ICorr Aberdeen Branch Welcome

2019 Corrosion Awareness Day
ABZ Branch Chair: Stephen Tate
Thank you for participating in the Aberdeen ICorr Corrosion Awareness Event.

We hope that you find the Day of benefit and that it will assist you in your understanding of the impacts of Corrosion.
2019 CORROSION AWARENESS DAY

This course is hosted by: ICorr Aberdeen through kind assistance of its local / national sponsors.
2019 CORROSION AWARENESS DAY

Our Local Branch / Mtg. Programme Sponsors are:
AGAINST ALL ODDS...

The ABZ Branch has trebled its Sponsorship in the last 3yrs.
2019 Corrosion Awareness Day

Our Local Branch / Committee is:

Aberdeen Branch

Key Sponsor
Aberdeen Branch

Key Sponsor

For the coming Session
Committee is: Pls Stand.

- **Chair:** Mr. Stephen Tate
- **Vice Chair:** Dr. Nigel Owen
- **Secretary - External:** Mr. Alistair Seton, Past Chair
- **Secretary - Internal:** Mr. Hooman Takhtechian
- **Treasurer/Finance Officer:** Mr. Bryn Roberts
- **Event Co-ordinator:** Mr. Amir Attarchi
- **University Liaison and CPD Officer:** Ms. Zahra Lotfi
- **Website Officer:** Dr. Yunnan Gao, Immediate Past Chair
- **Committee Members:** Dr. Muhammad Ejaz (Past Chair) and Mr. Jonathan Segynola.

With Special thanks to Dr Yunnan Gao, for his 2yr Service as Past Chair.
2019 Corrosion Awareness Day

Corrosion is of Course: A daily problem and our local branch sponsors support our ongoing education programmes with regular meetings here at the Palm Court and RGU.

Additionally there are 2-3 Industrial Visits ea. Yr.
2019 CORROSION AWARENESS DAY

Corrosion Happens Every Day!...4% GDP Annually
The ‘BROKEN’ BRIDGE OF ITALY: Severe External Corrosion
The ‘NEARLY BROKEN’ BRIDGE OVER THE FORTH: Cable Corrosion
THE ‘NEARLY BROKEN’ BRIDGE OVER THE TAY: Corrosion of Piers
2019 CORROSION AWARENESS DAY

The primary objective is to: improve understanding of corrosion processes and to raise awareness of corrosion management issues.

CAD Events have been run regularly by ICorr Aberdeen over the last 10 yrs.
ICorr Aberdeen Events
Corrosion Awareness Course
This Year - A full-day + Evening Course, comprising a number of lectures, providing essential information on corrosion principles and mechanisms of MIC. (microbially induced) corrosion control:
YOUR PROGRAMME TODAY SPECIFICALLY FOCUSES ON PIPELINES
Many North Sea pipelines have been lost due to ‘MIC Type’ corrosion especially oil export and water injection.
MIC INTERNAL:
2019 / 2020 Branch Programme

Continuing Education
Copy in Every Delegate Pack.
### ICorr Aberdeen Branch 2019/2020 Programme of Events

