MAINTENANCE

Goals

Short term Goal CUI cooperation Dutch Industry

To create a proven self assessment tool for Dutch Industry based on EFC guideline.

Definite Goal CUI Dutch Industry

To Implement a “Best Practice” in the Industry to mimimize the number of incidents with root cause "corrosion under insulation" .

To prevent reputational damage in the industry, unsafe situations and to decreaese the total cost of ownership for CUI projects.

WORLD CLASS MAINTENANCE

Development self assessment tool

Done

Self assessment is piloted at 4 plants and available for dutch speaking others

To do

- Translate assessment to english language and make it web enabled.
- Roll out to others via web

WORLD CLASS MAINTENANCE

Next steps CUI

Proposed follower projects

- Development communication and trainingstools for Contractors/operators and technicians to prevent damage to insulation and increase awareness on shop floor.
- Develop standard, modulair CUI strategy format based on EFC in order to manage CUI more uniform and easy.
- Set up of network and advisory board to develop adequate monitoring techniques for CUI.
- Develop and implement a pragmatic RBI tool to predict high risk situations and for early detection and timely resource allocation
- Exchange feasibility and application of Thermal Spray Alumina for greenfield, brownfield.

WORLD CLASS MAINTENANCE

Actual Situation and question to EFC

- Project on hold. Participating companies are not sure about next steps. WCM is looking around to involve more experienced participating parties in order to select best practices that will be broad accepted and to increase the rate of success. Uniform acceptance is a problem.
- The European Federation of Corrosion has produced the EFC guideline on CUI. What next steps on the guideline are foreseen at EFC?
- Can we, EFC & WCM, combine efforts to implement the guideline in dutch industry and/or can we transform the guideline to a NEN norm ?

WORLD CLASS MAINTENANCE

www.worldclassmaintenance.com

Dit project is mede mogelijk gemaakt door een bijdrage uit het Europees Fonds voor Regionale Ontwikkeling in het kader van Op-Zuid.

WORLD CLASS MAINTENANCE

Appendix 11

Failure cases

Material selection for corrosion protection

inside desalters

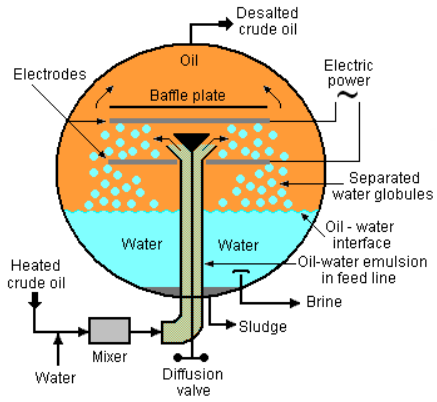
(S. Koller)

Desalter - Material and Corrosion

HOLBORN EUROPA RAFFINERIE GMBH

Desalter

Electrostatic crude oil desalter



Cross-sectional view of Electrostatic crude oil desalter

Technical data

- Material: WStE47 (P460NH) (40 mm)
- Pmax: 50 bar
- T: 110 to 140 °C

Corrosion phenomena

Corrosion phenomena

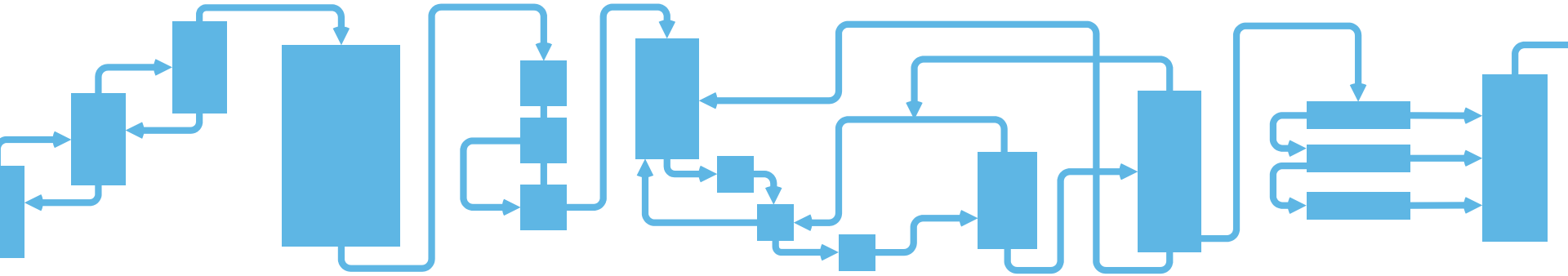
Discussion of countermeasures

- Material selection
- Organic coatings/liners
- Metal plating/lining
- …

Appendix 12

Acceptable low level caustic concentration for stainless steels to avoid SCC above 200°C

(S. Shapcott)



Acceptable low level caustic concentrations (<0.5%) for stainless steels to avoid SCC above 200°C. Reflections on the new austenitic stainless steel caustic service chart in NACE SP0403-2015.

Stephen Shapcott

EFC WP15 - Spring 2016 - Paris

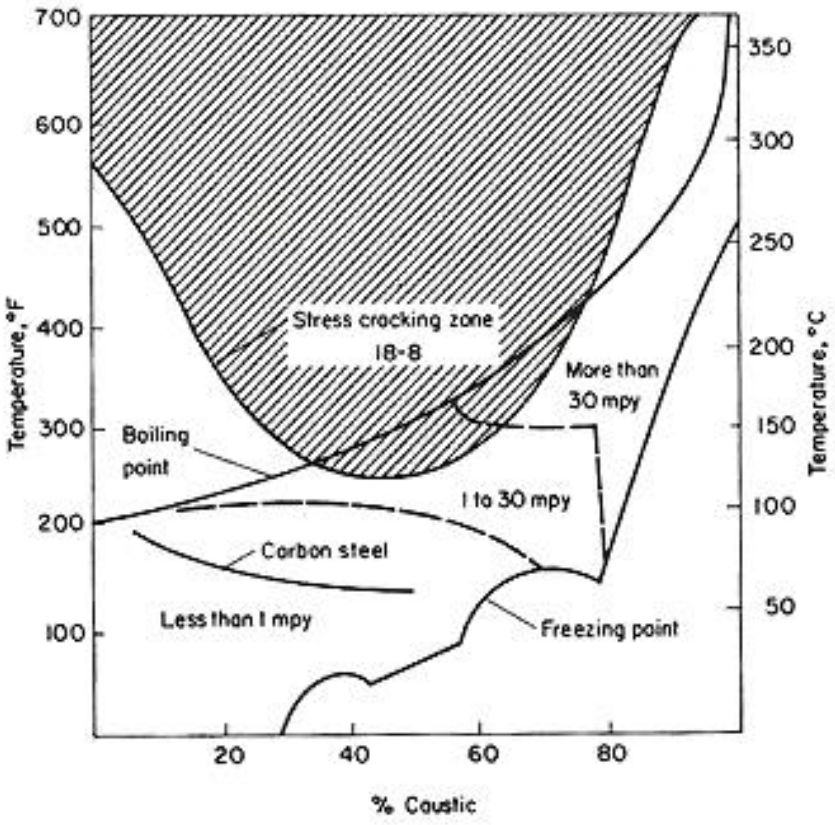
Johnson Matthey
Process Technologies

The beginning?

Johnson Matthey
Process Technologies

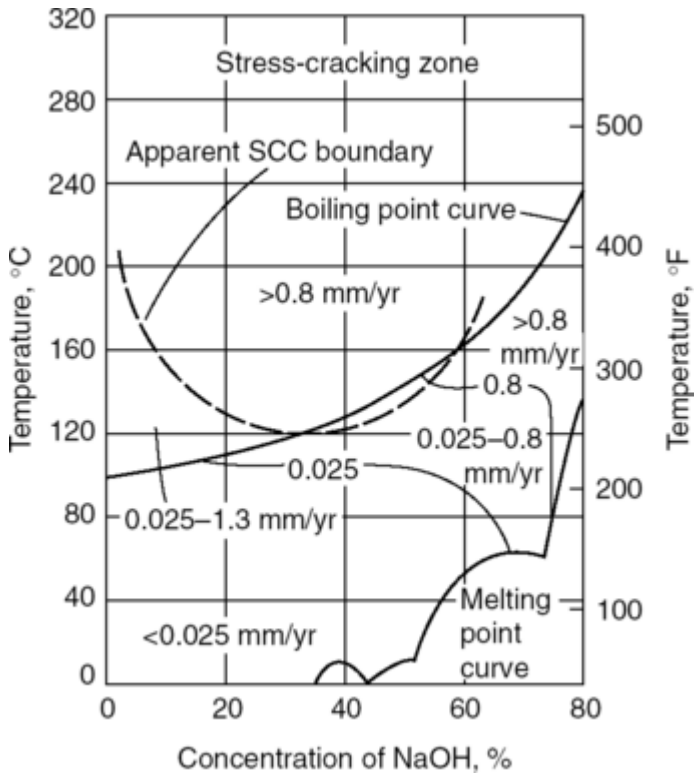
C P Dillon – 1986

Corrosion Control in the Chemical Process Industries



Recent recommended practice

Johnson Matthey
Process Technologies



ASM Handbooks Online - 2016

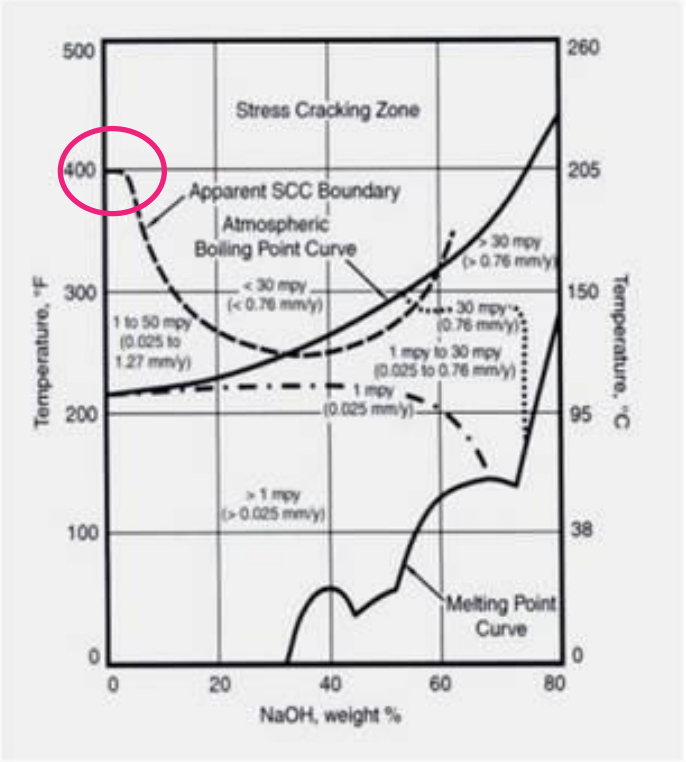


Figure 3. *Caustic stress corrosion cracking susceptible regions of 300 series SS*

MTI Bulletin - 2008

company confidential

Current advice from NACE

Johnson Matthey
Process Technologies

NACE SP0403 – 2015

Certain technologies can recycle effluent water.

