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SAFETY MOMENT - Fiona Butters

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2018 Corrosion Awareness Day

Venue: Emerson Process Management Ltd. Aberdeen Solutions Centre,
1 Harvest Avenue,
D2 Business Park, Aberdeen, AB21 0BQ

Our 1 Day Course to held on 14th August 2018, has **2 main purposes:**

1). To assist the development of those unfamiliar with Corrosion Prevention Issues.

2). To raise funds for ICorr to maintain its ongoing Education Programmes / Events.

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2018 Corrosion Awareness Day

Speaker 1 - Dr Odagboyi Philip Enegela, Ceng, MIMMM, MICorr, (Repsol Sinopec).
Speaker 2 - Dr Muhammad Ejaz, CEng FIMMM, MICorr, MPIE, (PIM).
Speaker 3 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
Speaker 4 - Dr Nigel Owen, B.Sc D.I.C, Ph.D, MIMMM, (Aberdeen Foundries).
Speaker 5 - Stephen Tate, MBA, PG. Dip. Eng, MICorr (CAN/TEPUK).
Speaker 6 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
Speaker 7 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Speaker 8 – Fiona Butters, BA (Hons), Roxar, (Emerson – Corrosion Monitoring).
Speaker 9 – John Thomson, (Emerson - Temperature & Pressure Instrumentation).
Speaker 10 – Steven Healy, (Emerson – Flow Measurement).
Speaker 11 – Chris Burke, BEng (Hons), MIET, Permasense, (Emerson - NDT).

Speakers 8 To 11 – Workshop Demonstrations

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ICorr Aberdeen Branch Welcomes

Dr Odagboyi Philip Enegela (Repsol)

Speaker 1 -

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Dr Odagboyi Philip Enegela

Corrosion Engineer

CEng MIMMM, MICorr

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- BEng. Metallurgical & Materials Engineering
- MSc Corrosion Control Engineering
- PhD Corrosion & Materials
- 9+ years Industry Experience
- Chartered Engineer, MICorr, MIMMM
- Affiliation with academia
- Aviation, Utilities, Oil & Gas Industries

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Principles & Costs of Corrosion

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- Materials
- What is Corrosion
- Important Concepts & Parameters
- Failure / Damage Mechanisms

Materials of Interest

- Metals / alloys – ferrous, non-ferrous
- Plastics / polymers
- Composites
- Wood

Why Metals?

- ✓ Mechanical properties (strength, hardness, ductility etc.)
- ✓ Availability
- ✓ Fabricability & Weldability

*Degradation resistance??

Why do metals corrode – surface condition, inherent composition, local environment,

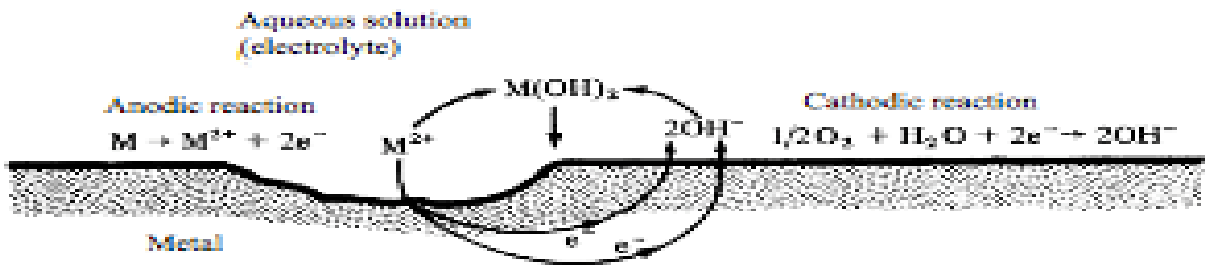
What is Corrosion

Destruction of a material (mostly metallic) due to interactions with its environment

- Requirements for (aqueous) corrosion – material, electrolyte, oxygen, electrical circuit

$$Fe = Fe^{2+} + 2e^{-} \qquad \text{(anodic reaction)}$$

- Electrochemical reactions (involve electrons and chemical species)



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Costs of Corrosion

- Lives

- Up to 3.5% of global GDP *annually*
  - Circa 4 trillion USD

- Reputational damage

Corrosion costs (Oil and Gas industry):

- 7 billion USD per year (gas & liquid transmission pipelines)
- 1.4 billion USD per year for oil & gas E&P

Concepts

- G = -nFE^o; spontaneity criterion

- Potential: voltage of a metal immersed in a solution, usually measured wrt to a reference electrode

$$E = E_0 + \frac{RT}{nF} \ln\left(\frac{[H^+]}{[H_2]}\right)$$

- Current: Transfer of charge. Dissolution / corrosion rate (mA/cm^2)
  - Determines corrosion kinetics
  - Derived from Faraday's Law

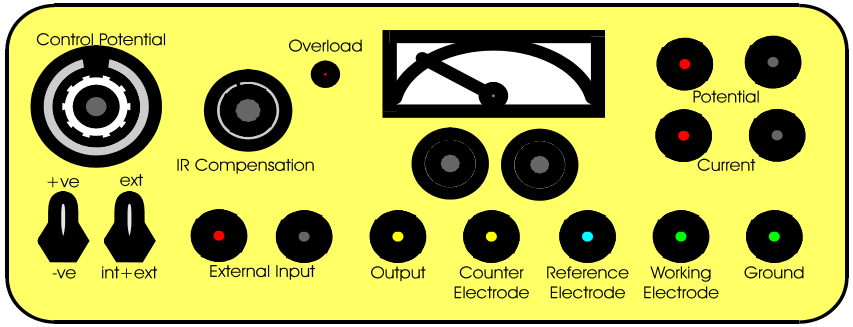
$$Q = \frac{nFm}{M}$$

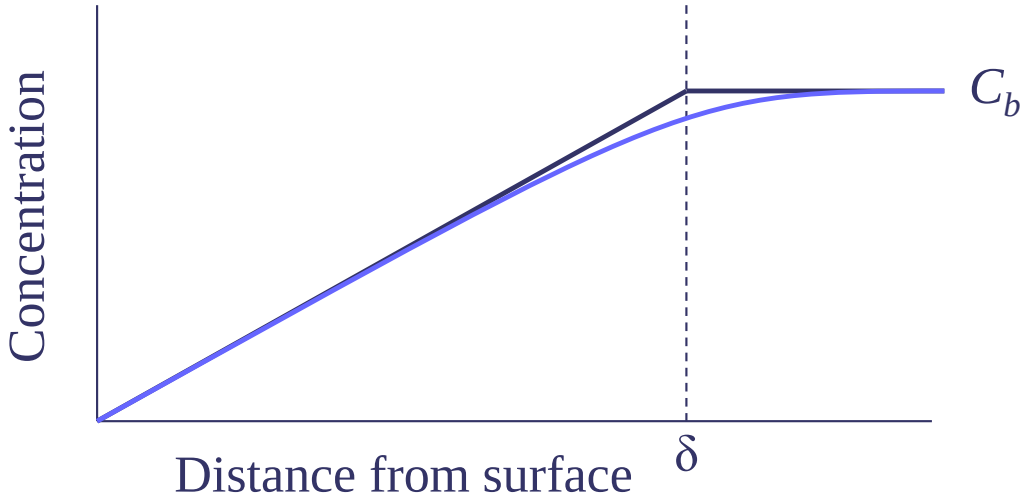
where Q = charge passed (C)
n = number of electrons for each metal atom
F = Faraday's constant (C/mole)
m = mass of metal oxidised (g)
M = atomic weight of metal (g/mole)

Concepts (2)

- Polarization / Overpotentials

- Mass Transport
  - Diffusion & Fick's Law
  - Convection
  - Migration





$$i = \frac{nFD(C_b - C_s)}{\delta}$$

where i = current density

n = number of electrons

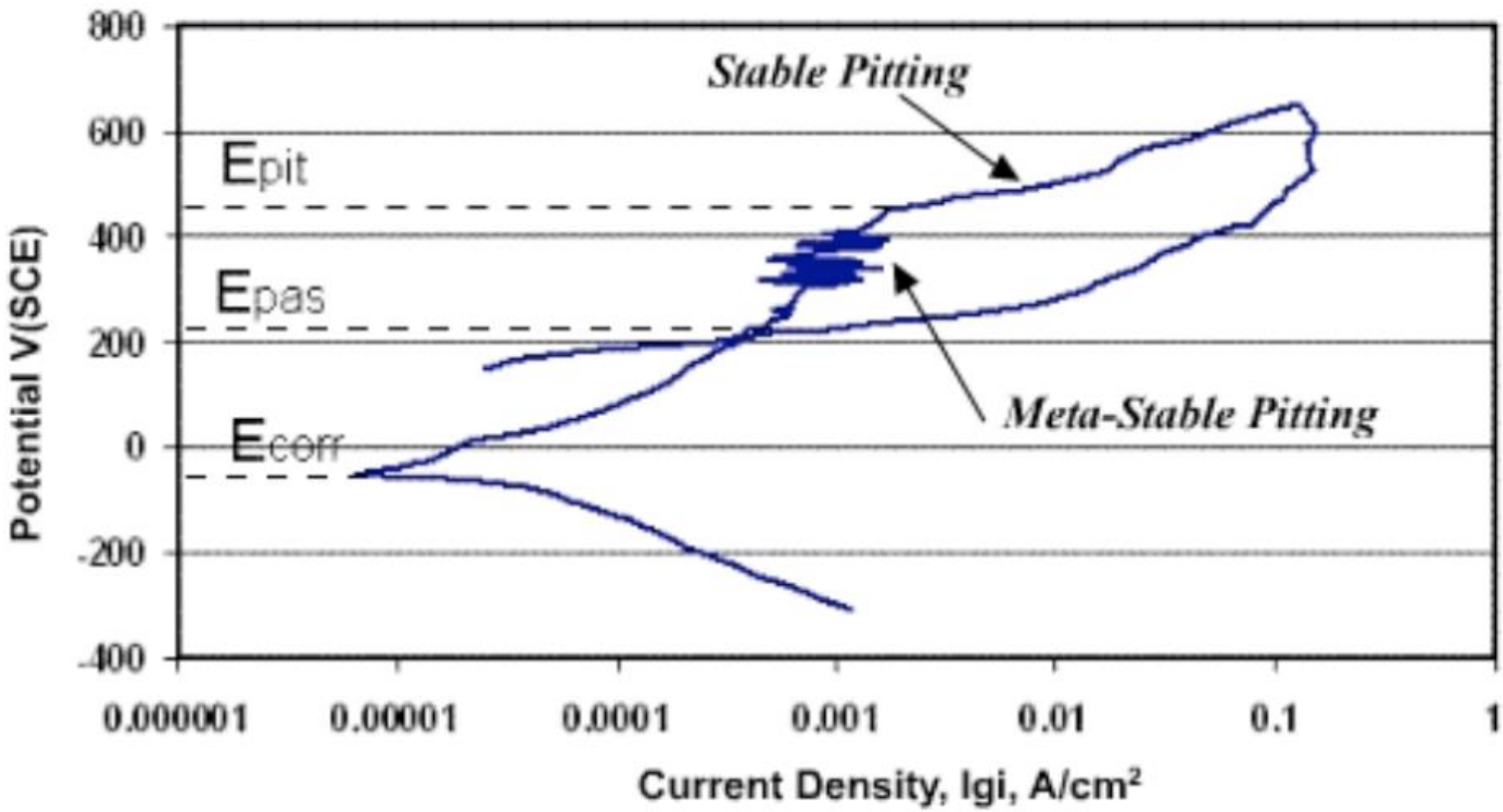
F = Faraday's constant

C_b = bulk concentration

C_s = surface concentration

δ = boundary layer thickness

Some Important Parameters



Pourbaix Diagrams

- Also referred to as “predominance diagrams” or “E - pH diagrams”

- Indicate the regions of immunity, corrosion and passivity for a given material wrt pH

- Provide a summary of the thermodynamic data as well as theoretical chemical / electrochemical conditions for corrosion to occur

Pourbaix Diagram for Iron

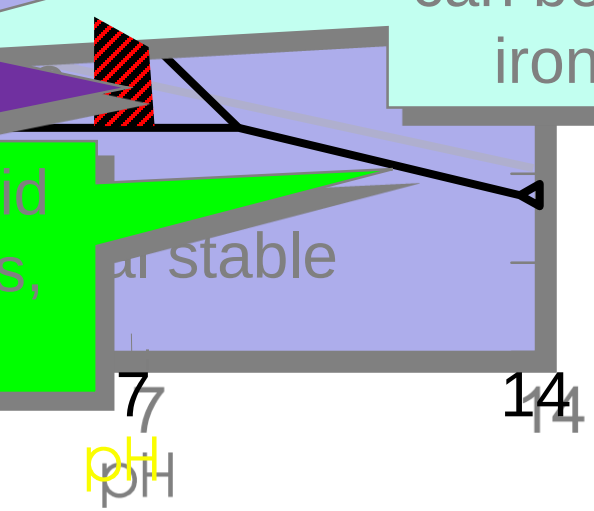
Will iron corrode in alkaline solution?

Yes - although iron can form an oxide in neutral solution, it tends not to form o metal, a is

No - iron forms a solid oxide at all potentials, and will passivate

Will iron c

Yes - there is a reasonably wide range of potentials where hydrogen can be evolved and iron dissolved



Types of Corrosion

- **Classification**

❖ Location: Internal / External

❖ Manifestation: Microscopic / Macroscopic

❖ Mechanism: General / Localized

❖ Medium: Aqueous / “Hot” corrosion

❖ Additional mechanical parameters: Corrosion Fatigue, SCC

General Corrosion

- Also referred to as uniform corrosion
- Results in thickness loss (may be visible)
- Surface roughening may result

www.reptech.co.nz

Atmospheric Corrosion

- Environments - classification of corrosivity (ISO 9223:2012)
  - Rural
  - Urban
  - Industrial
  - Marine

- Pollutants
  - CO_2
  - SO_2
- Relative humidity
- Effect of films (thick vs. thin)

Galvanic Corrosion

- Results from a difference in potential between

✓ Macro-anodes and cathodes
✓ Micro-anodes and cathodes

- Forms the basis for the galvanic series

- In general, connection of an anodic material to a cathodic material in an environment of sufficient conductivity will lead to galvanic corrosion

- Potential of the cell so formed can be calculated using Nernst's equation

Galvanic Corrosion (2)

Considerations

- 100 mV criterion
- Area effect
  - large cathode, small anode?
  - 1:1 ratio?
  - large anode, small cathode?
- Polarity reversal

Localized Corrosion

- Occurs at discrete locations on the surface of a material
- Local anodes and cathodes – could be in close vicinity to one another (order of angstroms) or spatially separated
- Could occur on a free surface or within “enclosed spaces” – occluded cells

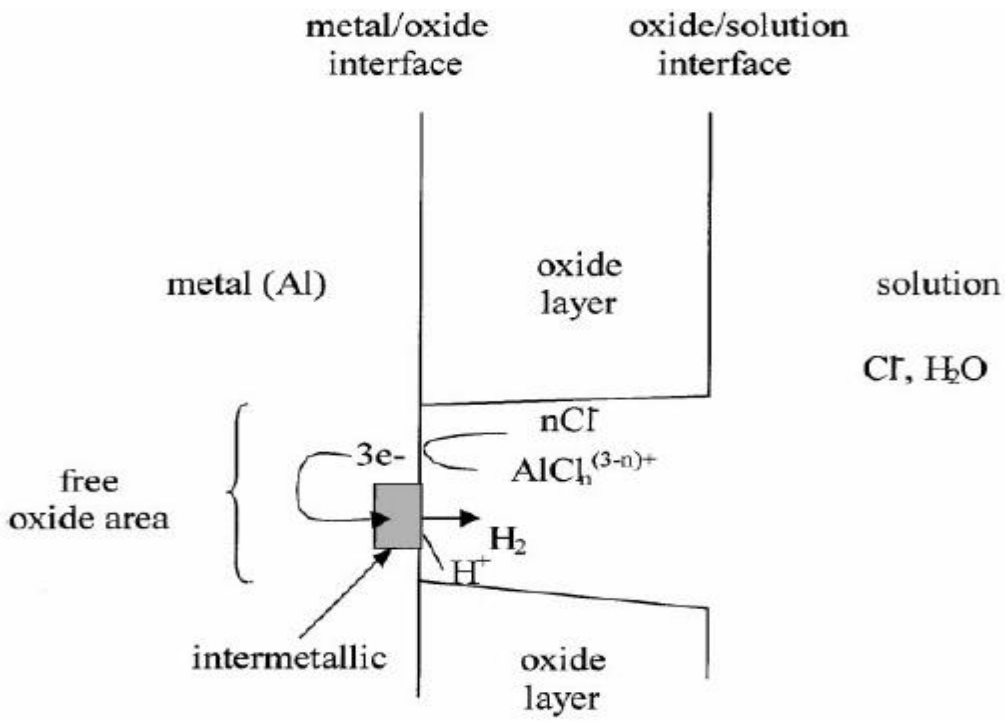
❑ Examples

- Pitting, crevice corrosion
- Filiform corrosion
- Intergranular corrosion
- Stress Corrosion Cracking (SCC)

Crevice Corrosion

- Similar to pitting. Can also occur under deposits
- Existing “cell” – no real need for initiation stage
- Driven by cathodic reaction outside the occluded cell
- Dependent on “differential aeration”
- Acidification occurs over time within the crevice

Pitting Corrosion



- Scratches / mechanical defects
- Grain boundaries
- Inhomogeneities in the passive film

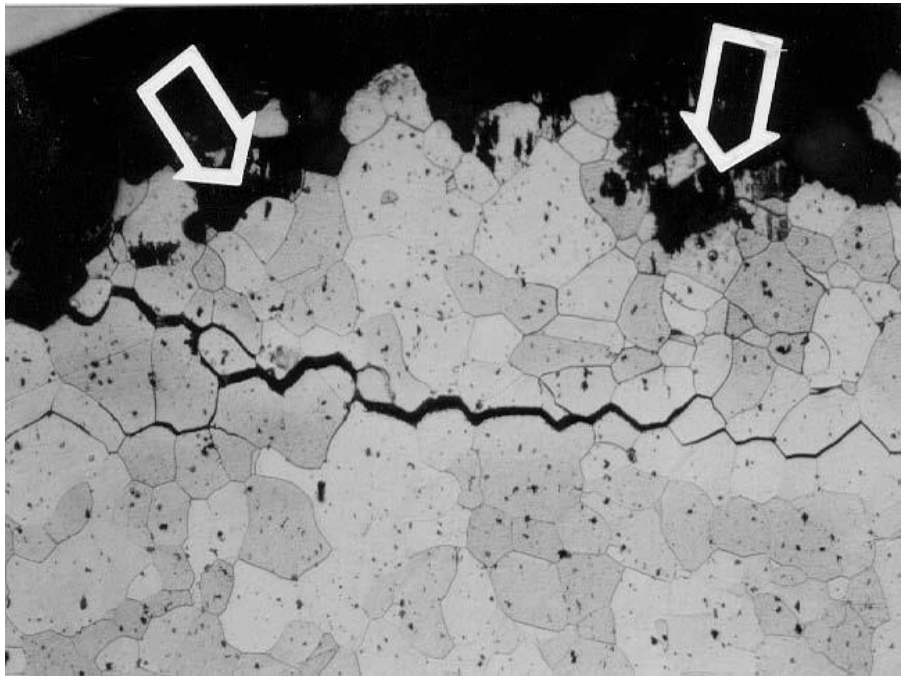
Pitting Corrosion

- Usually occurs on a free surface (on passive materials)*
- Results in a breakdown of the passive film
- Requires the presence of anions, most commonly Cl^-
- Generally, the process consists of a number of steps
  - Initiation / nucleation
  - Metastable pitting
  - Stable pit growth (propagation)

Stress Corrosion Cracking

- 3 components
  - Susceptible material
  - Environment
  - Stress – applied / residual

- Pitting may be a precursor



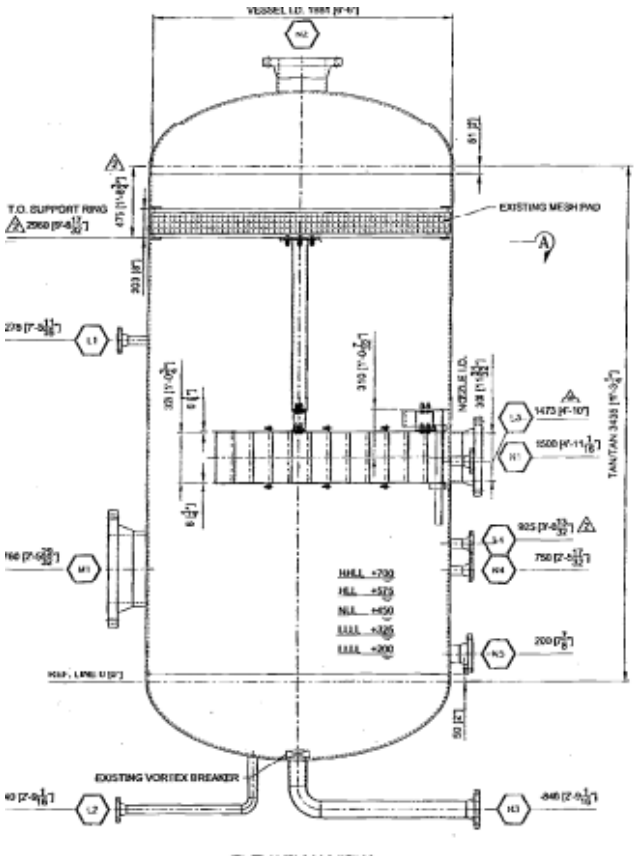
http://corrosion.ksc.nasa.gov/images/scc4.jpg

Sweet Corrosion

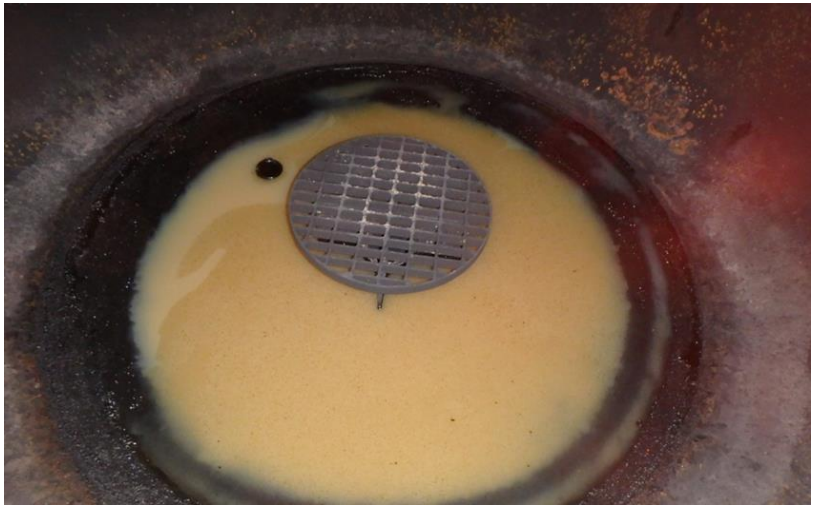
- Formation of weak carbonic acid

$$CO_2 + H_2O = H_2CO_3$$

- Dissociation and release of H^+

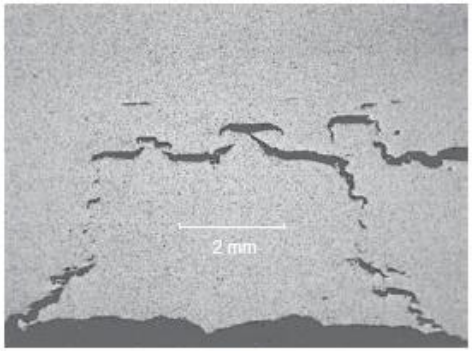


Sweet Corrosion



Sour Corrosion

- Hydrogen Damage – SSC, SWC, SOHIC, HE



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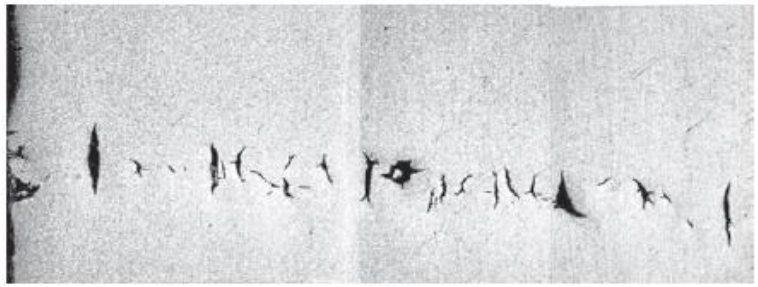

(b)

Microbial Corrosion

- Microbiologically Influenced Corrosion (MIC)
- Metabolites affect the environment
- Bugs may cause change in the potential of the material
- Different sources of nutrients

MIC

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THANK YOU FOR YOUR ATTENTION

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SPEAKER 2 - Dr Muhammad Ejaz (PIM)

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PIM WAS ESTABLISHED IN 2011 TO PROVIDE CONSULTANCY AND STRATEGIC MANAGEMENT SUPPORT FOR THEIR CLIENTS - HELPING THEM MANAGE THE FUNCTION AND INTEGRITY OF THEIR CRITICAL PLANT AND EQUIPMENT.

WHAT WE DO: STRATEGIC MANAGEMENT OF INTEGRITY AND THE PROVISION OF OPERATIONAL SUPPORT

WHERE WE ARE: UK, INTERNATIONAL SERVICES

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MUHAMMAD EJAZ

BSC, METALLURGICAL ENGINEERING DEGREE, PAKISTAN
MSC, MATERIALS DEGREE, SOUTH KOREA
PHD, CORROSION AND PROTECTION, THE UNIVERSITY OF MANCHESTER

2010 – 2014 CAN OFFSHORE / ENGTEQ
2014 – 2017 LR SENERGY / LLOYD'S REGISTER
2017 – TO DATE PLANT INTEGRITY MANAGEMENT

CENG FIMMM, FICORR, NACE CORROSION SPECIALIST, MIEP

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Corrosion Rate Modelling

Introduction
CO_2 Modelling Software
How to use calculated corrosion rate
A bit about H_2S corrosion
O_2 corrosion modelling
Summary

Scope and Objectives

This presentation covers

- Carbon steel - *not* Corrosion Resistant Alloys
- Linear corrosion mechanism (general corrosion) – *not* cracking

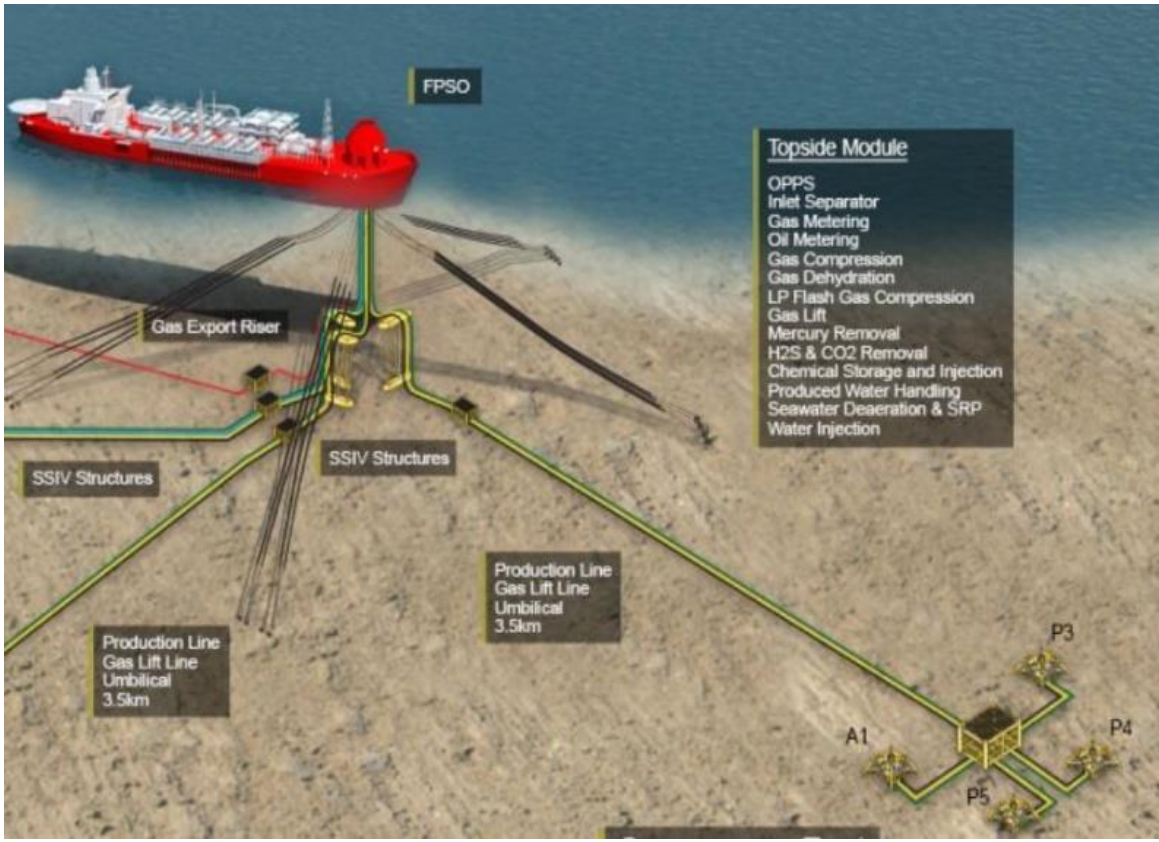
- Objective is to:
  - Provide an overview of corrosion modelling
  - Avoid black box approach – “Computer says…..”
  - Use engineering judgment with numbers
  - Understand limitation of modelling

Introduction

Corrosion Modelling - complete life cycle of the plant

- **Design of new facilities**

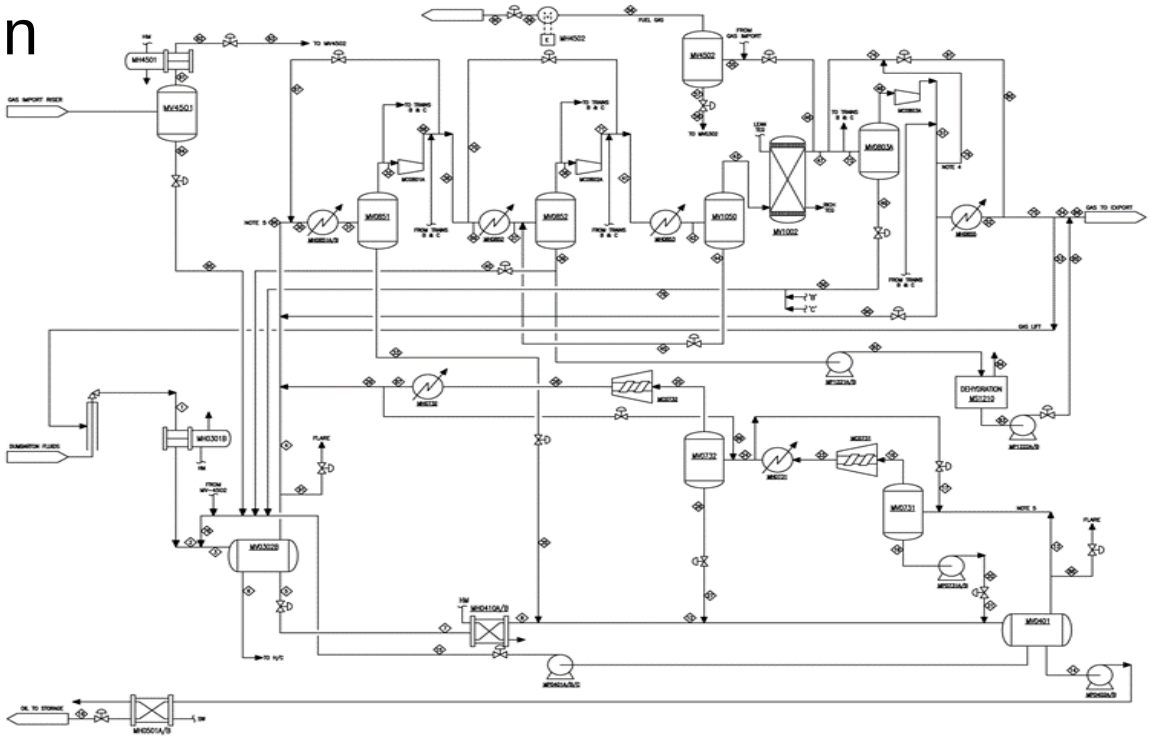
- Materials Selection (C-steel vs CRA)
- Corrosion barrier requirements (Inhibition, coating, CP etc.)



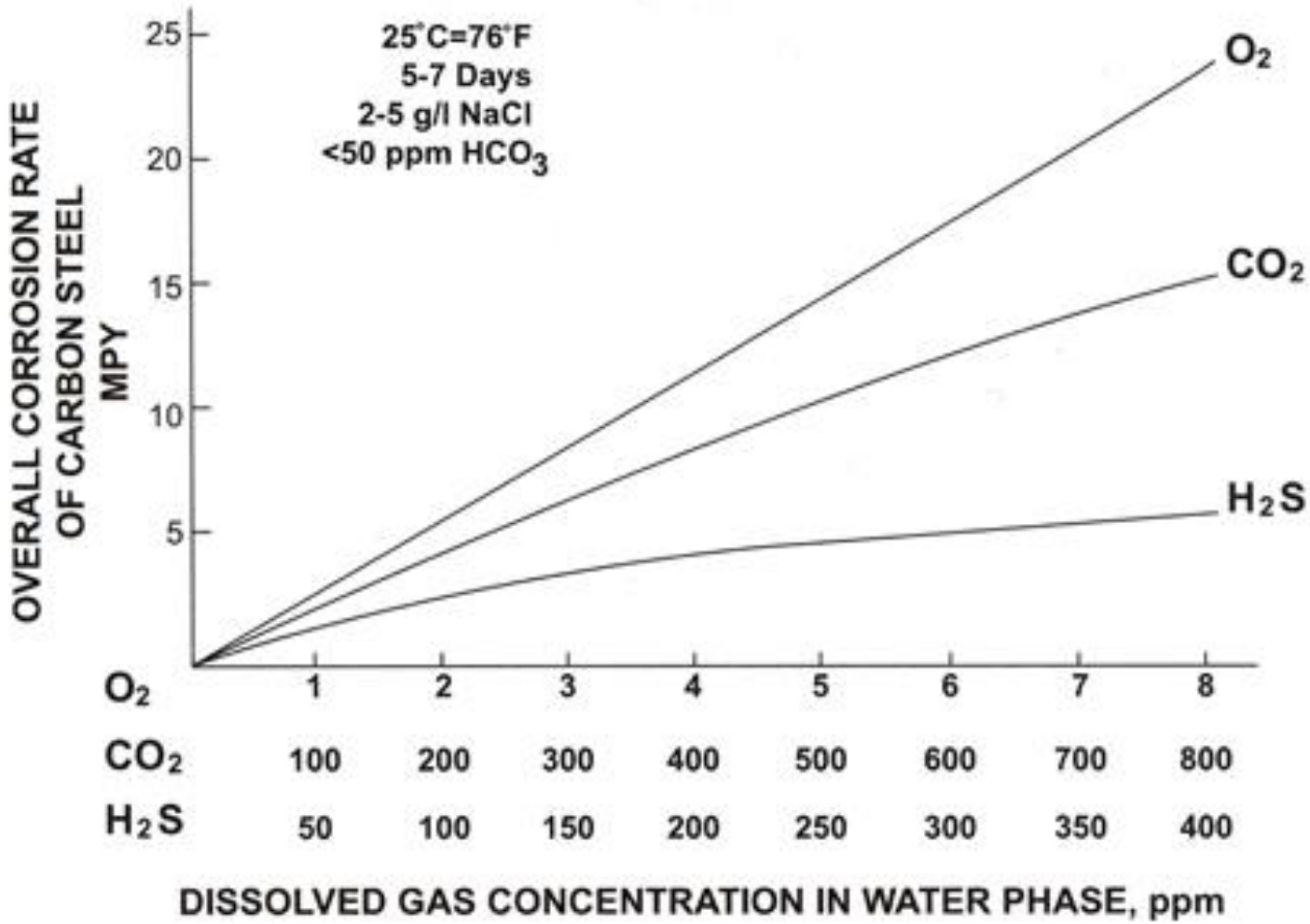
Introduction

Corrosion Modelling - complete life cycle of the plant

- **Integrity Management**
  - React to changes in process conditions
  - New facility tie-in

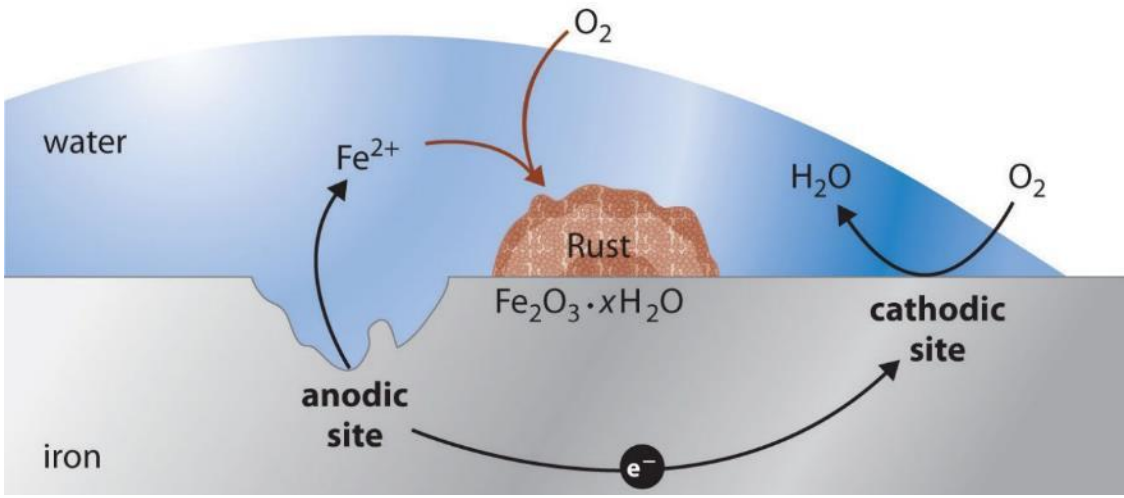


Oilfield Corrosion



Corrosion Modelling for Oil and Gas

- **CO_2 Corrosion**
- ***H_2S Corrosion***
- ***O_2 Corrosion***



- *Anodic Reaction*

$$Fe \leftrightarrow Fe^{2+} + 2e^-$$

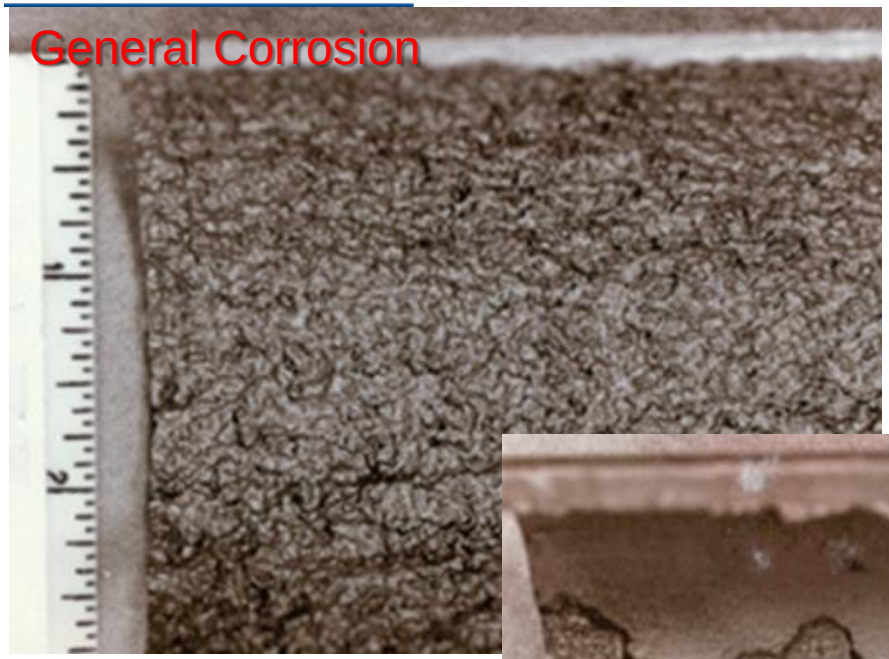
- *Cathodic Reaction(s)*

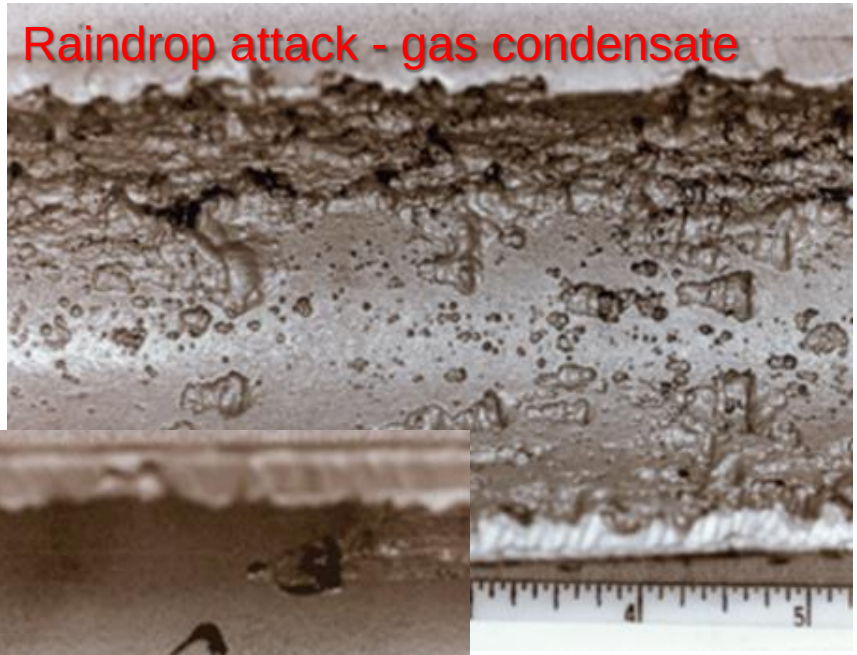
$$CO_2 + H_2O \leftrightarrow H_2CO_3 + 2e^- \leftrightarrow H_2 + CO_3^{2-} \text{ (CO_2 Corrosion)}$$

