SAFETY MOMENT - Fiona Butters
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.
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 11 – Chris Burke, BEng (Hons), MIET, Permasense, (Emerson - NDT).

SPEAKERS 8 TO 11 – Workshop Demonstrations

Corrosion Awareness Day 2018
The Continuing Assistance of all our Sponsors is greatly Appreciated.

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Corrosion Awareness Day 2018
ICorr Aberdeen Branch Welcomes Dr Odagboyi Philip Enegela (Repsol)

Speaker 1 -

Corrosion Awareness Day 2018 - Dr Odagboyi Philip Enegela, CEng, MIMMM, MICorr, (Repsol Sinopec).
ICorr Aberdeen Branch Welcomes Repsol Sinopec UK
REPSOL SINOPEC UK
OIL & GAS EXPLORATION & PRODUCTION
NORTH SEA, BRAZIL

Corrosion Awareness Day 2018 - Dr Odagboyi Philip Enegela, CEng, MIMMM, MIcorr, (Repsol Sinopec).
Dr Odagboyi Philip Enegela

Corrosion Engineer

CEng MIMMM, MICorr
Aberdeen Branch

- 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
Principles & Costs of Corrosion
• 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
  \[ \text{Fe} = \text{Fe}^{2+} + 2\text{e}^- \]  (anodic reaction)

- Electrochemical reactions (involve electrons and chemical species)
Corrosion Awareness Day 2018 - Dr Odagboyi Philip Enegela, CEng, MIMMM, MIcorr, (Repsol Sinopec).
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
• $G = -nF\Delta E^0$; 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)
• 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
\( \delta = \) 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 directly on the metal, as the potential is too low.

Will iron corrode in acid?
Yes - there is a reasonably wide range of potentials where hydrogen can be evolved and iron dissolved.

Will iron corrode in neutral waters?
Yes - although iron can form an oxide in neutral solution, it tends not to form directly on the metal, as the potential is too low.

Will iron corrode in alkaline solution?
No - iron forms a solid oxide at all potentials, and will passivate.
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
Atmospheric Corrosion

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

- Pollutants
  - $\text{CO}_2$
  - $\text{SO}_2$

- Relative humidity

- Effect of films (thick vs. thin)
• 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
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
Sweet Corrosion

- Formation of weak carbonic acid

\[ \text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3 \]

- Dissociation and release of H⁺
Sweet Corrosion
Sour Corrosion

- Hydrogen Damage – SSC, SWC, SOHIC, HE
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
THANK YOU FOR YOUR ATTENTION
ICorr Aberdeen Branch Welcomes

Speaker 2 - Dr Muhammad Ejaz (PIM)
PLANT INTEGRITY MANAGEMENT LTD

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
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
CORROSION RATE MODELLING

INTRODUCTION

CO₂ MODELLING SOFTWARE

HOW TO USE CALCULATED CORROSION RATE

A BIT ABOUT H₂S CORROSION

O₂ CORROSION MODELLING

SUMMARY
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 Awareness Day 2018 - Dr Muhammad Ejaz, CEng FIMMM, MICorr, MPIE, (Plant Integrity Management).
Corrosion Modelling for Oil and Gas

- **CO₂ Corrosion**
- **H₂S Corrosion**
- **O₂ Corrosion**

- **Anodic Reaction**
  \[ \text{Fe} \leftrightarrow \text{Fe}^{2+} + 2e^- \]

- **Cathodic Reaction(s)**
  \[ \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 + 2e^- \leftrightarrow \text{H}_2 + \text{CO}_3^{2-} \text{ (CO}_2 \text{ Corrosion)} \]
  \[ \text{O}_2 + 4\text{H}^+ + 4e^- \leftrightarrow 2\text{H}_2\text{O} \text{ (O}_2 \text{ corrosion)} \]
  \[ \text{H}_2\text{S} \leftrightarrow 2\text{H}^+ + \text{S}^{2-} \text{ (H}_2\text{S Corrosion)} \]

Corrosion Awareness Day 2018 - Dr Muhammad Ejaz, CEng FIMMM, MICorr, MPIE, (Plant Integrity Management).
CO₂ Corrosion