This effluent needs to be neutralised for use downstream, this is done with low level NaOH dosing.

Dosing leaves a slight residue of NaOH (1000-1500 ppm)

MTI curve is more conservative at very low concentrations, but less at higher concentrations

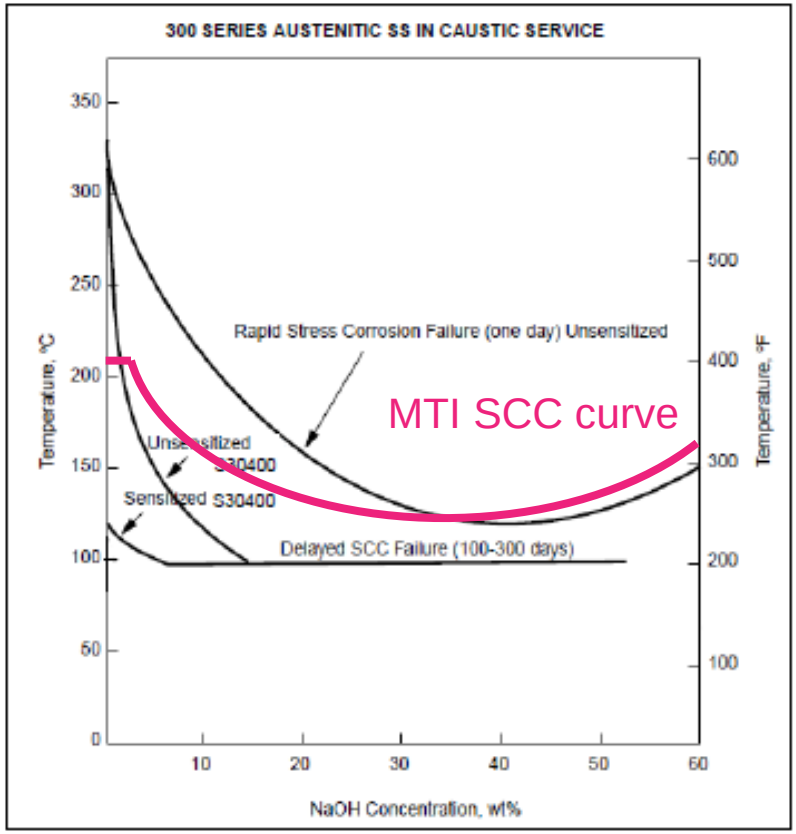
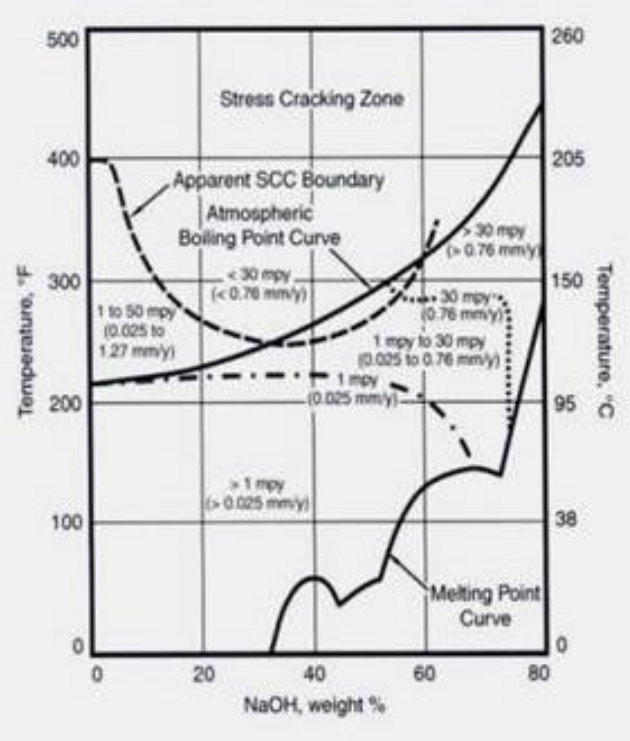


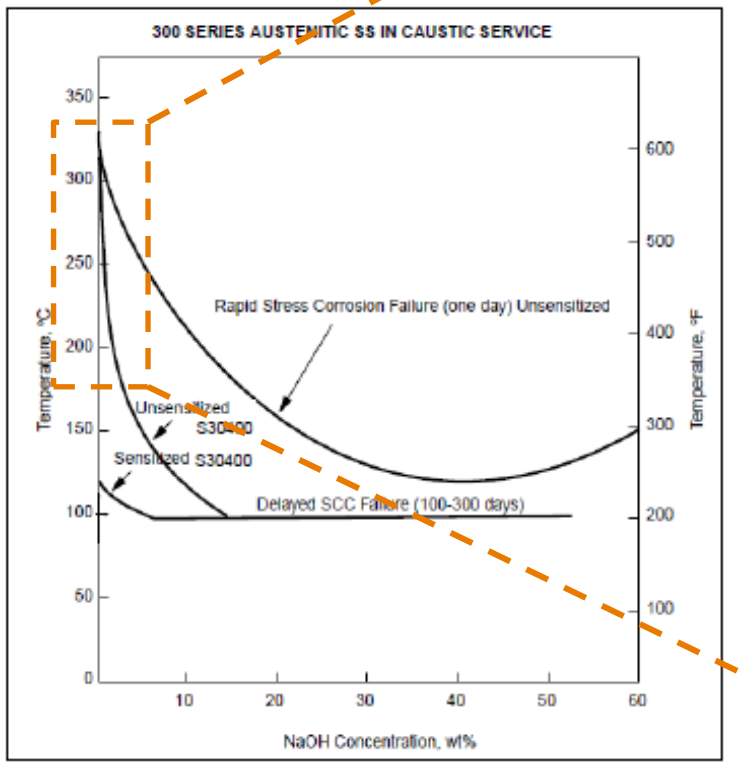
Figure 2: Caustic Service Chart for 300 Series Austenitic SS[9,10]

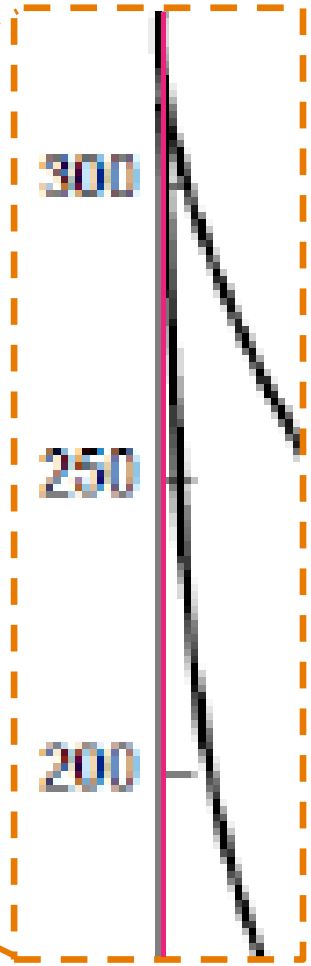
Which to choose?

Johnson Matthey
Process Technologies

Given the proximity of 0.15% NaOH to the NACE line, and the conservatism of the MTI curve. Which is a prudent choice based on industry experience? Where does the NACE curve come from?







company confidential

Duplex stainless steels for caustic service?

Questions for WP15

Johnson Matthey
Process Technologies

Which are the best duplex grades alloys to use?

Various sources indicate Mo may be detrimental to caustic corrosion performance. What are your experiences of this with low levels of caustic?

As NACE SP0403 recommends expensive nickel alloys once above the SCC curve for 300 series SS, how much improvement do duplex grades give?

Alloy vendors do not have data above boiling, and the literature is only qualitative.

Can excursions over an SCC boundary temperature initiate SCC?

Thank you!

Appendix 13

Real time corrosion prediction and monitoring

(S. Kus)

Dr. Slawomir Kus
26-April-2016

REAL TIME CORROSION PREDICTION AND MONITORING

EFC Working Party 15 - Corrosion in Refinery Industry

Honeywell

Agenda

- Traditional Methods of Corrosion Management
- Corrosion information flow – deficiencies in communication between Operation and Integrity/Corrosion Teams
- On-line, real time, corrosion management: Enhancements:
  - Step 1 – Monitoring
  - Step 2 – Prediction
- Architecture of real time monitoring/prediction integrated network
- Application example – Amine Unit
- Smarter Approach to Corrosion Management – on-line & real time
- Summary

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Honeywell

Traditional Methods of Corrosion Management

Methods

- Inspection
- Coupons
- NDT techniques
- pH and other analytical parameters
- Corrosion is not quantified as it happens, it is found after it happens!