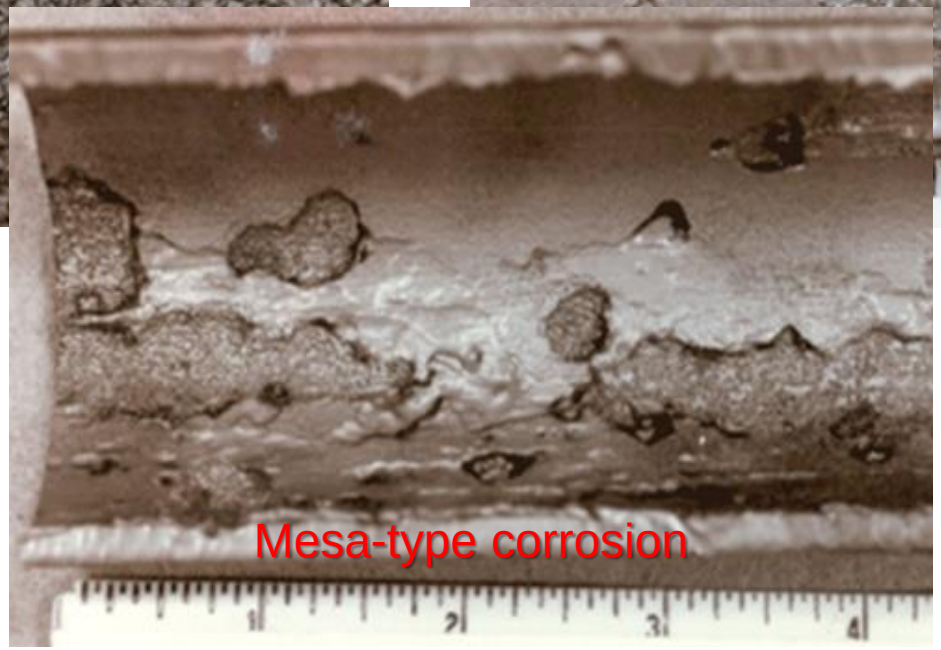
$$O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O \text{ (O_2 corrosion)}$$

$$H_2S \leftrightarrow 2H^+ + S^{2-} \text{ (H_2S Corrosion)}$$

CO_2 Corrosion







Types of Predictive Models

- **Mechanistic**

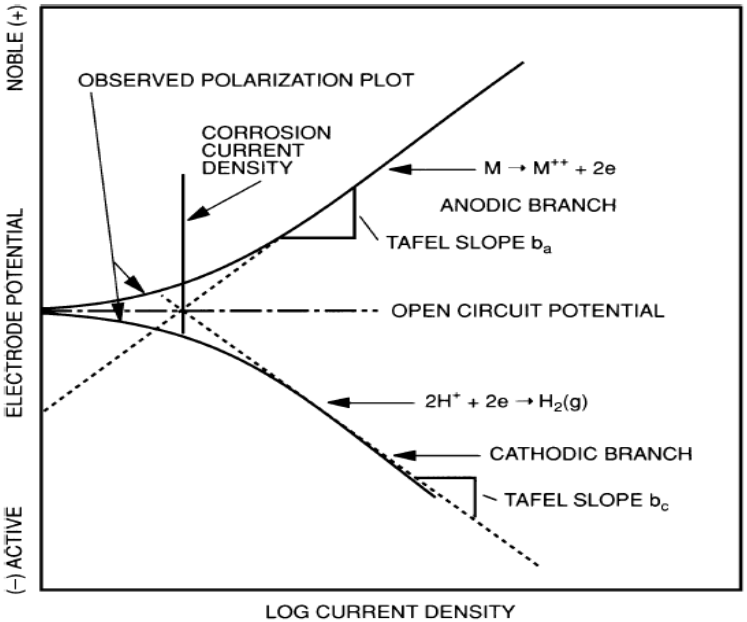
  - Formulated from quantitative knowledge of reaction *thermodynamic* and *kinetics*

- **Empirical**

  - Formulated from array of *experimental measurements*

- **Semi-empirical**

  - *Mix of Above*



Pioneering Work

De Waard and Milliams (Carbonic Acid Corrosion of Steel,1975)

$$\log V_{corr} = 5.8 - (1710 / (273 + T)) + 0.67 \log (P_{CO_2})$$

where

V_{corr} is corrosion rate
T is Temperature, and
P_{CO_2} is partial pressure of CO_2

(cathode reaction: H_2CO_3 reduction)

Partial pressure of a gas

- Partial pressure quantifies gas dissolved in water at equilibrium

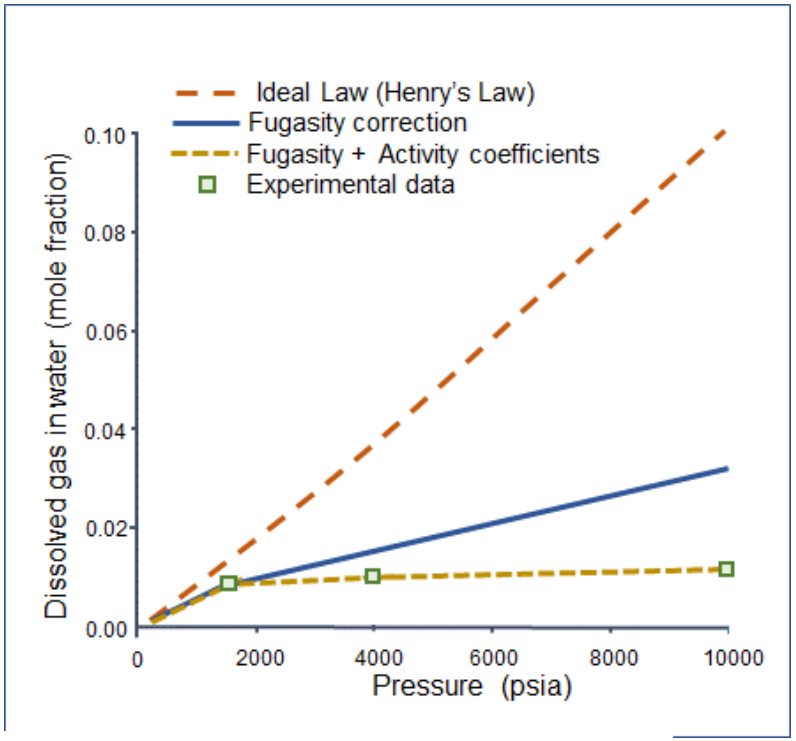
  *- Total pressure * Mole fraction in gas*

For example:
For 0.1% CO_2 in gas at pressure of 10 bara

$$P_{CO_2} = 10 * 0.1 = 1 \text{ bara}$$

- Ideal gas – Henry's law

- Fugacity correction

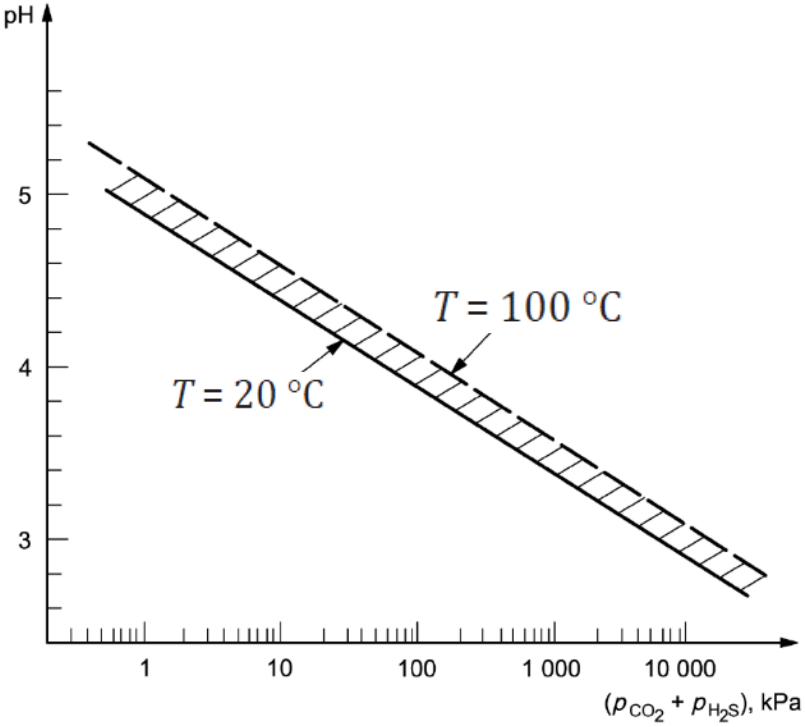


Effect of acid gases on pH

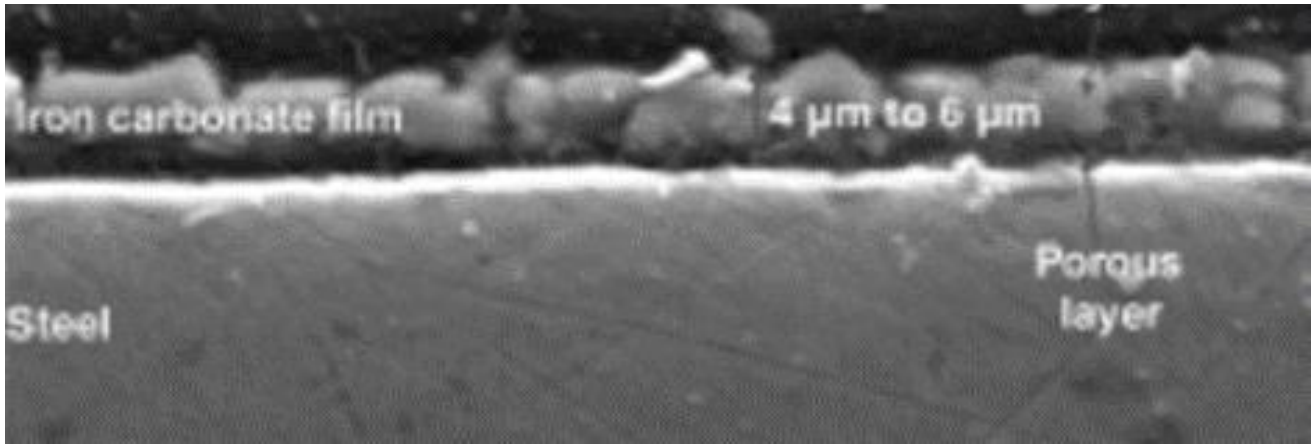
- pH is function of
  - Partial pressure of acid gases
  - Temperature
  - Organic acid (Acetates)
  - Formation water chemistry

e.g., bicarbonate ion (HCO_3^-)

  - Formation water >~ 4.5
  - Condensed water >= 3.5



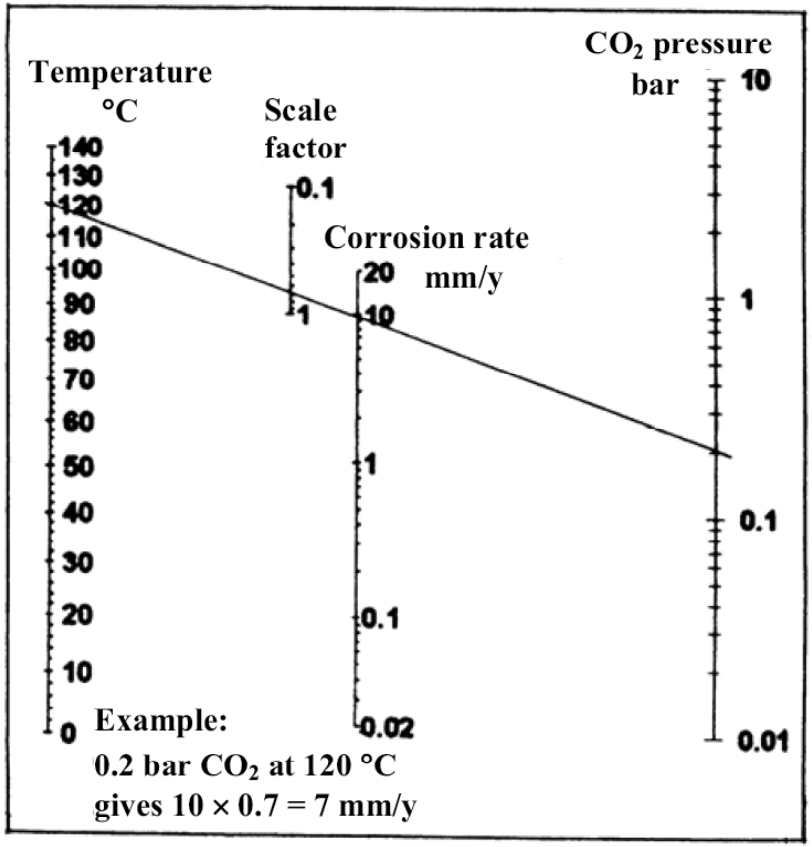
Temperature – scale formation



- About 60 - 70°C carbonate scale start forming on carbon steel surface

$$Fe + H_2O + CO_2 \leftrightarrow FeCO_3 \text{ (Siderite)} + H_2$$

De Waard & Milliams Nomogram



P_{CO2} (bar)	Temp (°C)	CR_{free} (mm/year)	Scale factor	CR_{scale} (mm/year)
1	20	1	-	1
1	40	2	-	2
1	60	5	-	5
1	80	9	-	9
1	100	16	0.5	8
1	120	30	0.2	6

$$CR_{scale} = CR_{free} \times SF$$

Development of Predictive Model Software

- pH
- Scale
- Steel composition
- Glycol %
- Inhibition
- Wettability
- Organic acids

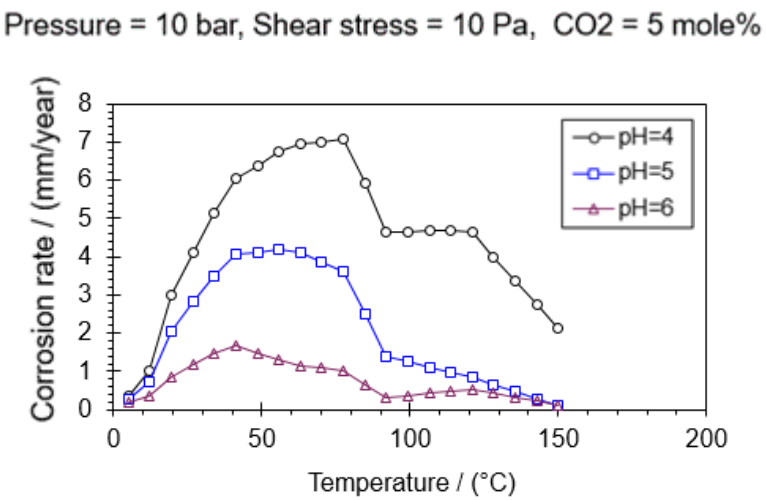
- de Waard et al (Shell)
- NORSOK model (Statoil, Saga, Hydro)
- HYDROCOR (Shell)
- Cassandra (BP)
- CORMED (Elf)
- LIPUCOR (Total)
- CORPLUS (Total)
- KSC Model (IFE)
- ECE model (Intetech)
- SweetCor (Shell)
- OLI model (OLI Systems)
- PREDICT (InterCorr)
- Tulsa model (University of Tulsa)
- Jepson model (University of Ohio)
- MULTICORP (University of Ohio)
- Corpos (CorrOcean)
- ULL model (University of Louisiana at Lafayette)
- DREAM (Oklahoma State University)

NORSOK M-506 (2005)

- Input

Temperature	40	°C
Pressure	10	bar
Mole percent CO2 in gas	5	mole%
Shear stress	10	Pa
pH	5	
Glycol concentration	0	%
Inhibitor efficiency	0	%

- Output



- Limitations

The model is valid for temperature 5 - 150 °C, pH 3.5 - 6.5, CO_2 partial pressure 0.1 - 10 bar and shear stress 1 - 150 Pa.
The model is not applicable when the H_2S partial pressure is higher than 0.5 bar, or when the ratio between the partial pressure of CO_2 and H_2S is less than 20.
The model can lead to underprediction of the corrosion rate when the total content of organic acids exceeds 100 ppm and the CO2 partial pressure is less than 0.5 bar.

Using Predictive model out put

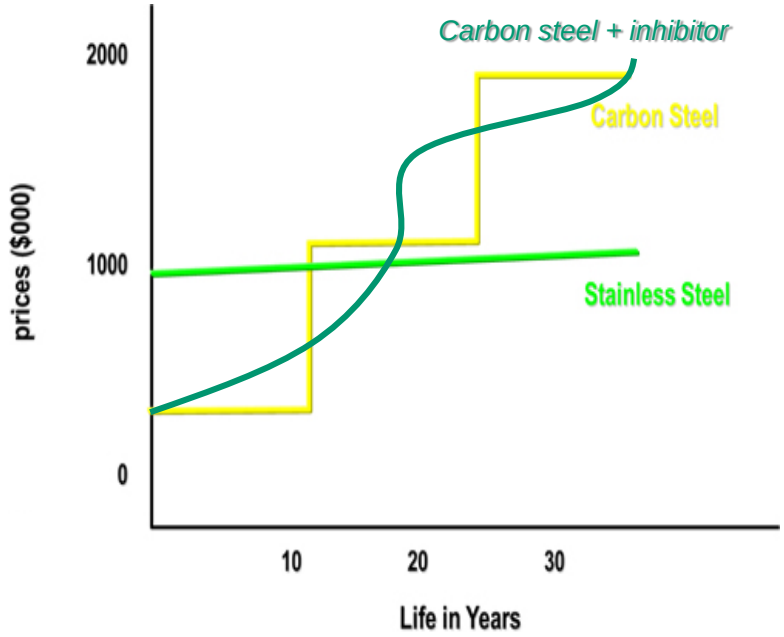
Corrosion allowance (mm)

- Calculated corrosion rate x design life

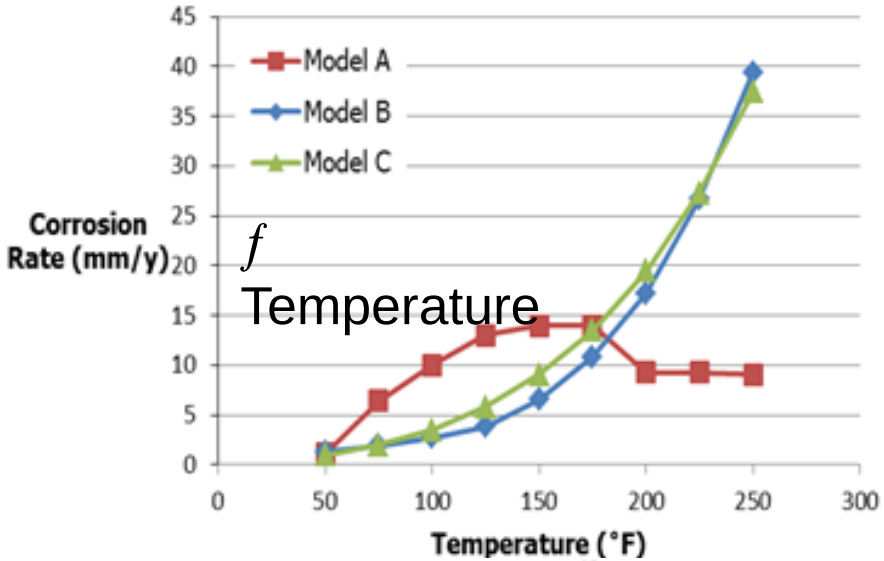
  If corrosion allowance is more than 10 mm for carbon steel – consider using corrosion resistant alloys (NORSOK M-001)

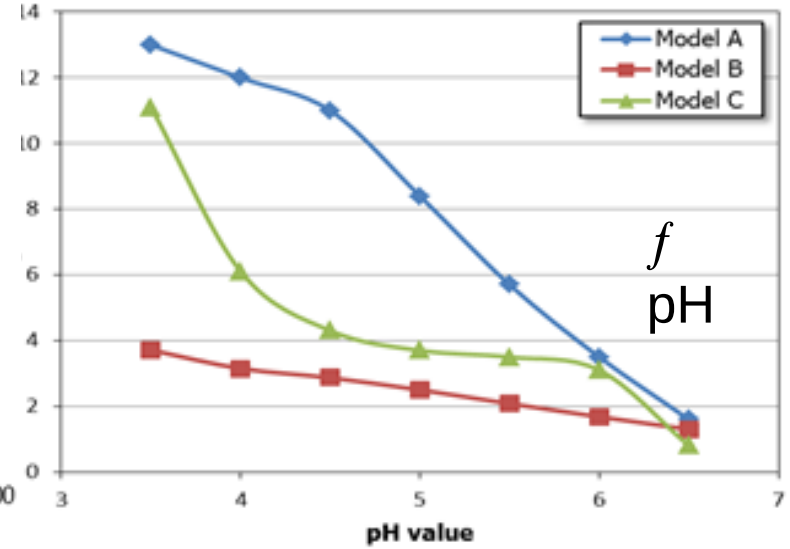
- Complete life cycle cost analysis with carbon steel + inhibition

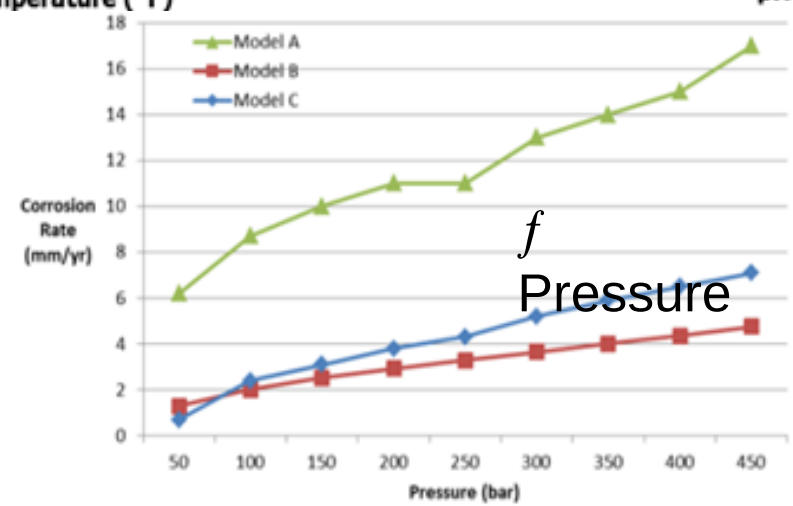
- Be aware of different corrosion rates (outputs) from different models



Comparison of Predictive models







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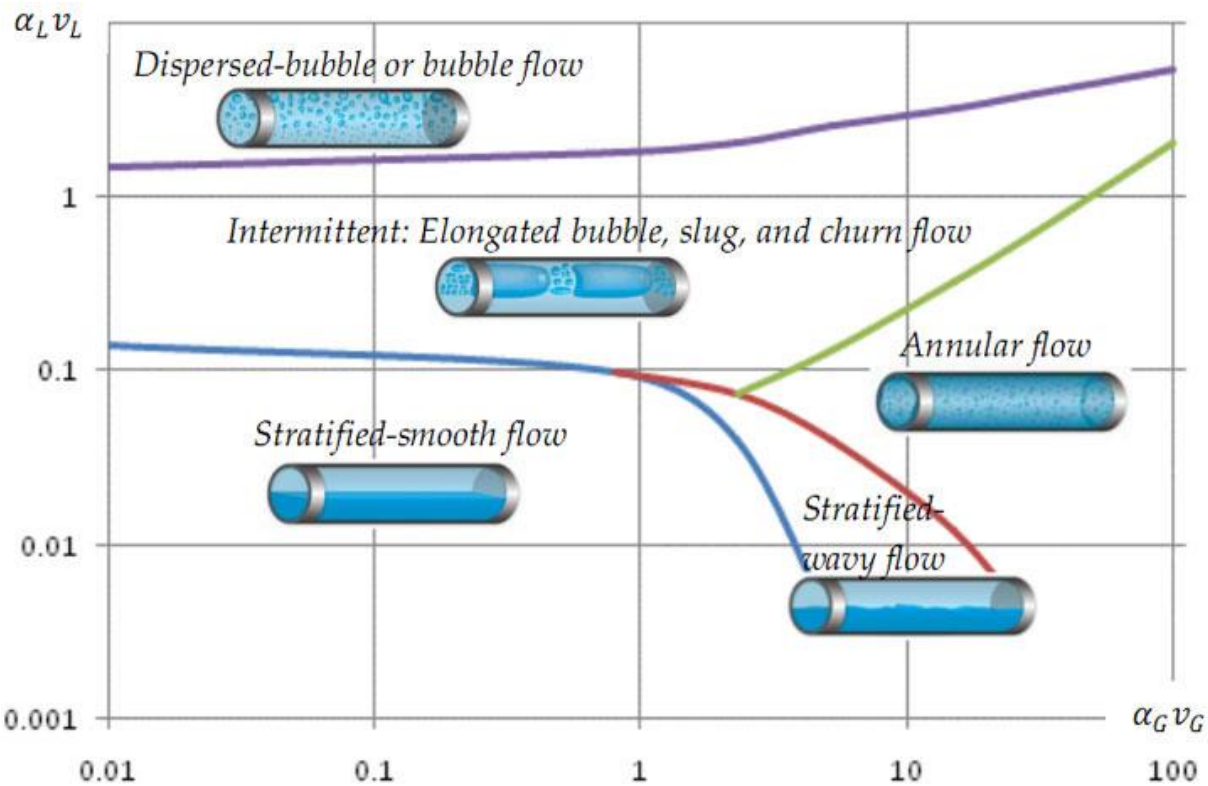
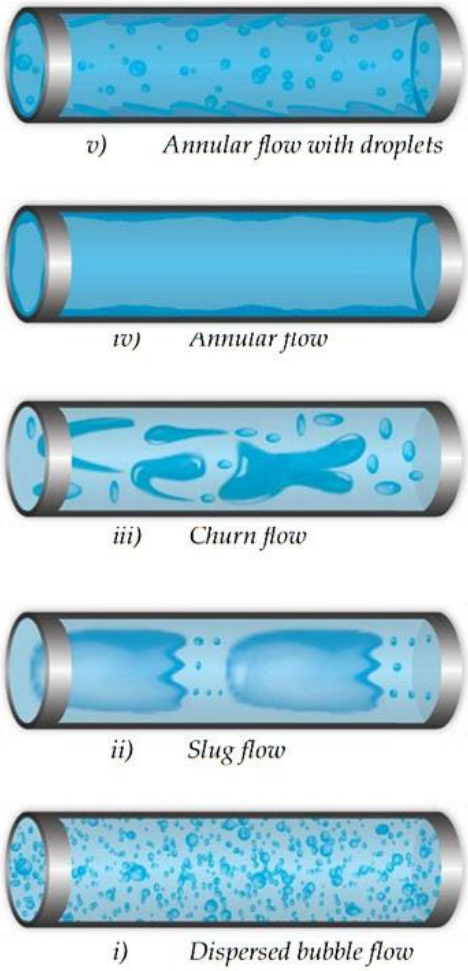
Example:

Cassandra				Norsok		ECE
Inhibited Rate mm/yr				Uninhibited	Inhibited	Inhibited
Basic		Flow-sensitive		mm/yr	mm/yr	mm/yr
BP93	DW93	BP95	DW95	M-506		
4.3	6.2	5.0	5.3		4.8	5.9
Required corrosion allowance						

Corrosion Inhibitor		95%								Pipe	OD		219.1	mm		196.5	mm ID
Design Life		15	years								WT		11.3	mm			
8" Production										Cassandra					Norsok		ECE
Year		Temperature	Pressure	Average Mol% CO_2	Mol% H_2S	Oil Flowrate	Water Flowrate	Gas Flowrate	pH	Inhibited Rate mm/yr					Uninhibited	Inhibited	Inhibited
		°C	bara			m3opd	m3wpd	sm3/d		Basic		Flow-sensitive			mm/yr	mm/yr	mm/yr
									PHACT	BP93	DW93	BP95	DW95		M-506		
1	1	67	73	6.50	0	2584	79	113267	4.4	0.8	1.2	0.9	1.0		20	1.1	0.1
1	11	67	73	0.89	0	2584	79	113267	5.3	0.2	0.3	0.2	0.2		2.7	0.2	0.01
2	1	67	73	6.50	0	3483	228	339802	4.4	0.8	1.2	1.2	1.4		23	1.2	0.3
2	11	67	73	0.89	0	3483	228	339802	5.3	0.2	0.3	0.3	0.3		3	0.2	0.1
3	1	67	73	6.50	0	1048	1984	339802	4.4	0.8	1.2	1.2	1.3		22	1.2	1.8
3	11	67	73	0.89	0	1048	1984	339802	5.3	0.2	0.3	0.3	0.3		3	0.2	0.4
4	1	67	73	6.50	0	911	2411	339802	4.4	0.8	1.2	1.2	1.3		23	1.2	1.8
4	11	67	73	0.89	0	911	2411	339803	5.3	0.2	0.3	0.3	0.3		3	0.2	0.4
5	1	67	73	6.50	0	804	2443	339802	4.4	0.8	1.2	1.2	1.3		23	1.2	1.8
5	11	67	73	0.89	0	804	2443	339803	5.3	0.2	0.3	0.3	0.3		3	0.2	0.4
6	1	67	73	6.50	0	578	2926	311485	4.4	0.8	1.2	1.2	1.3		23	1.2	1.8
6	11	67	73	0.89	0	578	2926	311486	5.3	0.2	0.3	0.3	0.3		3	0.2	0.4
7	1	67	73	6.50	0	470	3070	311485	4.4	0.8	1.2	1.2	1.3		23	1.2	1.8
7	11	67	73	0.89	0	470	3070	311486	5.3	0.2	0.3	0.3	0.3		3	0.2	0.4
8	1	67	73	6.50	0	340	3186	283169	4.4	0.8	1.2	1.2	1.3		22	1.2	1.7
8	11	67	73	0.89	0	340	3186	283170	5.3	0.2	0.3	0.3	0.3		3	0.2	0.3
9	1	67	73	6.50	0	291	3236	254852	4.4	0.8	1.2	1.1	1.2		22	1.2	1.7
9	11	67	73	0.89	0	291	3236	254853	5.3	0.2	0.3	0.3	0.3		3	0.2	0.3
10	1	67	73	6.50	0	240	3313	169901	4.4	0.8	1.2	1.0	1.1		21	1.1	1.6
10	11	67	73	0.89	0	240	3313	169902	5.3	0.2	0.3	0.2	0.3		2.9	0.2	0.3
11	1	67	73	6.50	0	196	3294	198218	4.4	0.8	1.2	1.1	1.2		22	1.2	1.6
11	11	67	73	0.89	0	196	3294	198219	5.3	0.2	0.3	0.2	0.3		2.9	0.2	0.3
12	1	67	73	6.50	0	164	3382	198218	4.4	0.8	1.2	1.1	1.2		22	1.2	1.6
12	11	67	73	0.89	0	164	3382	198219	5.3	0.2	0.3	0.3	0.3		2.9	0.2	0.3
13	1	67	73	6.50	0	154	3404	198218	4.4	0.8	1.2	1.1	1.2		22	1.2	1.6
13	11	67	73	0.89	0	154	3404	198219	5.3	0.2	0.3	0.3	0.3		2.9	0.2	0.3
14	1	67	73	6.50	0	135	3442	198218	4.4	0.8	1.2	1.1	1.2		22	1.2	1.6
14	11	67	73	0.89	0	135	3442	198219	5.3	0.2	0.3	0.3	0.3		2.9	0.2	0.3
15	1	67	73	6.50	0	121	3472	198218	4.4	0.8	1.2	1.1	1.2		22	1.2	1.6
15	11	67	73	0.89	0	121	3473	198219	5.3	0.2	0.3	0.3	0.3		2.9	0.2	0.3
										4.3	6.2	5.0	5.3			4.8	5.9
										Required corrosion allowance							

Flow regimes in horizontal pipe





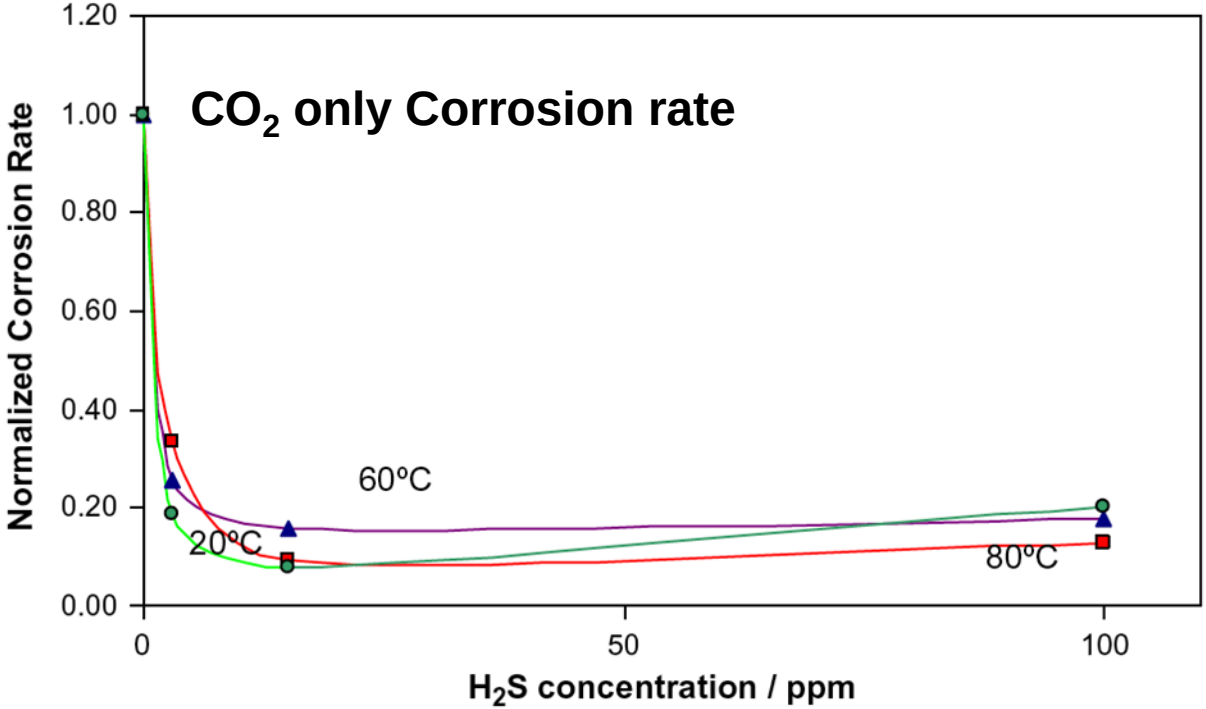
Example of steady-state flow regime map for a horizontal pipe. Superficial liquid velocity V_L *vs* superficial gas velocity V_G.