General Corrosion

Raindrop attack - gas condensate

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

\[ \log V_{corr} = 5.8 - \frac{1710}{(273 + T)} + 0.67 \log (P_{\text{CO}_2}) \]

where

- \( V_{corr} \) is corrosion rate
- \( T \) is Temperature, and
- \( P_{\text{CO}_2} \) is partial pressure of \( \text{CO}_2 \)

(cathode reaction: \( \text{H}_2\text{CO}_3 \) 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% CO₂ in gas at pressure of 10 bara
\[ P_{CO₂} = 10 \times 0.1 = 1 \text{ bara} \]

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

Effect of acid gases on pH
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

\[ CR_{scale} = CR_{free} \times SF \]

Example:
0.2 bar CO₂ at 120 °C gives \( 10 \times 0.7 = 7 \text{ mm/y} \)

<table>
<thead>
<tr>
<th>( P_{CO_2} ) (bar)</th>
<th>Temp (°C)</th>
<th>( CR_{free} ) (mm/year)</th>
<th>Scale factor</th>
<th>( CR_{scale} ) (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>5</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>80</td>
<td>9</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>16</td>
<td>0.5</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>120</td>
<td>30</td>
<td>0.2</td>
<td>6</td>
</tr>
</tbody>
</table>
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 (Intotech)
- 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
  - Pressure
  - Mole percent CO2 in gas
  - Shear stress
  - pH
  - Glycol concentration
  - Inhibitor efficiency

- **Output**
  - Graph showing corrosion rate vs. temperature with different pH levels.

- **Limitations**
  - The model is valid for temperature 5 - 150 °C, pH 3.5 - 6.5, CO2 partial pressure 0.1 - 10 bar and shear stress 1 - 150 Pa.
  - The model is not applicable when the H2S partial pressure is higher than 0.5 bar, or when the ratio between the partial pressure of CO2 and H2S 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.

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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

- Corrosion Rate (mm/y) vs Temperature
- Corrosion Rate (mm/y) vs pH
- Corrosion Rate (mm/y) vs Pressure

Dr. Muhammad Ejaz, CEng FIMMM, MICorr, MPIE, (Plant Integrity Management)
Example:

### Corrosion Inhibitor 95%

<table>
<thead>
<tr>
<th>Design Life</th>
<th>15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe OD</td>
<td>219.1 mm</td>
</tr>
<tr>
<td>Pipe ID</td>
<td>196.5 mm</td>
</tr>
<tr>
<td>8&quot; Production</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corrosion Inhibitor</th>
<th>BP93</th>
<th>DW93</th>
<th>BP95</th>
<th>DW95</th>
<th>M-506</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic</td>
<td>4.3</td>
<td>6.2</td>
<td>5.0</td>
<td>5.3</td>
<td>4.8</td>
</tr>
<tr>
<td>Flow-sensitive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.9</td>
</tr>
</tbody>
</table>

**Required corrosion allowance**

Corrosion Rates for Carbon Steel

- pH Model BP
- Water Composition Western Isles
- Corrosion Inhibitor

Example: Corrosion Allowance Calculation

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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 $V_G$. 

i) Dispersed bubble flow

ii) Slug flow

iii) Churn flow

iv) Annular flow

v) Annular flow with droplets

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### Exploiting Output – Inhibition categorisation

<table>
<thead>
<tr>
<th>Category</th>
<th>Maximum Required Availability</th>
<th>Maximum Expected Uninhibited Corrosion Rate (mm/yr)</th>
<th>Comment</th>
<th>Possible Category Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0%</td>
<td>0.4</td>
<td>Benign fluids where corrosion inhibitor usage is not anticipated (dry gas, stabilised oil). Predicted metal loss can be accommodated by corrosion allowance alone.</td>
<td>Benign</td>
</tr>
<tr>
<td>2</td>
<td>50%</td>
<td>0.7</td>
<td>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.</td>
<td>Low</td>
</tr>
<tr>
<td>3</td>
<td>90%</td>
<td>3</td>
<td>Corrosion inhibitor will be required for the majority of the field life but the facilities need not be available from day 1.</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>95%</td>
<td>6</td>
<td>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.</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>&gt;95%</td>
<td>&gt;6</td>
<td>Carbon steel and inhibition is unlikely to provide integrity for the full field life. Select corrosion resistant materials or plan for repairs &amp; replacements.</td>
<td>Unacceptable</td>
</tr>
</tbody>
</table>


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Fe$_2$S passive layer

CO$_2$ only Corrosion rate

Fe$_2$CO$_3$ is protective scale above ~60°C.