Limitations

- Reactive Response
- Historical based assessment
- Deviations and Peaks unknown
- Inspection Centric
- High Cost of Failure
- Inhibitor cost

Captures cumulative damage – reactive approach

Honeywell

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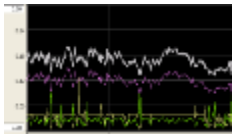
Typical flow of corrosion information

Operations Management

Integrity Management

Corrosion is “Invisible” to Operations



Process Data Historian OPC Compliant

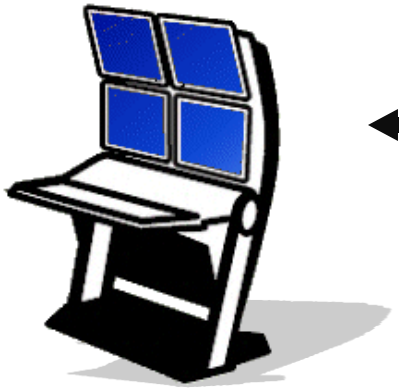
Inspection Personnel

Corrosion Engineer

Inspections

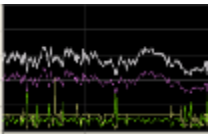
Corrosion Prediction Models Monitoring

Operators



Control and Instrumentation

Plant Assets



Control System

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On-line, real time, corrosion management

Evolutionary Enhancements – Step 1 - Monitoring

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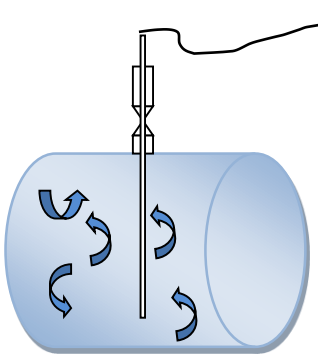
On-line, real time corrosion monitoring – typical setup

On-line ER, LPR, UT etc.
Data collection at intervals from minutes to hours

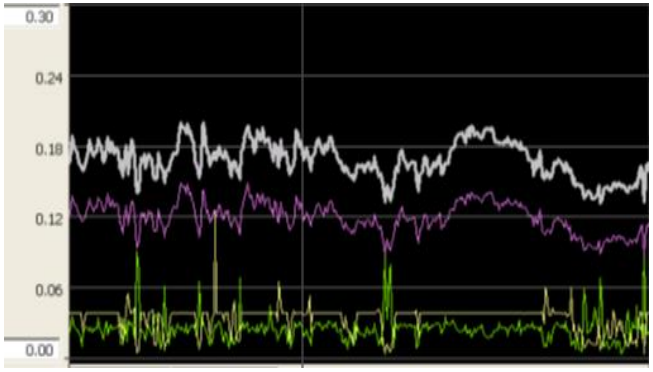


On-site junction box

4-20mA
HART
Modbus RTU

Fibre optic

DCS / Historian



Operator / Control Room

SME - Corrosion

Corrosion visible in “dynamic” mode

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Deficiencies of on-line, real time monitoring

- Very few monitoring locations
- Difficulties in proper selection of monitoring points and monitoring techniques
- Complicated integration with plant's DCS
- Complicated process-corrosion data analysis
- Operation does not see corrosion trends/alarms to be reliable
- Overall implementation and maintenance costs
- …..

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On-line, real time, corrosion management

Evolutionary Enhancements – Step 2 - Prediction

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Why real-time corrosion prediction?

- Intrusive corrosion monitoring cannot be implemented everywhere
- It is important to know how current corrosion situation may/will be developed over time
- Standard corrosion models are based on static, fixed input data
- Not possible for all process configurations to be predicted at design stage
- Increasing throughput may shift corrosion beyond designed scenarios
- Integrity Operating Windows, if left “static”, may become irrelevant

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Architecture of real time monitoring/prediction

Off-line

MERIDIUM

SAP

LIMS

Inspection

Coupons

Asset Integrity Dashboard

Web Browser

Web Browser

Web Browser

Client Users

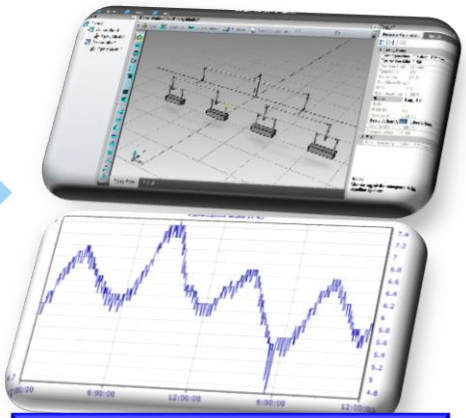
Business LAN

Firewall

Predict RT Server
Web Server
SQL Server
Historian OPC DA Client

Administrator

On-line (T, p, v etc.)



PCN

Historians
OPC DA Servers

Real time
Prediction Model

Control Systems

On-line CR

Corrosion Monitoring

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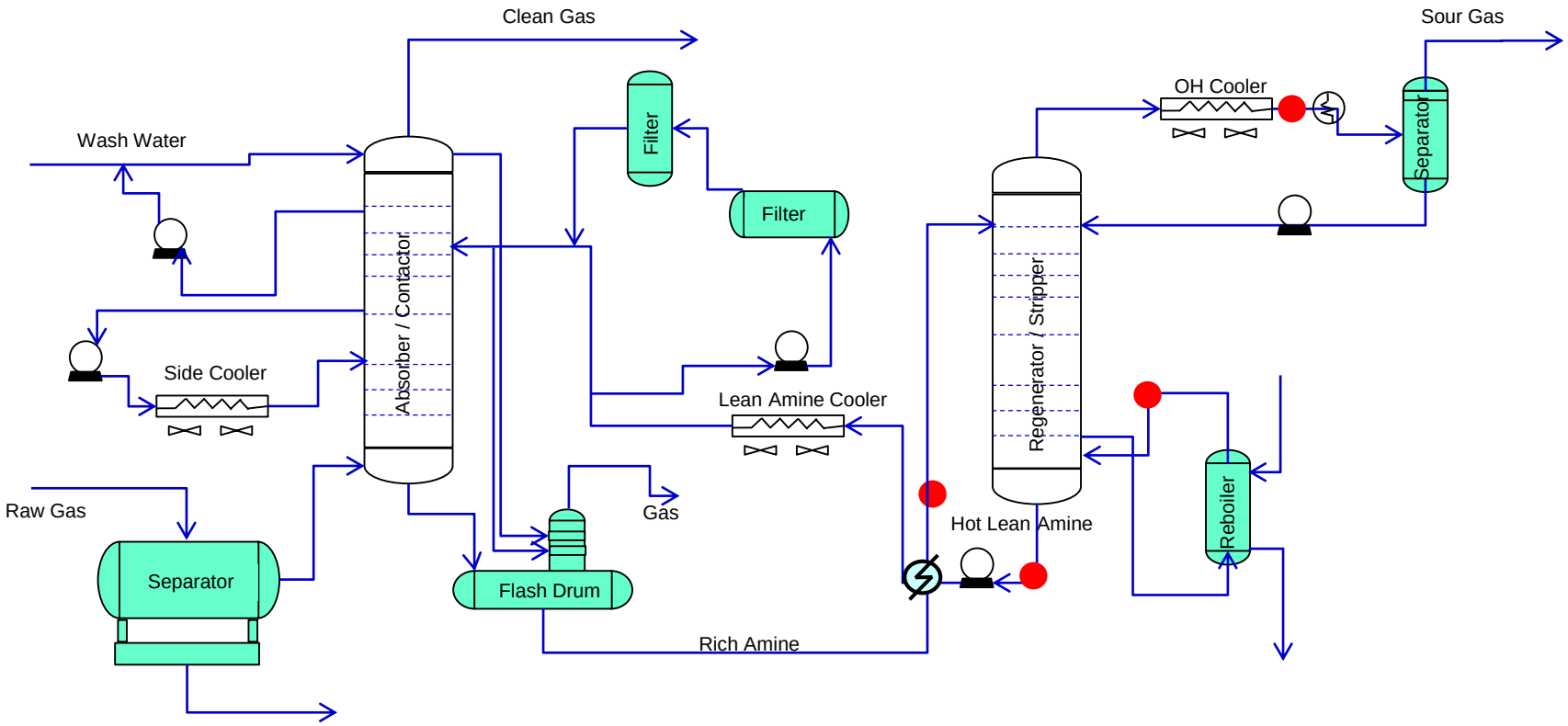
Amine unit – real time monitoring points (example)