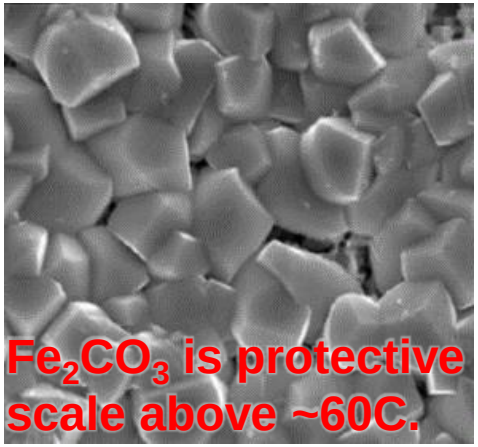
Exploiting Output – Inhibition categorisation

Category	*Maximum Required Availability*	*Maximum Expected Uninhibited Corrosion Rate (mm/yr)*	*Comment*	*Possible Category Name*
1	0%	0.4	Benign fluids where corrosion inhibitor usage is not anticipated (dry gas, stabilised oil). Predicted metal loss can be accommodated by corrosion allowance alone.	Benign
2	50%	0.7	Corrosion inhibitor will probably be required but at the expected corrosion rates there will be time to review the need for inhibition based on inspection data.	Low
3	90%	3	Corrosion inhibitor will be required for the majority of the field life but the facilities need not be available from day 1.	Medium
4	95%	6	Inhibition is relied on heavily and will be required for the lifetime of the operation. Inhibitor must be available from day 1 to ensure success of the inhibition programme.	High
5	>95%	>6	Carbon steel and inhibition is unlikely to provide integrity for the full field life. Select corrosion resistant materials or plan for repairs & replacements.	Unacceptable

B. Hedges, D. Paisley and R. Woollam, “The corrosion inhibitor availability model,” in Corrosion 2000.

Fe_2S passive layer

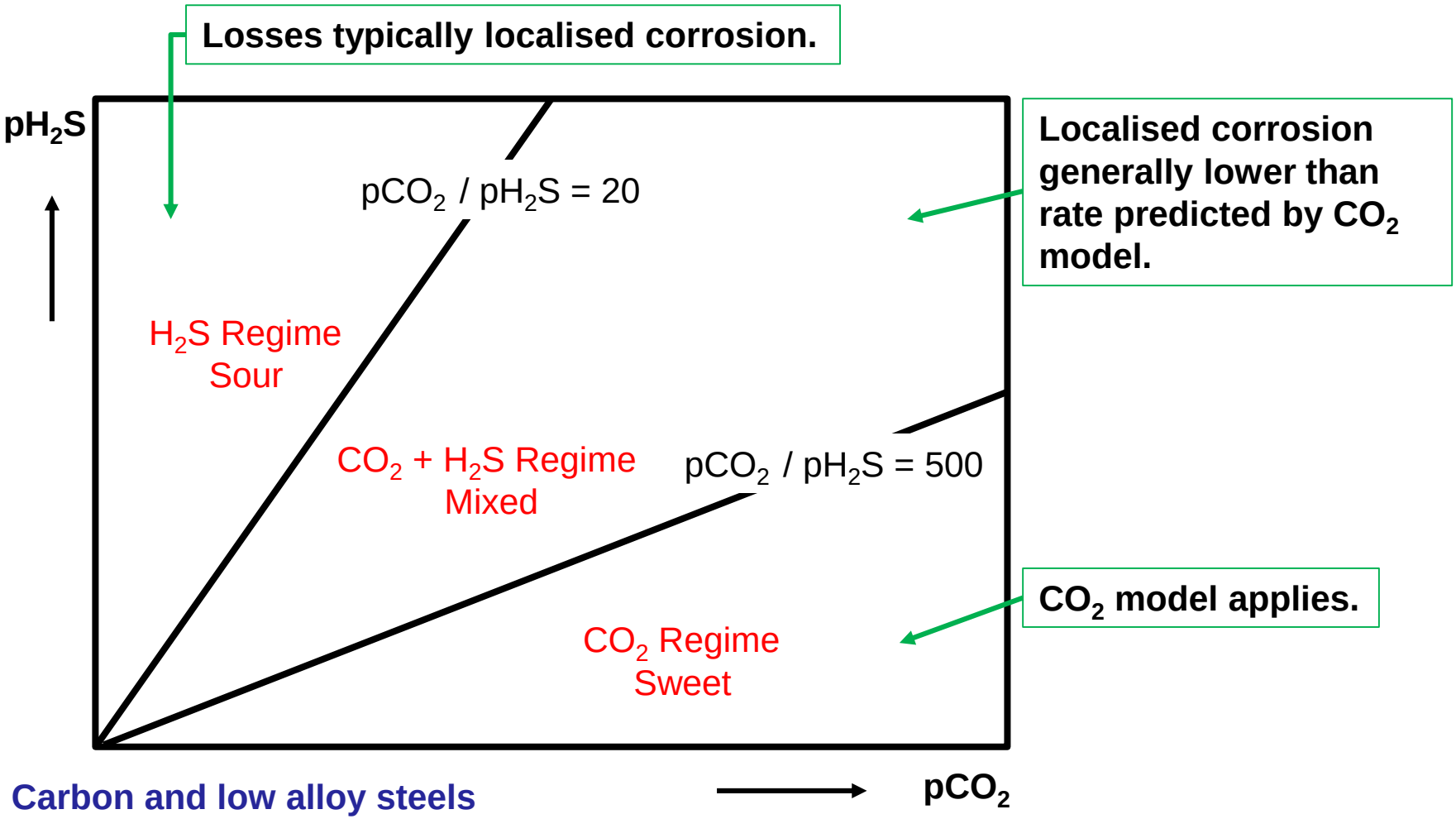




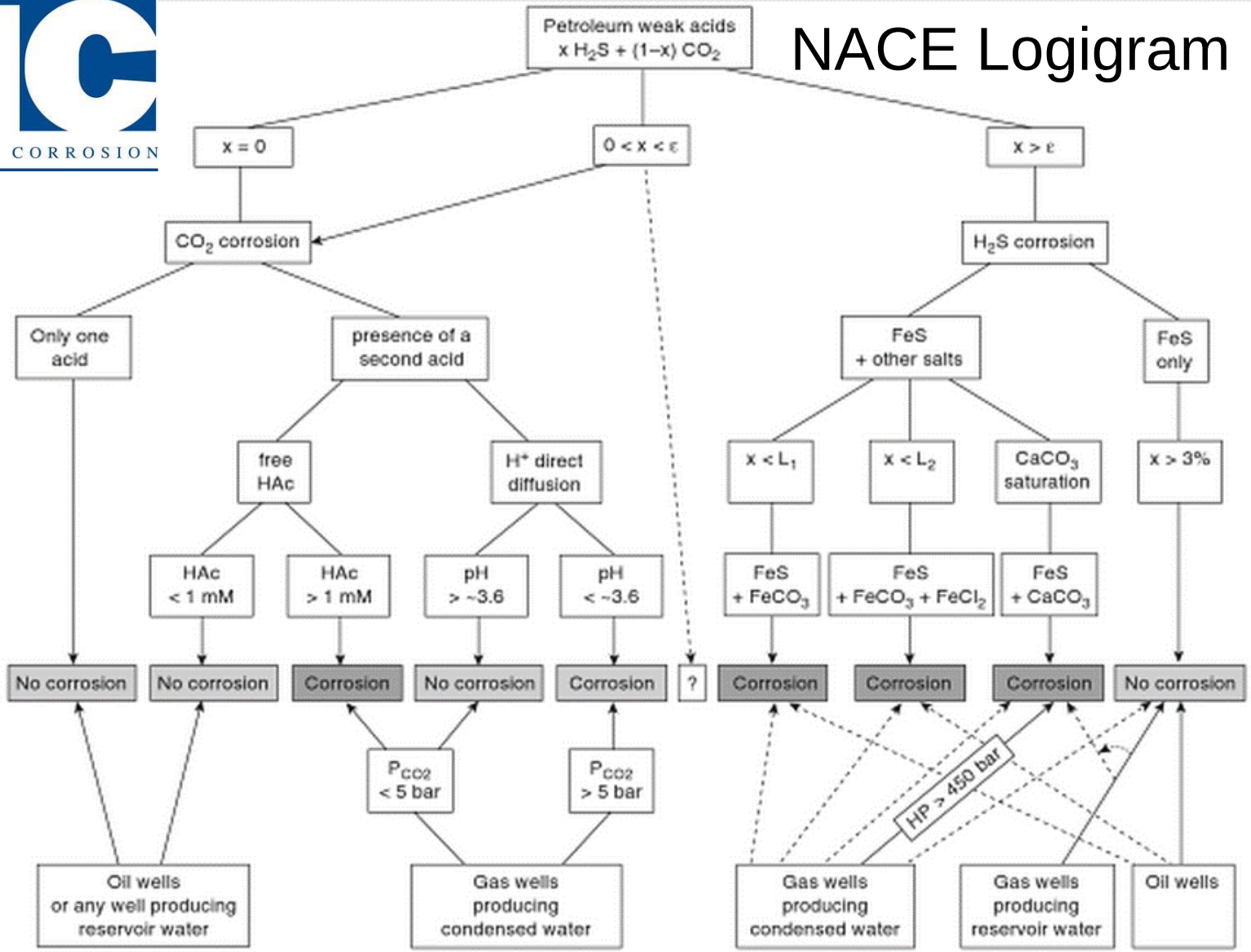
Fe_2S is semi-protective layer and does not provide corrosion inhibition. This leads to localised corrosion.

H_2S corrosion

NACE Corrosion Conference 02235, 06122 and 09564



NACE Logigram



Metallurgy and Corrosion Control in Oil and Gas Production by Robert Heidersbach, 2011

Corrosion Modelling for Oil and Gas

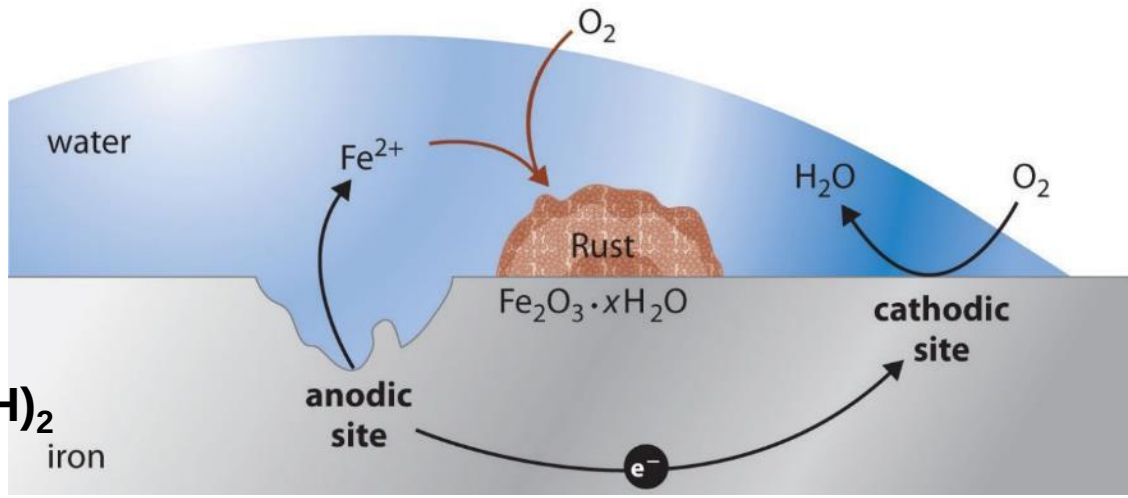
- ***O_2 Corrosion***
- **Corrosion Product:**

  Geothite – FeO(OH)

  Hematite – Fe_2O_3

  Magnetite – Fe_3O_4

  Ferous Hydroxide – $Fe(OH)_2$



- *Anodic Reaction*

$$Fe \leftrightarrow Fe^{2+} + 2e^-$$

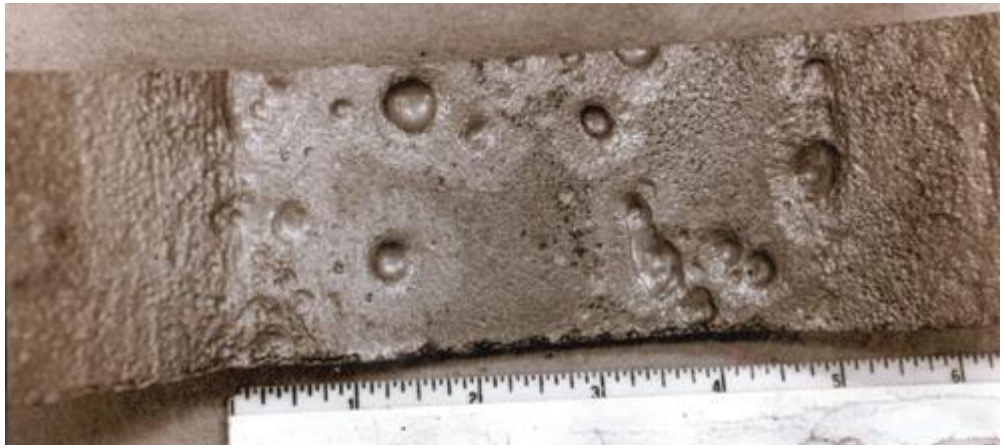
- *Cathodic Reaction(s)*

$$O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O \text{ (}O_2\text{ corrosion)}$$

O_2 Corrosion

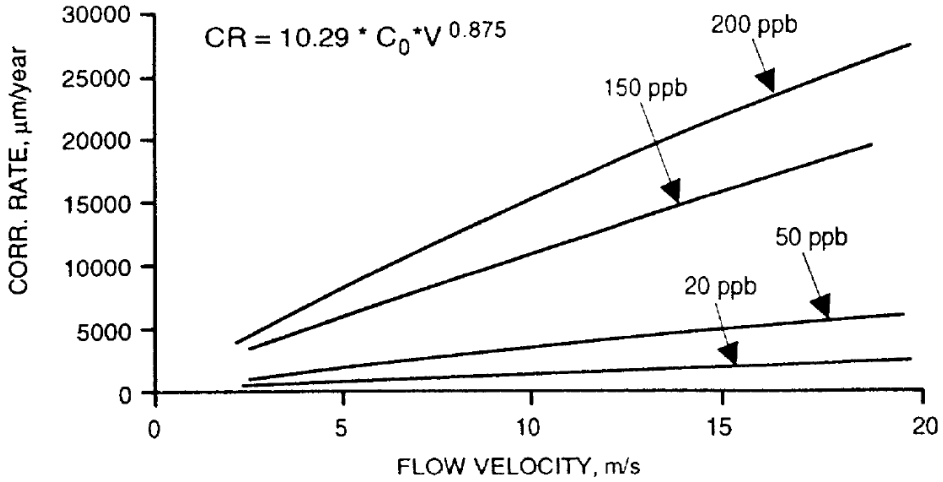
$$C_r = \frac{5.65}{Re^{0.125}} \cdot \frac{C_o U_o}{Pr^{0.75}}$$

Where:
C_o is the oxygen concentration in **ppb**,
U_o is the fluid velocity in **m/s**,
Re is the Reynolds number,
Pr is the Prandtl number
(temperature dependant), and
C_r is Corrosion rate in **mm/y**.



$$V_{CORR} = 0.020 \cdot C_{O2} \cdot 2^{\left(\frac{T-30}{30}\right)} \cdot U$$

Where:
V_{CORR} is the oxygen corrosion rate in mm/y,
U is the fluid velocity in m/s [assumed U=1 if U<1],
CO2 is the oxygen equivalent in ppm, and
T is temperature in °C [assumed T=30 if T<30].



Summary

Various Corrosion prediction models are available

- *Use corrosion prediction model with <u>care</u> and engineering judgment should always be applied.*
- *Always challenge and sense check the out put - Don't always believe what "Computer says……..".*
- *Understand the limitation of predictive models and compare results from at least two models.*

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THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

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ICORR ABERDEEN BRANCH WELCOMES

SPEAKER 3 - Dr Carol Devine (ICR Integrity)

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EMERSON

ICorr Aberdeen Branch Welcomes

Introduction to Oilfield Microbiology

Presented By Dr Carol Devine, Consultant Microbiologist

ICR.

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Chemical Injection Solutions

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ICR. PRESERVE, REPAIR & RE-INSTATE

PRESERVE

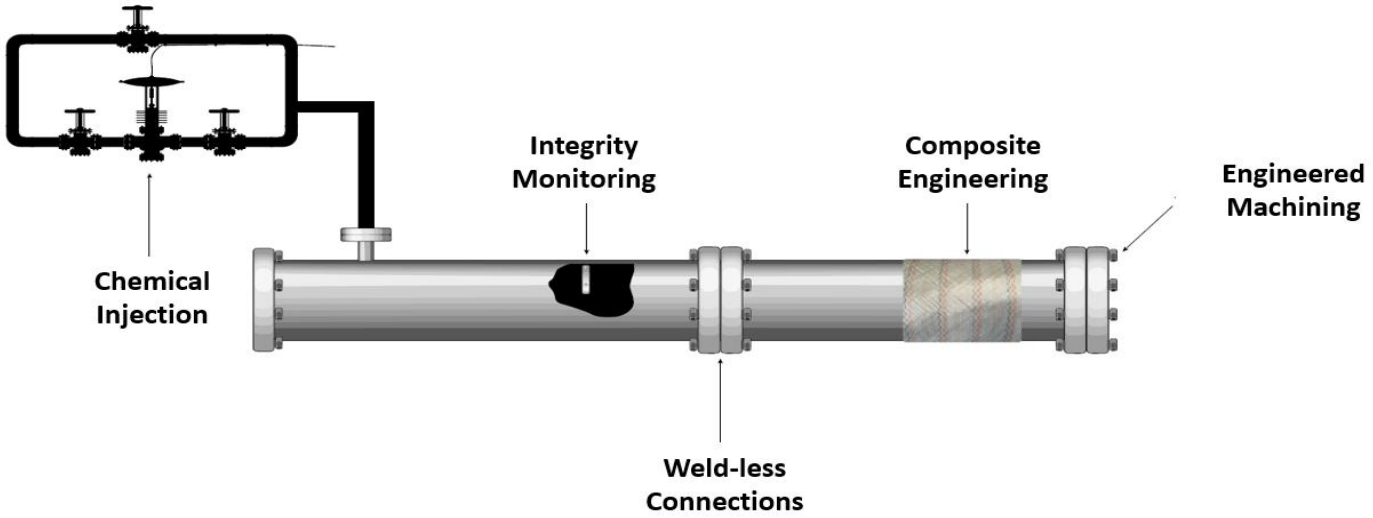
Chemical Injection
Integrity Monitoring

REPAIR

Weldless Connections
Composite
Engineering

RE-INSTATE

Engineered
Machining



ICR. GLOBAL FOOTPRINT

Dr CAROL DEVINE
CONSULTANT MICROBIOLOGIST

- BSc in Microbiology, University of Aberdeen
- PhD in Subsurface Molecular Microbial Ecology
- Commercial Microbiology - Intertek for 11 years
- **ICR.** (formerly NECE) for 6 years

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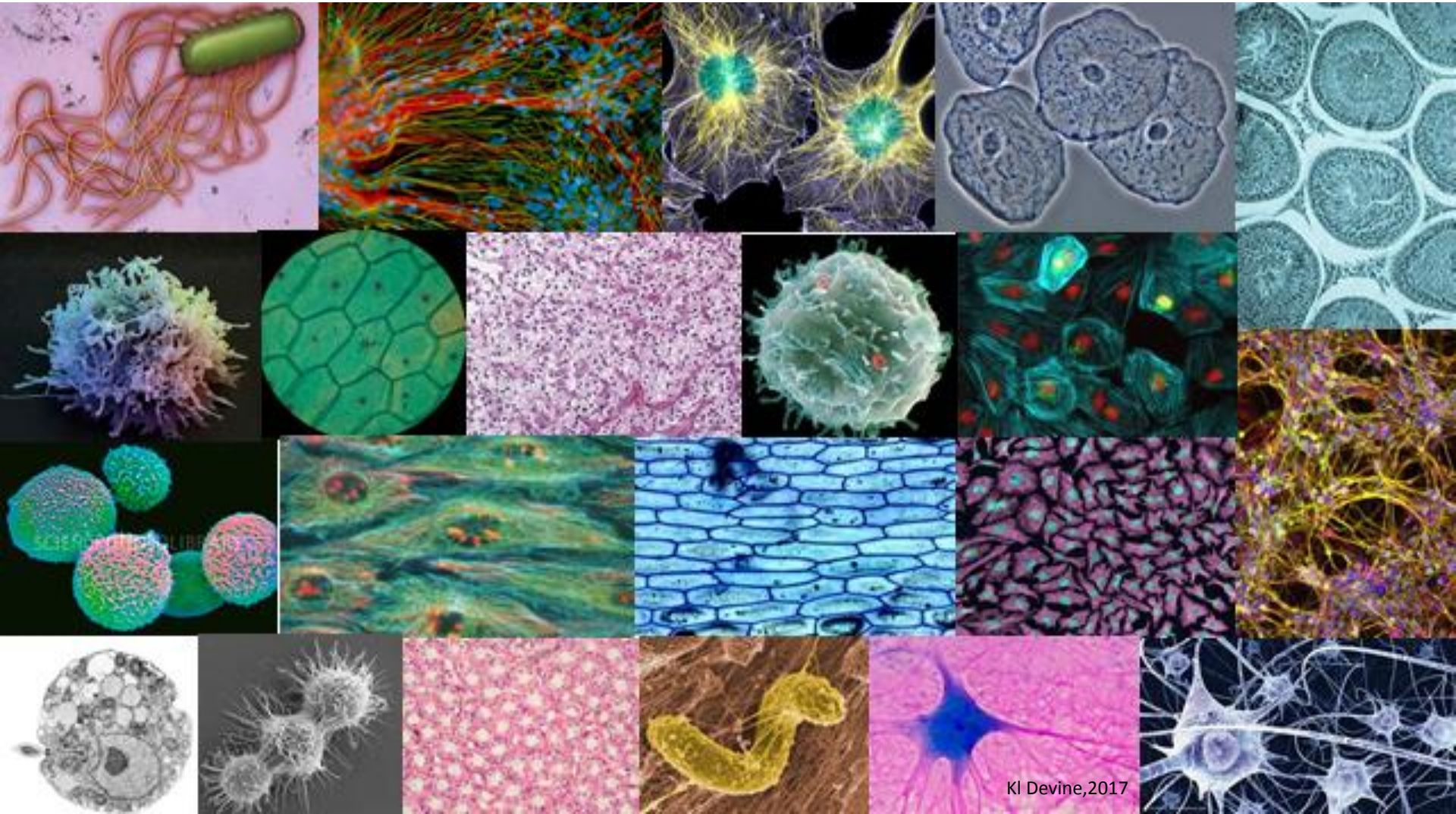
CORROSION AWARENESS DAY 2018

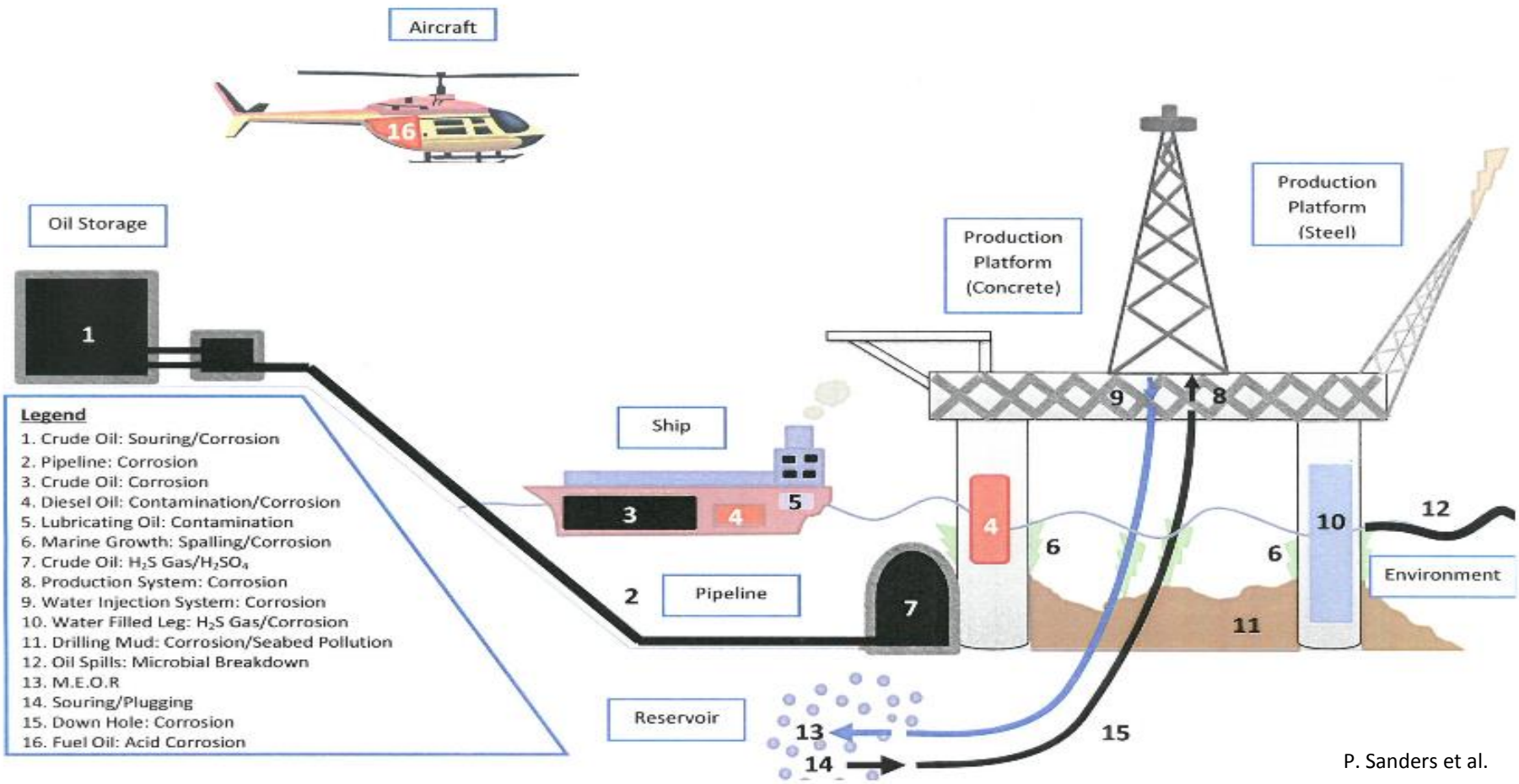


CORROSION AWARENESS DAY 2018

CORROSION MONITORING & MICROBIOLOGY

- Introduction to Oilfield Microbiology
- Microbiological Issues
- Systems
- Samples
- Analytical Techniques
- Data Trending

CORROSION AWARENESS DAY 2017



P. Sanders et al.

MICROBIAL ISSUES

- Biofouling
- Reservoir souring
- Microbiologically influenced corrosion (MIC)

MITIGATION STRATEGIES

- Biofouling – filtration, chlorination and biociding
- Souring – above plus sulphate removal or nitrate injection
- MIC – filtration, chlorination, biociding – and pigging

OILFIELD MICROBIOLOGY

The aim of the oilfield microbiologist is to generate useful and appropriate data in order to:

- **Predict** which particular systems, vessels, pipelines, locations are under threat from microbiologically influenced corrosion (MIC)
- **Prioritise** areas for treatment according to budget and time available
- **Apply** and monitor appropriate strategies to mitigate against the effects of MIC

SYSTEMS

- Production
- Water Injection
- Produced Water Reinjection (PWRI)
- Ballast water
- Seawater Cooling
- Cooling/heating
- Firewater
- Diesel storage and distribution

SAMPLES

Two main types of samples:

Planktonic – water, crude, diesel, cooling medium

Sessile – biofilm from coupons, bio-sidestreams and/or other intrusive devices

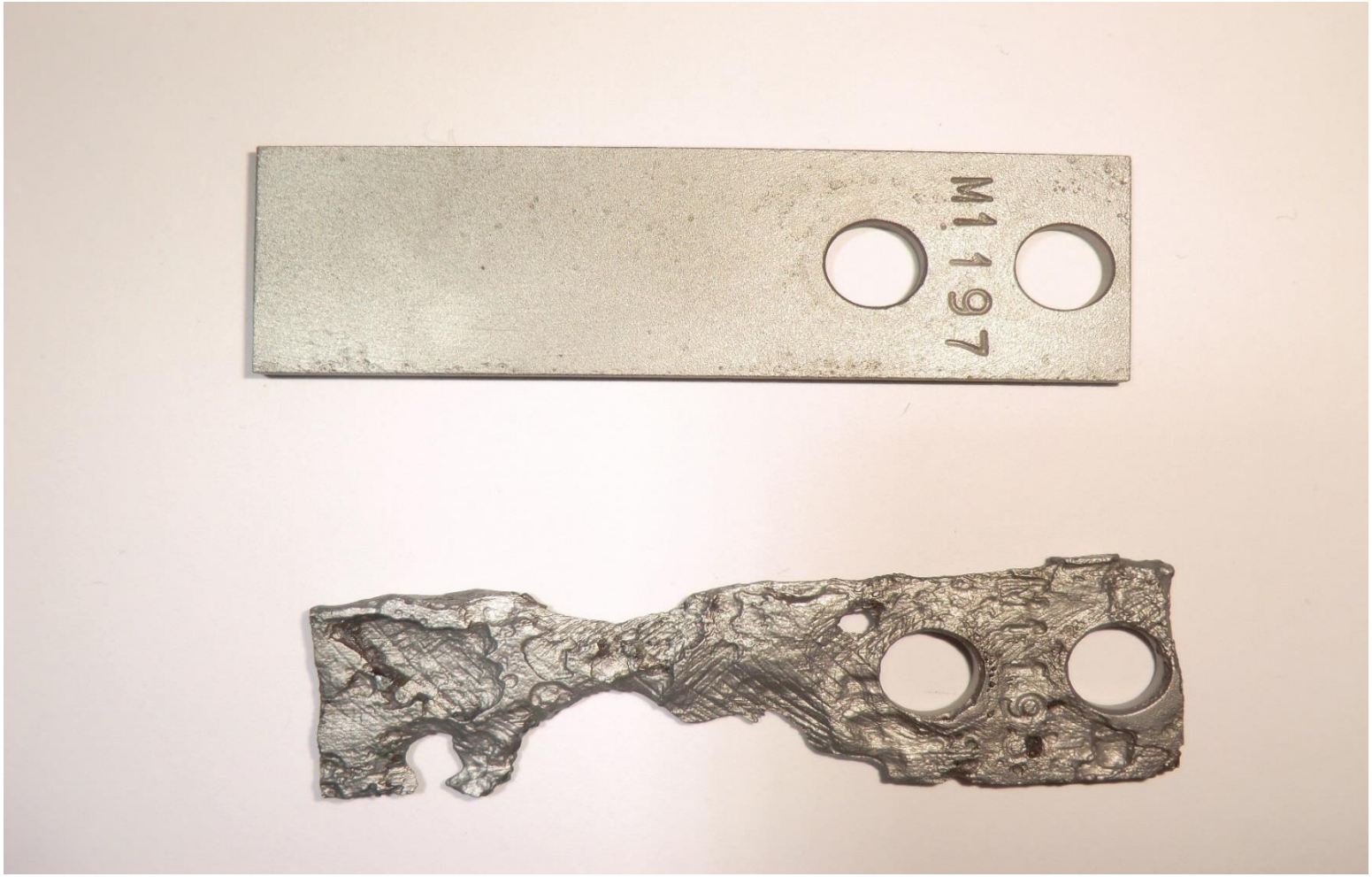
SESSILE SAMPLES COUPONS

Direct system exposure

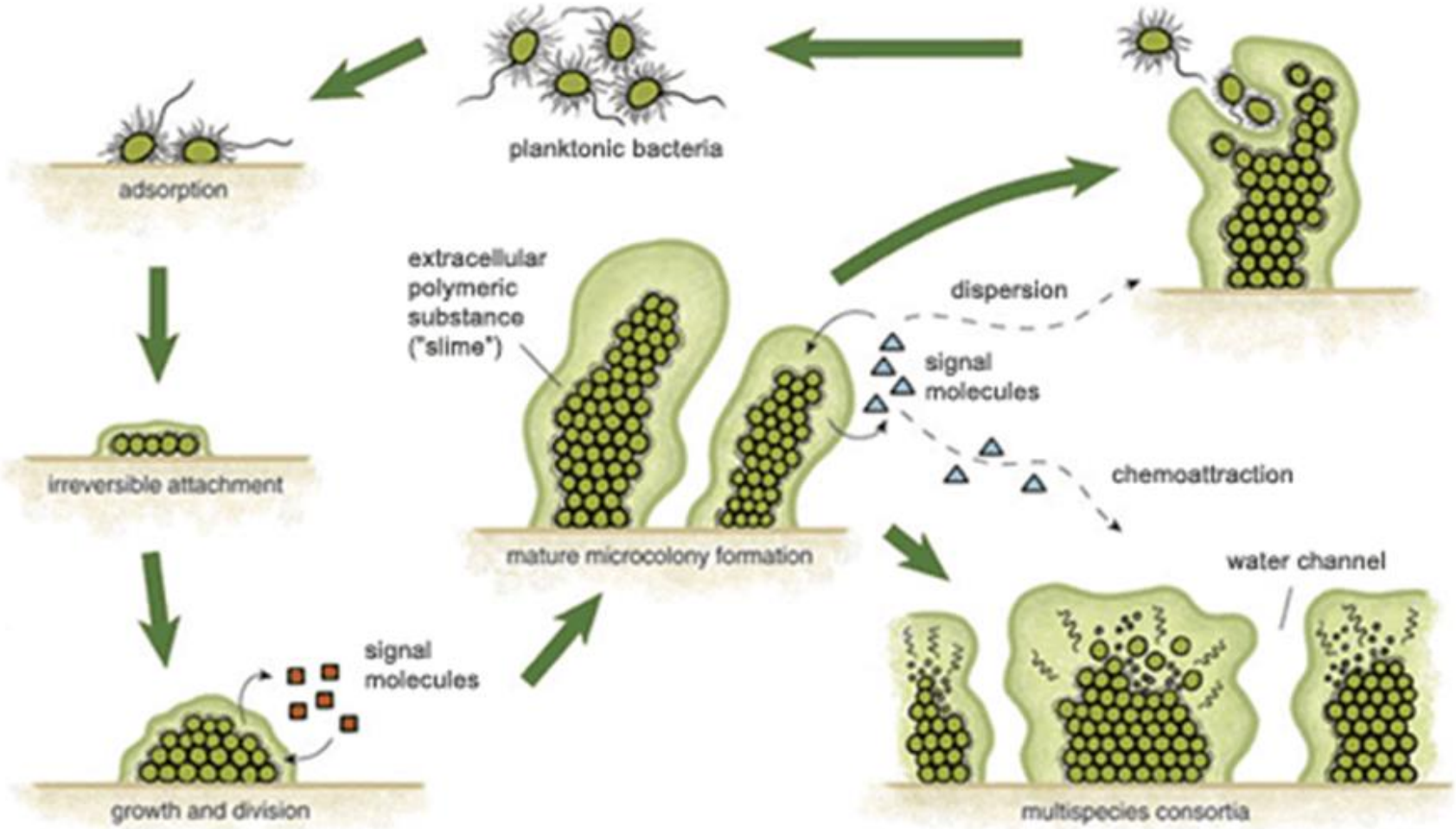
Sessile Microbial Samples and Weight Loss analysis

FLUSH DISC & STRIP COUPONS

3” STRIP COUPONS



BIOFILM GROWTH & DISPERSION



MICROBES & MACROBES

Production

Originally clean - but now contaminated with indigenous reservoir micro-organisms, plus contamination from injected seawater and from chemicals injected over the years.
Those microbes most suited to the environment will proliferate.

Seawater Injection

High levels of microbes and macrobes in seawater from psychrophiles to extreme thermophiles.
Main control regime is chlorination, with filtration and organic biocide treatments downstream of the D/A.
Poor water quality means a high threat of corrosion with high populations of a diverse microflora being injected into the reservoir = accelerated reservoir souring.

DEAERATOR
POOR WATER QUALITY

ALGAL BLOOM, SCOTTISH COAST

ANALYTICAL TECHNIQUES

Choice depends on what you are looking for – and on the budget!

Three groups of microbes – **archaea**, **bacteria** and **eukaryotes**

MIC is a highly complex microbial process which is thought to involve:

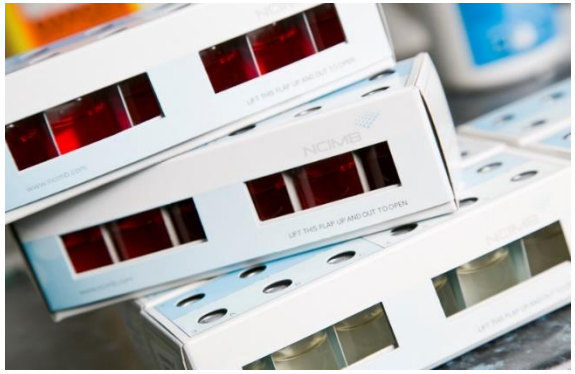
- sulphate-reducing bacteria
- sulphate-reducing archaea
- methanogens
- acid-producing general heterotrophic bacteria (APB)
- iron utilising bacteria
- (general heterotrophic bacteria)

VIABLE CELL COUNTS

1. Triplicate MPNs

- Can detect a variety of active microbes
- Can be performed in field by trained personnel
- Vast body of historic data

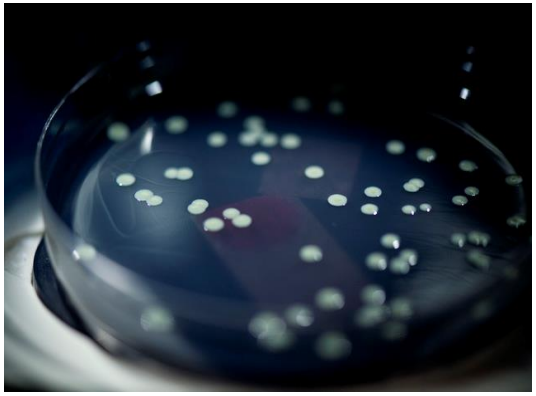
- Media must match the conditions of the environment the sample comes from i.e., temperature and salinity
- Detects less than 5% of the total community
- SRB incubation period is 28 days



VIABLE CELL COUNTS

2. Plate counts

- Can detect a variety of active microbes
- Difficult to perform in the field/offshore as plates do not travel well
- Need sterile anaerobic chambers to incubate plates for anaerobic bacteria
- Routinely used for diesel analysis, potable water monitoring and Legionella counts

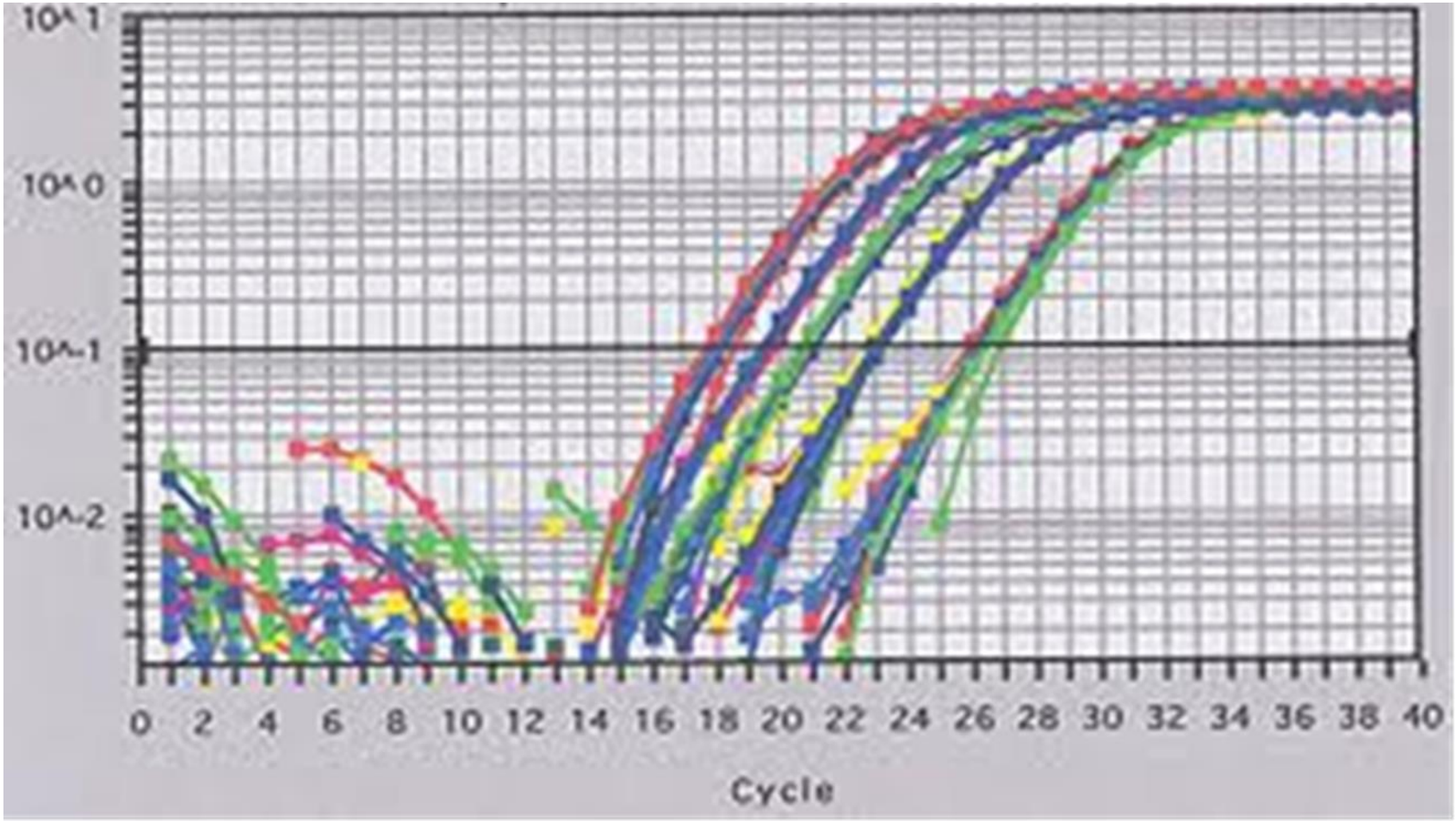


MOLECULAR TECHNIQUES

1. qPCR

- A laboratory technique based on the polymerase chain reaction
- Used to amplify and simultaneously quantify a targeted DNA molecule
- The cells are lysed and a chemical reaction set up where the DNA is amplified exponentially
- A DNA-binding dye binds to all double-stranded (ds)DNA in the PCR reaction, causing fluorescence of the dye
- An increase in DNA product therefore leads to an increase in fluorescence
- Allows DNA concentrations to be quantified and the number of cells present in the original sample to be estimated.