Fe$_2$S is semi-protective layer and does not provide corrosion inhibition. This leads to localised corrosion.
H$_2$S corrosion

Losses typically localised corrosion.

Localised corrosion generally lower than rate predicted by CO$_2$ model.

Carbon and low alloy steels

pH$_2$S

pCO$_2$ / pH$_2$S = 20

H$_2$S Regime Sour

CO$_2$ + H$_2$S Regime Mixed

CO$_2$ Regime Sweet

pCO$_2$ / pH$_2$S = 500

CO$_2$ model applies.

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

Corrosion Awareness Day 2018 - Dr Muhammad Ejaz, CEng FIMMM, MICorr, MPIE, (Plant Integrity Management).
• **O₂ Corrosion**

• **Corrosion Product:**
  - Geothite – FeO(OH)
  - Hematite – Fe₂O₃
  - Magnetite – Fe₃O₄
  - Ferrous Hydroxide – Fe(OH)₂

• **Anodic Reaction**

  \[ \text{Fe} \leftrightarrow \text{Fe}^{2+} + 2e^- \]

• **Cathodic Reaction(s)**

  \[ \text{O}_2 + 4\text{H}^+ + 4e^- \leftrightarrow 2\text{H}_2\text{O} \ (\text{O}_2 \text{ corrosion}) \]
O₂ Corrosion

\[ C_r = \frac{5.65}{\text{Re}^{0.125}} \cdot \frac{C_o U_o}{\text{Pr}^{0.75}} \]

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

\[ V_{\text{CORR}} = 0.020 \cdot C_{O2} \cdot 2^{(\frac{T-30}{30})} \cdot U \]

Where:
\( V_{\text{CORR}} \) is the oxygen corrosion rate in mm/y,
\( U \) is the fluid velocity in m/s [assumed \( U=1 \) if \( U<1 \)],
\( C_{O2} \) is the oxygen equivalent in ppm, and
\( T \) is temperature in °C [assumed \( T=30 \) if \( T<30 \)].
Various Corrosion prediction models are available

- *Use corrosion prediction model with care and engineering judgment should always be applied.*
- *Always challenge and sense check the output - Don’t always believe what “Computer says………..”.*
- *Understand the limitation of predictive models and compare results from at least two models.*
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?
ICorr Aberdeen Branch Welcomes

Speaker 3 - Dr Carol Devine (ICR Integrity)
ICorr Aberdeen Branch Welcomes

Introduction to Oilfield Microbiology

Presented By Dr Carol Devine, Consultant Microbiologist
ICR. INTEGRITY AND MAINTENANCE SOLUTIONS

Chemical Injection Solutions
Mechanical Onsite Services
Integrity Monitoring Solutions
Quickflange™ Weldless Connections
Technowrap™ Engineered Composites
ICR. PRESERVE, REPAIR & RE-INSTATE

PRESERVE
Chemical Injection Integrity Monitoring

REPAIR
Weldless Connections Composite Engineering

RE-INSTATE
Engineered Machining

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
ICR. GLOBAL FOOTPRINT

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
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

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
CORROSION MONITORING & MICROBIOLOGY

- Introduction to Oilfield Microbiology
- Microbiological Issues
- Systems
- Samples
- Analytical Techniques
- Data Trending
Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
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
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
• Production
• Water Injection
• Produced Water Reinjection (PWRI)
• Ballast water
• Seawater Cooling
• Cooling/heating
• Firewater
• Diesel storage and distribution
Two main types of samples:

**Planktonic** – water, crude, diesel, cooling medium

**Sessile** – biofilm from coupons, bio-sidestreams and/or other intrusive devices
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FLUSH DISC & STRIP COUPONS

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
3" STRIP COUPONS

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Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
Production

Originally clean - but now contaminated with indigenous reservoir microorganisms, 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.