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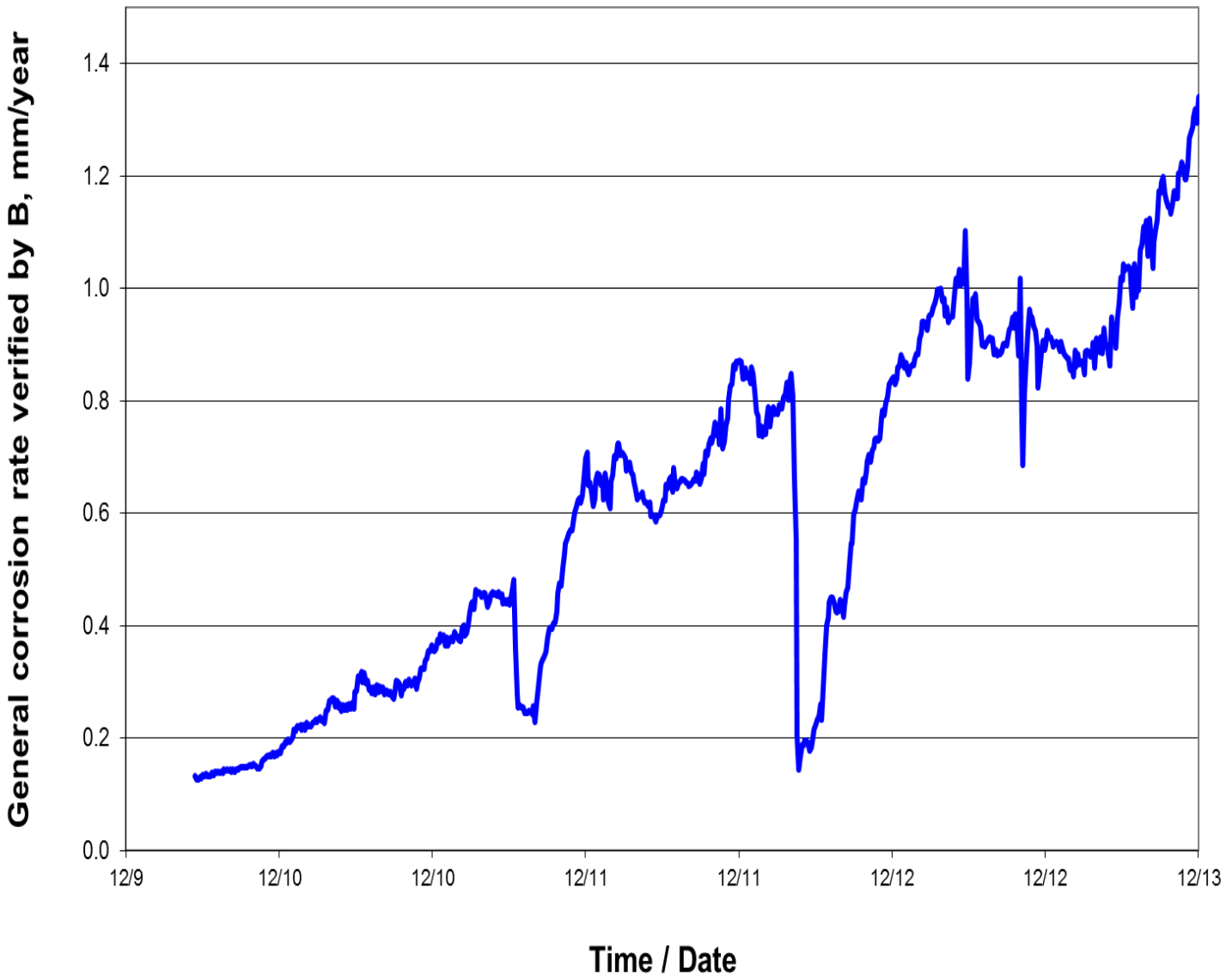
Amine unit – real time monitoring points (example)



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Calculate Reset

Environment

Solvent: MEA DGA DEA MDEA

Solvent Concentration: 45 %

Total Pressure: 500.00 kPa(g)

Temperature: 110.00 °C

H2S Loading: 0.45 mole H2S / mole solvent

CO2 Loading: 0.02 mole CO2 / mole solvent

Total Gas Loading: 0.47 mole total gas / mole solvent

Impurities: 0.45 wt%

Application

Pre-sets

Pipe Inner Diameter: 80.00 mm

Design Life: 25.00 years

Corrosion Allowance: 3.00 mm

Pipe Roughness: Lightly Corroded

Custom Roughness: 0.0000 mm

Process Stream Conditions

Custom Wall Shear Stress:

Type of Flow: Horizontal Vertical

Configuration: Weld Protrusion (5 mm)

Process Flow Rates and Properties

Vapor Properties

Flow Rate: Standard Actual

0.0000 m3/d(N)