qPCR - AMPLIFICATION

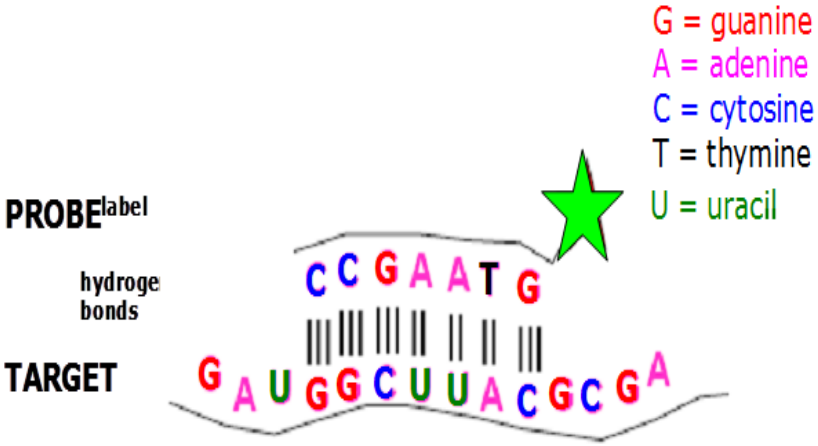


MOLECULAR TECHNIQUES

2. FISH

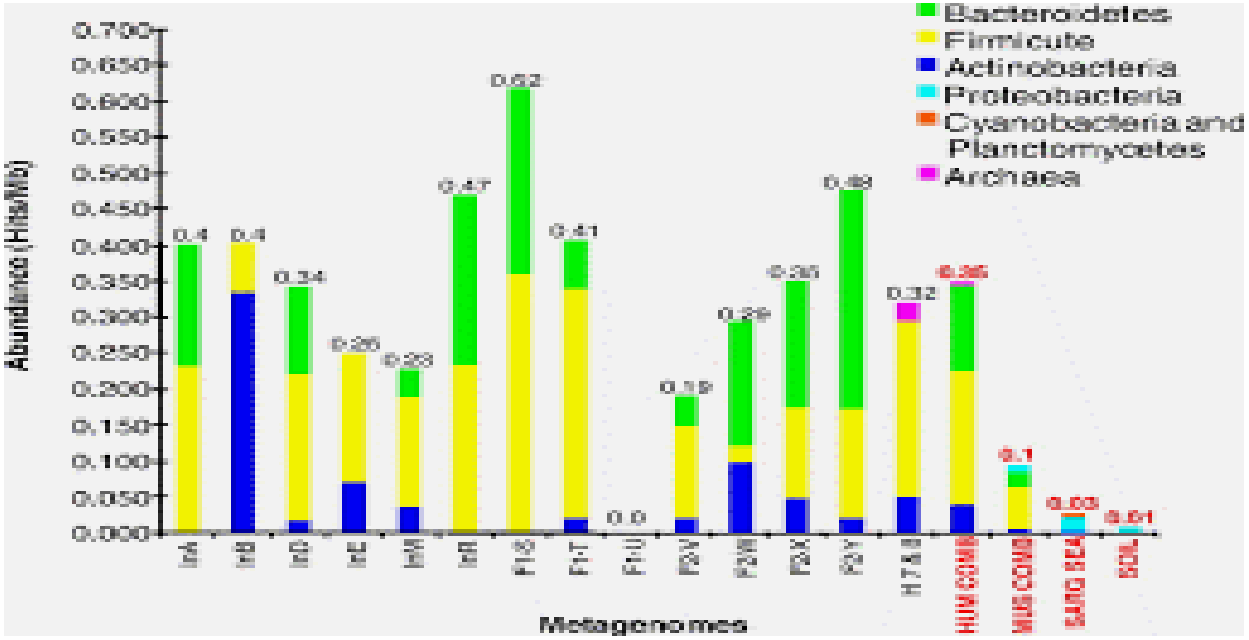
- A laboratory technique based on fluorescent microscopy
- Sample is fixed on site and fixative must be fresh
- In the lab, a DNA dye called DAPI, is added to give a ‘Total Cell Count’
- A DNA probe (a short section of nucleic acid labelled with a fluorescent dye) is added and hybridised to the nucleic acid in the target bacteria
- The cells are viewed under a UV microscope

FLUORESCENT IN-SITU HYBRIDISATION (FISH)



METAGENOMICS

- Application of New Generation Sequencing to characterise the total microbial community
- Identifies all micro-organisms



ATP TESTING

- Tests for actively growing cells
- ATP (adenosine triphosphate) plus Luciferase = light
- Results in relative light units is proportional to the quantity of ATP
- Non specific test designed for clean systems

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ADVANTAGES & DISADVANTAGES

Advantages (over traditional methods for bacterial enumeration)

- Speed
- Accuracy
- Picks up viable non-culturable cells and archaea
- Can determine which genera and species of bacteria are present
- Relatively easy to take, preserve and ship samples

Disadvantages

- Accuracy
- Cost
- Has to be carried out in the lab
- Samples should be kept chilled during shipping
- Cannot be carried out by offshore chemists (need skilled technicians and expensive equipment)

TESTING TECHNIQUES

Testing for : sulphate-reducing prokaryotes (SRB)
general heterotrophs
acid-producing bacteria
nitrite-reducing bacteria
bacteria and fungi in diesels
nitrate-reducing bacteria

sulphate-reducing archaebacteria (SRA)
archaebacteria
methanogens

Techniques: traditional viable counts (MPNs)
molecular techniques – qPCR, FISH, DAPI,

Chemistry: pH, sulphide, bisulphite, Volatile Fatty Acids (VFAs), chlorine residuals, total iron, nitrite, nitrate etc

DATA TRENDING

WORKSCOPE System	Current status	Actions required
PRODUCTION	Moderate to high planktonic SRB, low to moderate sessile SRB with low corrosion and moderate pitting rates. Risk of MIC.	**Regular kill dose of biocide required. Post biocide planktonic samples should sent in for analysis.**
WATER TREATMENT VESSELS	Moderate thermophilic SRB at Vessel B water outlet, low numbers at the remaining locations. Low sulphide levels. SRB growth and activity still occurring across vessels with a high risk of MIC.	**Close monitoring required as early intervention may be required to ensure control is maintained.**
DRAINS	Low thermophilic SRB in *Closed Drains*, moderate sulphide levels measured. Low risk of contamination being recirculated and of MIC	**No immediate action currently required. Regular monitoring should be maintained.**
WATER INJECTION	Low planktonic and sessile SRB numbers, sulphide levels below detection limit. Moderate to high corrosion and pitting rates. Risk of microbial proliferation and MIC	**System currently under reasonable control. Further investigations required to determine the cause of the high pitting measured at *CC-XOX-017*. The use of molecular techniques such as qPCR should be used to confirm or eliminate the role of MIC.**
DIESEL SYSTEM	Low aerobic bacteria, yeast and mould enumerated from all the tanks sampled. Low particulate contamination, fungal fragments and water content.	**No immediate action is required as the diesel tanks are currently under good control and water content is at a minimum. Regular monitoring should be maintained.**
FIREWATER SYSTEM	No SRB, but high GHB measured in all the hydrants sampled. No residual chlorine, high potential risk of biofouling.	**A regular firewater ring main flushing routine should be implemented to prevent stagnation and bring in freshly chlorinated water.**

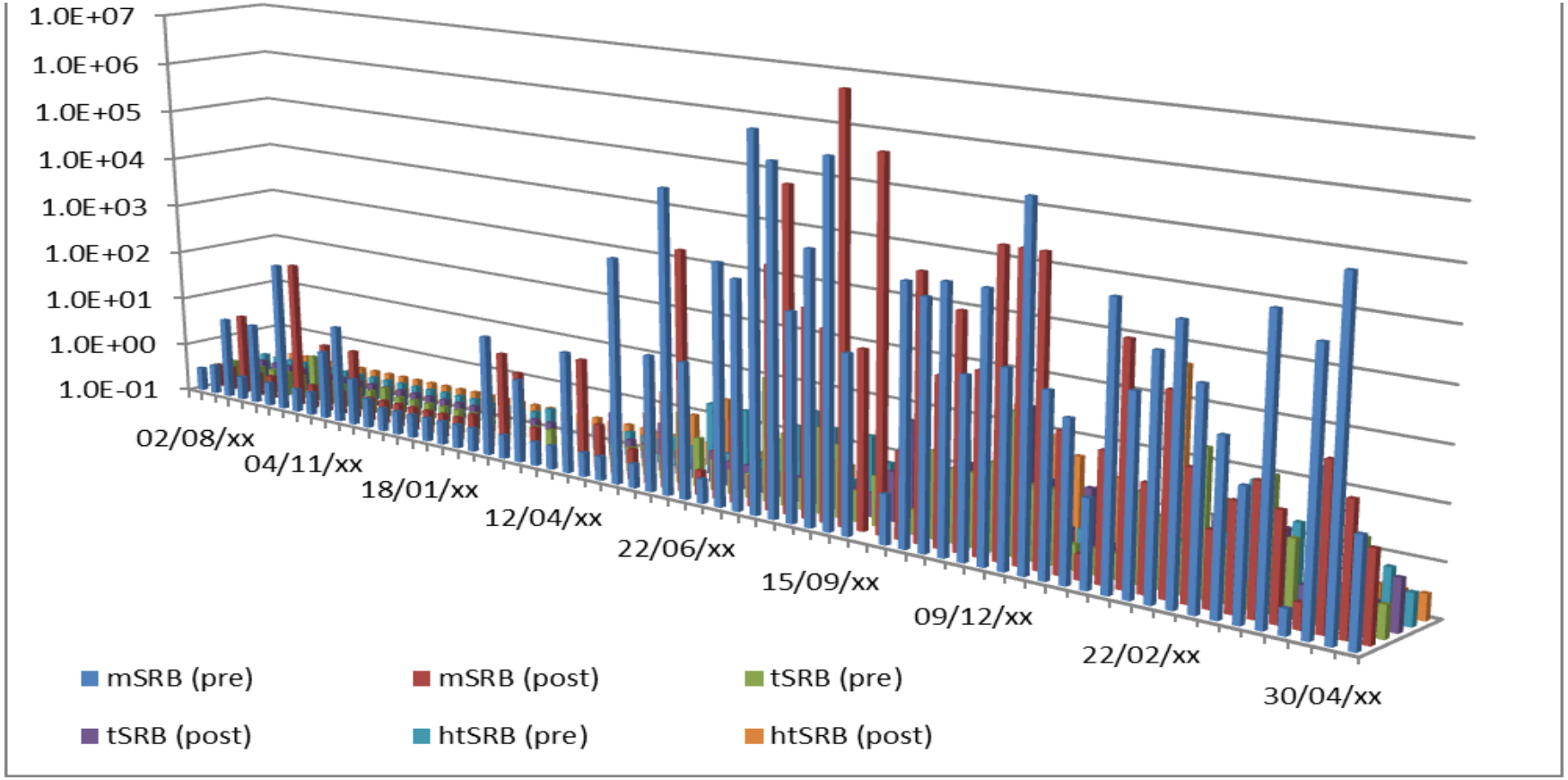
Green	Good Control, Low Risk, No Immediate Action Required
Yellow	Requires Careful Monitoring/Possible Early Intervention
Red	Risk Of MIC, Urgent Action Recommended

DATA TRENDING & INTERROGATION

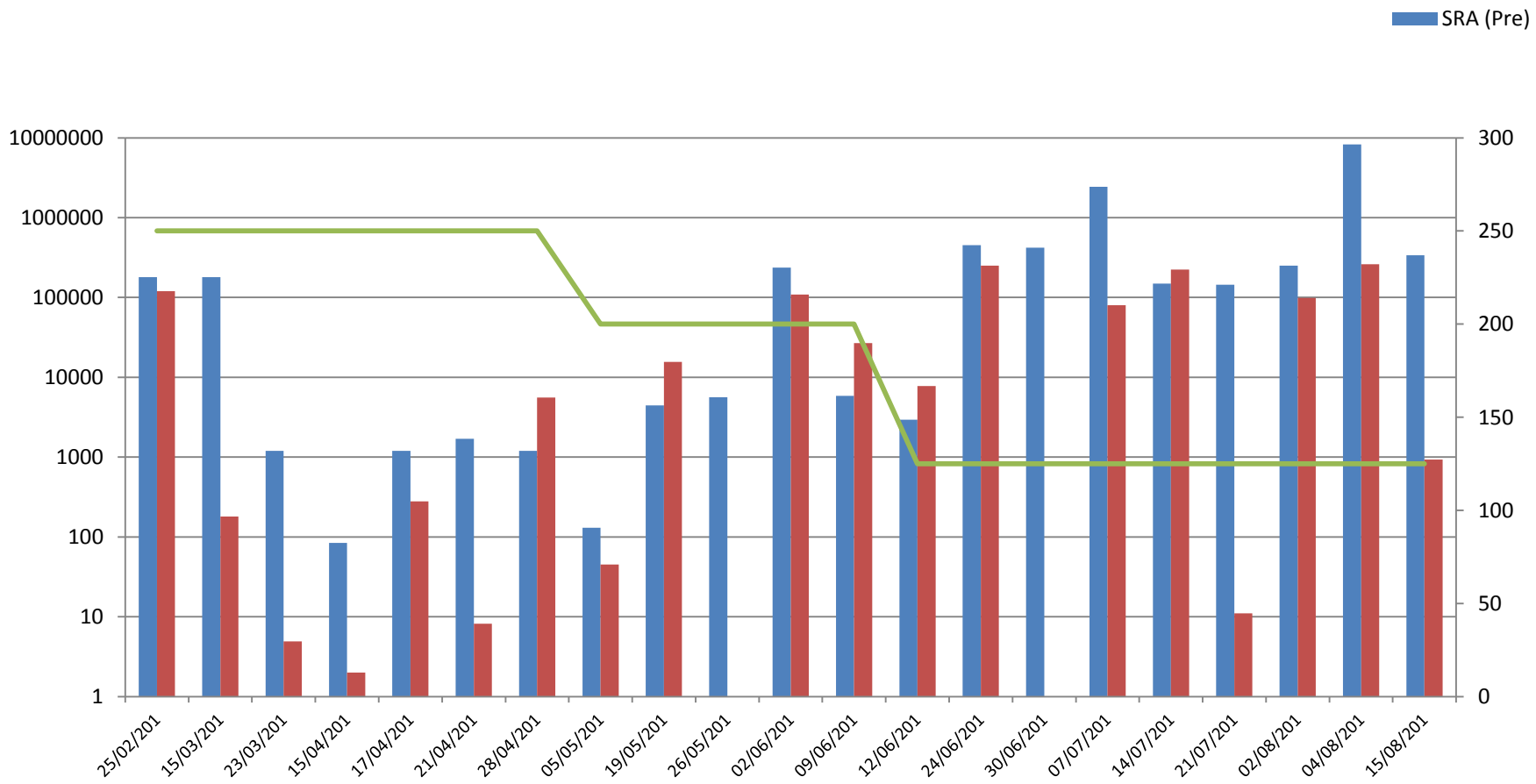
All data should be graphed/trended on a regular basis – pipelines, drains, deaerator tower etc.

- Trending of data pre and post biocide applications – especially if it is a long term project
- Biocide treatments can then be optimised
- Monitoring essential

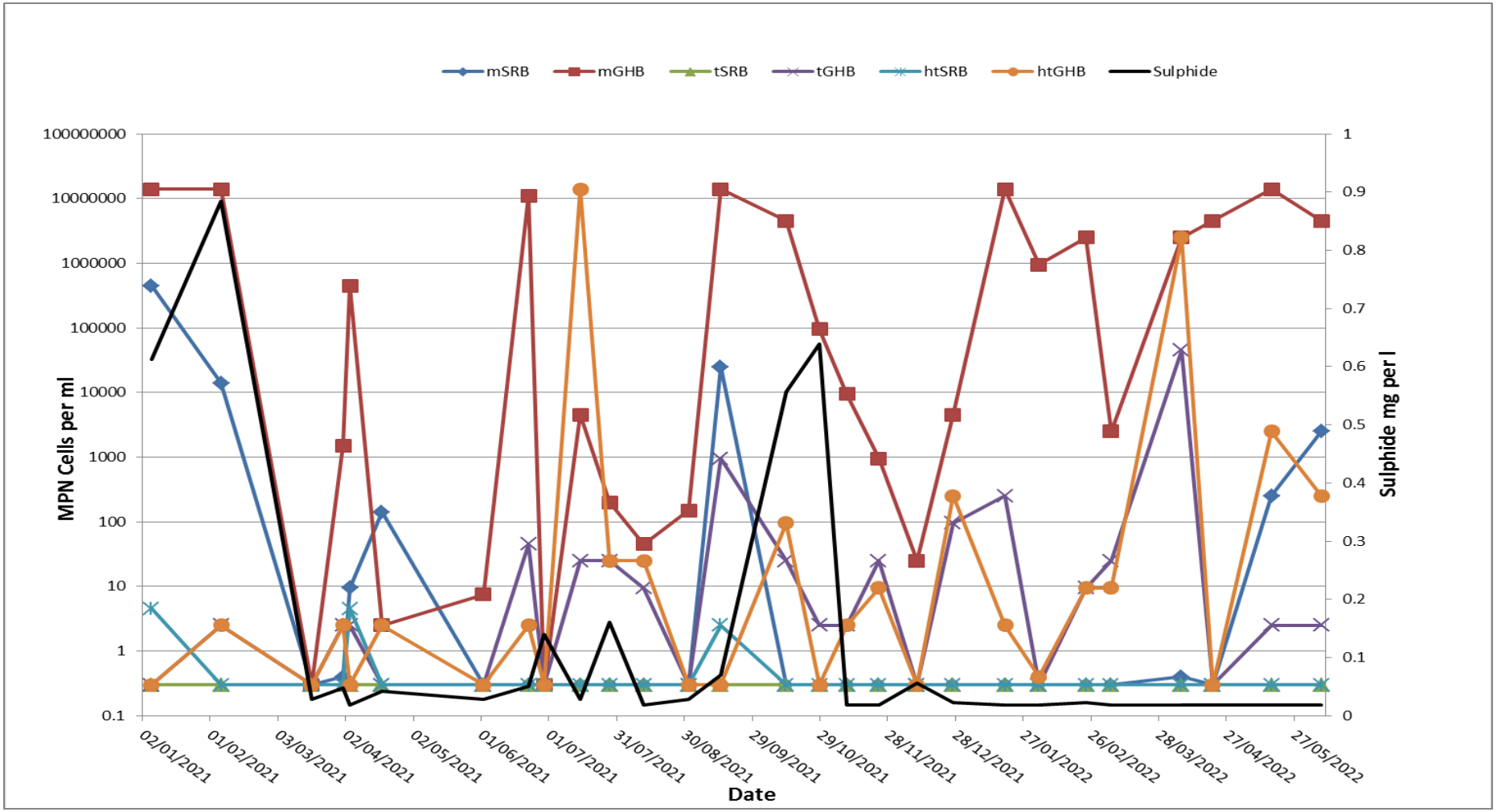
SRB BY MPN ENUMERATION
PRE & POST BIOCIDE DOSES



SRA NUMBERS BY qPCR
PRE & POS BIOCIDE DOSES



OPEN DRAIN VESSEL (MPNs)



PITS – MIC?

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ANY QUESTIONS?

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SPEAKER 4 - **Dr Nigel Owen** (Aberdeen Foundries)

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ABERDEEN FOUNDRIES

1976 - 1998- 2018

SACRIFICIAL ANODES AND NON FERROUS CASTINGS

SCOTLAND -> THE WORLD

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NIGEL OWEN

ABERDEEN FOUNDRIES

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Dr. Nigel Owen. B.Sc., D.I.C, Ph.D, MIMMM.

B.Sc. Metallurgical Engineering and Ph.D Materials.
Professional Member of Institute Metals: MIMMM & Member Inst. Corrosion.

After completing Degrees worked in the Aluminium Industry for over 35 years:
RTZ Australia & USA - R & D of Cast and Rolled Aluminium products and smelter waste recycling in New Zealand.
Worked as a Materials Consultant and in the Galvanising industry before joining Aberdeen Foundries as Sales, Technical and Plant Manager. At the Foundry he is in charge of manufacturing, testing and technical specification of Subsea and marine sacrificial anode systems.

Corrosion Mitigation by Cathodic Protection

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Corrosion Awareness Day 2018 - **Dr Nigel Owen**, BSc, D.I.C, Ph.D, MIMMM, (Aberdeen Foundries).

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Scope

CORROSION MITIGATION BY CATHODIC PROTECTION

- Galvanic System
- Materials for Sacrificial Anode Systems
- Manufacture and & Testing of sacrificial anodes
- Designing of a CP system to protect a structure
- Applications of Sacrificial Anodes
- The selection of the CP system: pros and cons of sacrificial and Impressed current
- Impressed current applications

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To Mitigate Corrosion by Cathodic Protection

•Means by imposing a current on the item of interest which will halt or reduce the corrosion level to one which is insignificant
•How?

•Either by:
• utilising the galvanic properties of 2 dis-similar metals when joined together in a conductive medium (Anode/Cathode)
or
•Imposing a current using an electrical system (Impressed Current) to achieve similar

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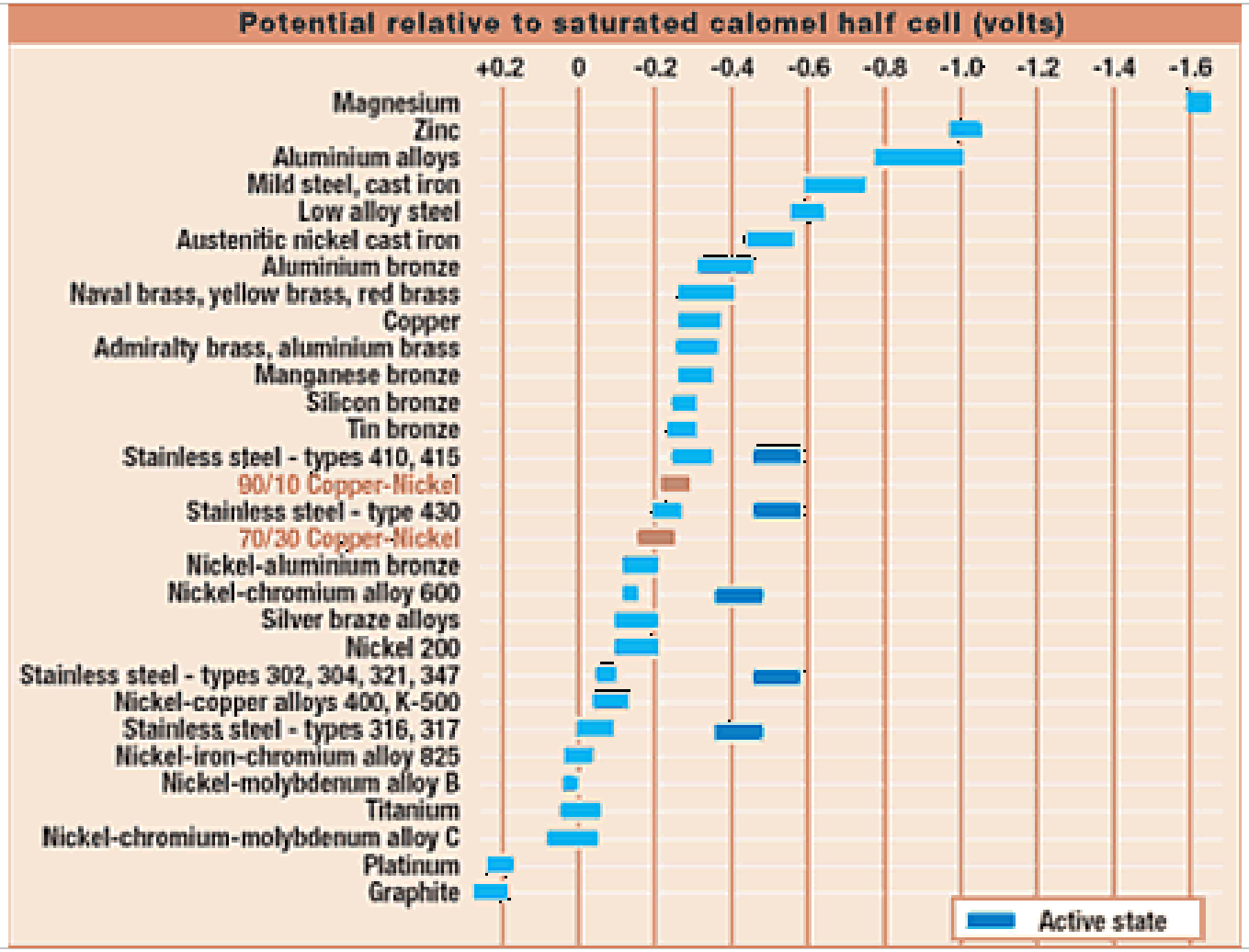
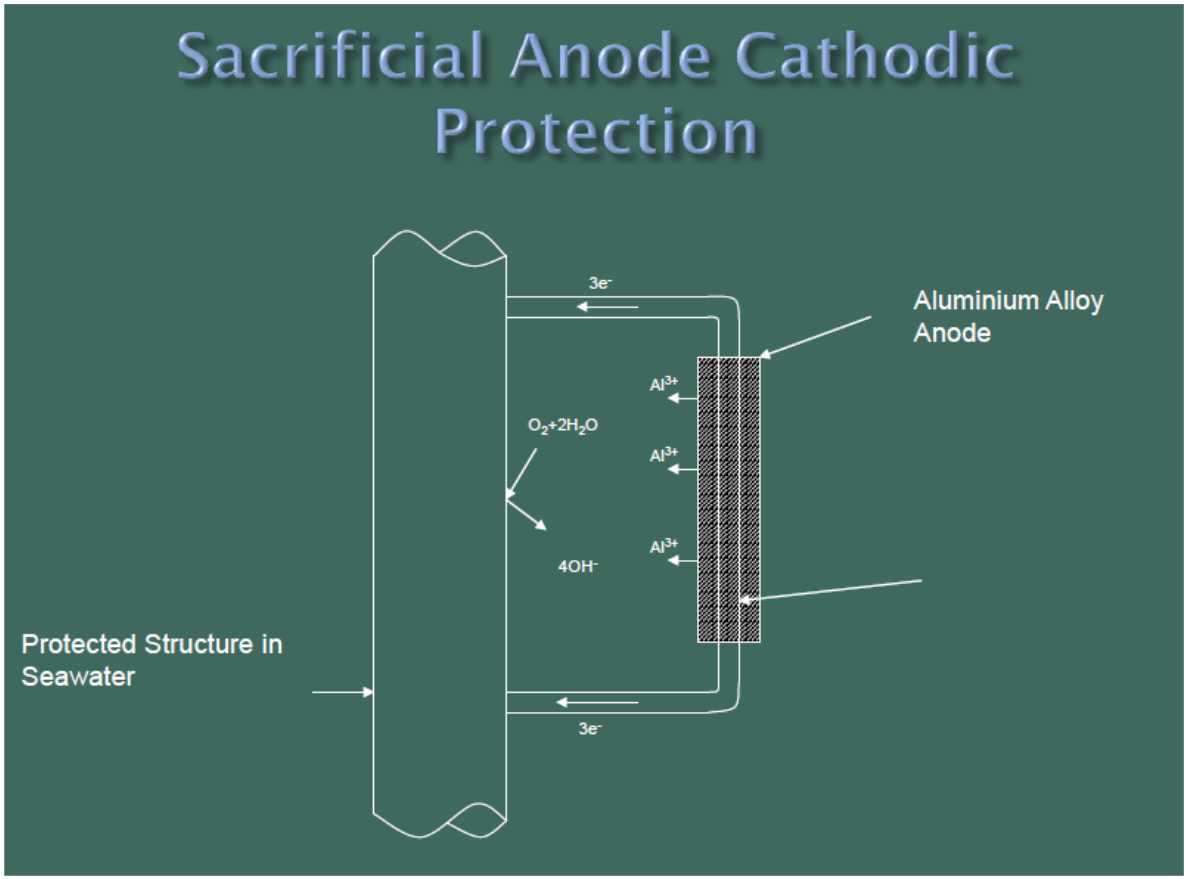


Sacrificial Anode System



Primary Requirements for Sacrificial Anode - Reasons for Selection

What makes the best anode material?

- Potential sufficiently electronegative – Galvanic Table vs you coupled material (driving potential)
- Temperature and Conductivity (salinity)
- High current output per Kg consumed
- Low Metal Cost (Amps per Kg)

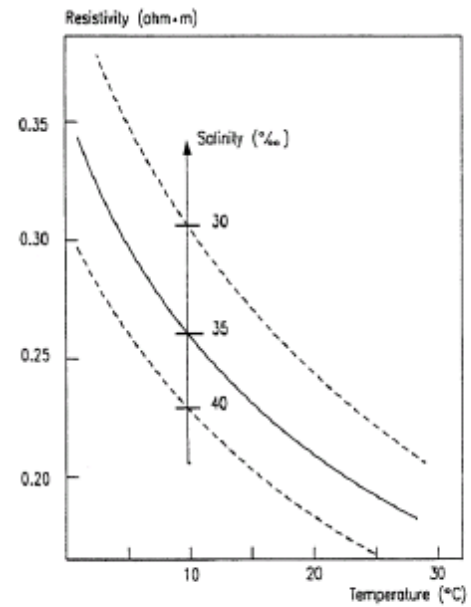


Figure 10-1
Seawater resistivity as a function of temperature for salinity 30 to 40 ‰.

Sacrificial Anode Material Types

- Magnesium
  - High Potential, low life, Fresh water (5-150 ohm. m) , High cost/Kg
- Zinc
  - Low capacity/ Kg (800), Limited Temp (50 ° C), water to 30 ohm. m
- Aluminium
  - High Capacity/Kg (2500), High Temp (80-100 ° C), water to 10 ohm. m

Primary Requirements for Sacrificial Anode - Reasons for Selection

– **Al-Zn-In Alloy Galvallum III Composition**

Al-Zn-In Anode Alloy								
	Element	**Al**	**Zn**	**Si**	**In**	**Cu**	**Fe**	**Others**
Wt%	**Min**	**Bal**	**2.8**	**0.08**	**0.010**	**0.000**	**0.00**	
Wt%	**Max**	**Bal**	**6.5**	**0.21**	**0.020**	**0.006**	**0.12**	**<0.02**
Wt%	Nom	Bal	**5.0**	**0.09**	**0.018**	**0.001**	**0.06**	<0.02

Typical Performance:
Nominal closed circuit anode potential -1050 (mV relative to. Ag/AgCl/seawater),
Short term test Capacity Ampere hours <2500 Amp. Hr/ Kg
Density Nominally 2750kg/m^3

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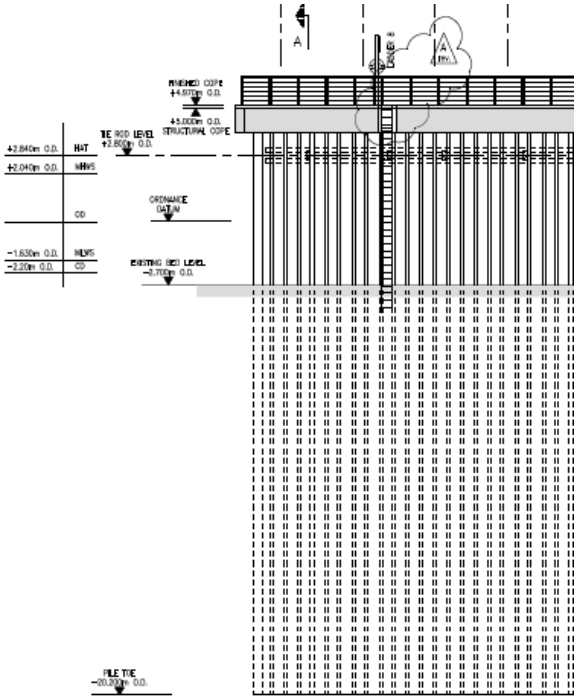
Example of a project to Design install a Sacrificial CP system

•Harbour wall CP protection system



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- SYSTEM PARAMETERS
- Design Life : Years or months

- Areas of the materials
  - Bare, Painted & immersed in mud
  - Type of materials.
  - All those conductive and have continuity to the main unit

- Design Current Densities
  - Initial mean and final (for bare surfaces)
    affected by Geographic region and depth
  - Coating Breakdown factors (discounts for coating integrity)

- Resistivity of Medium in which they are immersed: Seawater,
  Estuarine/River waters soils & muds/ sediment

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- Sacrificial Anodes- Design Solution

- Select sacrificial anode material (Al, Zn or Mg base)
  Material has properties of Amp Hr/ Kg and Potential

- Multiply areas of materials and Current density required with coating factors –
  Calculate mean current Demand
  Then calculate the Mean mass requirement for system design life

7.7 Anode Mass Calculations

7.7.1 The total net anode mass, M_a (kg), required to maintain cathodic protection throughout the design life, t_f (yrs), is to be calculated from I_{cm} (A) for each unit of the protection object (including any current drain):

$$M_a = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \qquad (2)$$

In (2), 8760 refers to hours per year. u and ε (Ah /kg) are to be selected based on (6.8) and (6.5), respectively.

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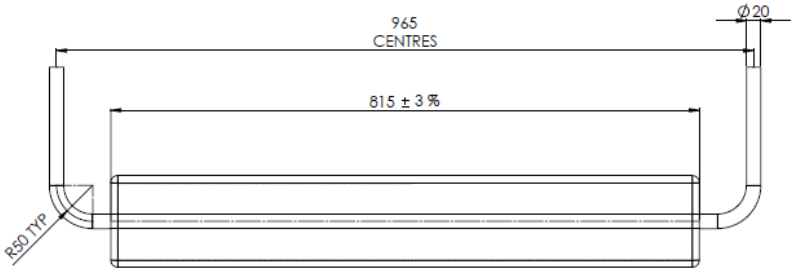
Sacrificial Anodes - Anode Type - solution

•Decide Type of anodes that can be fitted or will be most practical to fit (Flush fit, Standoff Type , Long or Short, Bracelet?)
•Estimate number, distribution of anodes (spacing/coverage) and anode mount type (position/utilisation factor)
•Proceed with Design

•Calculate anode resistance from shape & mount type
•Check the initial and final current output of the anode types meets the given required current for polarisation and final life



$$C_{a\ tot} = N \cdot C_a \geq I_{cm} \cdot t_f \cdot 8760$$
$$I_{a\ tot\ i} = N \cdot I_{ai} \geq I_{ci}$$
$$I_{a\ tot\ f} = N \cdot I_{af} \geq I_{cf}$$

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Long standoff anodes for Harbour wall installation

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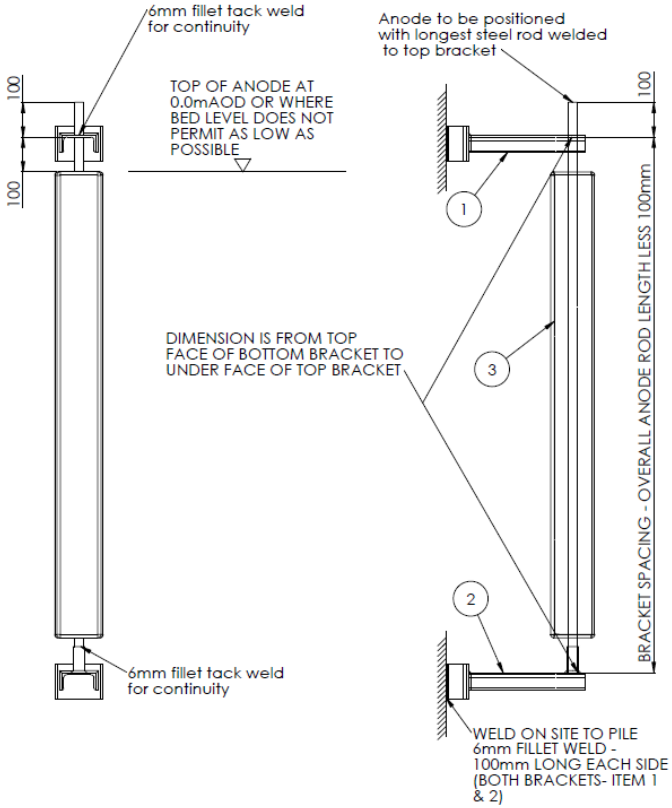
- Design & Install Anodes



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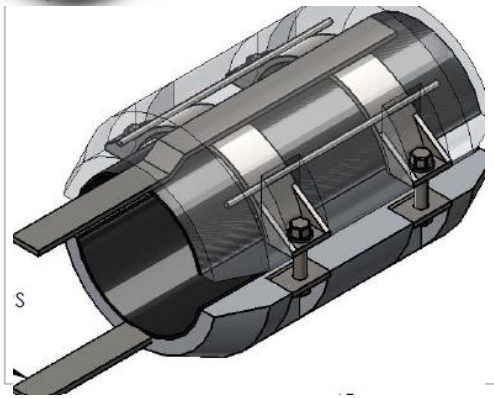
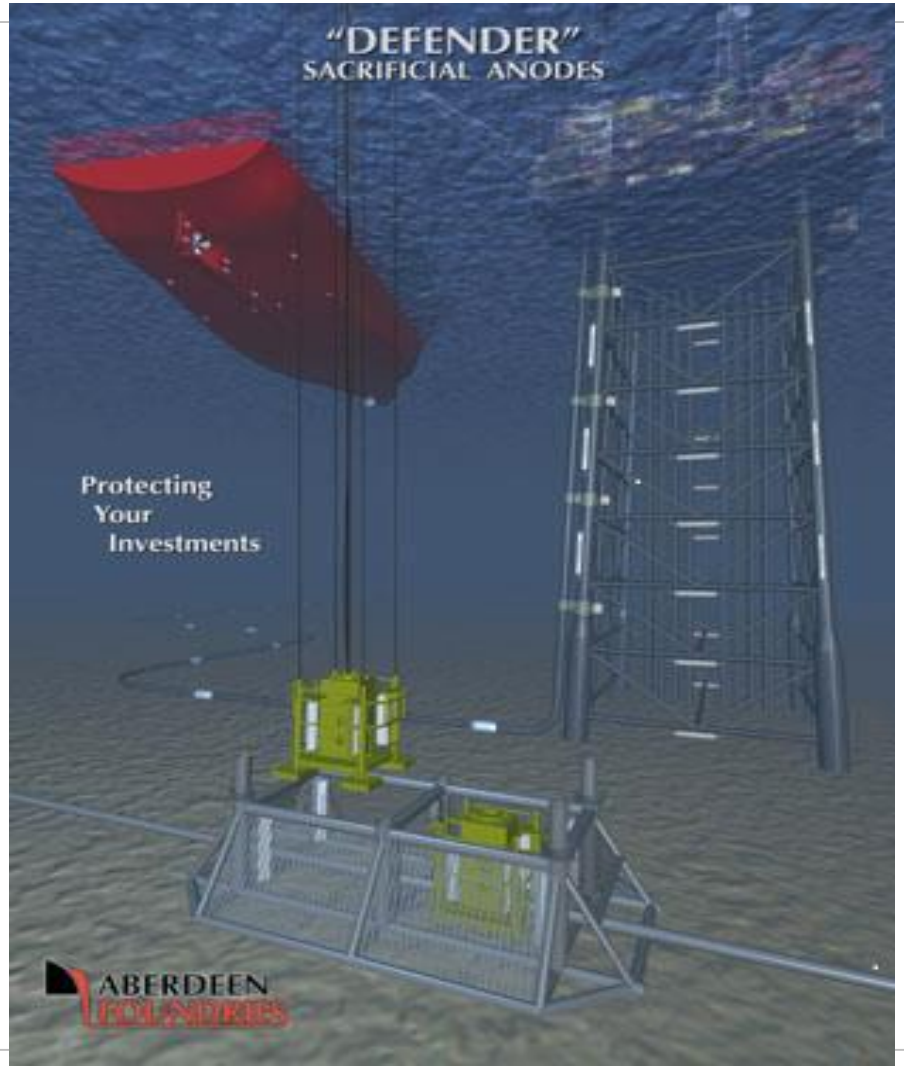
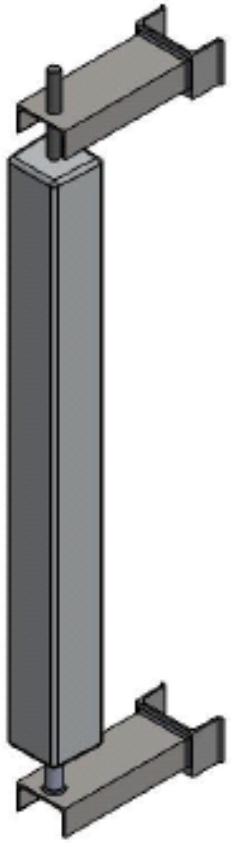
Sacrificial Anode Applications







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Sacrificial anodes in Zinc for flush fit (Hulls & steelwork)

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Slender Anodes for Subsea Manifold Frame

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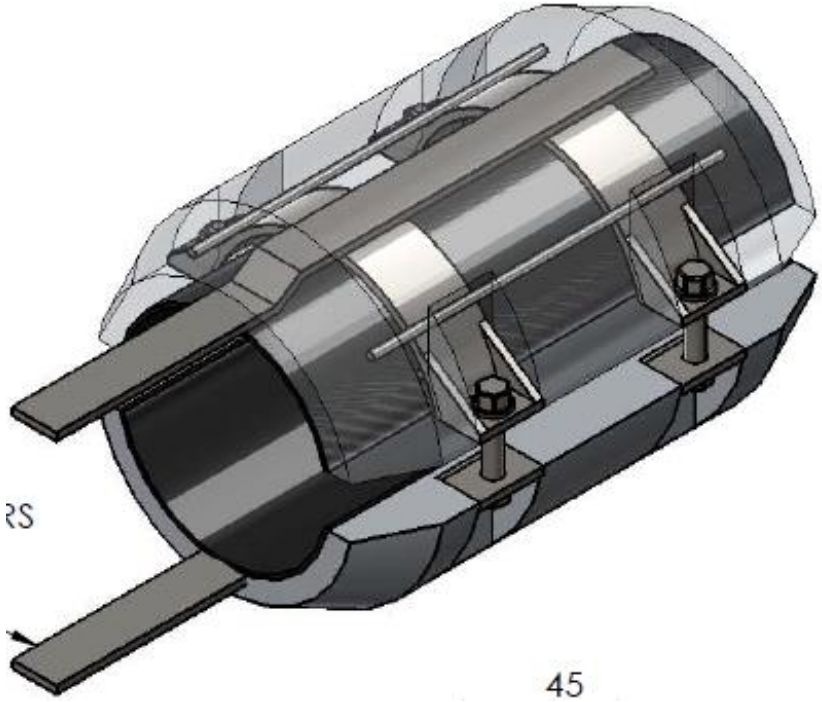
Bracelet Anodes for Pipelines & Spools



Anode Skids for Remote Retrofit of Manifold

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Design Parameters may limit the use of Sacrificial Anodes or make them impractical.