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
ALGAL BLOOM, SCOTTISH COAST

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
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)
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
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
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

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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)

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
• 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
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
## WORKSCOPE

<table>
<thead>
<tr>
<th>System</th>
<th>Current status</th>
<th>Actions required</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCTION</td>
<td>Moderate to high planktonic SRB, low to moderate sessile SRB with low corrosion and moderate pitting rates. Risk of MIC.</td>
<td>Regular kill dose of biocide required. Post biocide planktonic samples should sent in for analysis.</td>
</tr>
<tr>
<td>WATER TREATMENT VESSELS</td>
<td>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.</td>
<td>Close monitoring required as early intervention may be required to ensure control is maintained.</td>
</tr>
<tr>
<td>DRAINS</td>
<td>Low thermophilic SRB in Closed Drains, moderate sulphide levels measured. Low risk of contamination being recirculated and of MIC</td>
<td>No immediate action currently required. Regular monitoring should be maintained.</td>
</tr>
<tr>
<td>WATER INJECTION</td>
<td>Low planktonic and sessile SRB numbers, sulphide levels below detection limit. Moderate to high corrosion and pitting rates. Risk of microbial proliferation and MIC</td>
<td>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.</td>
</tr>
<tr>
<td>DIESEL SYSTEM</td>
<td>Low aerobic bacteria, yeast and mould enumerated from all the tanks sampled. Low particulate contamination, fungal fragments and water content.</td>
<td>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.</td>
</tr>
<tr>
<td>FIREWATER SYSTEM</td>
<td>No SRB, but high GHB measured in all the hydrants sampled. No residual chlorine, high potential risk of biofouling.</td>
<td>A regular firewater ring main flushing routine should be implemented to prevent stagnation and bring in freshly chlorinated water.</td>
</tr>
</tbody>
</table>

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

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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

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity)
Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
PITS – MIC?
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

Corrosion Awareness Day 2018 - Dr Carol Devine, BSc, PhD, (ICR Integrity).
ICorr Aberdeen Branch Welcomes

Speaker 4 - Dr Nigel Owen (Aberdeen Foundries)
ICorr Aberdeen Branch Welcomes Aberdeen Foundries
ABERDEEN FOUNDRIES
1976 - 1998- 2018
SACRIFICIAL ANODES AND NON FERROUS CASTINGS
SCOTLAND -> THE WORLD
NIGEL OWEN
ABERDEEN FOUNDRIES
Dr. Nigel Owen. B.Sc., D.I.C, Ph.D, MIMMM.
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
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
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
Sacrificial Anode System

Sacrificial Anode Cathodic Protection

Protected Structure in Seawater

Aluminium Alloy Anode

$O_2 + 2H_2O \rightarrow 4OH^-$

$3e^- \rightarrow 3e^-$
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)
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

<table>
<thead>
<tr>
<th>Al-Zn-In Anode Alloy</th>
<th>Element</th>
<th>Al</th>
<th>Zn</th>
<th>Si</th>
<th>In</th>
<th>Cu</th>
<th>Fe</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt%</td>
<td>Min</td>
<td>Bal</td>
<td>2.8</td>
<td>0.08</td>
<td>0.010</td>
<td>0.000</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Wt%</td>
<td>Max</td>
<td>Bal</td>
<td>6.5</td>
<td>0.21</td>
<td>0.020</td>
<td>0.006</td>
<td>0.12</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Wt%</td>
<td>Nom</td>
<td>Bal</td>
<td>5.0</td>
<td>0.09</td>
<td>0.018</td>
<td>0.001</td>
<td>0.06</td>
<td>&lt;0.02</td>
</tr>
</tbody>
</table>

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/m³
Example of a project to Design install a Sacrificial CP system

• Harbour wall CP protection system
• 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
• 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):

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

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

\[ C_{a\,tot} = N \cdot C_a \geq I_{cm} \cdot t_f \cdot 8760 \]
\[ I_{a\,tot\,i} = N \cdot I_{ai} \geq I_{ci} \]
\[ I_{a\,tot\,f} = N \cdot I_{af} \geq I_{cf} \]
Long standoff anodes for Harbour wall installation
• Design & Install Anodes