Density: 3.20 kg/m3

Viscosity: 0.000015 Pa-s

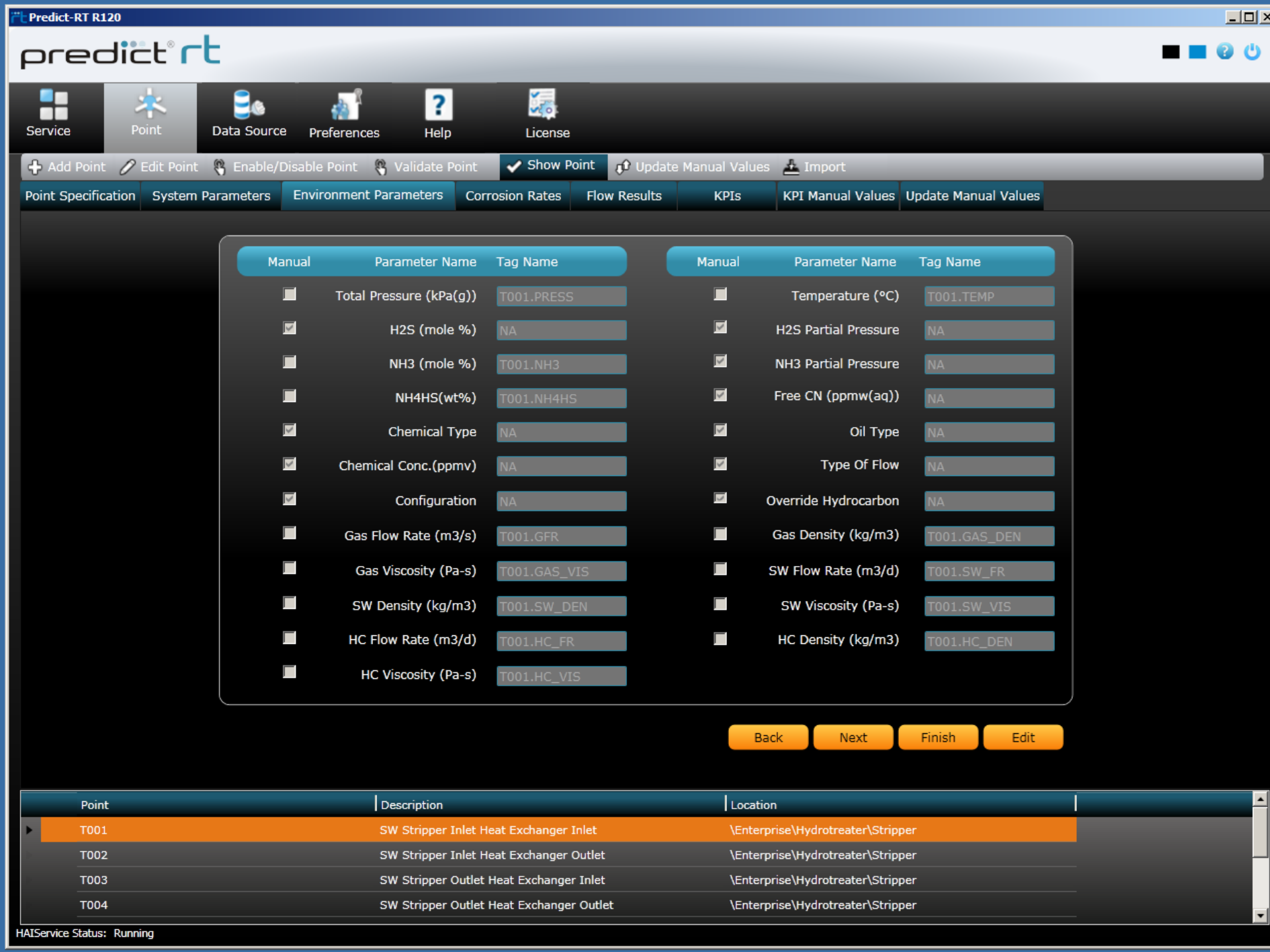
Liquid Amine Properties

Flow Rate: 300.0000 m3/d

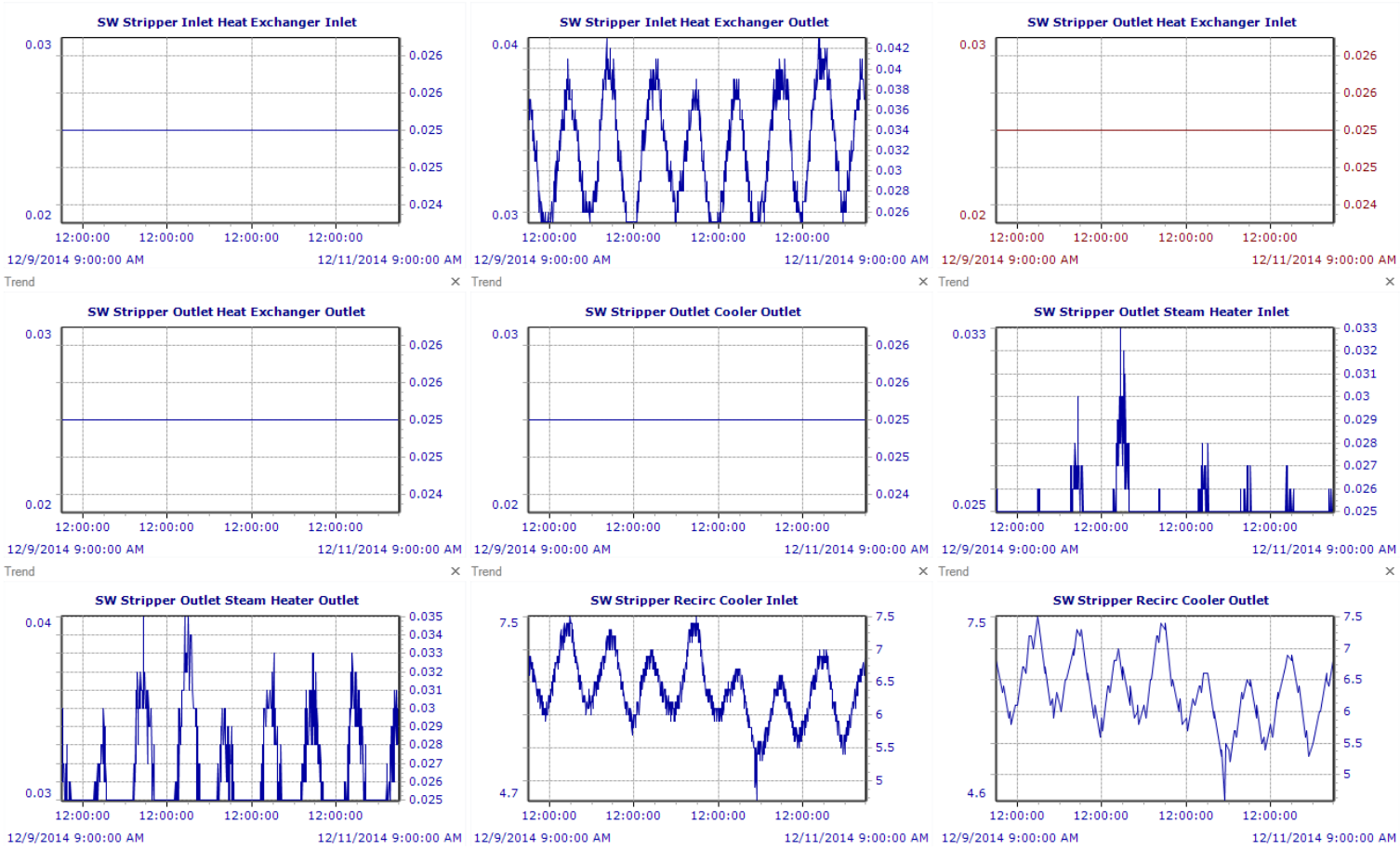
Density: 1001.15 kg/m3

Viscosity: 0.002330 Pa-s

Input Data


Predict-RT R120
predict rt
Service
Point
Data Source
Preferences
Help
License
Add Point
Edit Point
Enable/Disable Point
Validate Point
Show Point
Update Manual Values
Import
Point Specification
System Parameters
Environment Parameters
Corrosion Rates
Flow Results
KPIs
KPI Manual Values
Update Manual Values
Manual
Parameter Name
Tag Name
Total Pressure (kPa(g))
T001.PRESS
H2S (mole %)
NA
NH3 (mole %)
T001.NH3
NH4HS(wt%)
T001.NH4HS
Chemical Type
NA
Chemical Conc.(ppmv)
NA
Configuration
NA
Gas Flow Rate (m3/s)
T001.GFR
Gas Viscosity (Pa-s)
T001.GAS_VIS
SW Density (kg/m3)
T001.SW_DEN
HC Flow Rate (m3/d)
T001.HC_FR
HC Viscosity (Pa-s)
T001.HC_VIS
Manual
Parameter Name
Tag Name
Temperature (°C)
T001.TEMP
H2S Partial Pressure
NA
NH3 Partial Pressure
NA
Free CN (ppmw(aq))
NA
Oil Type
NA
Type Of Flow
NA
Override Hydrocarbon
NA
Gas Density (kg/m3)
T001.GAS_DEN
SW Flow Rate (m3/d)
T001.SW_FR
SW Viscosity (Pa-s)
T001.SW_VIS
HC Density (kg/m3)
T001.HC_DEN
Back
Next
Finish
Edit
Point
Description
Location
T001
SW Stripper Inlet Heat Exchanger Inlet
\Enterprise\Hydrotreater\Stripper
T002
SW Stripper Inlet Heat Exchanger Outlet
\Enterprise\Hydrotreater\Stripper
T003
SW Stripper Outlet Heat Exchanger Inlet
\Enterprise\Hydrotreater\Stripper
T004
SW Stripper Outlet Heat Exchanger Outlet
\Enterprise\Hydrotreater\Stripper
HAIService Status: Running

Monitor “virtually” Corr. Rates at multiple locations



Example of on-line, real time corrosion modelling in Sour Water Stripper

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Smarter Approach to Corrosion Management

- **Understand**
  - Document damage mechanisms and corrosion loops
  - Use **prediction models** to identify critical locations and variables that may impact asset integrity
  - Establish **effective** Integrity Operating Windows
  - Plan and design to avoid corrosion failures

- **Monitor Real-time**
  - Regard corrosion as a **process variable**
  - Correlate process changes to corrosion
  - Know and correctly quantify **current** health of assets; everyday
  - Incorporate Boundary and Deviation Management
  - Leverage Predictive Models to Detect Abnormal Events
  - Review the effectiveness of Integrity Operating Windows on preventing excessive damage

- **Focus Resources**
  - Alert Operators, Engineers and Managers of abnormal conditions as they occur.
  - Focus resources where they are needed most at the appropriate time.

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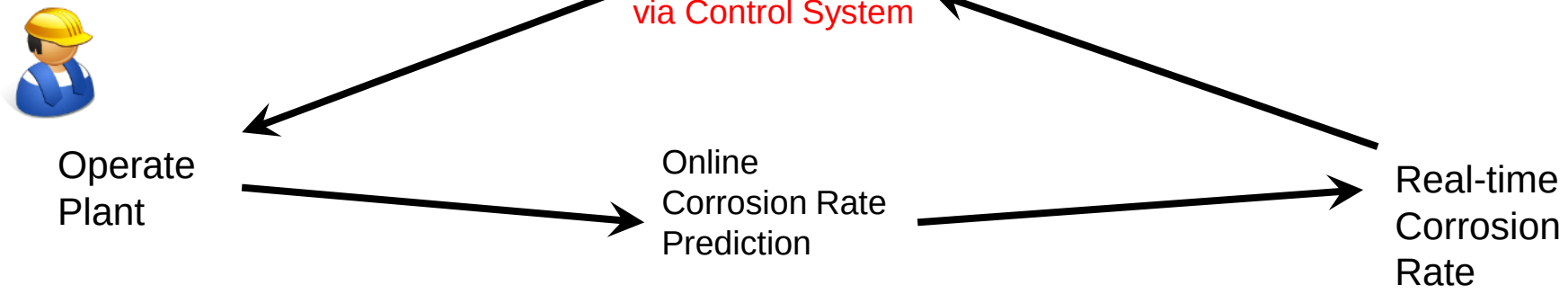
Step 1: making corrosion visible to Operation



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Step 2: making corrosion relevant to Operation

Present Corrosion Rate to Operators via Control System

Operate Plant

Online Corrosion Rate Prediction

Real-time Corrosion Rate

Optimize operating variables to minimize Corrosion rates

Correlate Corrosion Rates to process variables

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Step 3: making corrosion actionable by Operation

Operate Plant

Online Corrosion Rate Prediction

Real-time Corrosion Rate

Rate OK?

Generate Alarms and Alerts

Present Corrosion Rate to Operators via Control System

Correlate Corrosion Rates to process variables

Optimize operating variables to minimize Corrosion rates

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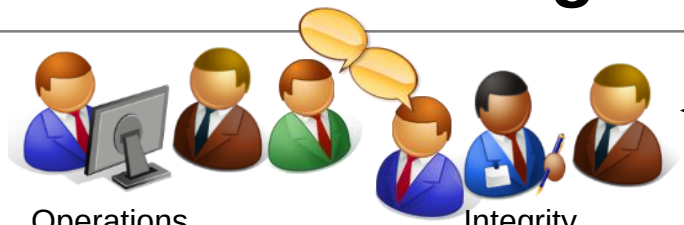
Real-Time Predictive Modeling Solutions



Operations Management

Integrity Management

Online Corrosion Prediction Model
On-line corrosion monitoring

Prediction Engine

Online Corrosion Prediction Models

Online Corrosion monitoring

Process Data Historian
OPC Compliant

Corrosion Engineer

Offline Corrosion Prediction Models

Inspection Personnel

Operators

Control System

Control and Instrumentation

Plant Assets

Inspections

Corrosion is now “Visible” to Everyone and Actionable by Operators

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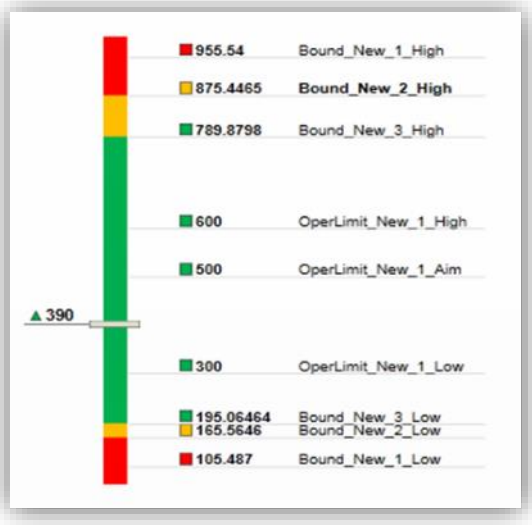
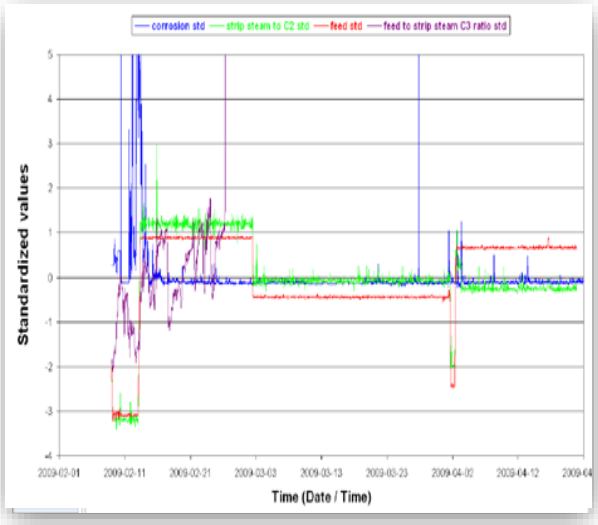
On-line, Real-time Integrity Management