- Conductivity / Resistivity of the environment
- Size of the areas to be protected by the system
- Location and water depth
- Availability of Power sources or personnel (operation & monitoring)
- Ability to install
- Design Life of the system short term submersion or 60 year lifespan

- Impressed Current Cathodic protection can be utilised to cover most other fields of protection.

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Sacrificial Protection vs Impressed Current

- Sacrificial Anode
- Simple
- Short term (Days to 30 years)
- Low/no maintenance
- Welded, secure installation
- Conductive environments (seawater)
- Restricted by anode material
- No adverse effects on structures, coatings etc
- Doesn't overprotect

Impressed Current

- Anodes are not consumed (inert)
- Use for long term systems (20-50 yrs)
- Requires regular maintenance
- Remote anodes & wiring
- Complex - has to be accurately set up
- Works in Low conductivity water areas (& onshore buried pipelines & Concrete)
- Can cause:
  - Coating de-bonding
  - Hydrogen embrittlement of steel piles
  - Cathodic corrosion of Al (hulls etc)
  - Stray current corrosion

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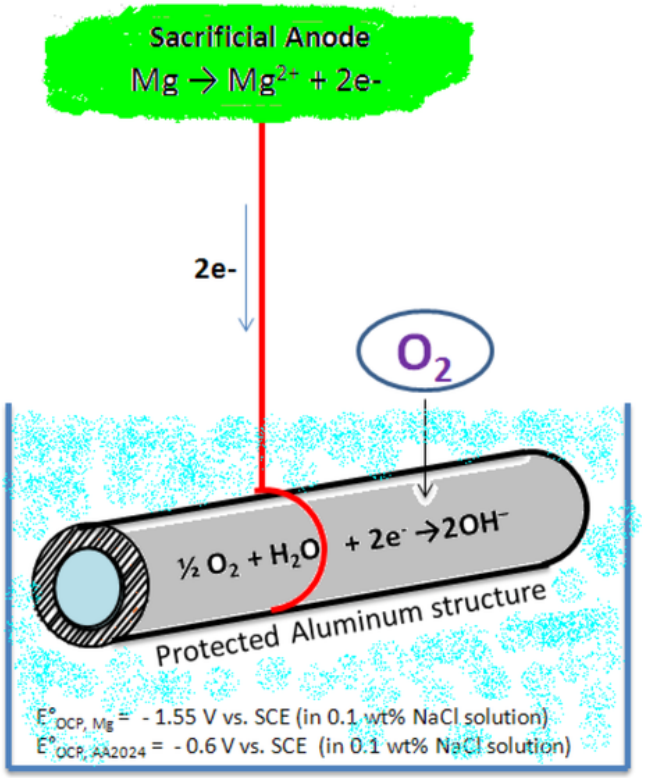
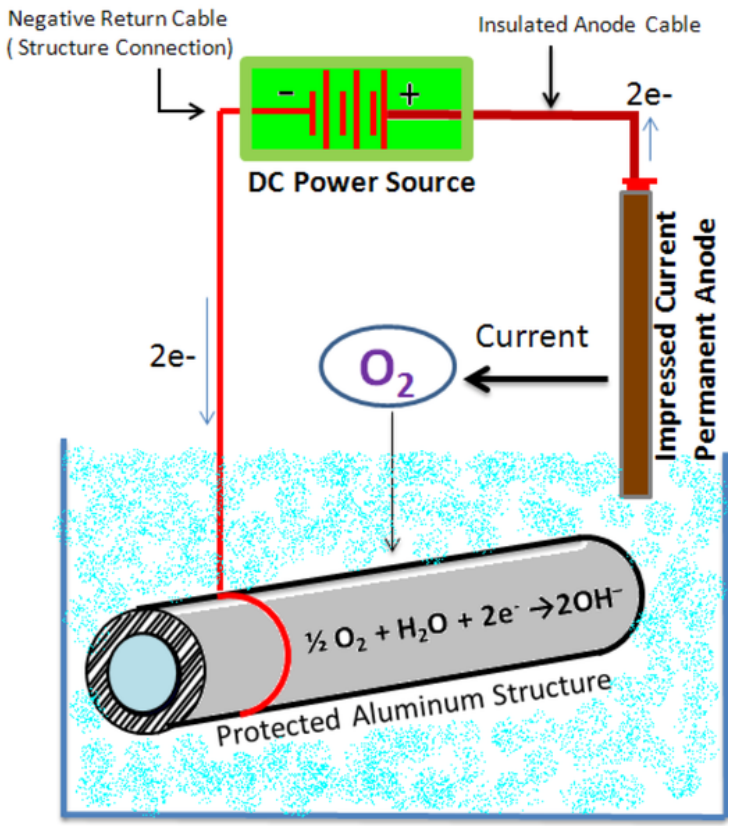
Sacrificial Anode CP Method

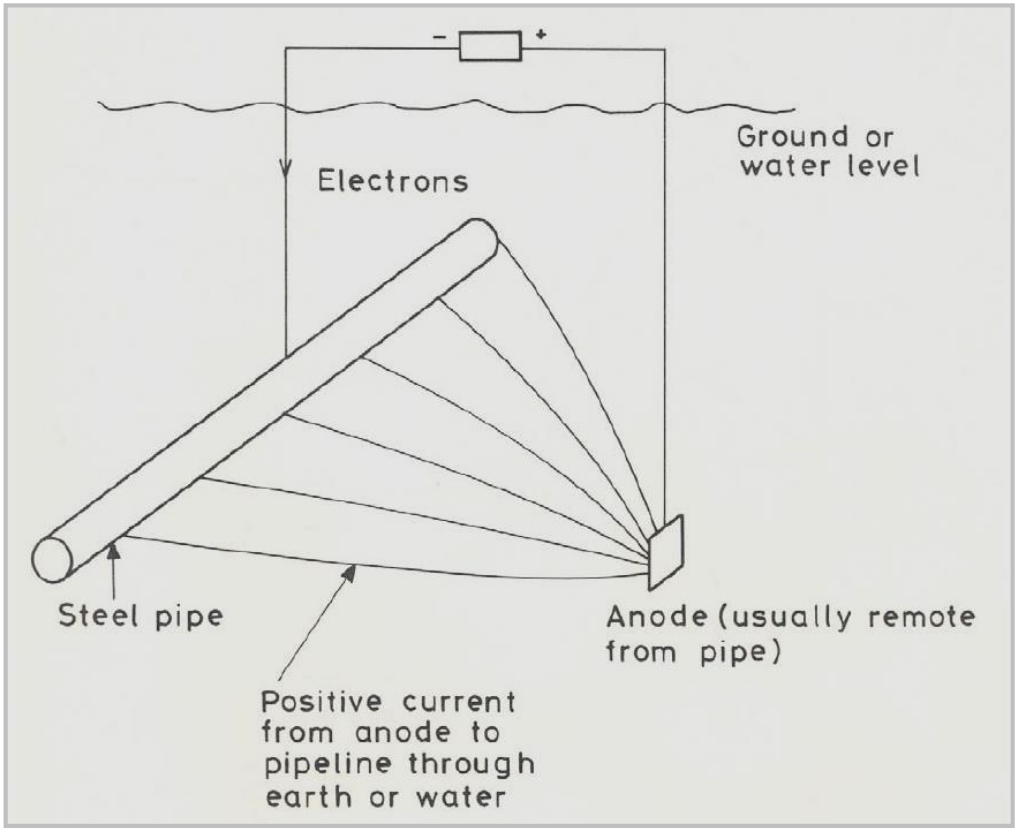


Impressed Current CP Method



Cathodic Protection (CP) Methods

Cathodic Protection - Impressed Current Systems



Mains and Solar Power Sources.

Impressed Current Systems

Common Applications of IP Systems

- Large Ships, Crude Oil Tankers.
- Long-Distance Pipelines.
- Highways / Bridge Foundations.
- Loading Jetties.
- Bases Of Storage Tanks.
- Protection Of Reinforced Concrete

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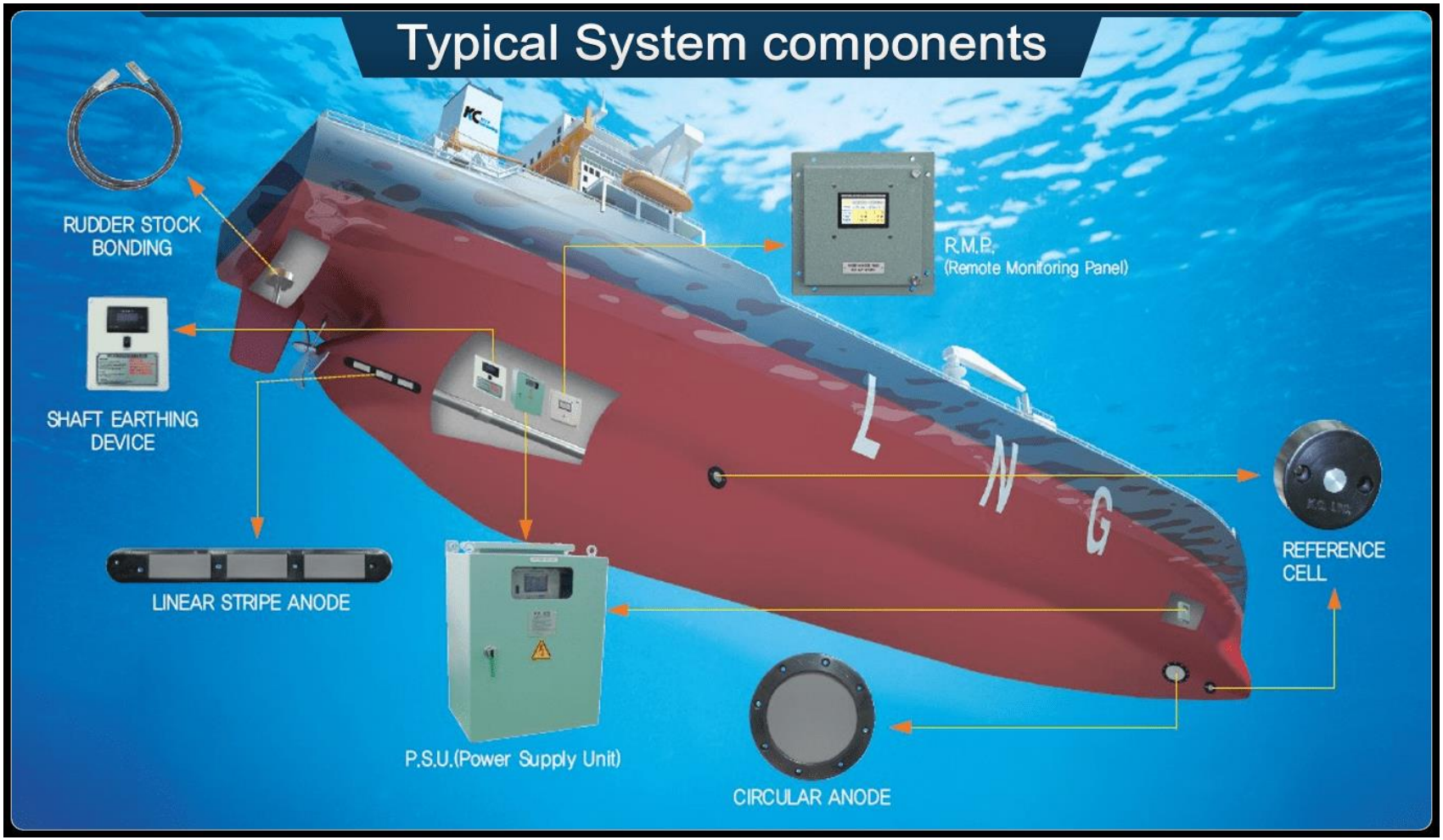

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Impressed Current Systems

WHITECART VIADUCT GLASGOW AIRPORT AND TAY ROAD BRIDGE DUNDEE BOTH HAVE CP – FOUNDATIONS AND RC CONCRETE SUPPORTS, AS DO M9 BRIDGES

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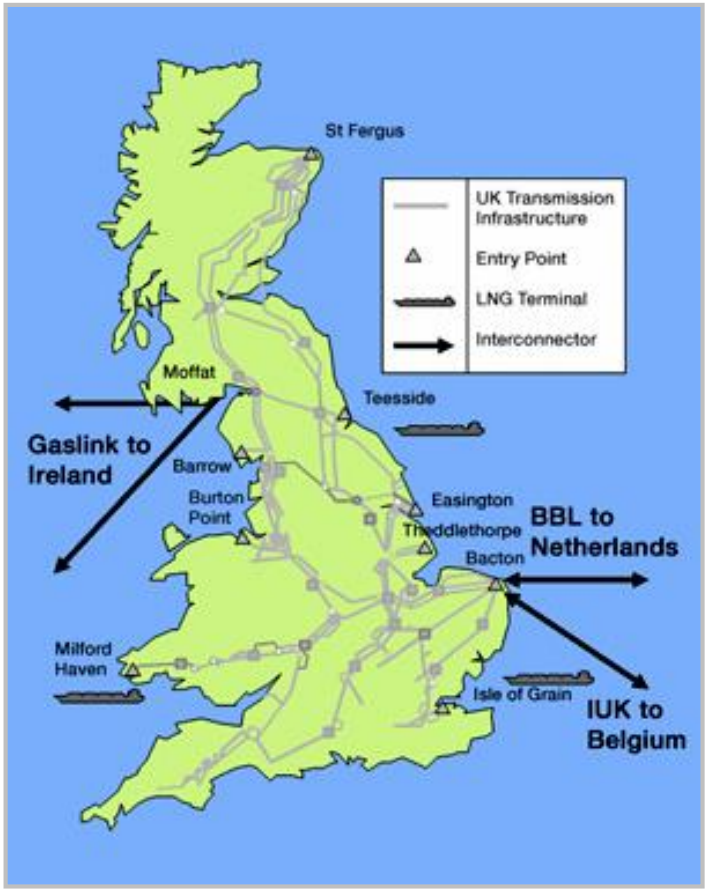
Protection of reinforced Concrete

Impressed Current Systems



Tanks, Jetties,
Tankers, Large Ships
and
Pipelines.

Laying Modern Pipelines for Cathodic protection

Impressed Current Systems

Recent Innovations in Monitoring IP Systems

- Remote Data Collection (Operating Characteristics and Performance).
- More Advanced / More Durable Anode Materials.
- Wider Range of Anode Types To Suit Many Applications.
- Use of Drones and Helicopters To Assist CP Monitoring (Esp. Of Pipelines).

THE END

- More Anodes Please!

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SPEAKER 5 - Stephen Tate - (CAN/TEPUK)

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INTEGRITY MANAGEMENT SPECIALISTS

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ICorr Aberdeen Branch Welcomes

Stephen Tate (CAN / TEPUK)

MBA, PG.Dip. Eng, MICorr

Operations Corrosion Engineer

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TOTAL

UK Ops

CAN GROUP COMPANIES

CAN (OFFSHORE) LTD WAS FOUNDED IN 1986 WHEN IT INTRODUCED INDUSTRIAL ROPE ACCESS IN TO THE NORTH SEA AND WAS A FOUNDING MEMBER OF THE INDUSTRIAL ROPE ACCESS TRADE ASSOCIATION (IRATA). **CAN GROUP** IS NOW A MARKET LEADING 'LIFE OF ASSET' INTEGRITY SERVICES PROVIDER.

ENG TEQ CAN VEN TEQ

WHAT WE DO: CAN (INSPECTION SERVICES), **ENGTEQ** (INTEGRITY MANAGEMENT) AND **VENTEQ** (VENDOR INSPECTION)

WHERE WE ARE: UK (TEPUK / OTHER OFFSHORE), INTERNATIONAL.

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Stephen Tate

MBA, Integrity Management, the University of Aberdeen
P.G Diploma in Offshore Materials and Corrosion
B.Gas Snr. Coating Inspector

1980 – 1982, Ferranti Subsea Systems (Now Aker Solutions)
1983 – 1999, Aberdeen Corrosion Engineers Ltd (Acel)
1999 – 2018, Integrity Management Contracts – Apache, BP, ConocoPhillips, Fairfield Energy, Talisman and Tepuk.

Use of CRA’s

Reactivity and Relative' Costs of CRA's

Reactivity series of metals

Element	Symbol
Potassium	K
Sodium	Na
Calcium	Ca
Magnesium	Mg
Titanium	Ti
Aluminium	Al
Carbon	**C**
Zinc	Zn
Iron	Fe
Lead	Pb
Hydrogen	**H**
Copper	Cu
Silver	Ag
Gold	Au

Note: Carbon and hydrogen are not metals.

Titanium	£8000
Iron	£250
Stainless steel	£1500
Aluminium	£1500
Titanium alloys	£25000

The reason for common (95%) use of Non Exotic Iron / Steel, is immediately obvious.

Uses of Corrosion Resistant Alloys (CRA's)

- Carbon Steel remains the Most Commonly Used 'Day to Day' Material (Norm. with Sacrificial Barrier or Coating).

- Alloys are Expensive and only used where they can be Justified on Grounds such as:

- Highly Aggressive / Highly Corrosive Conditions.
- High Flow Rates.
- Hygiene Reasons, e.g. Food Production.
- But Remember – They Are Usually Very Thin Walled.

Partial Use of Alloys

- CRA's have specific applications.

- Partial Use is often more appropriate:

- As Liners.
- As Instrument Feeds.
- As Flow Enablers.
- As Decorative / Easily Maintainable Surfaces.

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Full CRA Vessel

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Hastelloy® and **Incoloy®** are both members of the **"superalloy"** family, also known as high-performance alloys and have several key characteristics in common. They both possess excellent mechanical strength, especially at high temperatures, and they are both **highly resistant to corrosion and oxidation.**

Very High Cost

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Alternative Use of Liners

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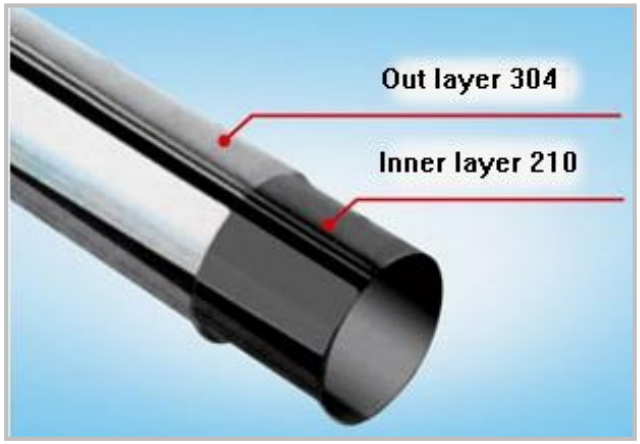
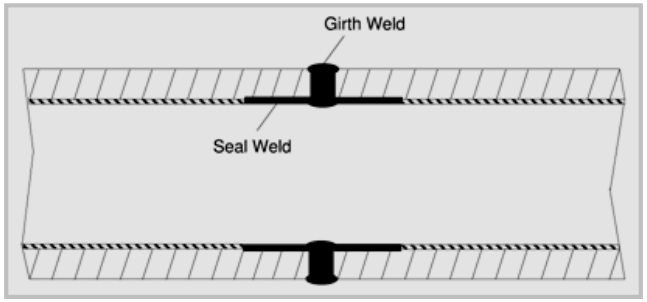


Much Lower Cost



Jointing

Claddings are OK For Short Lengths

Corrosion Mitigation by Materials

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As Instrument Feeds

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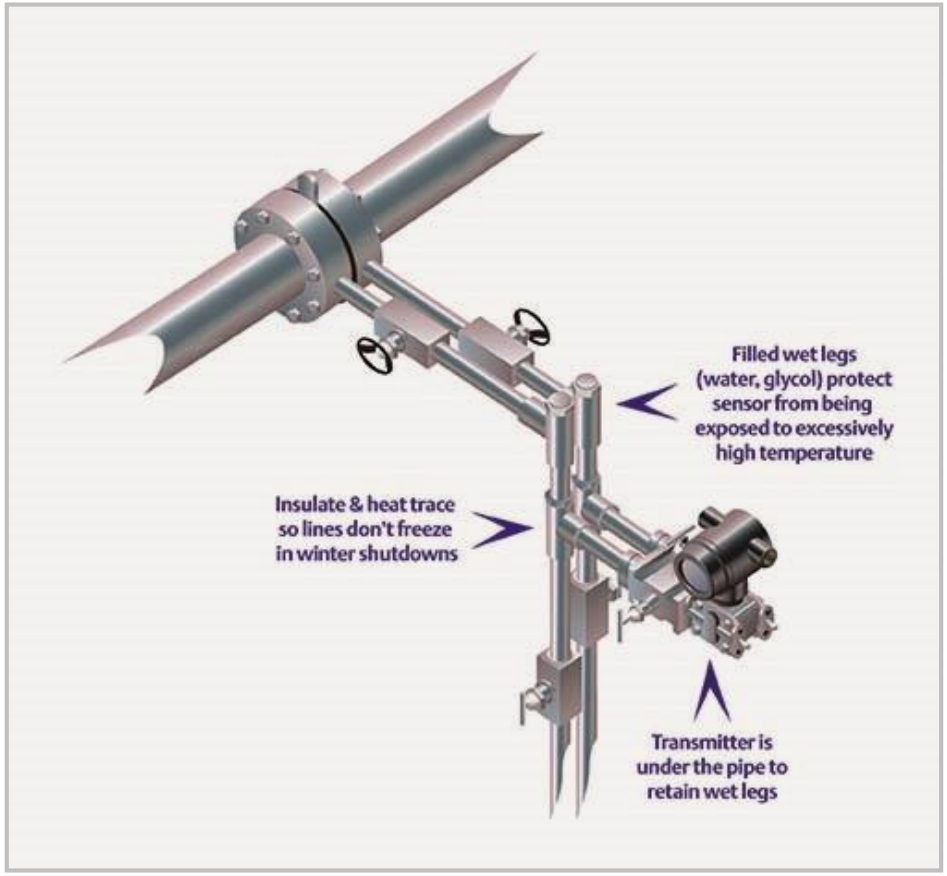

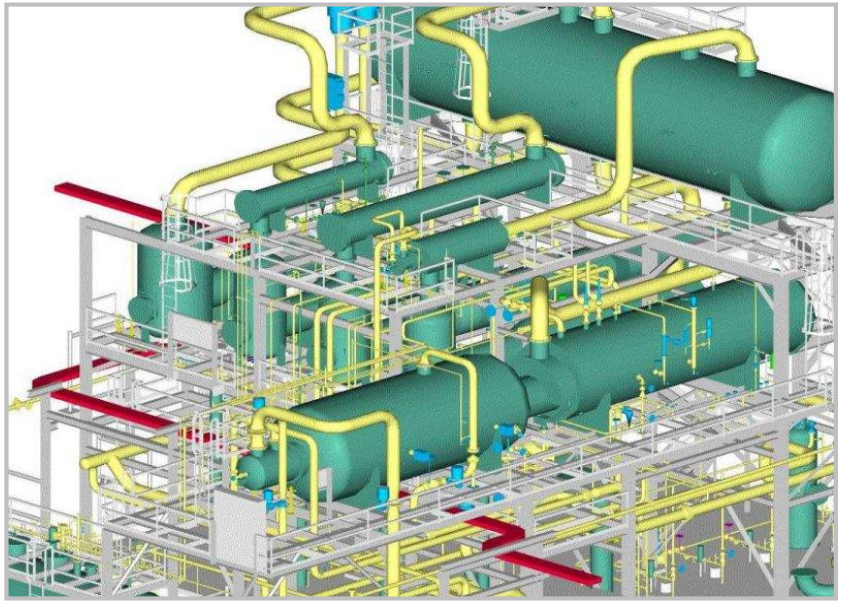

316L is Common

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Corrosion Mitigation by Materials

As Flow Enablers

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Super Duplex Stainless Steel - Often Used for High Flow / High Erosion Risk Conditions

Corrosion Mitigation by Materials

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As Decorative Surfaces

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1928 Chrysler Building NYC, 1st Major Use of Stainless Steel in Architecture. Type 302

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Installation / In-Service Issues

Good Installation Essential

Great Care Required At All Stages.

- **SUCCESSFUL** USE OF CRA'S – CORROSION RESISTANT ALLOYS, JUST LIKE PROTECTIVE COATINGS, IS DEPENDANT ON:

- GOOD SYSTEM DESIGN.
- GOOD INSTALLATION PROCEDURES.
- CORRECT APPLICATION AND FLOW CONDITION.
- CORRECT CHOICE OF MATERIALS.

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Corrosion Mitigation by Materials

CRA Liners Can Buckle

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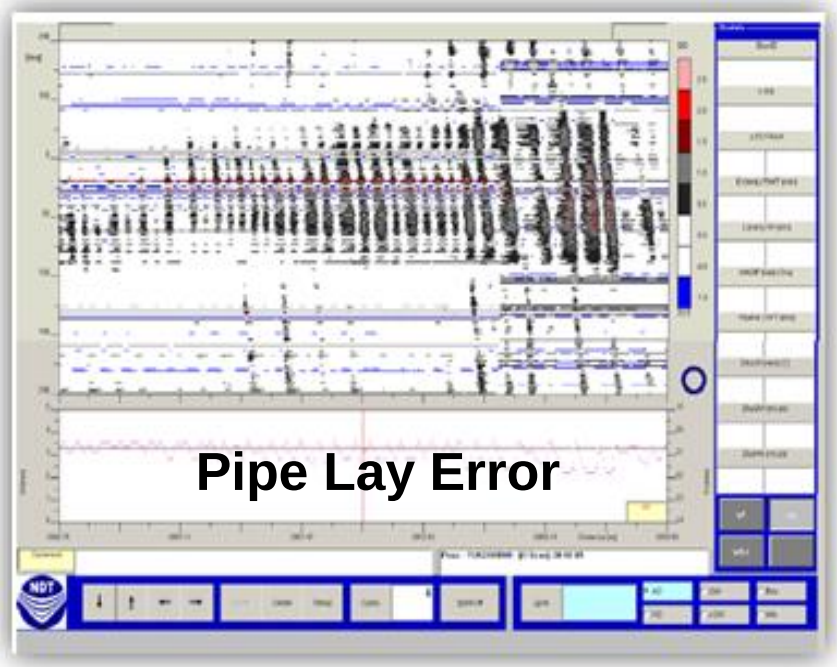

Scan of Long-Distance Pipeline

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Corrosion Mitigation by Materials

Seawater Piping

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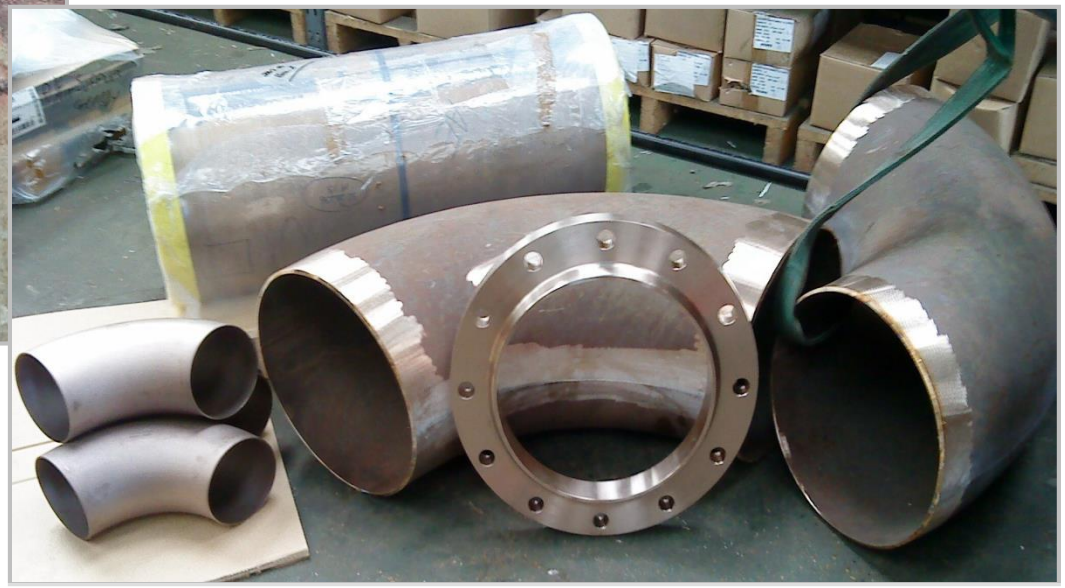
THIN 3mm Cunifer 90/10 Copper Nickel Piping, showing Repair

Often used for **Marine Applications and Fire Mains**



Has **GOOD** Corrosion Resistance but **POOR** Erosion Resistance

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Corrosion Mitigation by Materials

Can Suffer Crevice Attack

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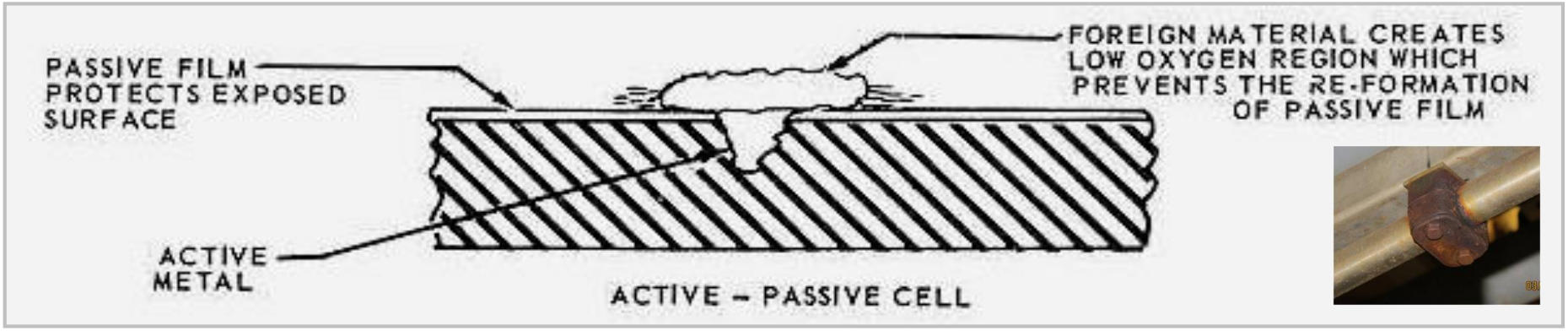
Pitting and Crevice Corrosion of Stainless Piping is Common in Marine Environments **(Unless Coated)**



Stainless Alloy Limits

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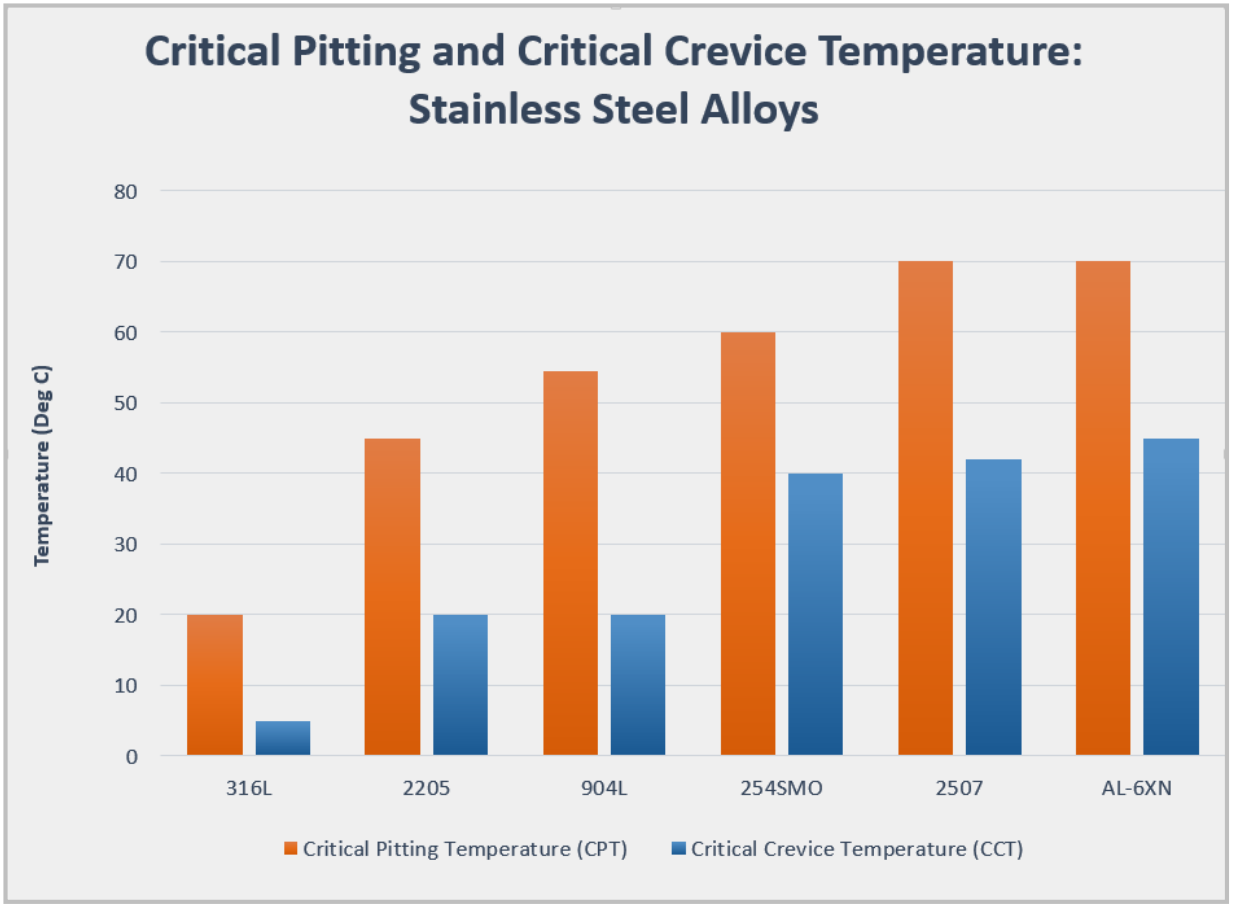
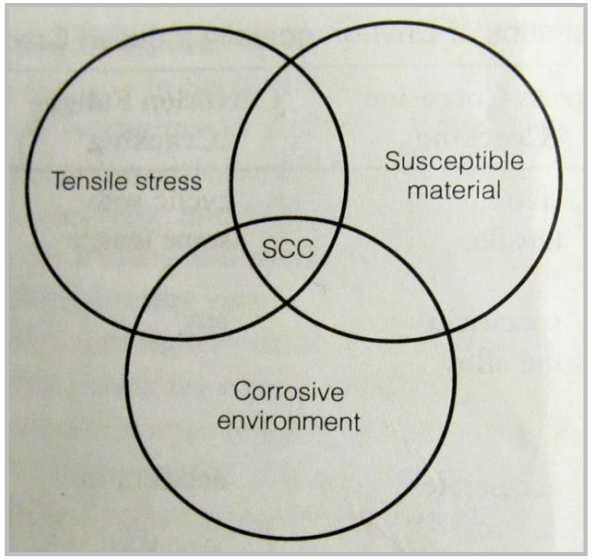
According to Service Application and Installation Methods

Alloys will require Protective Coatings Above Critical Temperatures.