- 6mm fillet tack weld for continuity
- TOP OF ANODE AT 0.01m & WHERE BED LEVEL DOES NOT PERMIT AS LOW AS POSSIBLE
- Anode to be positioned with longest steel rod welded to top bracket
- DIMENSION IS FROM TOP FACE OF BOTTOM BRACKET TO UNDER FACE OF TOP BRACKET
- WELD ON SITE TO FILE 6mm FILLET WELD - 100mm LONG EACH SIDE (BOTH BRACKETS - ITEM 1 & 2)

Sacrificial Anode Applications
Sacrificial anodes in Zinc for flush fit (Hulls & steelwork)
Slender Anodes for Subsea Manifold Frame
Bracelet Anodes for Pipelines & Spools
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.
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
CATHODIC PROTECTION - IMPRESSED CURRENT SYSTEMS

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

**Impressed Current Systems**

Whitecart Viaduct Glasgow Airport and Tay Road Bridge Dundee both have CP – Foundations and RC Concrete Supports, as do M9 Bridges.
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).
Corrosion Awareness Day 2018

THE END

• More Anodes Please!
THANK YOU FOR YOUR ATTENTION ANY QUESTIONS?
ICorr Aberdeen Branch Welcomes

Speaker 5 - Stephen Tate - (CAN/TEPUK)
ICorr Aberdeen Branch welcomes CAN (Offshore) Ltd, Integrity Management Specialists.
ICorr Aberdeen Branch Welcomes

Stephen Tate (Can / TEPUK)
MBA, PG.Dip. Eng, MICorr
Operations Corrosion Engineer

CAN GROUP COMPANIES

CAN (OFFSHORE) LTD was founded in 1986 when it introduced industrial rope access into 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.

WHAT WE DO: CAN (Inspection Services), ENGTEQ (Integrity Management) and VENTEQ (Vendor Inspection)
WHERE WE ARE: UK (TEPUK / Other Offshore), International.
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

The reactivity series of metals

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>K</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Al</td>
</tr>
<tr>
<td>Carbon</td>
<td>C</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
</tr>
<tr>
<td>Gold</td>
<td>Au</td>
</tr>
</tbody>
</table>

Note: Carbon and hydrogen are not metals.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titanium</td>
<td>£8000</td>
</tr>
<tr>
<td>Iron</td>
<td>£250</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>£1500</td>
</tr>
<tr>
<td>Aluminium</td>
<td>£1500</td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>£25000</td>
</tr>
</tbody>
</table>

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.
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.
Alternative Use of Liners

Much Lower Cost

Claddings are OK For Short Lengths

Jointing

Corrosion Mitigation by Materials

As Instrument Feeds

316L is Common

Corrosion Mitigation by Materials

As Flow Enablers

Super Duplex Stainless Steel - Often Used for High Flow / High Erosion Risk Conditions
Corrosion Mitigation by Materials

As Decorative Surfaces

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

Installation / In-Service Issues
Corrosion Mitigation by Materials

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.**
Corrosion Mitigation by Materials

CRA Liners Can Buckle

Pipe Lay Error

Scan of Long-Distance Pipeline

Corrosion Mitigation by Materials

Seawater Piping

Often used for Marine Applications and Fire Mains

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

Has GOOD Corrosion Resistance but POOR Erosion Resistance

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

Stainless Alloy Limits

According to Service Application and Installation Methods

Alloys will require Protective Coatings Above Critical Temperatures.

Critical Pitting and Critical Crevice Temperature: Stainless Steel Alloys

- 316L
- 2205
- 904L
- 254SMO
- 2507
- AL-6XN

Critical Pitting Temperature (CPT) vs Critical Crevice Temperature (CCT)
Stress Corrosion Cracking

Seawater Deluge System Can Cause This! i.e. Chloride Contamination to Hot Surfaces
Effects of Combining Materials
Combining Materials

Look For The Weakest Link!

Think Of The Risks!
Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Galvanic Couple

Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Multiple Material Types – Check For Compatibility
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!