Set and Prioritize IOW Boundaries	Monitor & Predict On-line, Real time	Analyse and act before incident





Parameter: CDU Top temperature
Tag: IOW-TI-CD1-001
IOW type: Critical
Damage mode: NH_4Cl & HCl corrosion
Risk Rank: 20 (Medium-High)
Target L/H: 118/138ºC

T = >115
Real time predicted CR = 15mpy
On-line measured: 13.8mpy

Operator's Action:
Adjust the OVHD T within 1 hour
Corrosion Engineer notification:
High risk for OVHD corrosion
Management Dashboard feedback:
Rising Cost of Inspection

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Summary

- Effective corrosion management requires timely corrosion information
- On-line, real time corrosion monitoring cannot cover all corrosion areas within given process unit
- Traditional, corrosion prediction can statically highlight a corrosion hot-spots within the process unit, but cannot reflect their changes upon process dynamics
- Modern, DCS-integrated real time corrosion models facilitate continuous analysis of multiple process streams
- Based on on-line, real-time modelling data it is possible to predict future locations for corrosion monitoring - e.g. change of throughput may shift corrosion to new hot spots
- Integration with operations / boundary management systems (including IOW alarming and management) and plant KPI dashboard makes corrosion visible to Plant Management

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Appendix 14

Naphtenic crude management

(A. Pothuaud)

GE Power & Water
Water & Process Technologies

How CFD Audit Helped Refinery to Manage Naphthenic Corrosion

EFC – La Defense – 26th April 2016

Alain POTHUAUD

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Why HAC in 2016 ….

Crude oil price is low at # 42$/bbl and should remain low in 2017

Discount between “classical” and “High TAN” crudes is also low

But

- Independent companies can increase their benefits
- Integrated companies can prepare the future with serenity

Predator Objectives

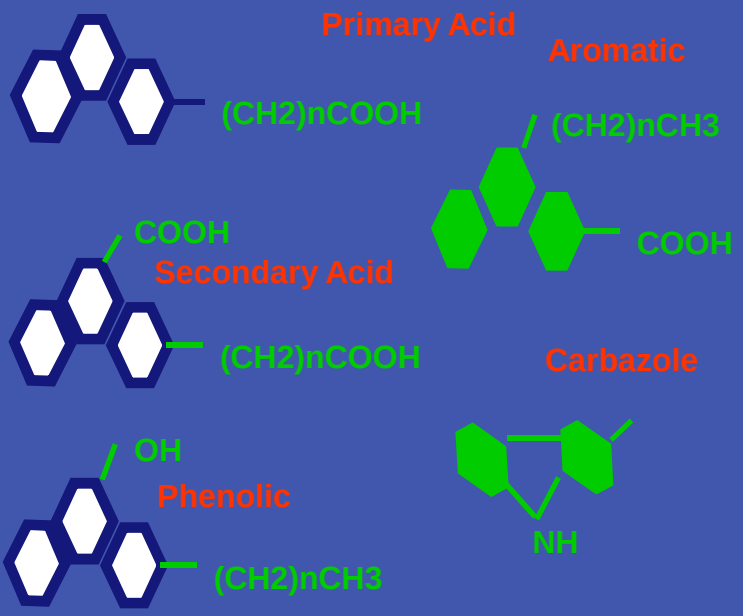
Provide the refining industry with an increased and unique level of reliability while processing discounted or difficult crude feedstock

Predator is a 3 fundamental pole program :
Prediction, Protection, Detection

Risk must become an opportunity

imagination at work

Naphtenic Corrosion



Different species of cyclic compounds (12 to up to 30 Carbons)

Corrodent if

- T° between 220 and 400 °C
- Turbulence area
- Velocity
- Metallurgy
- TAN
- NAN
- TAN/S

$$Fe + 2\,RCOOH \longrightarrow Fe(RCOO)_2 + H_2$$

Iron naphtenate
Oil soluble

$$Fe(RCOO)_2 + H_2S \longrightarrow FeS + 2RCOOH$$

Iron Sulfide
Non soluble

Protection

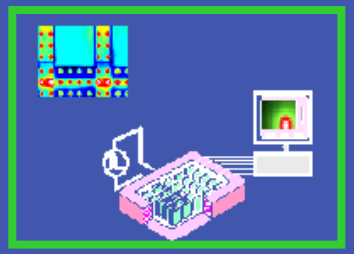
Product

- *Predator chemical – Low P product*
  - Low phosphorous patented product
  - Low fouling potential P product
  - Different phosphate esters working in synergy
  - Recommended especially with low S crude blends
  - Recommended also for high temperature sulphur corrosion

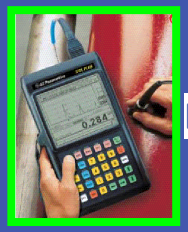
Fe + P = Iron Phosphate film

Detection

Rightrax

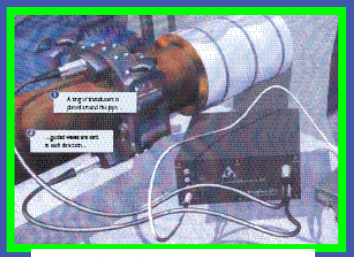


PEC



Hi Temp UT

permasense



Guided Acoustics

GE W&PT

Third party

Current

Integrated Measurement

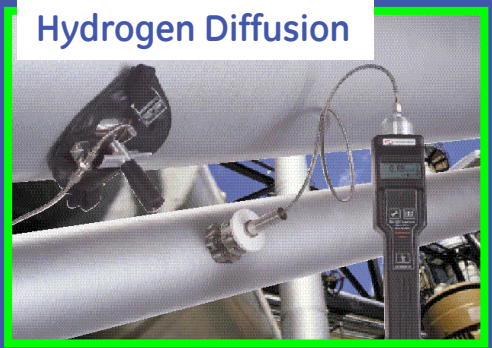
Coverage

Local (more sensitivity)

Global (less sensitivity)

Rate Measurement

Hydrogen Diffusion



Probes / Coupons

Fe / Ni Ratios

Challenge is Prediction

- TAN is increasing
- S is decreasing
- Better understand where to put representative and adapted corrosion monitoring tools

- Audit conducted on-site to better understand impacts of
  - Unit configuration
  - Naphthenic crudes

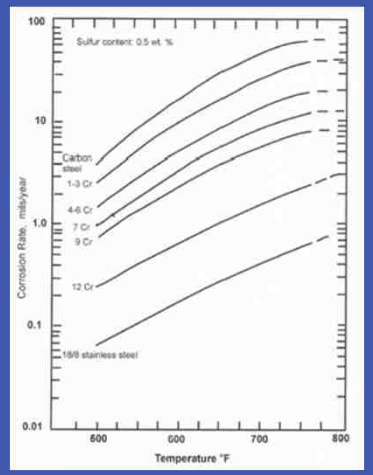
➢ Select right monitoring tool ifo available place

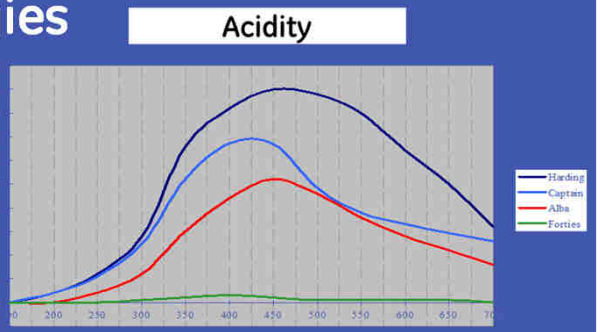
➢ Design chemical treatment

Corrosion Prediction

Different models try to predict corrosion

- McConomy curves
  - Applied to S corrosion
  - Nap Acid corrosion is not taken into account
- API 581
  - Estimated corrosion for different metallurgies
- Crude characterization
  - Based on distillation curve of Nap'Acids
- All define independent informations





➢ Need to correlate unit configuration and naphthenic acidity with specific unit parameters

Solution For Processing Opportunity Crudes

Crude Characterization

- NAN & TAN
- Fingerprint & Corrosion
- Characterization Sulfur etc.
- Corrosion Model

Asset Determination

Flow, Pipe Size, Velocity, Temperature, Pipe Configuration and Spatial Relationship, Pipe Geometry, Shear Stress, Metallurgy,

Assessment Output

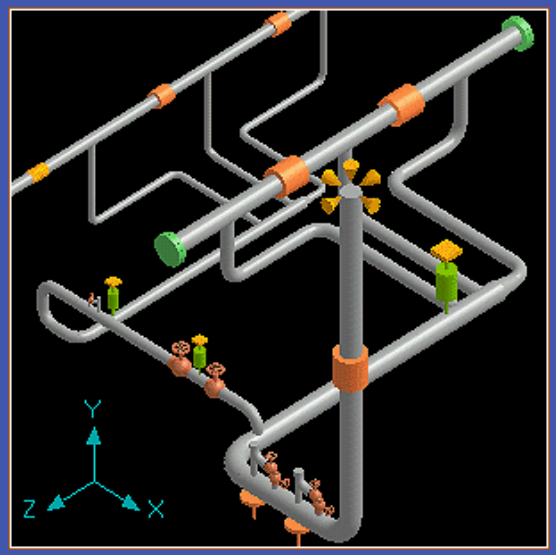
- Highlight critical areas
- Identify hot spots for corrosion
- Analysis requirements/schedule & location
- Chemical injection requirements /chemistry & application
- Monitoring requirements/schedule, location & sensor type