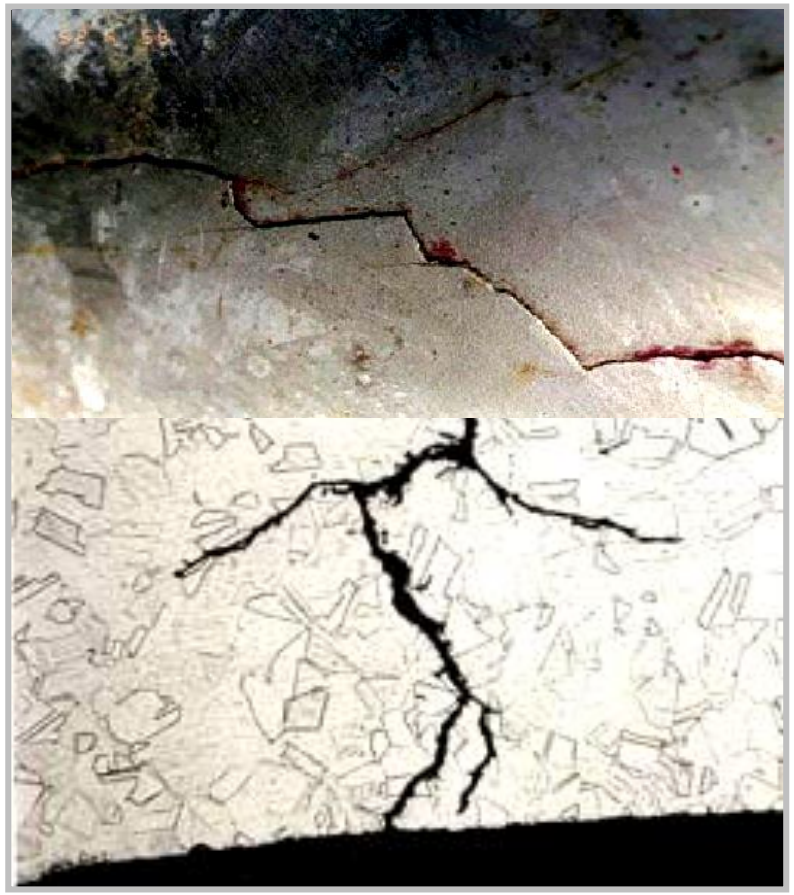


Stress Corrosion Cracking

Properties	Ferritic	Austenitic
Toughness	Moderate	Very high
Ductility	Moderate	Very high
Weldability	Limited	Good
Thermal expansion	Moderate	High
Stress corrosion cracking resistance	Very high	Low
Magnetic properties	Ferro magnetic	Non-magnetic



Seawater Deluge System Can Cause This ! i.e. **Chloride Contamination to Hot Surfaces**



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Effects of Combining Materials

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Materials Failure Risks

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !

Simplified Galvanic Series of Metal Reactivity in Seawater

Active	Magnesium
	Zinc
	Aluminium
	Mild steel
	Copper
	Nickel
	Titanium
Passive	Platinum

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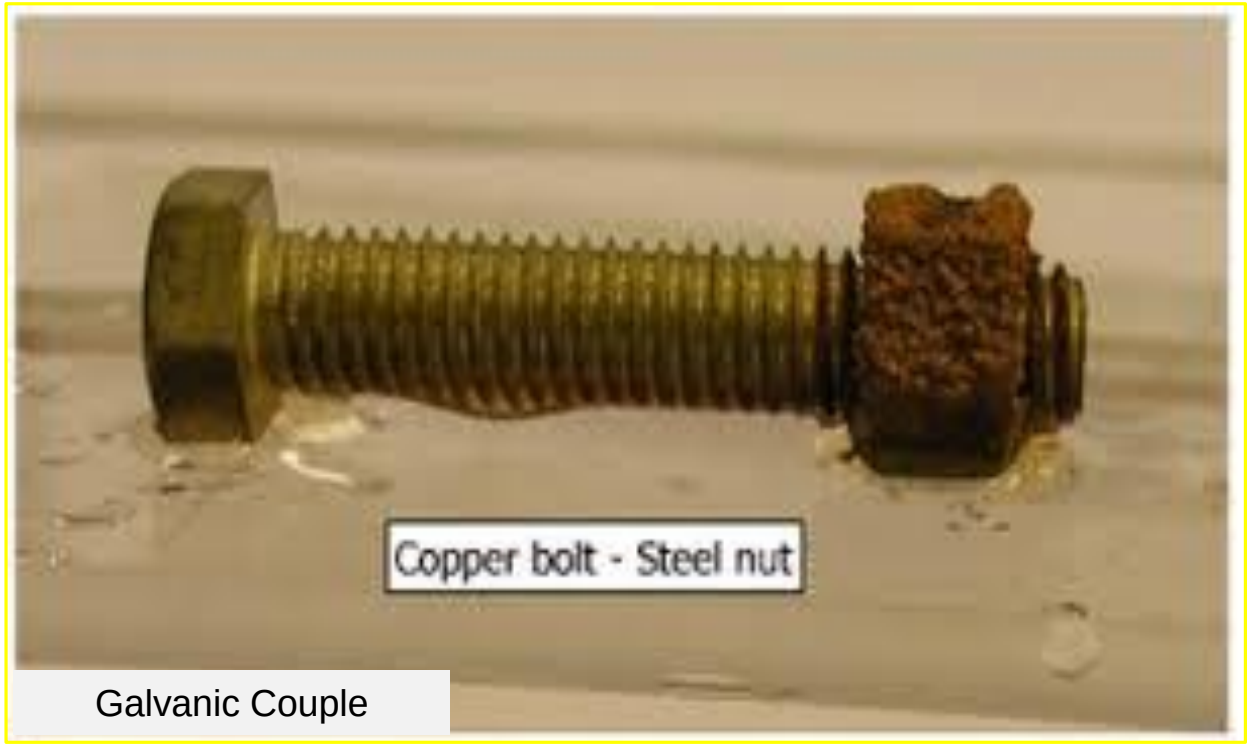
Materials Failure Risks



Galvanic Couple

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !

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Materials Failure Risks

Multiple Material Types – Check For Compatibility

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !

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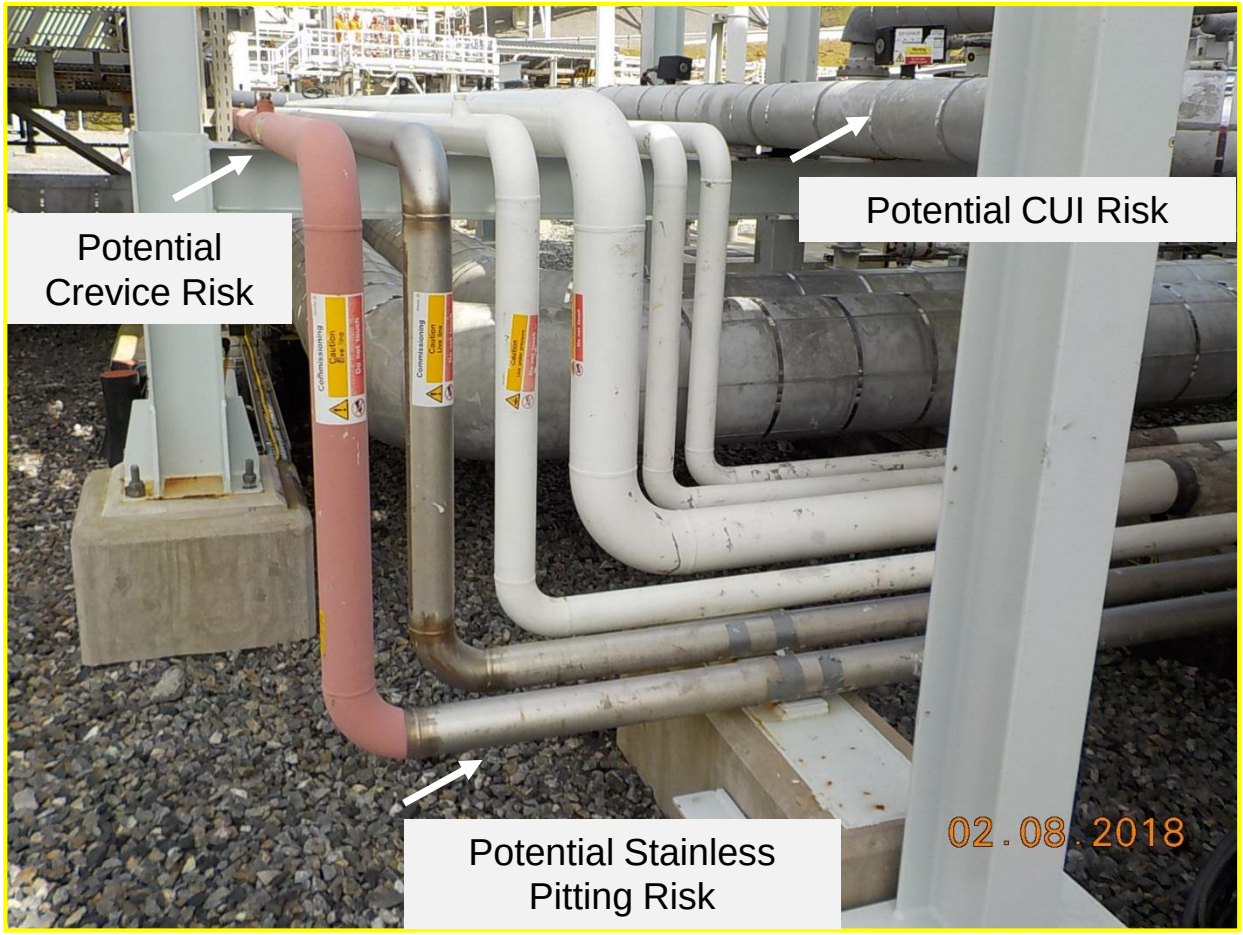
Materials Failure Risks



Combining Materials

Look For The Weakest Link !

Think Of The Risks !

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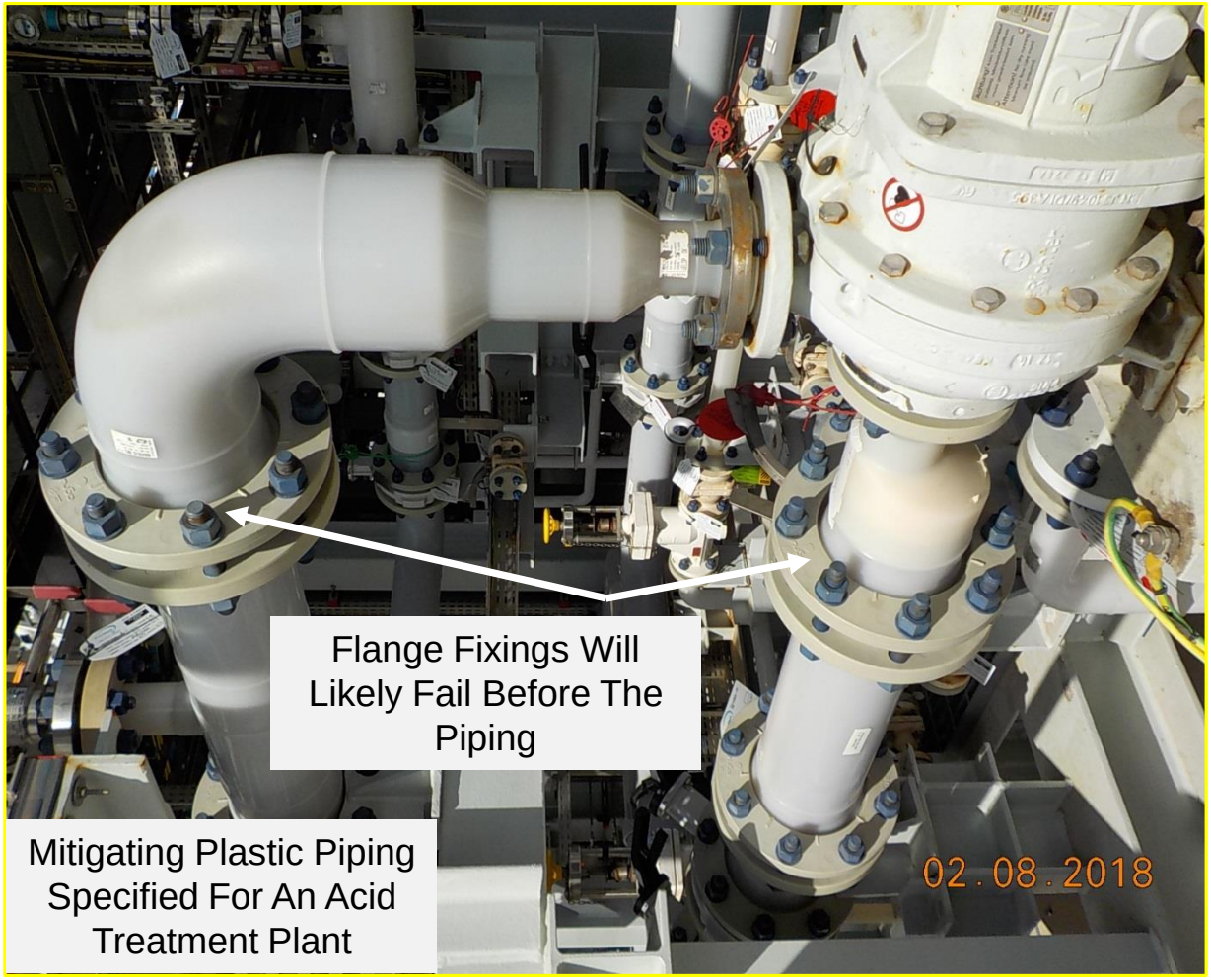
Materials Failure Risks

Combining Materials

Look For The Weakest Link !

Think Of The Risks !



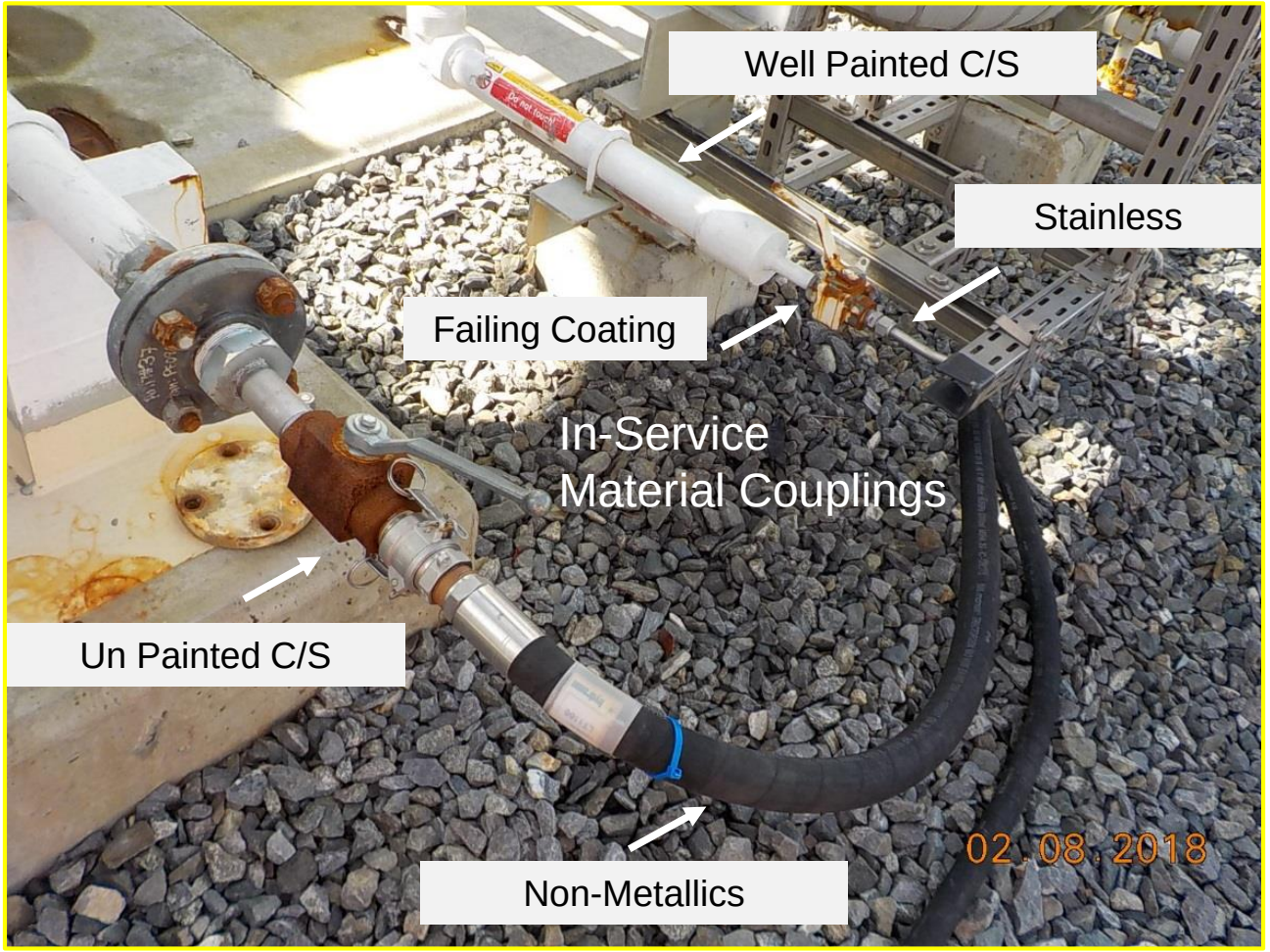
Materials Failure Risks

Aberdeen Branch

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !



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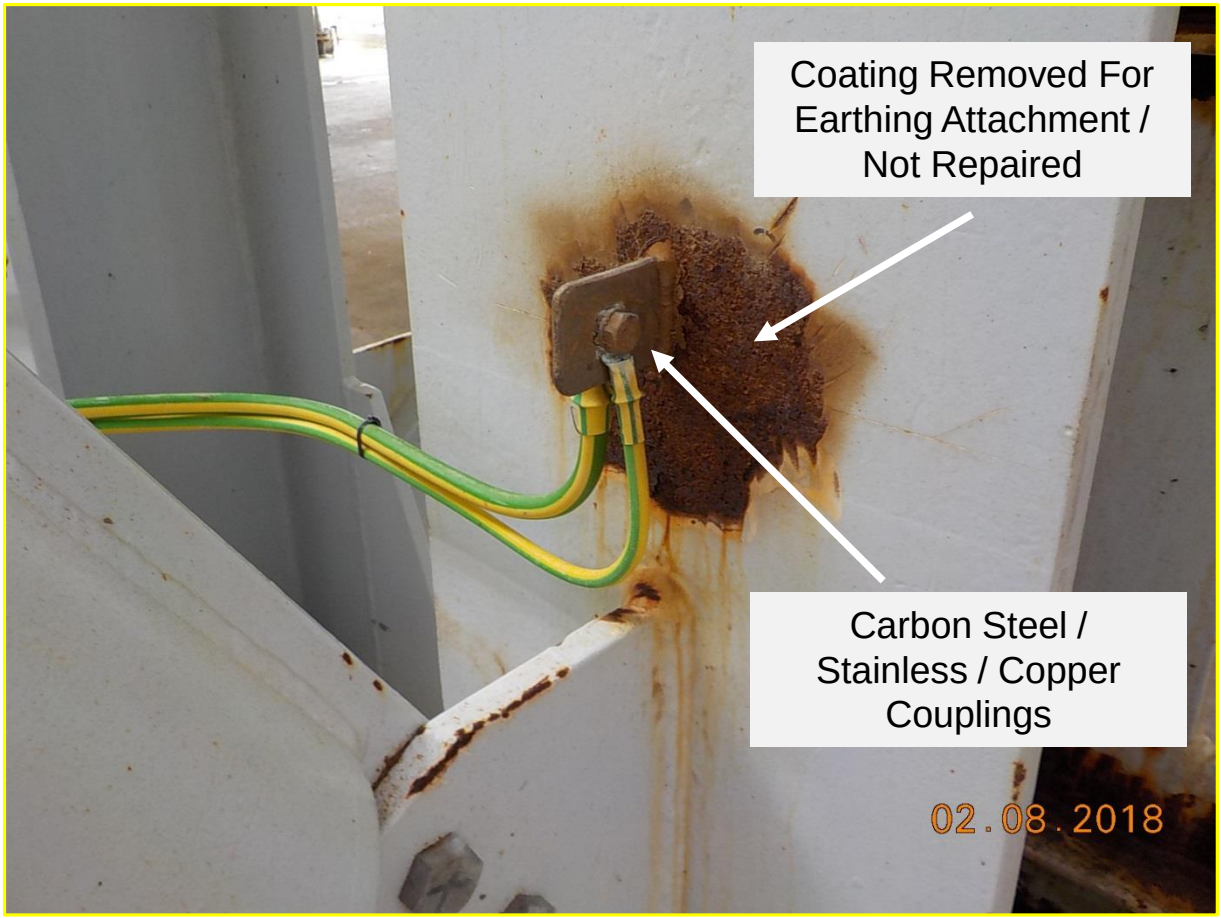
Materials – Construction Detailing Risks



Combining Materials

Look For The Weakest Link !

Think Of The Risks !

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Examples of Poor Site Detailing

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Materials – Construction Detailing Risks

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !

Materials – Construction Detailing Risks

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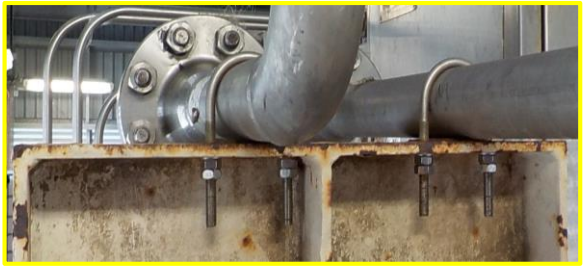
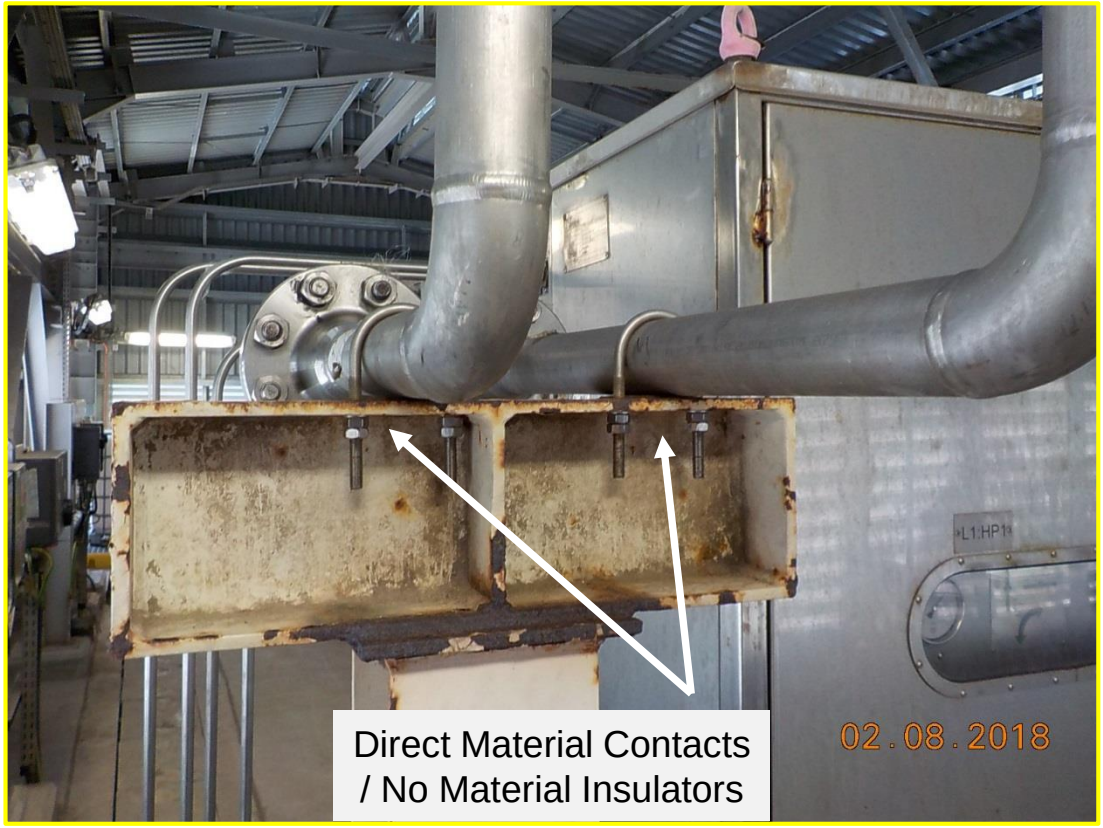
Combining Materials

Look For The
Weakest Link !

Think Of The Risks !





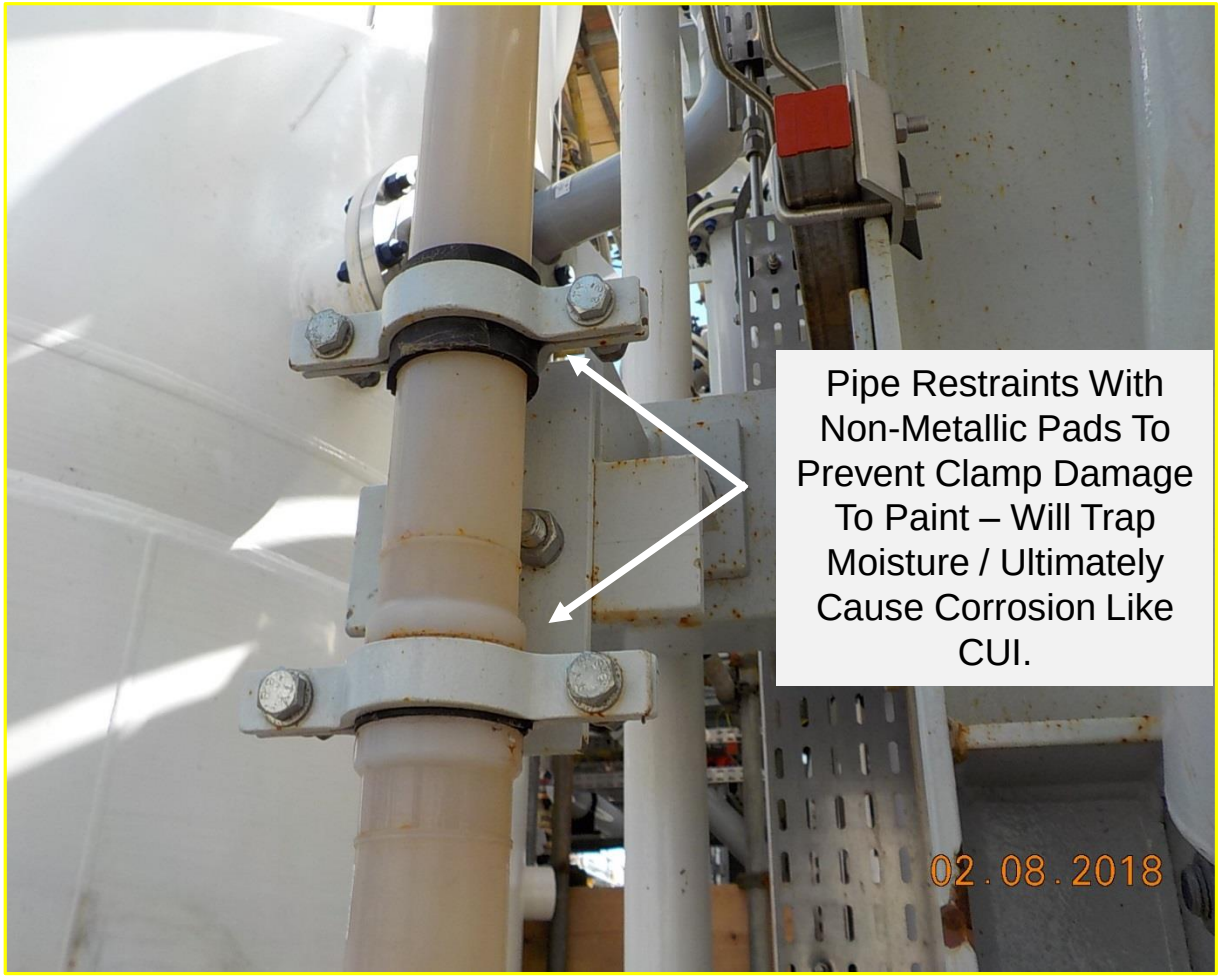
Materials – Construction Detailing Risks

Aberdeen Branch

Combining Materials

Look For The Weakest Link !

Think Of The Risks !



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Coatings - High Risk Areas

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Coating / Insulation Failures

Essential Maintenance Req.

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Coating / Insulation Failures

Essential Maintenance Req.

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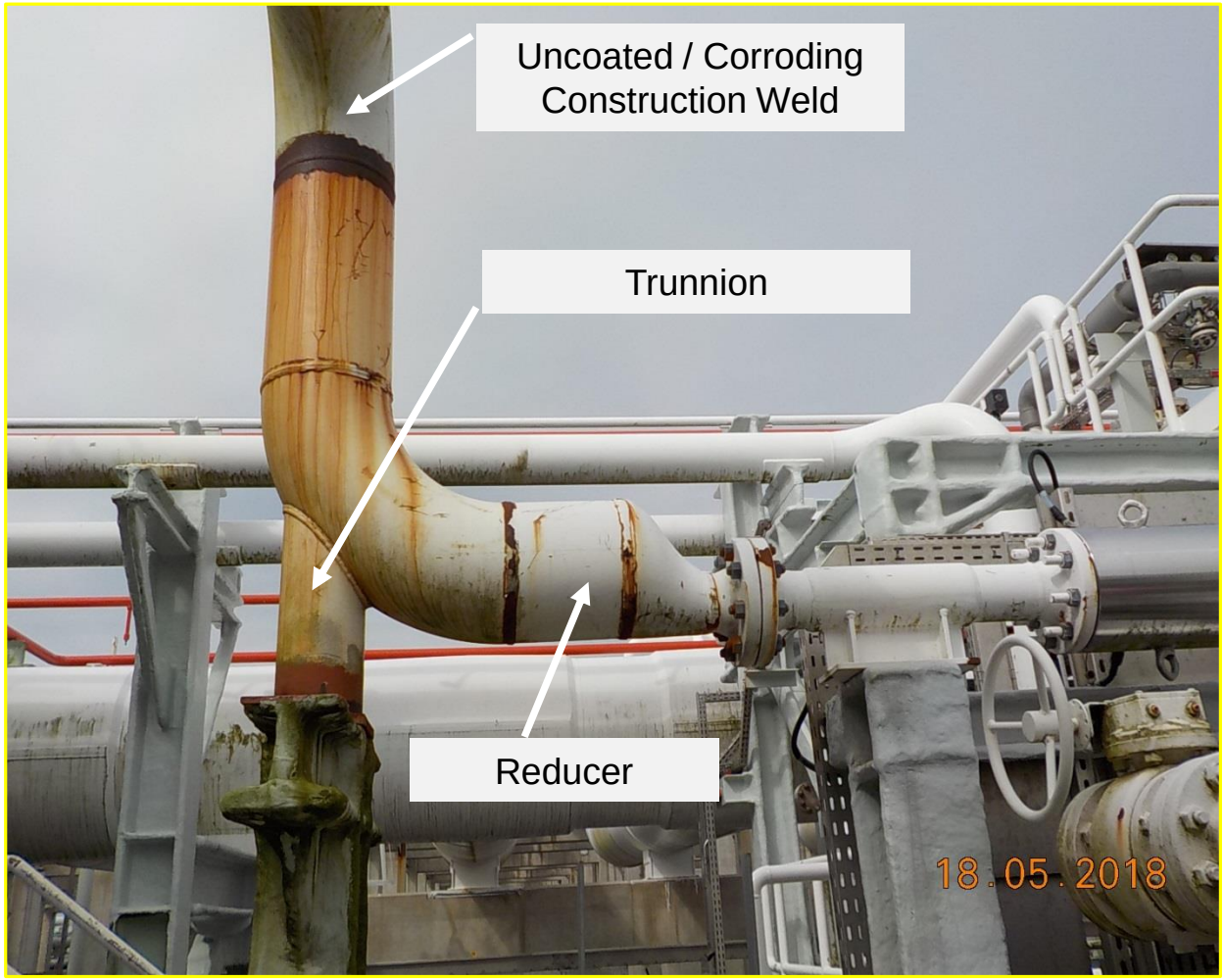
Coating / Insulation Failures



Essential Maintenance Req.

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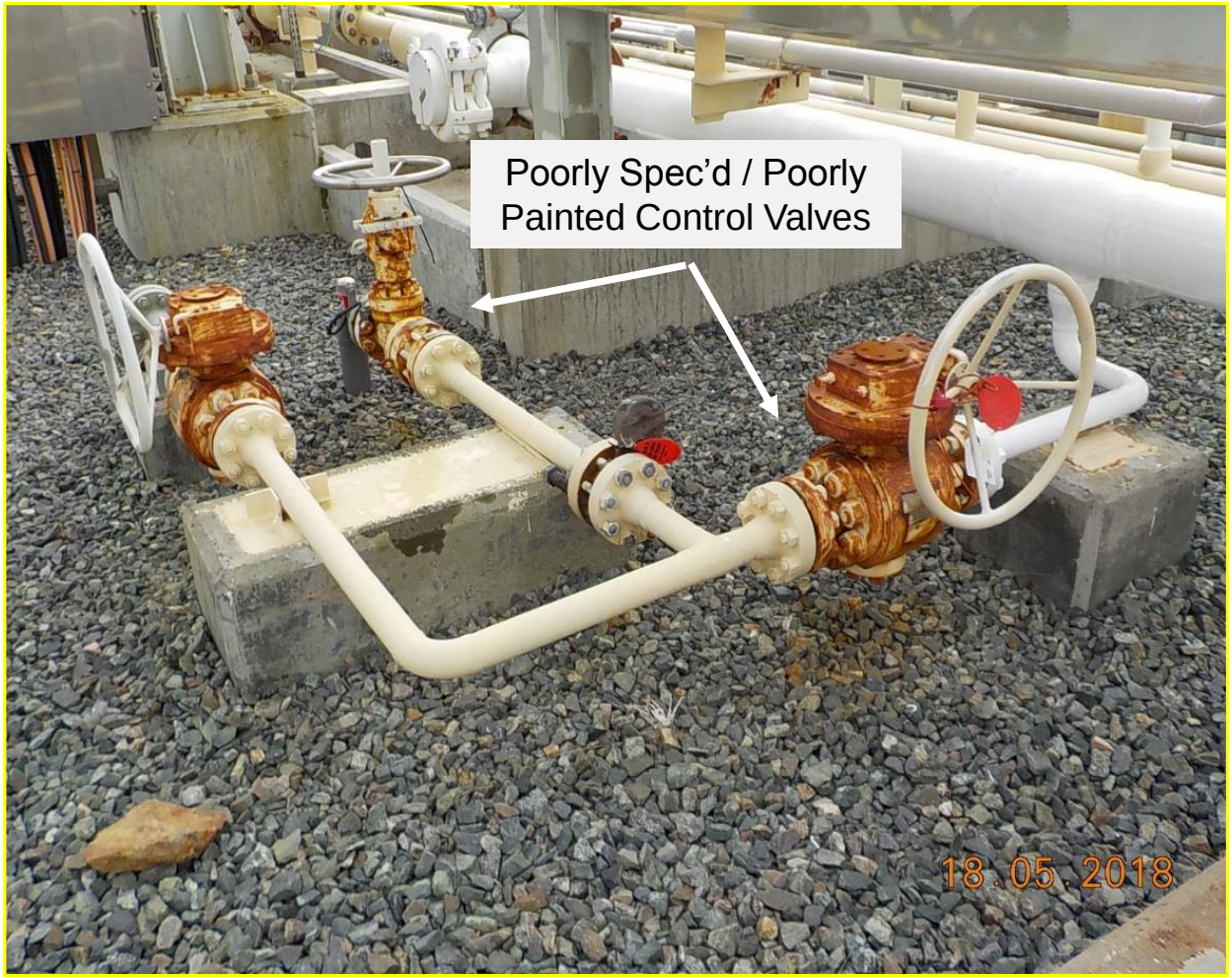
Coating / Insulation Failures



Essential Maintenance Req.

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Coatings Future Maintenance

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Materials Failure Risks

Combining Materials

Look For The
Weakest Link !

Think Of The Risks !

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Materials Failure Mitigation

Essential Maintenance

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ICORR ABERDEEN BRANCH WELCOMES

SPEAKER 6 - Hooman Takhtechian (Oceaneering)

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HOOMAN TAKHTECHIAN, MSC, CENG, MIMMM

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- M.Sc. Metallurgical Engineering - University of Tehran;
- M.Sc. Corrosion Control Engineering - University of Manchester;
- International Welding Engineer - IIW (International Welding Institute);
- Charter Engineer - IOM3 (Institute materials, minerals, and mining);

- More than 18 years experience in oil and gas industry;
- 4 years in EPC contractor;
- 10 years in third party certification body - Bureau Veritas;
- 5 years in service provider - Oceaneering;
- Work experience in Iran, Abu Dhabi, Malaysia, Indonesia and the UK;
- Providing service to major operators like NIOC, ADNOC, Total, Saudi Aramco, Petronas, Talisman, and BP.

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Corrosion Management Overview / Risk Based Inspection

- Background to Corrosion Management
- Basic concepts
- Corrosion Management Processes
- Corrosion Management tools
- Corrosion Risk Assessment
- Corrosion Mitigation methods
- Corrosion Management Systems
- Conclusions

Background to Corrosion Management

The need for corrosion management

1. Catastrophic events due to poor corrosion management / human error

Errors:

- the selection of corrosion control options,
- application of mitigation technologies and
- day-to-day activities to ensure that systems are monitored / corrective

Background to Corrosion Management

The need for corrosion management

2. Legislative requirements (Audits, Policies, etc.)

UK HSE has been asking organizations for copies of the corrosion policies

Older legislation		*Principles-based legislation*
Detailed rules and regulations	⟶	Framework rules with guidelines
What must be done		How it must be managed
Prescriptive		Risk-based
Do it anyway		Identify hazards and risks first and prioritize actions accordingly

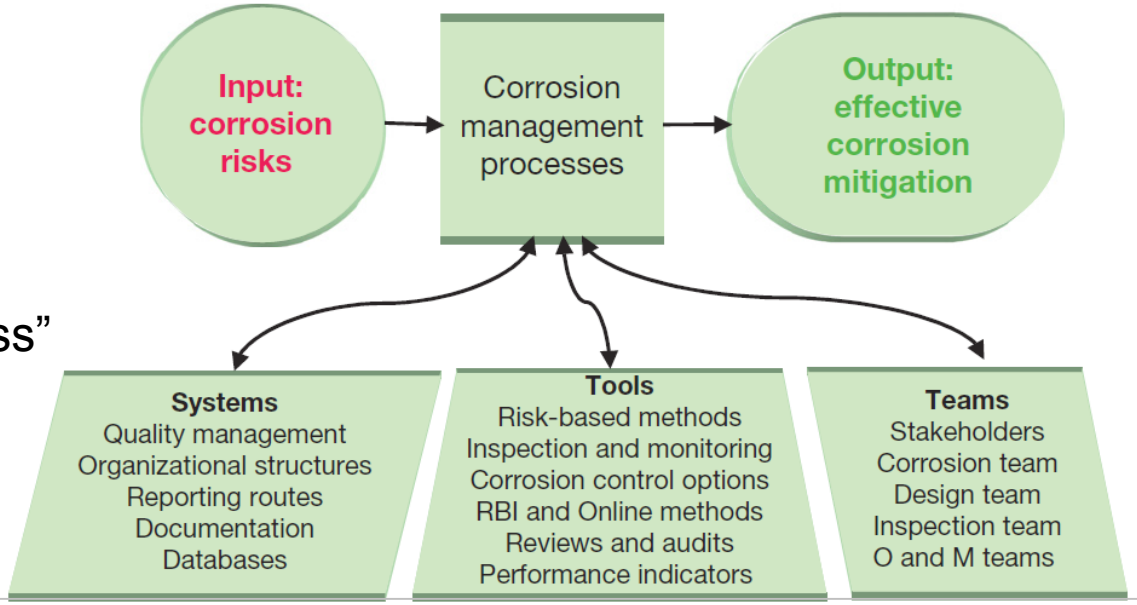
The challenge for industry arising from these legislative drivers is to demonstrate to the licensing authorities that the equipment is operating under safe conditions, while from a business perspective continuing to operate cost effectively, often under more aggressive conditions, and in some cases, to extend the life of aging facilities.