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Type</th>
<th>Speaker(s) / Company</th>
<th>Topic(s)</th>
<th>Time</th>
<th>Venue</th>
</tr>
</thead>
</table>
| Tuesday 08/09/2019 | Industrial Visit - 1          | NCIMB – Dr Daniel Swan | An integrated molecular approach to microbial monitoring. Tour and demonstrations (rotating in groups of 10):  
- The National Collection of Industrial Food and Marine Bacteria. Most people are quite surprised to learn that such a thing exists but our collection includes bacteria isolated from all kinds of places including hippocampus bathing water and the dental plaque of a baboon. Bacteria from the collection have been used in a broad range of research and industrial applications, and the collection has also had a long-standing connection with the oil and gas industry.  
- Most Probable Number (MPN) demonstration. The importance of including sessile and planktonic samples and the issue of NORM contaminated coupons.  
- Molecular lab – demo of what is involved in the different molecular techniques. | 18.00. Presentation at 18.30. | NCIMB Laboratories, Ferguson Building, Crabstone Estate, Buckburn, Aberdeen AB21 9YA |
| Tuesday 24/09/2019 | Joint Meeting with TWI         | ROSEN – Daniel Sandena | SCC on Offshore Assets with emphasis on Weldments and HSC. | Sign In & Network from 17.45. Complementary Buffet from 18.00. Presentation at 18.30. | RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB9 2TJ |
| Tuesday 26/10/2019 | ICorr Technical Event         | ICorr UK + BAWWATER. (Various) | President's Lecture + Reservoir Management / H2S Mitigation. Speaker 1: ICorr - Growing our Membership and ICorr Awards. Call for Nominations. Speaker 2: "An understanding of Reservoir Scouring and Mitigation". | Sign In & Network from 17.45. Complementary Buffet from 18.00. Presentation at 18.30. | RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB9 2TJ |
| Tuesday 25/02/2020 | ICorr Technical Event         | DNV (Various)        | Key Areas of RBI: Paper 1 - PSVs are classed as safety critical when protecting hydrocarbon containing equipment and, even on non-hazardous services are always safety related. Pressure Safety Valve RBI will be discussed using Half a Billion Hours of Data. Paper 2 – For FPSO cargo tanks the main degradation threats are fatigue cracking and corrosion / coating degradation. This presentation gives an overview of DNV-GL methods for carrying out an RBI assessment for each of these threats and how they may be used to develop an optimized inspection schedule. Paper 1 Speaker: John Morgan / Chris Bell. Paper 2: Speaker: David Baxter. | Sign In & Network from 17.45. Complementary Buffet from 18.00. Presentation at 18.30. | RGU, Room N242, Sir Ian Wood Building, Robert Gordon University (RGU), Garthdee Road, Aberdeen AB9 2TJ |
### ICorr Aberdeen Branch Sponsors

**ICorr Aberdeen Branch Sponsors**

- Aberdeen Foundries
- Atkins
- Deepwater
- IndCor
- Lloyd's Register Energy
- Presserv
- Cosasco
- ROSEN
- Clockspring
- NURI
- Total

### ICorr Gold Sponsors

**ICorr Gold Sponsors** - Commo Companies Europe Ltd, Helvetica Technical Consulting Sagi, Midis Energy Services Ltd, Miller Fabrications Ltd, Pipeline Technique, Pittsburgh Corning.

### ICorr Sustaining Sponsors


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**Note:** This Technical Programme is subject to Amendment / Continuous Improvement. Any changes to planned Events, will of course be advised to you.

Should you have any queries, please refer in the first instance to the 2019/2020 Session Chair: Stephen Tate.

Thank You for your continued support of ICorr. [Stephen.Tate@external.total.com](mailto:Stephen.Tate@external.total.com)
2019 Corrosion Awareness Day

Further Sources of Information

The ICcorr Website: Is an excellent resource.

https://www.icorr.org/sources-of-information/
The BBC Website: Is also an excellent resource.

http://www.bbc.co.uk

Particularly for Corrosion related incidents
THANK YOU FOR ATTENDING

PLEASE ENJOY YOUR DAY WITH US

And Don’t be Afraid to Ask any Questions.
ICorr – ROSEN
CAD – MICROBIAL INFLUENCED CORROSION
# AGENDA FOR TODAY