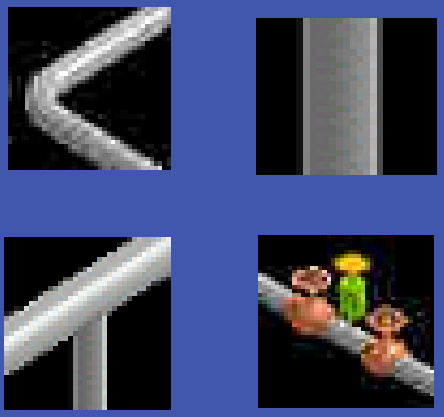
Corrosion & Shear Stress

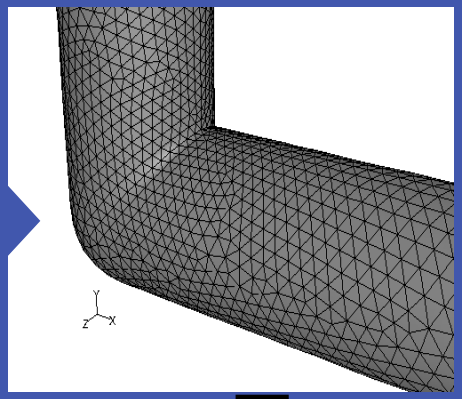
Shear Stress is critical to understand Corrosion

- Need to identify hot spots based on Shear Stress calculation

Computational Fluid Dynamic Purpose





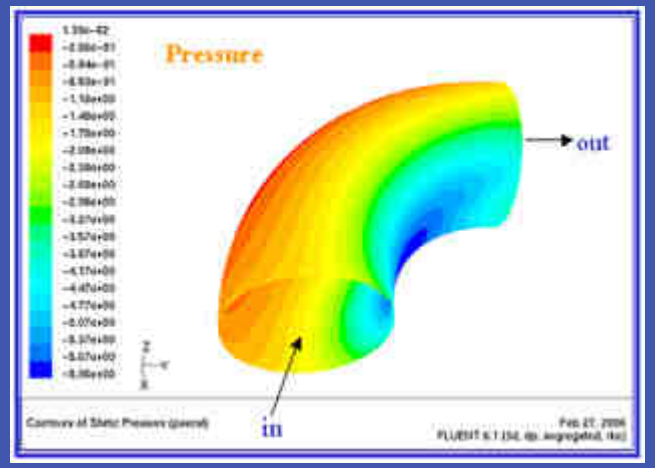


Refinery piping configuration → Pipeline configuration, components and geometry → Corrosion models developed for individual components through CFD

- Shear Stress calculation
- Hot spot identification
- Monitoring Placement

Computational Fluid Dynamic - CFD

Proprietary GE software technology incorporates various process and operating variables to predict specific areas of higher corrosion potential



Inputs

Characteristics of each element of turbulence (valve, reducer, pump, T, 90...)

Existing system metallurgy

TAN, NAN, S, temperature, and line size for each node

Outputs

Calculates Shear Stress for each node

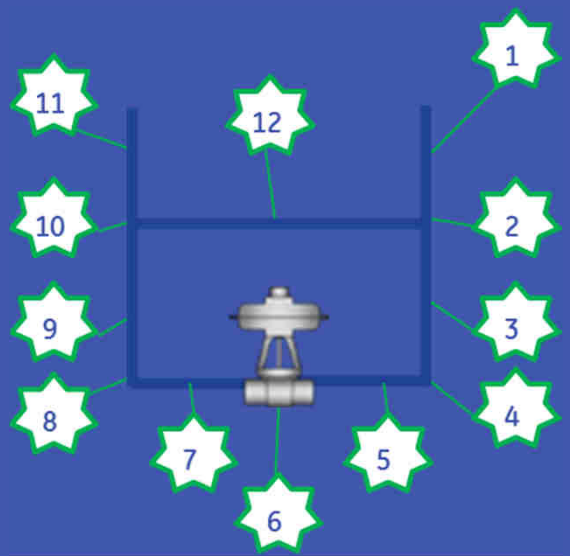
Calculates velocity for each node

☞ PRIORITIZES EACH PIECE OF EQUIPMENT FOR ELEVATED CORROSION POTENTIAL

Data Input

- All nodes of all circuits in CDU and VDU
- Need for isometrics and P&iD's
- Temp, pipe size, flow, metallurgy, acidity....
- Geometry and configuration
- Each of the element for each node (valve, by-pass...)

- Up to 250 lines for each circuit
- About 1 day at least per circuit to fill in all the data



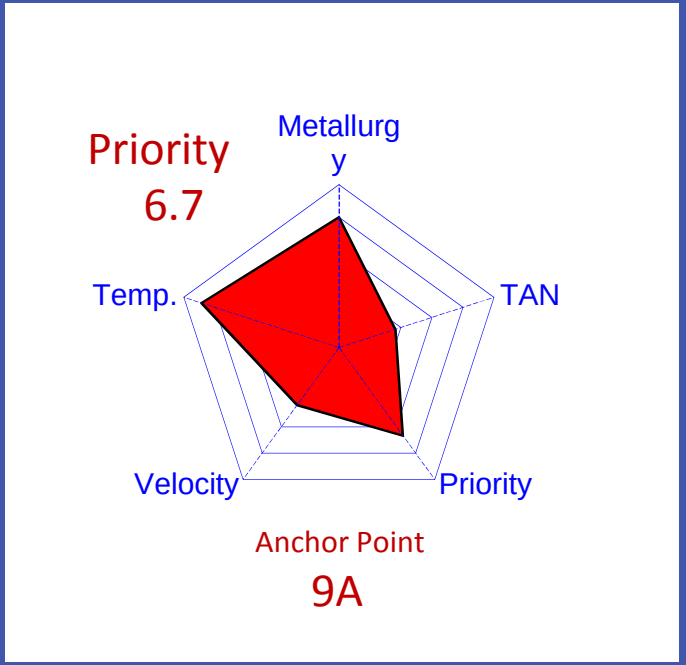
Data Output

Shear stress value

Rank higher priority hot-spots

Weight relative parameters impact

- Define monitoring hot spots
- Determine inhibition needs



Conclusions

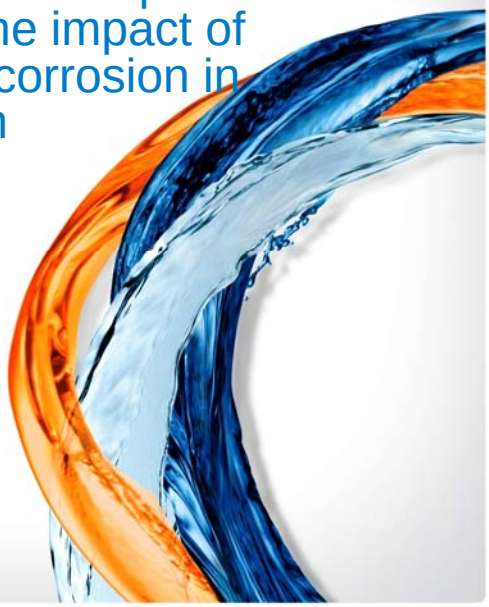
1. The highest priority hot-spot revealed by the project was not being monitored, inspected and was not getting fresh chemical
2. New corrosion monitoring equipment installed to cover weak spots
3. Explain un-expected corrosion issues

Appendix 15

Use of chlorine dioxide to optimize bio-control and reduce the impact of oxidizing biocide on corrosion in cooling water systems

(V. Bour-Beucler)

Use of chlorine dioxide to optimize bio-control and reduce the impact of oxidizing biocide on corrosion in cooling water system



Valerie Bour Beucler

EFC WP15 Spring meeting

La Défense 26/04/2016

Agenda

- Introduction
- Regulation and cooling system management
- Advantages of chlorine dioxide / hypochlorite
- Chlorine dioxide technology / Purate technology
- Chlorine dioxide PURATE case studies
- Questions

Cooling water system successful management

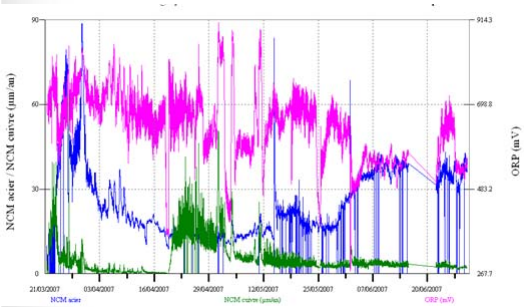
- Cooling water successfull management
  - A good equilibrium between corrosion, scaling and MIC

Regulation and cooling system

- **Legionella Control and regulation**
- **Biocidal Product Directive / Regulation**
  - harmonise the European market for biocidal products and their active substances.
- **REACH (European Commity Regulation on Chemical and their safe Use (EC 1907/2006)**
  - It deals the Registration Evaluation Authorisation and Restriction of Chemical substances.
- **The Future**
  - **Less non oxidizing biocides**
  - **More oxidizing biocide but with AOX control**
    - **Chlorine dioxide (ClO_2), a good alternative**

Biomanagement in cooling water system

Legionella results $< 10^3$ ufc *Lp* / l



Use of oxidizing biocides (bleach)

- ✓ Continuous injection
- ✓ Shock injection

- ❑ Corrosion on copper alloys
- ❑ Increase chlorides
- ❑ Increase pitting corrosion on carbon steel

Bio-population + Biofilm

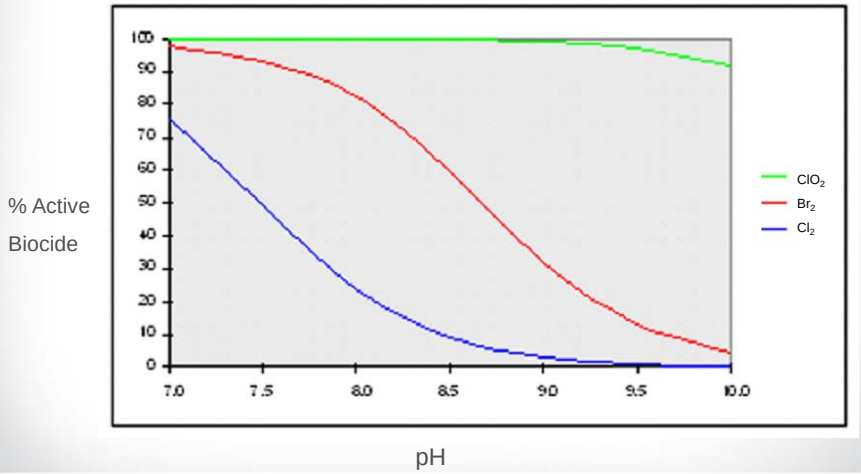
Why is ClO_2 a Good Biocide?