Background to Corrosion Management

Corrosion control strategy is defined here as the management of available resources, including finance, materials, equipment and manpower, to provide the policies, procedures and organizational systems that are required to mitigate the effects of corrosion

- long-term objectives (Cost, Leaks, etc.)
- standard corrosion control procedures
- Corrosion control tactics (inspection/Monitoring)
- Performance standards/KPI

Based on
"Quality Management Process"



Risk Management

Hazards and risks

A hazard has the potential to cause harm or damage; often defined as a physical condition or release of hazardous material as a result of component failure that can cause human injury or death, loss or damage, or environmental degradation.

Risk is the combination of the severity of the effect (the consequences) and the likelihood of it happening (damage mode and probable frequency).

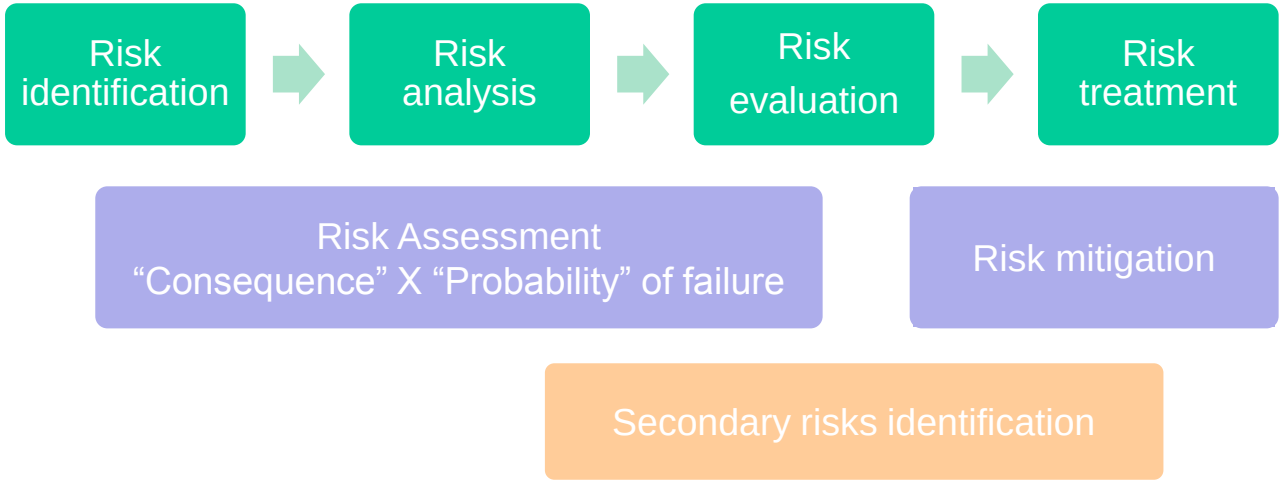
A risk is the likelihood that a hazard will actually cause its adverse effects

Risk Management

Risk Management Processes

- Strategic decisions
- Tactical decisions
- Operational decisions

1. Significant undesired or unexpected outcomes can be identified, and
2. Opportunities for improvement can be considered.

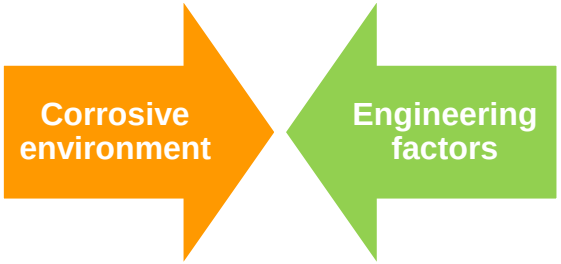


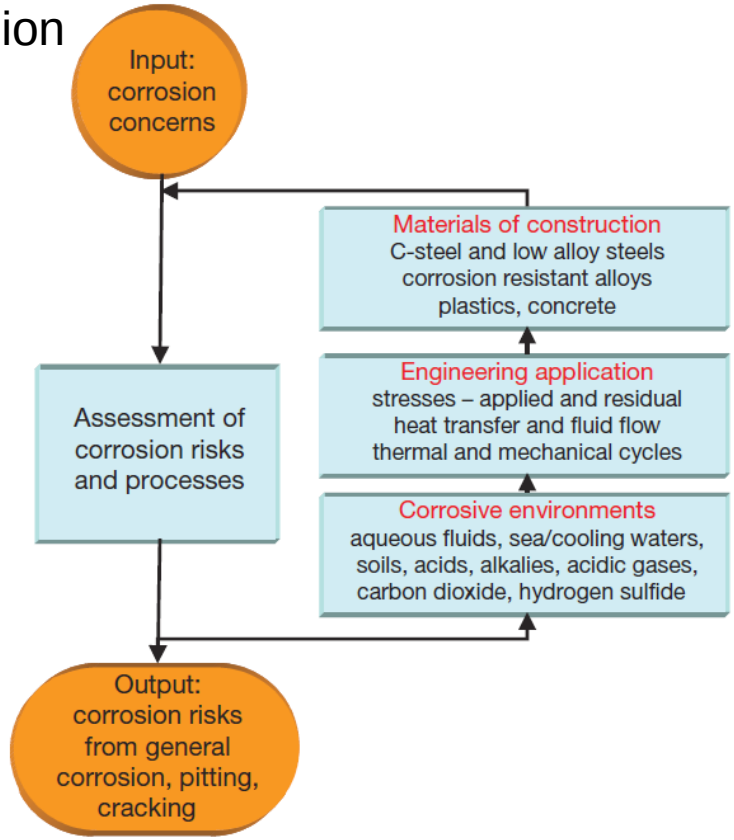
Identification of Corrosion Risks

Corrosion damage and failure modes

- Uniform corrosion
- Galvanic corrosion
- Localized attack – pitting and crevice corrosion
- Flow induced corrosion – erosion corrosion
- Environmentally assisted cracking
- Corrosion fatigue

Basic corrosion risk assessment steps

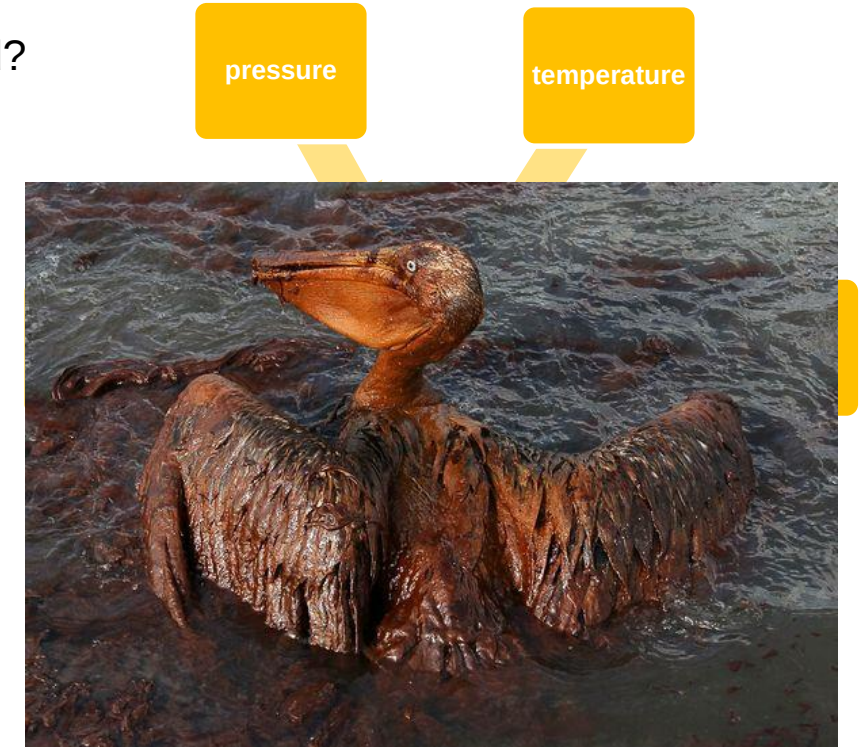




Corrosion Risk Assessment Processes

Risk = Consequence × Likelihood of Failure

1. What would be the worst case scenarios?
2. How likely are they to occur?
3. What would be the damage?
4. How many people could be injured or killed?
5. How will these events affect the business?



Corrosion Risk Assessment Processes

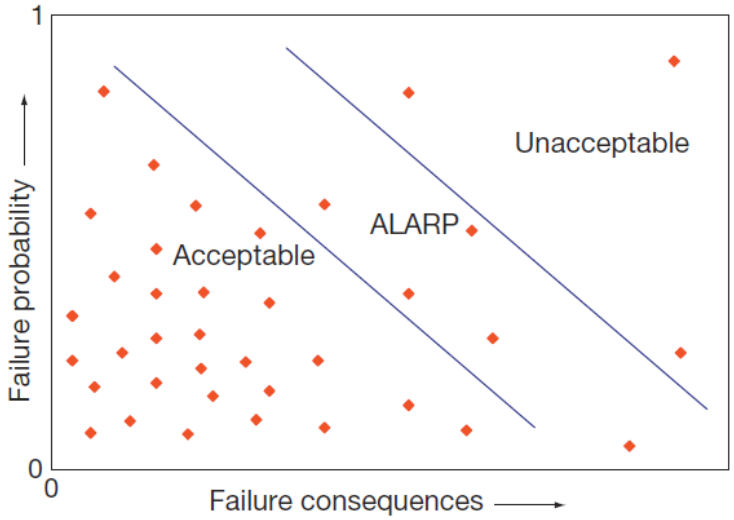
Risk = Consequence × Likelihood of Failure

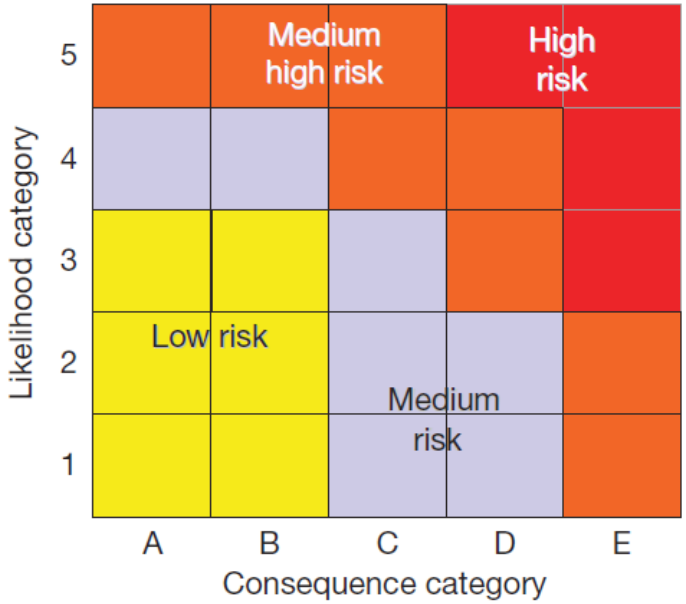
1. Failure mode – what could go wrong?
2. Failure effect – how will it affect the project/plant integrity/operations?
3. Failure criticality – how likely is it?

Corrosion Risk Assessment Processes

Matrix analysis Criticality = Likelihood of failure X Effect of failure

Level 1 – Qualitative risk analysis, a simple ranking of equipment
Level 2 – Semi-quantitative risk analysis, a more accurate prioritization that retains vital inputs of a Level 3 analysis but simplifying assumptions
Level 3 – Quantitative risk analysis, an in-depth study including assessment of reliability, financial and limited environmental issues

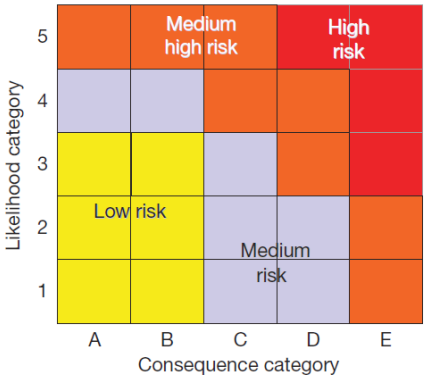




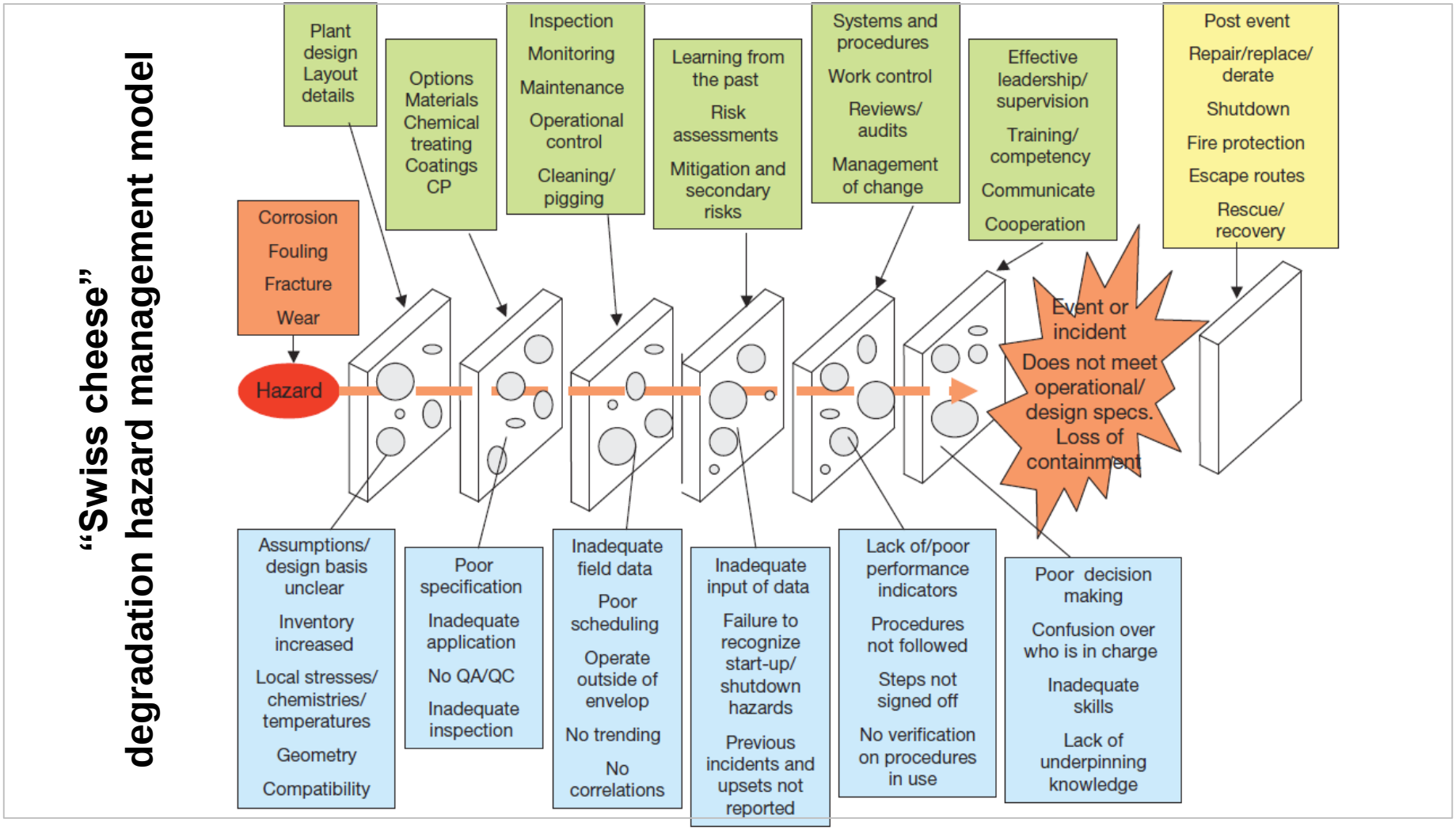
Corrosion Risk Mitigation Requirements

<u>Unacceptable high risks</u>
requiring a redesign in more corrosion resistant materials or alternative processing routes to be employed.

<u>Medium–high risks</u>
Could be assessed to see if increased inspection frequencies would allow continuing operation but obviously with a limited life (a predictive maintenance strategy) or if improved corrosion control measures would be effective at decreasing the likelihood of failure and moving the item into a medium risk level and also extending the life.



Corrosion Risk Mitigation Requirements

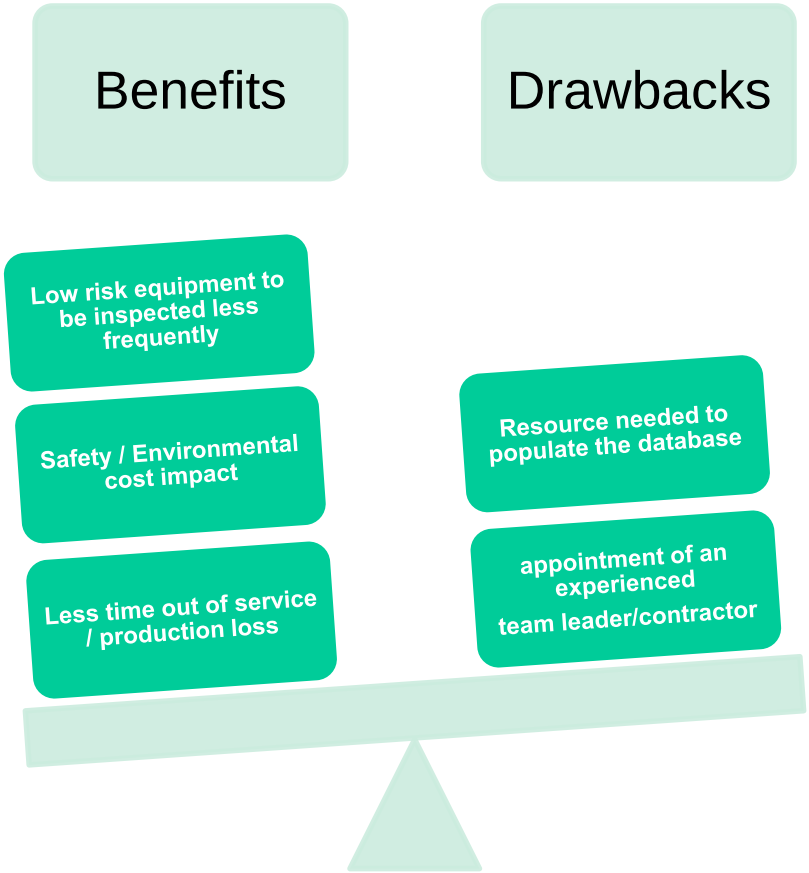


Corrosion Risk Mitigation Requirements

Corrosion Risk Assessment Outcome:

An optimized level of inspection.

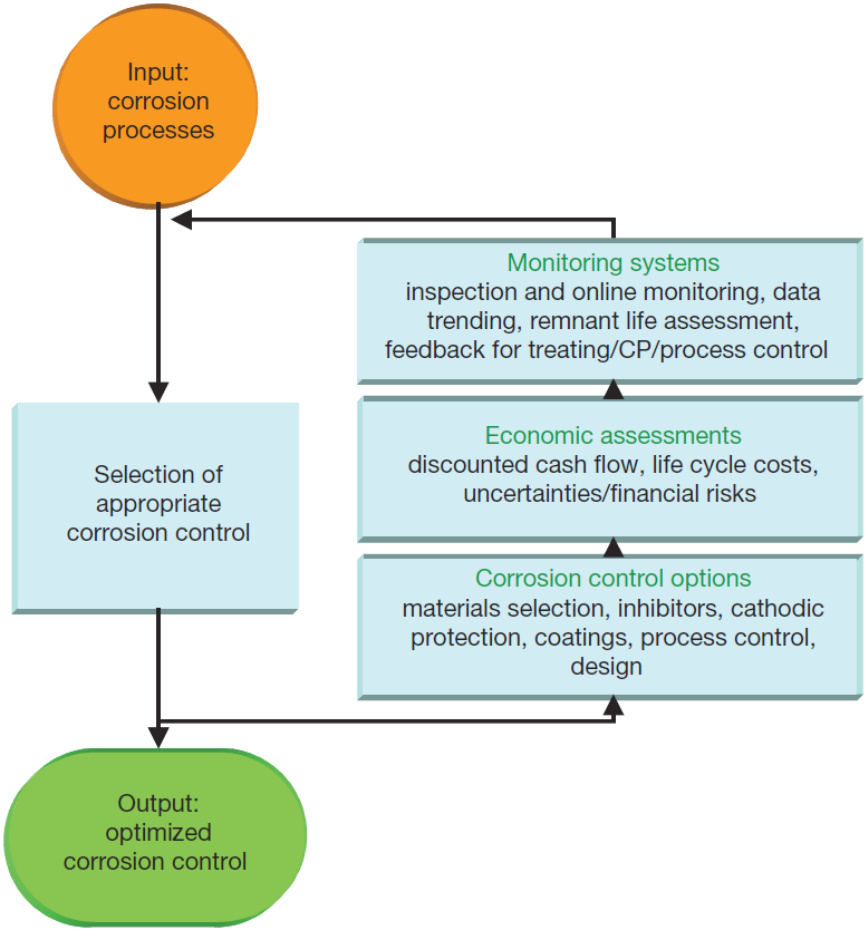
- Inspection frequency can be adjusted
- the methods and tools used for the test and inspection (T&I) schedule can be changed.
- The scope, quality, and extent of the inspection and data collection / interpretation can also be modified.



Corrosion Risk Mitigation Requirements

Corrosion risk mitigation:

1. Materials selection
2. Chemical treatments
3. Use of coatings
4. Cathodic and anodic protection
5. Process and environmental control
6. Design (standards, Spec.)
7. Construction (QA/QC, ITP)
8. Inspection and monitoring



Corrosion Risk Mitigation Requirements

<u>Corrosion risk mitigation by Inspection:</u>

1. condition of equipment
2. requirements for repair
3. rates of localized corrosion or cracking

<u>Corrosion risk mitigation by monitoring</u>

Changes in fluid corrosivity due to

i. damaging excursions in composition
ii. chemical treatments.

<u>Location of Inspection/monitoring</u>

Inspection Conventional

- Visual, UT, RAD, MPI, DPI, Electromagnetic Test, …

Inspection Advanced/Specialised

- Computerised Rad, intelligent pigging, ACFM, Phased array, TOFD, M-SKIP, PEC, …

Inspection Permanently installed/on-line

- UT mat, piezoelectric sensors

Monitoring Conventional

- coupons, ER probes, electrochemical measurements, LPR, …

Monitoring Advanced/Specialised

- field signature method (FSM), sand probes, …

Monitoring Data handling

- supervisory control and data acquisition (SCADA) systems

Corrosion Risk Mitigation Requirements

The effectiveness of inspection programs in finding and monitoring identified damage mechanisms.
Ranking typical inspection methods for various forms of damage modes

Example for General thinning:

Effectiveness	Inspection method/coverage
Highly effective (90%)	complete internal visual examination plus ultrasonic thickness testing (UT).
Usually effective (80%)	partial internal visual examination plus UT
Fairly effective (50%)	external spot UT
Poorly effective (40%)	hammer testing/telltale holes
Ineffective (33%)	external visual examination

Increase in the number of effective inspections → Increase in the confidence in the outcome

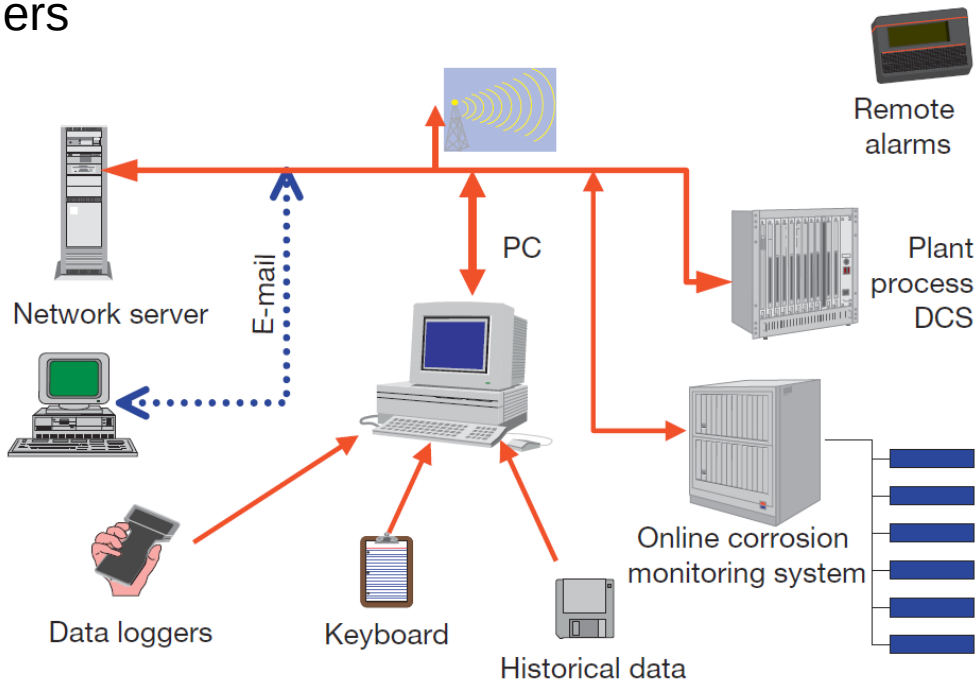
Data Management Systems

Information needed for corrosion assessment

- asset register (structures/vessels/pipework/storage tanks, etc.),
- historical data (inspection/monitoring/maintenance),
- theoretical analysis (new systems based on published data/models),
- opinions and concerns of stakeholders
- field data where available.

The choice will depend on the size of the project/operation.

1. An asset register
2. A documentation system
3. Data collection input and interfaces
4. Data analysis capability
5. Planning/work control
6. Reporting
7. Functionality enhancement / interfaces



Further studies

- Review of Corrosion Management for Offshore Oil and Gas Processing. Offshore Technology Report 2001/044, UK Health and Safety Executive, 2001
- The Offshore Installations (Safety Case) Regulations, SI 1992/2885
- The Pipelines Safety Regulations, SI 1996/825
- The Control of Major Accident Hazard Regulations, SI 1999/743
- Pressure Systems Safety Regulations, SI 2000/128
- API Recommended Practice RP580, Risk Based Inspection.
- API Publication 581, Risk Based Inspection Resource Document;
- DnV RP G101 Risk Based Inspection of Offshore Topsides Static Mechanical Equipment;
- DnV RP G103 Non-Intrusive Inspection;
- Guidance for Corrosion Management in Oil and Gas Production and Processing; Energy Institute: May 2008.

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SPEAKER 7 - Chris Burke (Emerson)

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CHRIS BURKE, BENG (HONS), MIET

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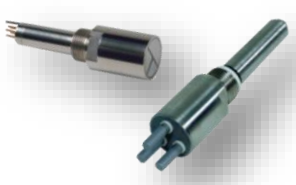
Emerson Corrosion Monitoring Solutions

EVALUATE RISK

Intrusive

Electrochemical (LPR, Galvanic)



Corrosivity

Electrical resistance (ER)

Corrosivity or erosion through metal loss

Acoustic

Solids detection

High sensitivity, quick response

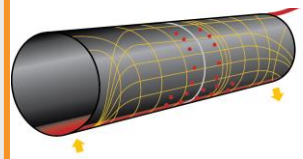
MEASURE IMPACT

Non- intrusive

Ultrasonic (UT)

Wall thickness

Field Signature Method (FSM)



Wall thickness, area coverage

Actual metal loss, wall thickness

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permasense®

Experts in remote monitoring solutions

ConocoPhillips

PHILLIPS 66®

MARATHON

Chevron

ExxonMobil

TESORO

BR PETROBRAS

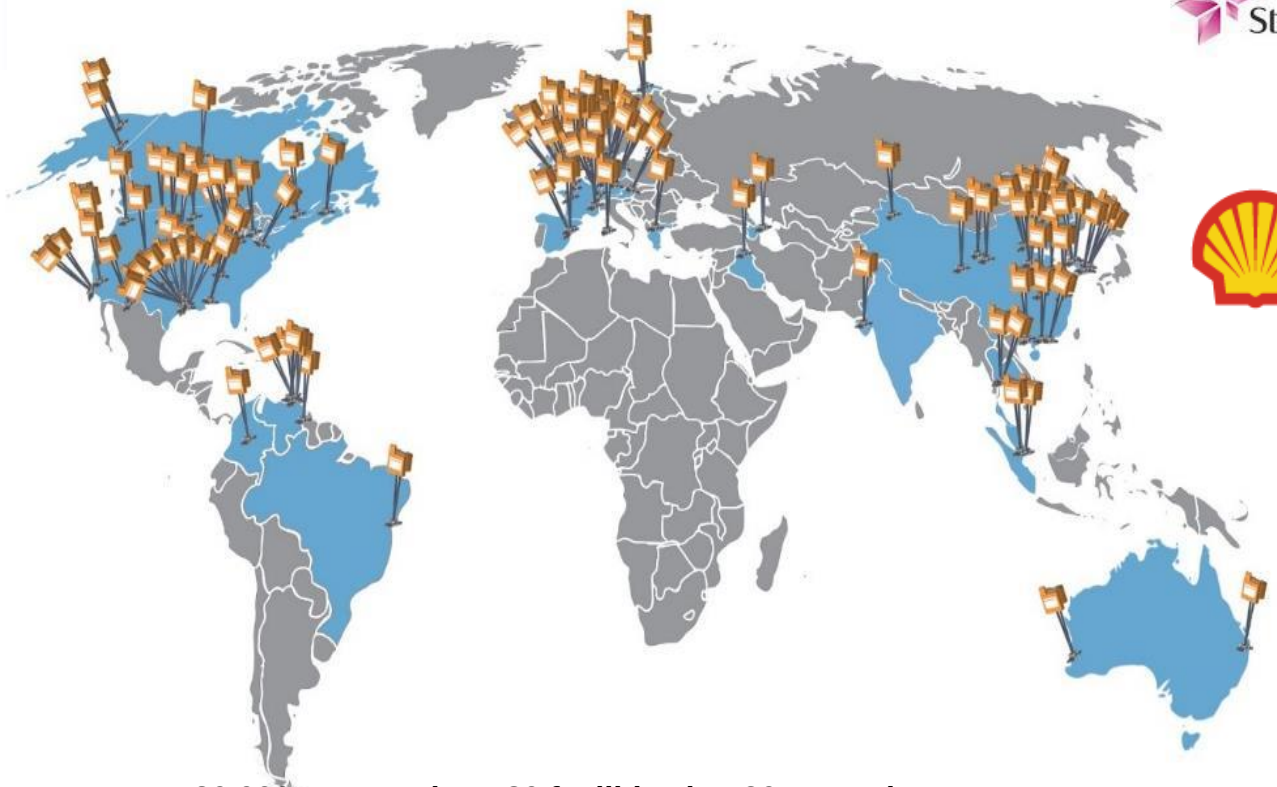
Statoil

bp

TOTAL

VALERO

Sinopec



>20,000 sensors in >180 facilities in >30 countries

>18 million wall thickness measurements delivered to desk, >170 million operating hours

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Chris Burke

Upstream Sales Manager

- BEng (Hons) Electronic & Communication Engineering – Robert Gordon University
- Member of the Institute of Engineering and Technology
- 20+ years experience in the Oil and Gas Industry
- 15+ years Asset Integrity Experience:
  - Support Engineer - Roxar
  - Corrosion & Erosion Monitoring Engineer - ConocoPhillips
  - Senior Engineer – Oceaneering
  - Senior Project Engineer – SMS
  - Consultant – Sandman Engineering
  - Sales Manager - Permasense

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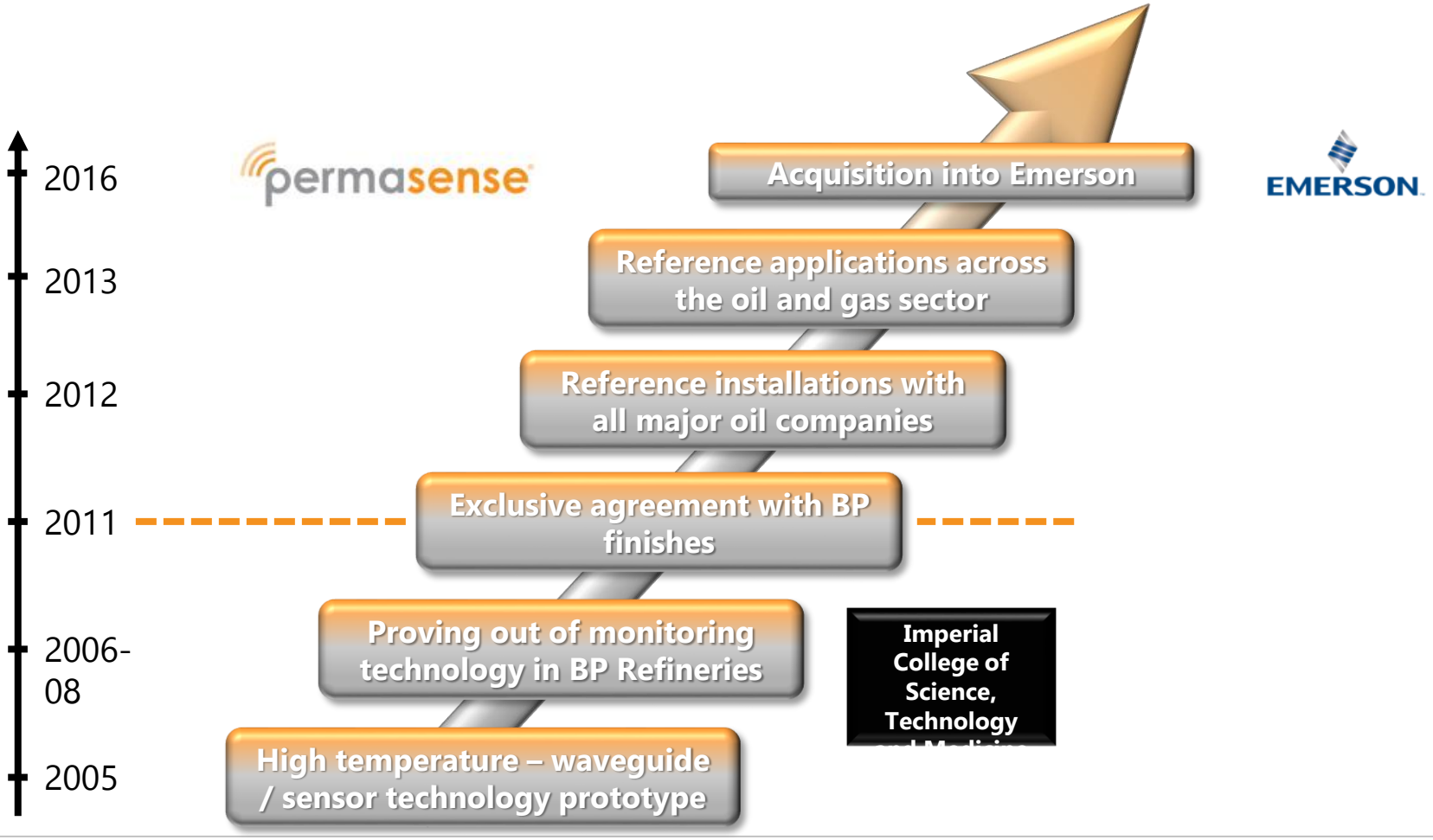
Permasense Equipment Demonstration

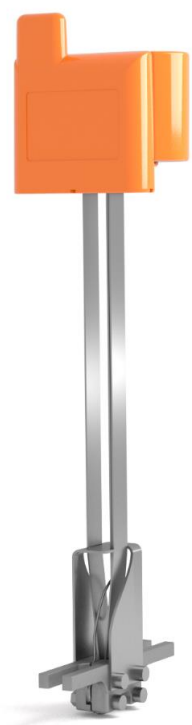
- Permasense Technology
- Data Accuracy and Repeatability
- Challenges Facing Ultrasonics
- Data to Desk: Datamanger
- Questions

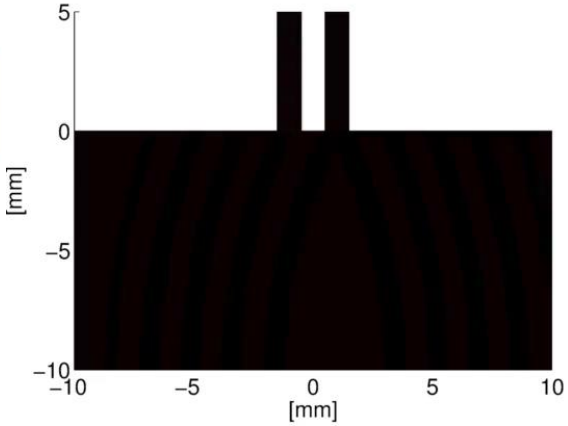
Permasense History

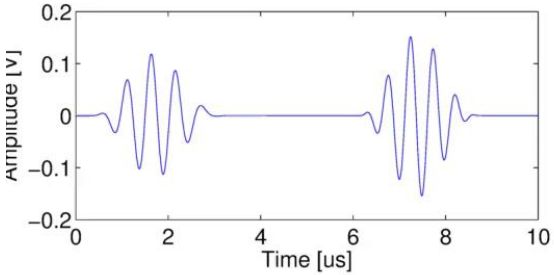


WT Technology - Unique High Temperature Capability

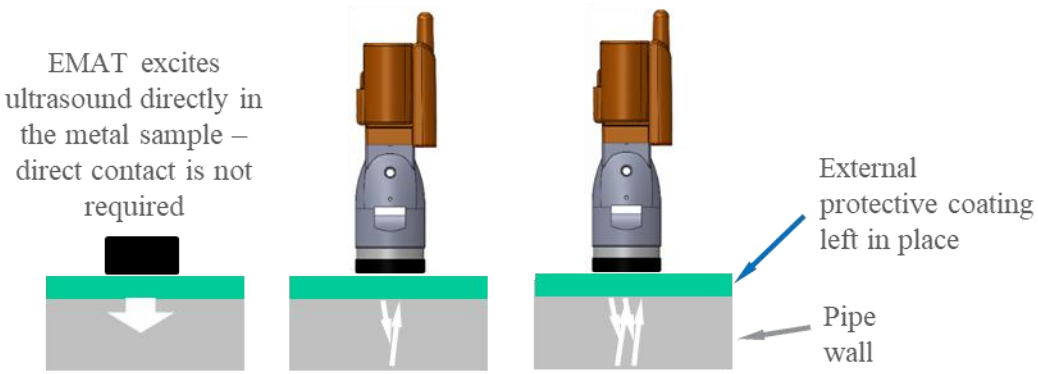
- **Based on established ultrasound technology**
  - Unique waveguide transducer
  - Permanent installation
- **Install anywhere**
  - Temperatures up to 600 C (1100°F), e.g. refinery crude unit pipework
  - Temperatures down to -180 C (-292°F), e.g. LNG plants
  - Intrinsically safe (Class1 Div1)
- **Data to Desk**
  - WirelessHART
  - 7-9 year battery life
  - Remotely adjustable data acquisition rate
  - Automated temperature and material compensation
  - Unique and patented processing to eliminate internal surface roughness effects and detect onset of corrosion activity



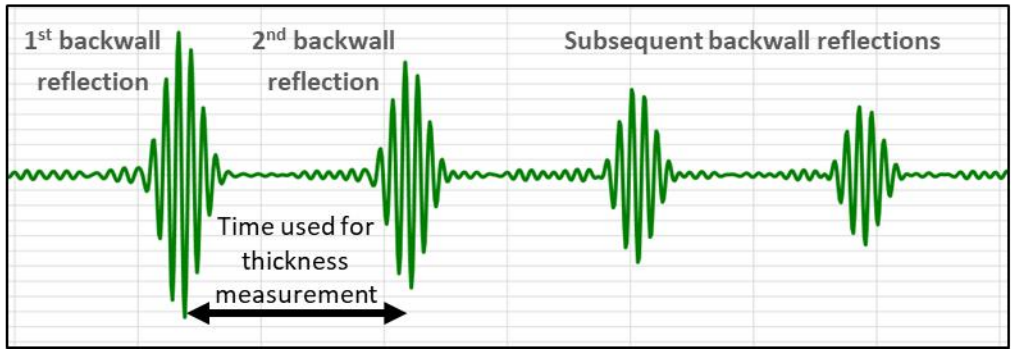




ET Technology – Magnetic Mountis, Measure Through Coatings



Magnetic mounting with secondary security strap



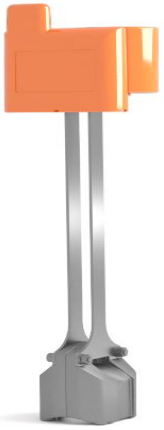
EMAT based sensor specifications

- Very low power
- Very simple, strong magnetic attachment
- Easy-fix retention strap
- 120°C/250°F maximum wall temperature
- Automated temperature and material compensation
- Advanced proprietary signal processing