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0900</td>
<td>Arrival Tea, Coffee and Breakfast Rolls</td>
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<tr>
<td>0930</td>
<td>Introduction to ICorr / ABZ Corrosion Awareness Programme</td>
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<tr>
<td>0945</td>
<td>Presentation 1 – My Life in MIC (Carol Devine)</td>
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<tr>
<td>1030</td>
<td>Tea, Coffee and Shortbread</td>
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<tr>
<td>1045</td>
<td>Presentation 2 – MIC Experiences from a Global Operator (Mabel Ntim – Shell)</td>
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<tr>
<td>1130</td>
<td>Presentation 3 – Sampling, Analysis and Monitoring of Pipelines for MIC (Laura Tiano – DTI)</td>
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<tr>
<td>1230</td>
<td>Lunch</td>
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<tr>
<td>1330</td>
<td>Presentation 4 - Modelling of Pipeline Susceptibility to MIC (Steve Loftus – ROSEN)</td>
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<tr>
<td>1415</td>
<td>Presentation 5 – Chemical Management of Pipelines for MIC: Strategies for Improved Mitigation</td>
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<tr>
<td>1500</td>
<td>Tea, Coffee and Shortbread</td>
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<tr>
<td>1515</td>
<td>Presentation 6 – Inspecting for MIC (Daniel Sandana – ROSEN)</td>
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<tr>
<td>1600</td>
<td>Presentation 7 – Cleaning and Mitigation for MIC (Ian Laing – ROSEN)</td>
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<td>1645</td>
<td>Presentation of Certificates of Appreciation to Speakers</td>
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<tr>
<td>1650</td>
<td>End of Day Round-up / Close-out / Issue of CPDs</td>
</tr>
</tbody>
</table>
## EVENING AGENDA

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
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</thead>
<tbody>
<tr>
<td>1830</td>
<td>Synopsis of CAD programme delivered earlier in the day</td>
</tr>
<tr>
<td>1930</td>
<td>Grab a beer token and a slice</td>
</tr>
<tr>
<td>2015</td>
<td>Panel question time</td>
</tr>
</tbody>
</table>

**EXHIBITION**
- Michael Bruns (ROSEN – Field Products and Services)
- Marc Pages (ROSEN – Integrity Solutions)

**COMPETITION**
- Highest score wins the drone
WHAT IS MIC

• Microbial Influenced Corrosion (MIC) or Bio-corrosion is described as….

“The initiation and acceleration of materials deterioration due to microbiologically mediated processes”

• Microbial species involved …. bacteria, archaea, algae and fungi
  • SRB, APB, IOB, NRB, Methanogens

• MIC has been associated with general & localised forms of corrosion, de-alloying, SSC, SCC, HAC and corrosion fatigue.

• MIC rates typically…. 0.5 to 3 mm/yr (up to 10 mm/yr)

• Its complex and difficult to predict.
WHY ARE WE HERE TODAY

1.

2.

3.
1. MIC AWARENESS

Awareness → Exploration & Filtration

Sharing & Reflection → Learning

Personal & Professional Application
MIC KPI?
2. THE IMPORTANCE OF MIC

- Internal Corrosion: 51%
- External corrosion: 15%
- 3rd Party: 10%
- Joint: 5%
- Pipe: 3%
- Overpressure: 3%
- Const./Inst. damage: 8%
- Weld: 5%

Total Annual Cost of Corrosion = 14 Billion USD
100 Million USD = MIC
3. ROSEN – DTI...WORKING TOGETHER

Microbiological Management Services
Teaming up against microbiologically influenced corrosion
HIGHLIGHTING GAPS IN CURRENT PRACTICES

Predictive model for assessing MIC risk, corrosion rate, severity and location along a pipeline
ICORR ABERDEEN BRANCH WELCOMES

Microbiologically Influenced Corrosion (MIC)
Presented By Dr Carol Devine, Consultant Microbiologist
• BSc (Hons) in Microbiology, University of Aberdeen
• PhD in Subsurface Molecular Microbial Ecology, University of Aberdeen
• Commercial Microbiology and Intertek for 11 years
• ICR. Integrity (formerly NECE) for 8 years
ICR. PRESERVE, REPAIR & RE-INSTATE

PRESERVE
Chemical Injection
Integrity Monitoring

REPAIR
Weldless Connections
Composite Engineering

RE-INSTATE
Engineered Machining

Chemical Injection
Integrity Monitoring
Composite Engineering
Engineered Machining
Weld-less Connections
The aim of the oilfield microbiologist is to generate useful and appropriate data in order to:

- **Predict** which particular systems, vessels, pipelines, specific locations are under threat from microbiologically influenced corrosion (MIC)
- **Prioritise** areas for treatment according to budget, time and facilities available
- **Monitor** the strategies chosen to mitigate against the effects of MIC
- **Recommend** and monitor strategies to control reservoir souring, plugging and reduced flow

The data generated will feed into the Asset Corrosion Management System
Two main types of samples:

**Planktonic** – crude, produced water, injection water, diesel, cooling and heating media

**Sessile** – biofilm from coupons, bio-sidestreams and/or other intrusive devices
BIOFILM GROWTH & DISPERSION
CHALLENGES

- Environment
- Sample Quality
  - Location
  - Cleanliness
  - Transportation
- Analytical Methods/Techniques
  - Viable counts vs molecular
- Nature of the Industry
Choice depends on what you are looking for – and on the budget available!

Three branches of microbes – archaea, bacteria and eukaryotes

**MIC** is a complex microbial process in which many groups of microbes can be involved:
- sulphate-reducing bacteria (SRB)
- sulphate-reducing archaea (SRA)
- Methanogens (Met)
- acid-producing general heterotrophic bacteria (APB)
- iron utilising bacteria (IUB)
- general heterotrophic bacteria (GHB)
- bacteria and fungi in diesels/gas oil
- (nitrite utilising bacteria) NRB/NUB
Techniques:  traditional viable counts (MPNs, plate counts) 
molecular techniques – ATP, qPCR, FISH, DAPI, NGS

Chemistry:  pH, sulphide, bisulphite, Volatile Fatty Acids (VFAs), 
chlorine residuals, total iron, nitrite, nitrate etc
Tests for actively growing cells. Every cell contains ATP.

Several commercial kits on the market (LuminUltra, InstaCheck (Schlumberger), AccuCount (EcoLab), etc)

ATP (adenosine triphosphate) plus Luciferase = light

Results are in relative light units which is proportional to the quantity of ATP.

Can be converted to ME/ml or ME/cm²

Non specific test originally designed for clean systems
Plate counts

- Can detect a variety of viable 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/gas oil analysis, potable water monitoring and Legionella counts
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., salinity and pH
- Detects less than 5% of the total community
- Incubation period for SRB is 28 days as per NACE Standard TM0194-2014
qPCR (quantitative Polymerase Chain Reaction)

- 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
FISH (Fluorescent *In-situ* Hybridisation)

- A laboratory technique based on fluorescent microscopy
- Sample is fixed on site and the fixative must be fresh
- In the lab, a DNA binding dye (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 and counted under a UV microscope
FLUORESCENT IN-SITU HYBRIDISATION (FISH)