Flange Fixings Will Likely Fail Before The Piping

Mitigating Plastic Piping Specified For An Acid Treatment Plant

Materials Failure Risks

Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Materials – Construction Detailing Risks

Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Coating Removed For Earthing Attachment / Not Repaired

Carbon Steel / Stainless / Copper Couplings

Examples of Poor Site Detailing
Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Crevice Site Created
Aberdeen Branch

Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Direct Material Contacts / No Material Insulators
Materials – Construction Detailing Risks

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Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Pipe Restraints With Non-Metallic Pads To Prevent Clamp Damage To Paint – Will Trap Moisture / Ultimately Cause Corrosion Like CUI.
Coatings - High Risk Areas
Coating / Insulation Failures

Essential Maintenance Req.

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Torn / Leaking Insulation
Requiring Immediate Repair

Coating / Insulation Failures

Essential Maintenance Req.

Corrosion Under PFP – Passive Fire Protection

18.05.2018

Coating / Insulation Failures

Uncoated / Corroding Construction Weld

Trunnion

Reducer

Essential Maintenance Req.
Coatings Future Maintenance
Combining Materials

Look For The Weakest Link!

Think Of The Risks!

Non Metallic Piping – Free of Corrosion Risk

Other Piping Requires Regular Fabric Maintenance
Materials Failure Mitigation

Essential Maintenance

Piping FM – Fabric Maintenance by RAT – Rope Access Team
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?
ICorr Aberdeen Branch Welcomes

Speaker 6 - Hooman Takhtechian (Oceaneering)
ICorr Aberdeen Branch Welcomes

Hooman Takhtechian, MSc, CEng, MIMMM

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
Aberdeen Branch

Integrity Management: Engineering Services
- Data Management
- Development, management, and maintenance of customer and company software systems
- Analytics and Modelling
  - Failure mechanism predictions, equipment-specific algorithms, mathematical and statistical engineering
- Risk, Reliability, and Maintenance
  - Risk assessments, critical analysis reliability studies, CMMS optimization, maintenance programs, spare parts analysis

Engineering Solutions
Solutions for corrosion, structural, pipeline, and process plant requirements including asset life assessments

Subsea Engineering Solutions
Fitness-for-service engineering and inspection, due diligence studies, inspection campaign management, pipeline engineering

Note: Year End 2015

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
- 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.
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
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 actions are undertaken.

To manage has been defined as ‘to succeed in one’s aims (often with inadequate materials etc).’

Corrosion risk

Cost effective mitigation

194
The need for corrosion management

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

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

<table>
<thead>
<tr>
<th>Older legislation</th>
<th>Principles-based legislation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed rules and regulations</td>
<td>Framework rules with guidelines</td>
</tr>
<tr>
<td>What must be done</td>
<td>How it must be managed</td>
</tr>
<tr>
<td>Prescriptive</td>
<td>Risk-based</td>
</tr>
<tr>
<td>Do it anyway</td>
<td>Identify hazards and risks first and prioritize actions accordingly</td>
</tr>
</tbody>
</table>

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”

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
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 Processes

- Strategic decisions
- Tactical decisions
- Operational decisions

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

Risk Assessment

“Consequence” X “Probability” of failure

Secondary risks identification

Risk mitigation
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

Corrosive environment → Engineering factors

Input: corrosion concerns

Assessment of corrosion risks and processes

Output: corrosion risks from general corrosion, pitting, cracking

Materials of construction
C-steel and low alloy steels, corrosion resistant alloys, plastics, concrete

Engineering application
stresses – applied and residual heat transfer and fluid flow thermal and mechanical cycles

Corrosive environments
aqueous fluids, sea/cooling waters, soils, acids, alkalies, acidic gases, carbon dioxide, hydrogen sulfide

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
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?