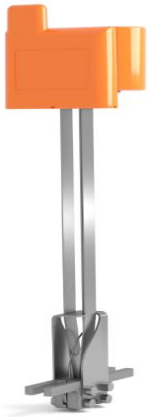
Sensor for *Any* Location, Operating at *Any* Temperature

ET210

ET410

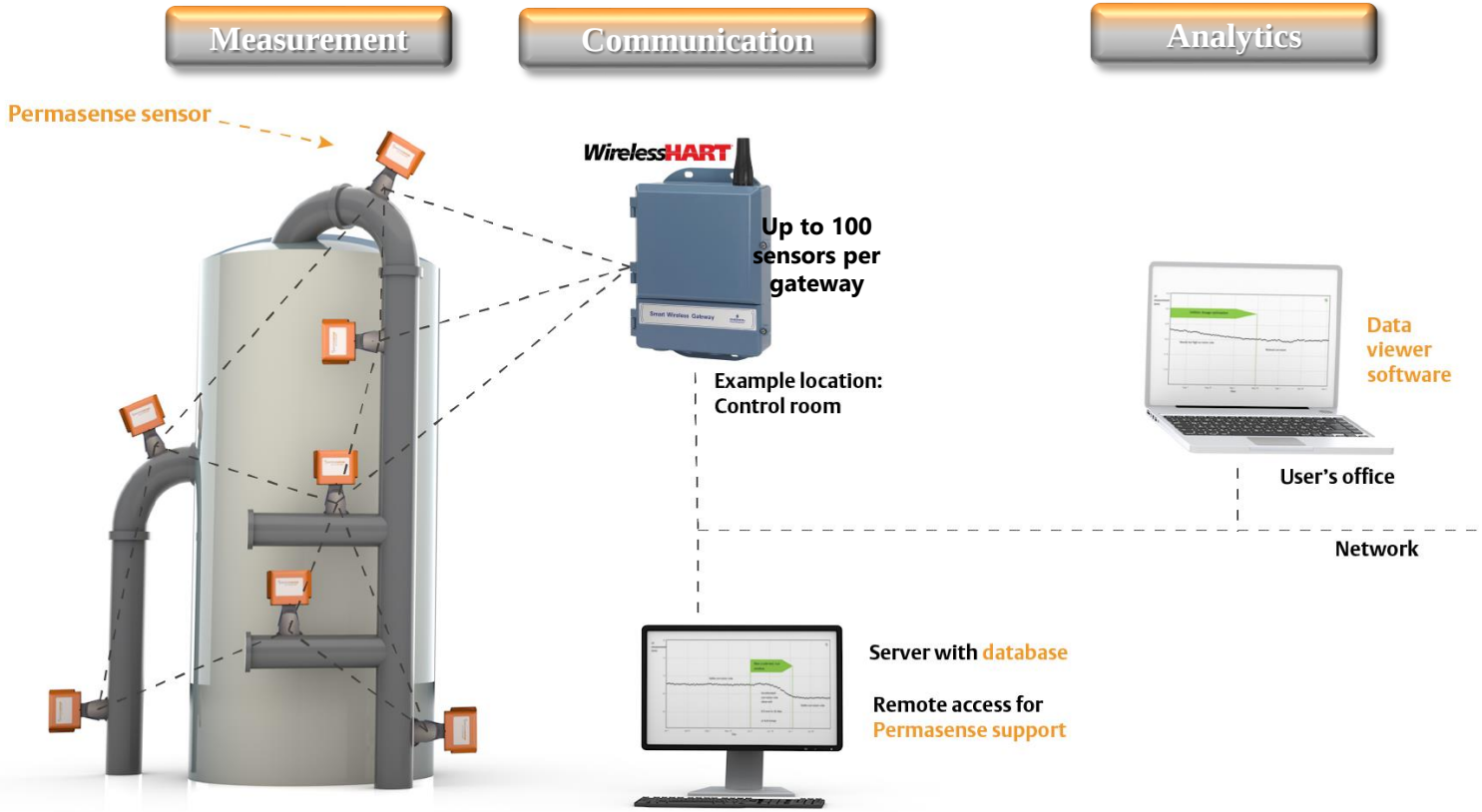


WT210



Temperature range		
Up to 120ºC (248ºF)	Up to 300ºC (572ºF)	Up to 600ºC (1100ºF)
Measurement technique		
Ultrasound - EMAT		Ultrasound - Waveguide
Sharing WirelessHART infrastructure - All data viewed in Data Manager, at desk		

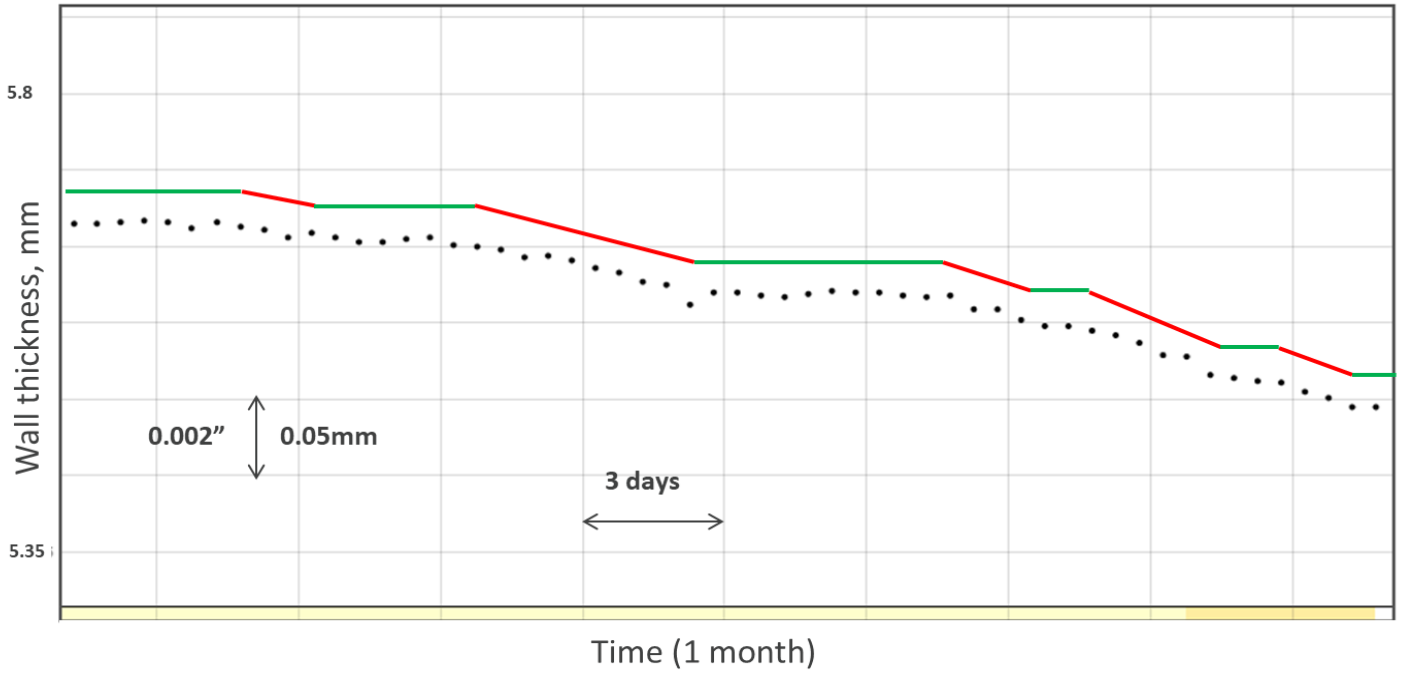
System Overview – Real Time Data to Desk



Easily installed, on-line. Typical size system installed in 3-4 days.

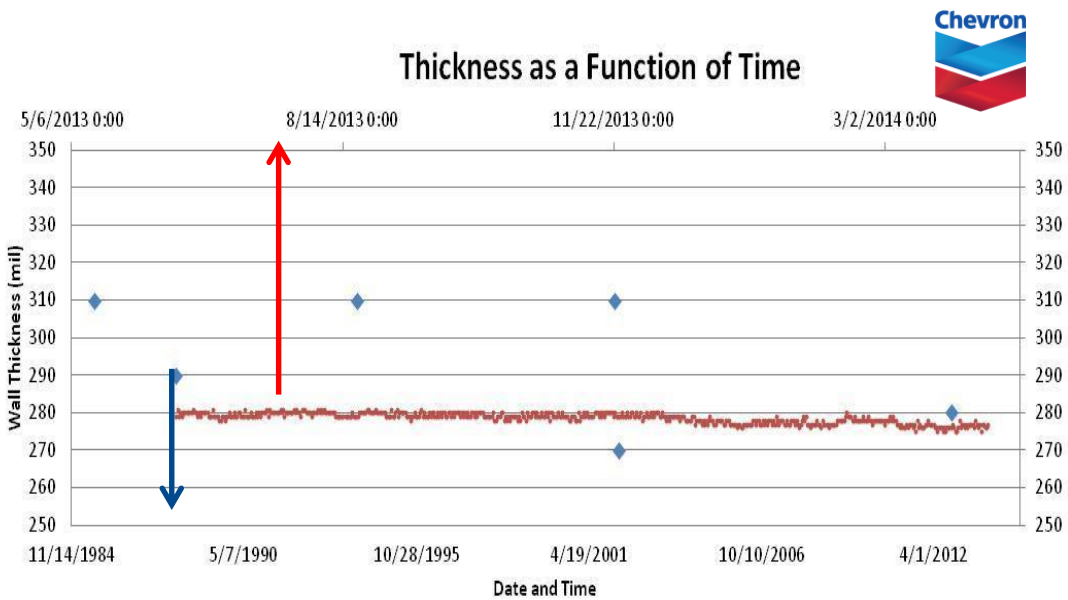
Best Quality and Frequency of Thickness Measurements

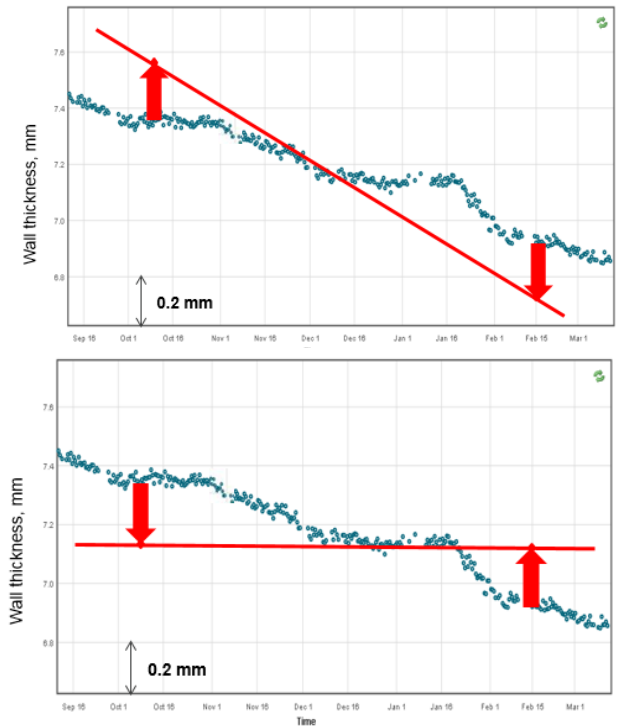
- **Fast response to corrosion and/or erosion**
  - Excellent measurement repeatability affords detection and measurement of ≈ 10 microns of metal wall loss
  - Regular data delivery (e.g. every 12 hours) allows detection of corrosion or erosion events within days



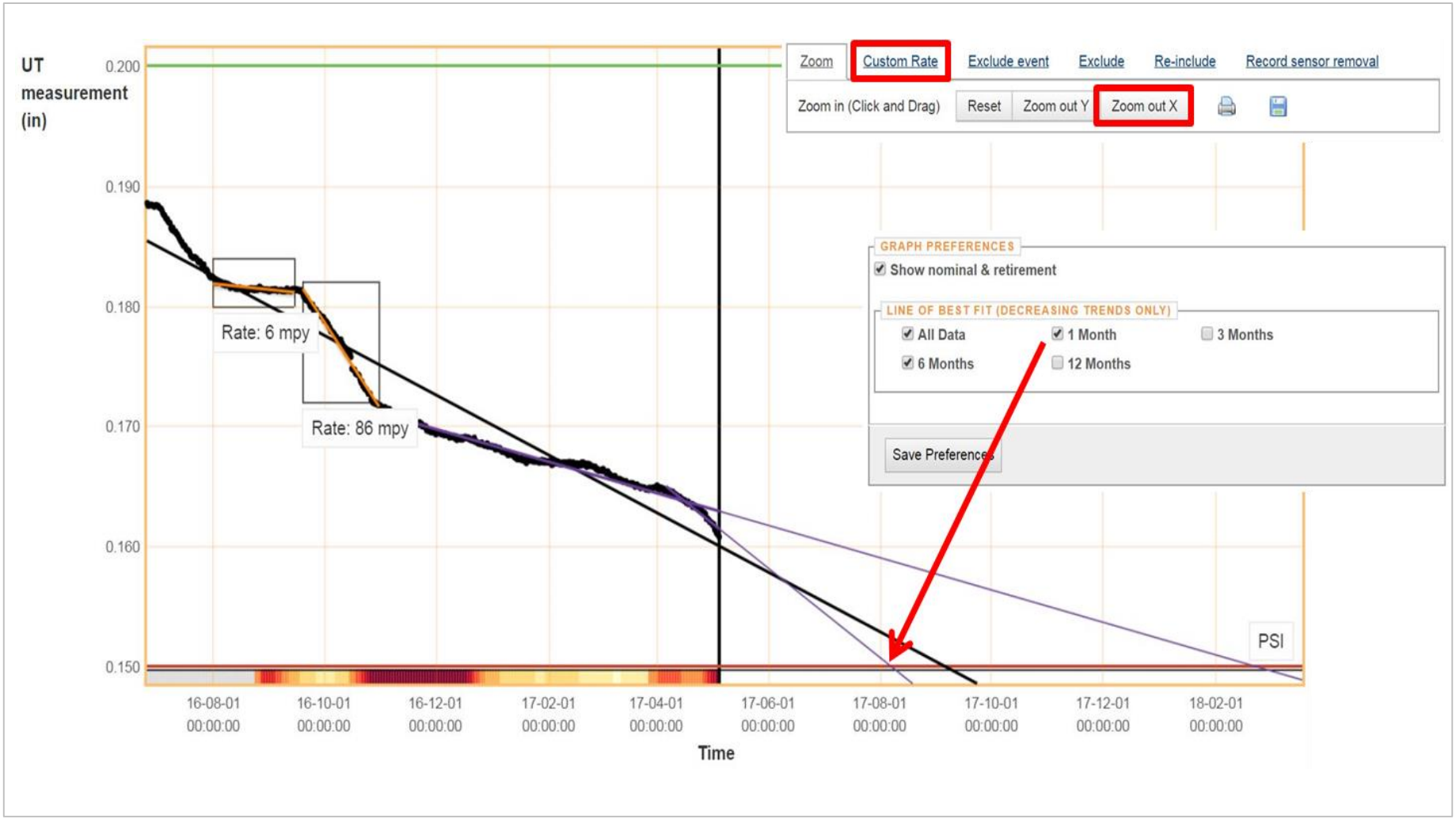
Significant Enhancement Over Traditional Manual Inspection

- **Permasense:** measurements every 12 hours within +/- 10 microns variation; catch onset of corrosion events within days
- **Manual UT inspection:** years between measurements with +/- 0.5-1.0 mm variation; corrosion rate calculation not possible, corrosion events missed

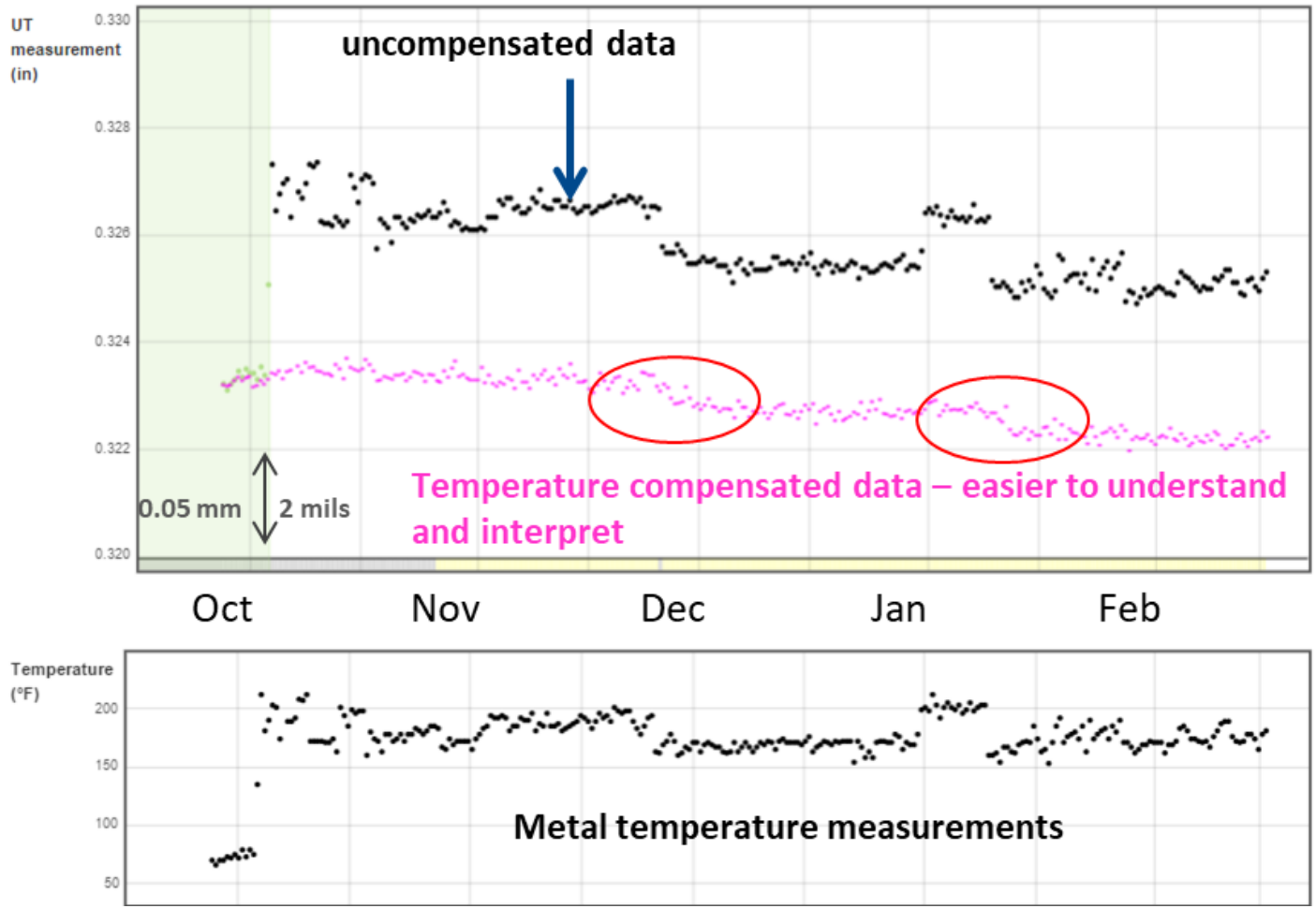




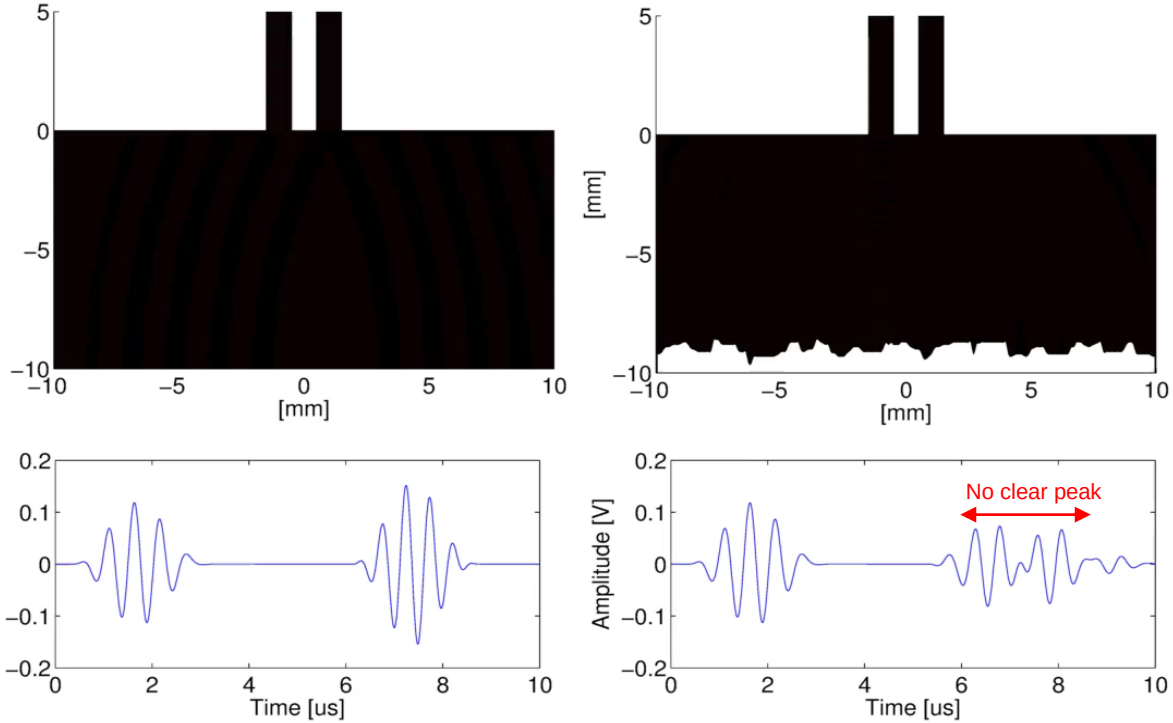
Turnaround Planning



Temperature Compensation Simplifies Data Interpretation

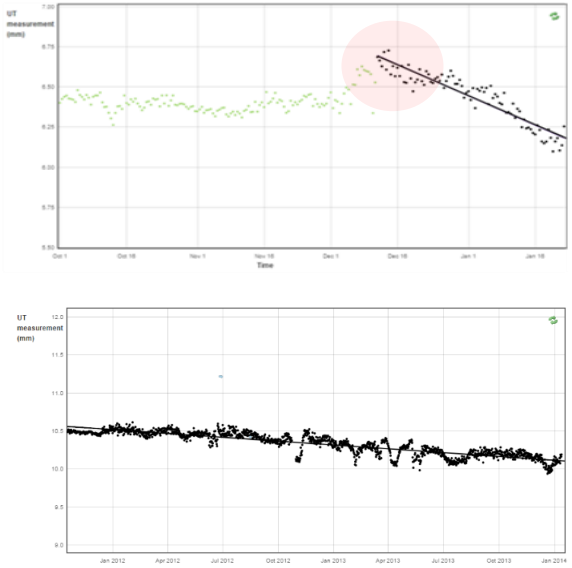


Dealing With Internal Surface Roughness or Pitting



Roughness scattering

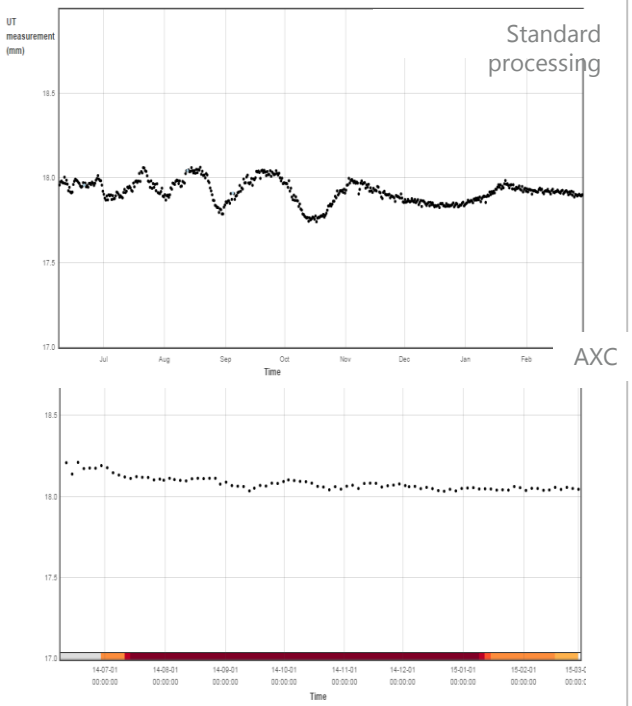
affects <u>all</u> ultrasound-based thickness measurements

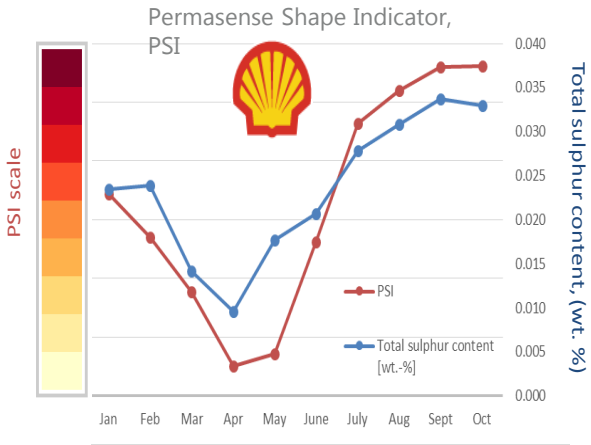


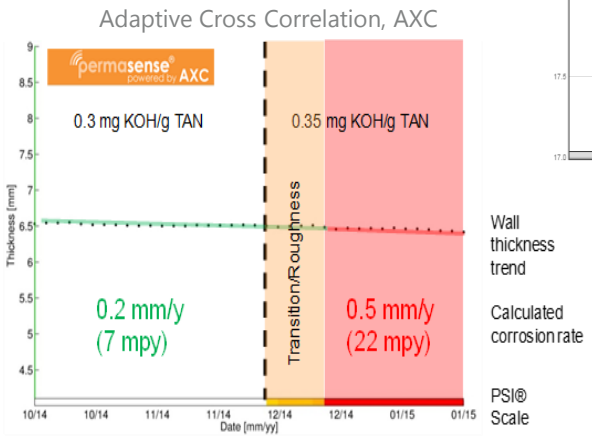
Permasense is unique in solving this challenge

Unique Advanced Signal Processing

- **Adaptive Cross Correlation, AXC**
  - Correlation where signal matches previous backwall signal most closely
  - Roughness scattering effect is overcome
- **Permasense Shape Indicator, PSI**
  - Correlation to previous backwall signal introduces backwall reflection and morphology change indicator
  - Early warning of the onset of localised corrosion / pitting





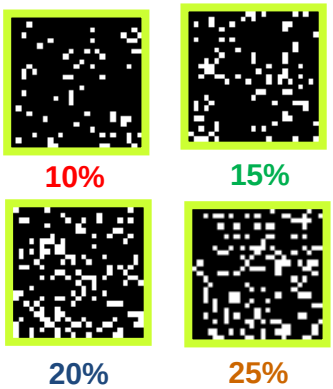


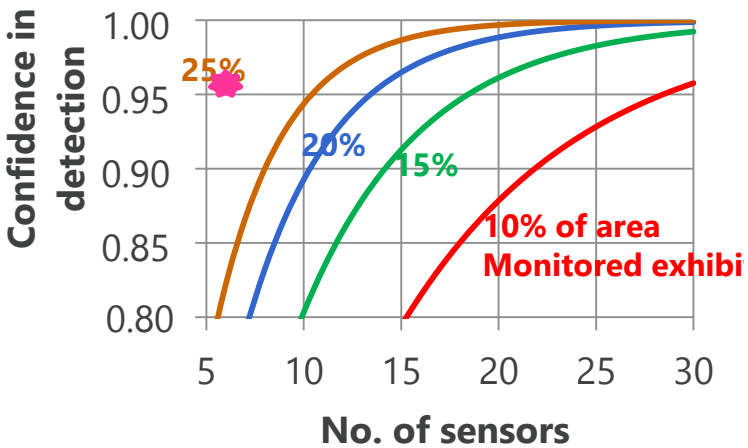
Arrays of Sensors for Localised Corrosion

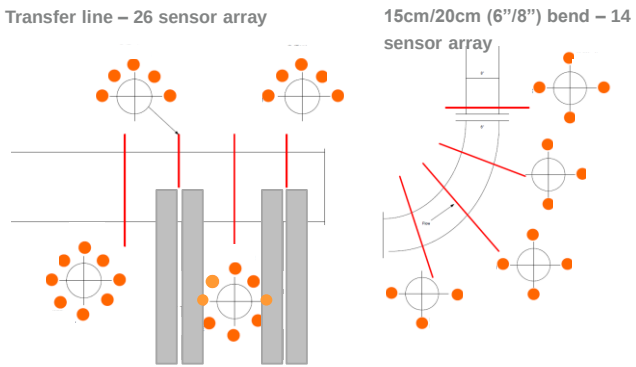
e.g. of area monitored by sensor grid

- No. of sensors required decreases as % of area monitored exhibiting corrosion activity increases
- Choose area monitored to maximise % showing activity

Examples of localised corrosion attack

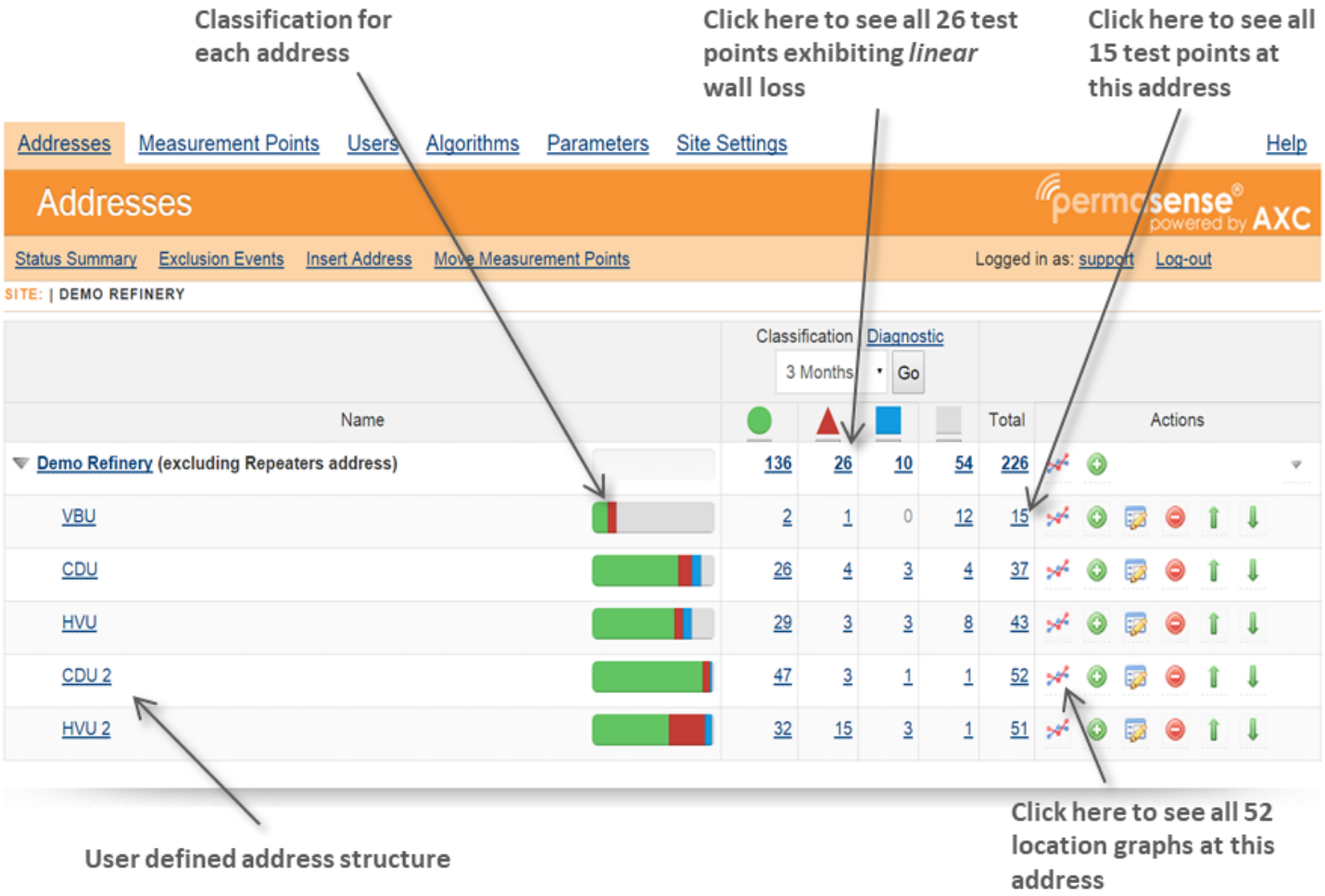






Example: 25% of area experiences corrosion attack. 10 sensors give 95% confidence of detection

Data Manager: Data Visualisation and Analytics



Data Manager: Data Visualisation and Analytics

User defined test point ID and name

Classification of activity at each test point

Click here to view graph of measurements

Addresses | Test Points | Users | permasense | Help

#22 Crude Heater (F-2) Desalted Crude Outlet Test Points

Status Summary | Analysis Summary | Logged in as: administrator | Log-out

ADDRESS: REFINERY > #2 CRUDE > #22 CRUDE HEATER (F-2) DESALTED CRUDE OUTLET

Number of Test Points: 8

Recent data				Measurements		Line of best fit analysis		Actions
Rec.	Unique ID	Name	MAC Address	Remaining Thickness (mm)	Last (mm)	Rate through all data (mm/yr)	Classification	
	32AT9501C	10067217C	3906	4.67	7.62	0.00 ±0.00		
	32AT9501H	10067217H	3895	3.65	6.60	0.02 ±0.00		
	32AT9501E	10067217E	388C	4.29	7.29	0.04 ±0.00		
	32AT9501D	10067217D	3888	3.96	6.95			
	32AT9501F	10067217F	382A	3.17	7.18	0.04 ±0.00		
	32AT9501G	10067217G	3799	2.16	5.10	0.61 ±0.06		
	32AT9501A	10067217A	3796	3.74	6.73	0.03 ±0.00		
	32AT9501B	10067217B	377F	7.86	5.50	0.05 ±0.01		

Data recently received

Remaining wall thickness to retirement

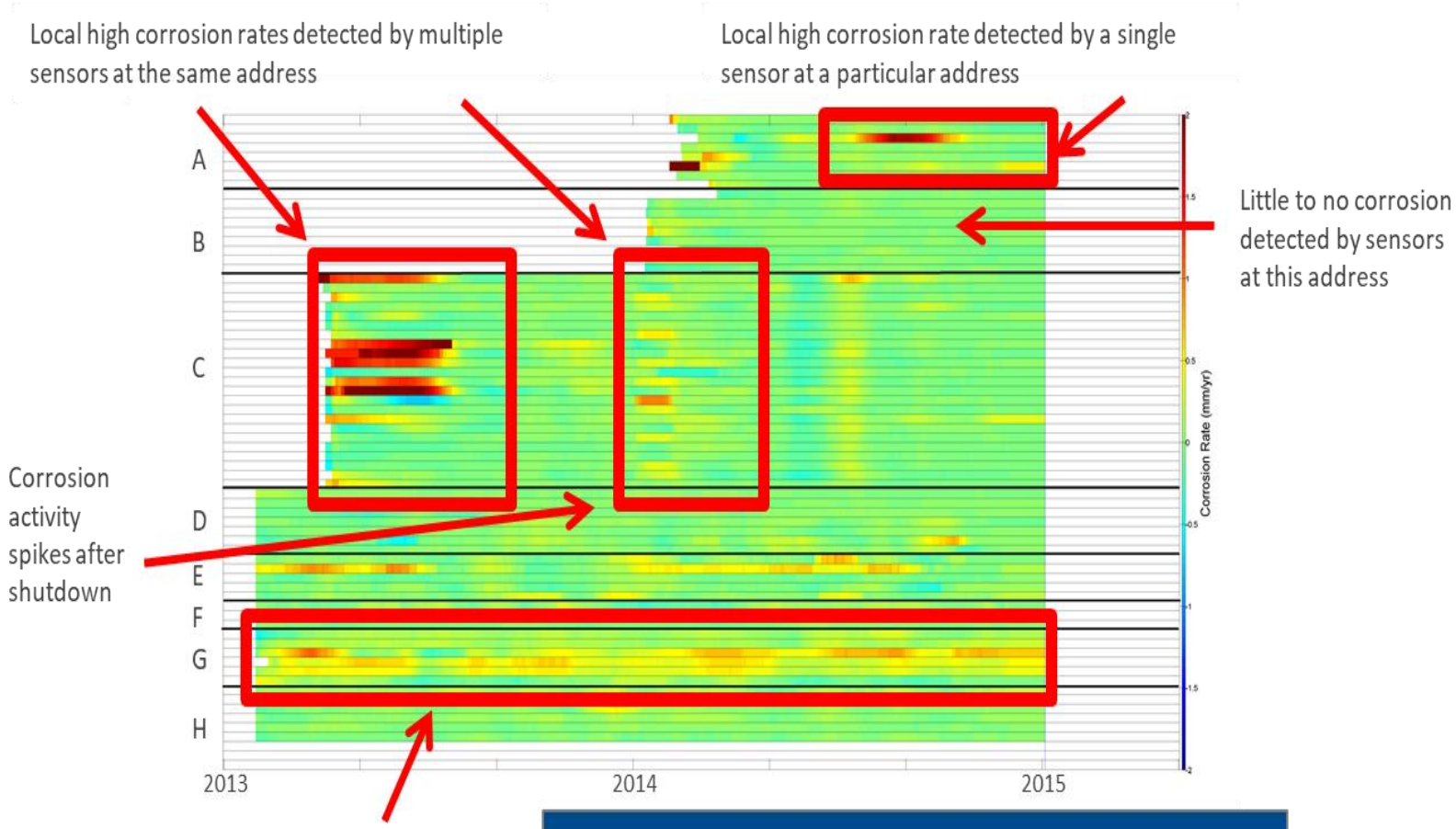
Rate calculated with confidence bound

NB: Users can switch between Metric and Imperial units

Data Manager: Data Visualisation and Analytics

NB: Users can switch between Metric and Imperial units

Data Manager: Data Visualisation and Analytics



Unique to Permasense technology

Aberdeen Branch

Key Sponsor

THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

Aberdeen Branch

Key Sponsor

2018 Corrosion Awareness Day Technical Demonstrations

Demonstration 1 - Chris Burke, (Permasense' - Non-Intrusive NDT).
Demonstration 2 - Fiona Butters, (Roxar' – Intrusive Corrosion / Erosion Probes and FSM Technology).
Demonstration 3 - John Thompson, (Emerson' - Temperature & Pressure Instrumentation).
Demonstration 4 - Steven Healy, (Emerson' - Flow Measurement).

INSTITUTE OF CORROSION

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EMERSON

Key Sponsor - CAD

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