- It's a gas that is highly soluble in water, diffuses into biofilms attacking the bacteria generating the biofilm
- It doesn't hydrolyze like chlorine gas or bleach: no loss of effectiveness at higher pHs
- It is non-reactive to most organics and ammonia
  - No loss of biocide effectiveness due to byproduct reaction
  - Doesn't react with the cooling water program
- It oxidizes (no chlorination)**- no byproduct AOX or THMs after hydrocarbon leaks

Typically 10-40% of the bleach requirement

7

Biocide Efficacy With Increasing pH



NALCO Champion
An Ecolab Company

Taking Energy Further™ 7

8

ClO_2 Reactivity

Reacts with:

- Reduced sulfur, iron, manganese
- Phenols
- Cyanide
- Mercaptan (thiol)
- Organic sulfides
- Secondary amines (R_2NH)
- Nitrite

Doesn't react with:

- Ammonia, 1^0 amines
- Al-kane, kene, kyne
- Alcohols, glycols, diols
- Aldehydes, ketones, ethers
- Organic acids
- Unsub aromatics
- Azoles
- PBTC

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Onsite ClO_2 Generation- The acid factor

- Industrial Scale technologies to produce chlorine dioxide that are gaseous chlorine-free require the use of a strong mineral acid to convert a salt into chlorine dioxide.
- Some technologies use hydrochloric acid while others use sulfuric acid.
- Both hydrochloric acid and sulfuric acid require special handling as they are industrial chemicals; as are sodium chlorite, sodium chlorate, hydrogen peroxide and sodium hypochlorite.

Some common gaseous chlorine free industrial processes

Chlorite

$NaClO_2 + ½\ NaOCl + HCl \longrightarrow ClO_2 + 1½\ NaCl + ½\ H_2O$

$5\ NaClO_2 + 4\ HCl \longrightarrow 4\ ClO_2 + 5\ NaCl + 2\ H_2O$

$NaClO_2 + ½\ NaOCl + ½\ H_2SO_4 \longrightarrow ClO_2 + ½\ Na_2SO_4 + ½\ NaCl + ½\ H_2O$

Purate®

Purate $+ ½\ H_2SO_4 \longrightarrow ClO_2 + ½\ Na_2SO_4 + ½\ O_2 + H_2O$

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What is purate

On site on demand generation of chlorine dioxide in a water solution

- Chlorine dioxide
  - Powerful oxidation agent
  - Well proven
  - Reacts more selective with organic compounds than Cl_2 and Hypo
  - Gaseous molecule readily soluble in water

$$\text{Purate}^{TM} + H_2SO_4 \rightarrow 2\ ClO_2 + O_2 + Na_2SO_4 + 2\ H_2O$$

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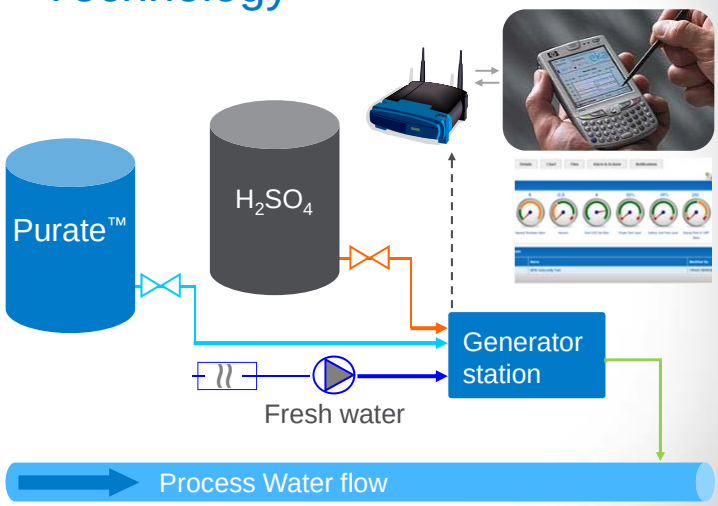
Purate™ Technology



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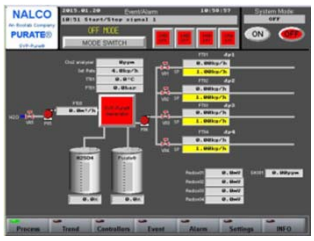
Purate™ - ClO_2 Generator



AD DS model

DSX unit

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Case studies

Sea water once-through cooling system

- Major refinery complex in Middle East
- Biofouling and heat transfer issues
  - Chronic leaks on heat exchanger of the large sea water once through cooling system (20 000 m3/h).
  - HE leaks due to under-deposit corrosion associated to biofouling
  - Historically Chlorine gas then Hypochlorite
  - A trial with chlorine dioxide (Purate Technology) has been done (6months)

$$NaClO_3 + {}^1/_2\,H_2O_2 + {}^1/_2\,H_2SO_4 \rightarrow ClO_2 + {}^1/_2\,O_2 + {}^1/_2\,Na_2SO_4 + H_2O$$

Performance monitoring

- Safety, microbio visual (seawater strainers and fouling plate)
- Microbio testing
- Chlorine dioxide residual and ORP reading
- Sea water heat exchnager performance

Microbio counts and heat transfer monitoring

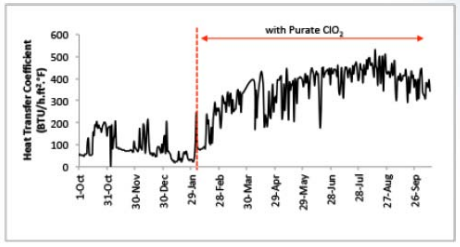

Figure 3: MED train C heat transfer coefficient improvement

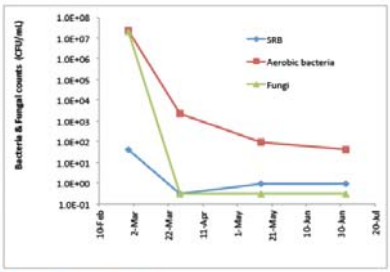

Figure 2: Microbial and fungal counts in seawater system

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Results

ASPECT	IMPROVEMENT
Safety	A safer system for employees and environment
Monitoring and Control	Rigorous testing, additional ORP monitoring recommended
Analysis & Visual	Log 2 to Log 7 reduction in TVC, Cleaner Surfaces
P15-VDU strainer backwash frequency reduction	80%
P15-VDU HX Heat Transfer Coefficient	22%
MED-Heat Transfer Coefficient	70%

Figure 4: Impact of Purate technology on customer operation

Customer Impact	eROI™	Economic Results
Heat transfer rate improved by 70%; 85.72 MBTU/h. Natural gas savings equal to 700,000 MBTU/year.	ENERGY	Natural gas savings of $4 million/Year
Above energy savings equates to 20 million Nm^3 of natural gas, avoiding 37,000 tons of CO_2	AIR	
Reduced the cost of maintenance and increased the reliability of the heat exchangers in the plant	ASSETS	Savings worth $ 0.5 Million/year

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Visual results before and after purate

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Sea water once-through cooling system

- Petrochemical plant in scandinavia
- Macrofouling and biofilm control
  - Macrofouling and unplanned shutdown for heat exchangers cleaning
  - Once through cooling systems is used for controlling the temperature of the process.
  - Mussel and barnacles from sea water piping reduce flowrate and cause high pumping cost.
  - Unplanned shutdown impacts the total cost of operation and reliability

$$NaClO_3 + {}^1/_2\,H_2O_2 + {}^1/_2\,H_2SO_4 \rightarrow ClO_2 + {}^1/_2\,O_2 + {}^1/_2\,Na_2SO_4 + H_2O$$

  - Historically high level of Hypochlorite but without efficiency
  - A trial with chlorine dioxide (Purate Technology) has been done
  - Trial successful

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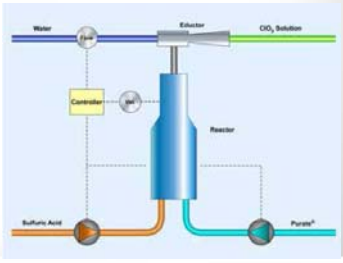
Chlorine dioxide / Purate technology

Key benefits of ClO_2

- Chlorine free process – no AOX and THM formation
- Preferred oxidizer for removing biofilm and preventing biofilm formation
- Practically pH independent (pH 4-9)
- Very effective for controlling Legionella, Gardia, cryptos sporidium etc.
- Effective against mussels

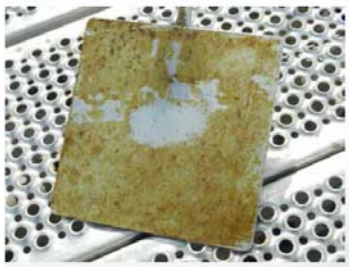


Results

Environmental Indicators	eROI	Economic Results
Cleaning including confined space entry no longer required several times per year	SAFETY	Reduced reliability costs
No unplanned plant down time to clean the cooling system	ASSETS	Cost saving of prevented down time: €2 Million per year €220000 for cleaning 8 heat exchangers, typically 2x per year

Results

With hypochlorite



With purate chlorine dioxide after 8 weeks

THANK YOU