Hazard (HC release)
- flammability
- stored energy
- pressure
- temperature
- toxicity
- volume

Consequences of Failure,
- leakage/rupture
- size of holes
- general and localized corrosion and cracking.
- various scenarios (flammable/toxic effects together with safety, environmental and business interruption effects)

Risk = Consequence × Likelihood of Failure

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
Corrosion Risk Assessment Processes

Risk = Consequence \times \text{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 × 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

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

Medium–high risks
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

"Swiss cheese" degradation hazard management model

- Plant design Layout details
- Options Materials Chemical treating Coatings CP
- Inspection Monitoring Maintenance Operational control Cleaning/ pigging
- Learning from the past Risk assessments Mitigation and secondary risks
- Systems and procedures Work control Reviews/ audits Management of change
- Effective leadership/ supervision Training/ competency Communicate Cooperation
- Post event Repair/replace/ derate Shutdown Fire protection Escape routes Rescue/ recovery

Event or incident Does not meet operational/ design specs. Loss of containment

Assumptions/ design basis unclear
- Inventory increased
- Local stresses/ chemistries/ temperatures
- Geometry Compatibility

Poor specification
- Inadequate application
- No QA/QC
- Inadequate inspection

Inadequate field data
- Poor scheduling
- Operate outside of envelop
- No trending
- No correlations

Inadequate input of data
- Failure to recognize start-up/ shutdown hazards
- Previous incidents and upsets not reported

Lack of/poor performance indicators
- Procedures not followed
- Steps not signed off
- No verification on procedures in use

Poor decision making
- Confusion over who is in charge
- Inadequate skills
- Lack of underpinning knowledge
**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.

**Benefits**

- Low risk equipment to be inspected less frequently
- Safety / Environmental cost impact
- Less time out of service / production loss

**Drawbacks**

- Resource needed to populate the database
- Appointment of an experienced team leader/contractor

Corrosion Awareness Day 2018 - Hooman Takhtechian, MSc, CEng, MIMMM, (Oceaneering).
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

Corrosion risk mitigation by Inspection:

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

Corrosion risk mitigation by monitoring

Changes in fluid corrosivity due to

i. damaging excursions in composition
ii. chemical treatments.

Location of Inspection/monitoring
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:

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

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

- 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;
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?
ICorr Aberdeen Branch Welcomes

Speaker 7 - Chris Burke (Emerson)
ICorr Aberdeen Branch welcomes

Chris Burke, BEng (Hons), MIET
Emerson Corrosion Monitoring Solutions

**Evaluate Risk**
- **Intrusive**
  - Electrochemical (LPR, Galvanic)
  - Electrical resistance (ER)
  - Corrosivity or erosion through metal loss
  - High sensitivity, quick response

**Measure Impact**
- **Non-intrusive**
  - Ultrasonic (UT)
  - Field Signature Method (FSM)
  - Wall thickness, area coverage
  - Actual metal loss, wall thickness

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
>20,000 sensors in >180 facilities in >30 countries
>18 million wall thickness measurements delivered to desk, >170 million operating hours
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
PERMASENSE EQUIPMENT DEMONSTRATION

- PERMASENSE TECHNOLOGY
- DATA ACCURACY AND REPEATABILITY
- CHALLENGES FACING ULTRASONICS
- DATA TO DESK: DATAMANGER
- QUESTIONS
Permasense History

- 2011: Exclusive agreement with BP finishes
- 2012: Reference installations with all major oil companies
- 2013: Reference applications across the oil and gas sector
- 2016: Acquisition into Emerson

- 2005-2008: Proving out of monitoring technology in BP Refineries
- 2005: High temperature – waveguide / sensor technology prototype

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
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

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
ET Technology – Magnetic Mountis, Measure Through Coatings

EMAT excites ultrasound directly in the metal sample – direct contact is not required.

External protective coating left in place.

Pipe wall.

1st backwall reflection
2nd backwall reflection
Subsequent backwall reflections

Time used for thickness measurement.

Magnetic mounting with secondary security strap.

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
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

<table>
<thead>
<tr>
<th>Temperature range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 120°C (248°F)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound - EMAT</td>
</tr>
</tbody>
</table>

Sharing WirelessHART infrastructure - All data viewed in Data Manager, at desk

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
System Overview – Real Time Data to Desk

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

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
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

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Turnaround Planning

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Temperature Compensation Simplifies Data Interpretation

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Dealing With Internal Surface Roughness or Pitting

Permasense is unique in solving this challenge

Roughness scattering affects all ultrasound-based thickness measurements

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
**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

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Arrays of Sensors for Localised Corrosion

- 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

10% 15% 20% 25%

Examples of corrosion awareness day

e.g. of area monitored by sensor grid

Examples of localised corrosion attack

10% 15% 20% 25%

Confidence in detection

No. of sensors

Transfer line – 26 sensor array
15cm/20cm (6”/8”) bend – 14 sensor array

Close-proximity locations for high probability of detection

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

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).

Data Manager: Data Visualisation and Analytics

<table>
<thead>
<tr>
<th>Addresses</th>
<th>Measurement Points</th>
<th>Users</th>
<th>Algorithms</th>
<th>Parameters</th>
<th>Site Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Summary</td>
<td>Exclusion Events</td>
<td>Insert Address</td>
<td>Move Measurement Points</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**User defined address structure**

Classification for each address

Click here to see all 26 test points exhibiting *linear* wall loss

Click here to see all 15 test points at this address

<table>
<thead>
<tr>
<th>Name</th>
<th>Classification</th>
<th>Diagnostic</th>
<th>Total</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Refinery (excluding Repeaters address)</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
<tr>
<td>VBU</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
<tr>
<td>CDU</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
<tr>
<td>HVU</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
<tr>
<td>CDU 2</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
<tr>
<td>HVU 2</td>
<td>[Classification details]</td>
<td>[Diagnostic details]</td>
<td>Total</td>
<td>Actions</td>
</tr>
</tbody>
</table>

Click here to see all 52 location graphs at this address
## Data Manager: Data Visualisation and Analytics

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

<table>
<thead>
<tr>
<th>Unique ID</th>
<th>Name</th>
<th>MAC Address</th>
<th>Remaining Thickness (mm)</th>
<th>Last (mm)</th>
<th>Line of best fit analysis</th>
<th>Classification</th>
<th>Rate calculated with confidence bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>32AT9501C</td>
<td>3900</td>
<td>10007217C</td>
<td>4.67</td>
<td>7.62</td>
<td>0.00 ±0.00</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>32AT9501H</td>
<td>3895</td>
<td>10007217H</td>
<td>3.65</td>
<td>5.60</td>
<td>0.02 ±0.00</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>32AT9501E</td>
<td>388C</td>
<td>10007217E</td>
<td>4.29</td>
<td>7.29</td>
<td>0.04 ±0.00</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>32AT9501D</td>
<td>3880</td>
<td>10007217D</td>
<td>3.96</td>
<td>5.95</td>
<td></td>
<td>Blue</td>
<td></td>
</tr>
<tr>
<td>32AT9501F</td>
<td>382A</td>
<td>10007217F</td>
<td>3.17</td>
<td>7.18</td>
<td>0.04 ±0.00</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>32AT9501G</td>
<td>3799</td>
<td>10007217G</td>
<td>2.16</td>
<td>5.10</td>
<td>0.01 ±0.00</td>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>32AT9501A</td>
<td>3796</td>
<td>10007217A</td>
<td>3.74</td>
<td>5.73</td>
<td>0.03 ±0.00</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>32AT9501B</td>
<td>377F</td>
<td>10007217B</td>
<td>7.86</td>
<td>5.50</td>
<td>0.05 ±0.01</td>
<td>Green</td>
<td></td>
</tr>
</tbody>
</table>

**NB:** Users can switch between Metric and Imperial units.

[Dashboard Image]

**Classification of activity at each test point**

**Click here to view graph of measurements**

**User defined test point ID and name**

**Data recently received**

**Remaining wall thickness to retirement**

**Rate calculated with confidence bound**

---

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
Data Manager: Data Visualisation and Analytics

- Local high corrosion rates detected by multiple sensors at the same address.
- Local high corrosion rate detected by a single sensor at a particular address.

Corrosion activity spikes after shutdown.

Constantly high corrosion rates detected across multiple sensors at the same address (Naphtha/Reflux).

Little to no corrosion detected by sensors at this address.

Unique to Permasense technology.

Corrosion Awareness Day 2018 - Chris Burke, BEng (Hons), MIET, (Emerson Automation Solutions).
THANK YOU FOR YOUR ATTENTION ANY QUESTIONS?
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).
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