PROBE

TARGET

hydrogen bonds

G = guanine
A = adenine
C = cytosine
T = thymine
U = uracil

ICorr ABZ - CAD 2019
• Application of New Generation Sequencing to characterise the total microbial community
• Identifies all micro-organisms present
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)
<table>
<thead>
<tr>
<th>Cell Count ME/ml or cm²</th>
<th>mGHB MPNs</th>
<th>mSRB MPNs</th>
<th>Total MPN count</th>
<th>qPCR SRB</th>
<th>qPCR SRA</th>
<th>qPCR Total Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2 x 10⁵</td>
<td>2.8 x 10¹</td>
<td>8.2 x 10²</td>
<td>8.5 x 10²</td>
<td>5.7 x 10⁶</td>
<td>2.8 x 10⁷</td>
<td>2.4 x 10⁹</td>
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<tr>
<td>1.4 x 10³</td>
<td>2.8 x 10¹</td>
<td>1.0 x 10²</td>
<td>1.3 x 10²</td>
<td>&lt;2.1 x 10³</td>
<td>&lt;2.2 x 10²</td>
<td>4.7 x 10⁵</td>
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<tr>
<td>2.2 x 10⁵</td>
<td>&lt;3.2 x 10⁰</td>
<td>4.9 x 10³</td>
<td>4.9 x 10³</td>
<td>4.9 x 10⁶</td>
<td>4.2 x 10⁷</td>
<td>3.3 x 10⁹</td>
</tr>
<tr>
<td>9.0 x 10⁴</td>
<td>1.0 x 10²</td>
<td>1.0 x 10²</td>
<td>2.0 x 10²</td>
<td>1.4 x 10⁶</td>
<td>2.6 x 10⁷</td>
<td>9.0 x 10⁸</td>
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<tr>
<td>3.8 x 10⁵</td>
<td>1.0 x 10¹</td>
<td>1.0 x 10³</td>
<td>1.0 x 10³</td>
<td>1.9 x 10⁵</td>
<td>1.5 x 10⁶</td>
<td>2.6 x 10⁸</td>
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<td>5.1 x 10⁴</td>
<td>4.2 x 10²</td>
<td>2.0 x 10³</td>
<td>2.4 x 10³</td>
<td>&lt;2.2 x 10²</td>
<td>&lt;2.1 x 10³</td>
<td>3.1 x 10⁶</td>
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<tr>
<td>7.3 x 10⁴</td>
<td>&lt;1.3 x 10¹</td>
<td>4.2 x 10³</td>
<td>4.2 x 10³</td>
<td>&lt;2.2 x 10²</td>
<td>&lt;2.1 x 10³</td>
<td>4.1 x 10⁶</td>
</tr>
</tbody>
</table>
All data should be graphed/trended on a regular basis – pipelines, drains, water injection, produced water etc.

• Trending of data pre and post biocide applications – especially if it is a longterm project

• Biocide treatments can then be optimised

• Monitoring essential
SRA NUMBERS BY qPCR PRE & POS BIOCIDES DOSES
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?
ICorr Aberdeen Branch Welcomes

Operator’s Experience

Presented By M Ntim, Materials and Corrosion Engineer, Shell UK
1. MIC has been found in oil pipelines where flowrates are low or stagnant for short periods (batch production).
2. MIC has also been found in water injection pipelines
3. MIC risk is usually detected from topsides bacteria survey and/or pig trash data
4. The mitigation for MIC is to deploy biocide treatment (usually deployed with the pigging frequency if possible).
5. Corrosion rates from prediction models can vary based on flowrates, pigging frequency and effectiveness, and biocide treatment.
6. Corrosion assessment can be conservative
7. Inspection tool limitations – due to the size of pits on pipe surface
Examples – Oil Pipeline (intermittent service)
Examples – Multiphase oil pipeline

- Carbon steel pipeline – in operation from 1998. The main degradation mechanism expected was CO₂ corrosion.
- In 2007, intelligent pigging was completed (1\textsuperscript{st} inspection) and significant wall loss was reported.
- Review of the pipeline system highlighted the following:
  - Increase of bacteria count in the wash water system – this was required when producing specific wells to ensure corrosion inhibitor effectiveness
  - Metal loss morphology appeared circular in shape
- Pipeline was re-inspected after 5 years. However no change was detected when compared to 2007 data – manufacturing defects or better control?
Sampling, Analysis and Monitoring of Pipelines for MIC

Laura Tiano
DTI Oil & Gas
Life Science
Danish Technological Institute
Contacts: lti@dti.dk / +45 72 20 10 39
DTI: WHO ARE WE?

- Founded 1906, 1000+ employees
- Leading research and technology company

Objective: Bridging knowledge with production.

Around 50 employees working with Oil & Gas
- Operations support team
- Offshore field staff
- R&D scientists and engineers

Facilities
- Extensive analysis labs, state-of-the-art equipment
- Dedicated oil field laboratory
- Large-scale coating production facility
Outline

1. Microbial challenges
2. Samples and sampling
3. Analyses
4. Monitoring and system management
Microbially influenced corrosion (MIC)

- Caused by **presence or activity** (or both) of **microorganisms** adhering to the metal (**biofilms**) and accelerating a-biotic corrosion mechanisms.

- Various metals and some nonmetals are affected (e.g. carbon steel, stainless steel, copper & aluminum alloys)

- Typically seen in the presence of **microbial consortia**, comprising more than one type of microorganism:
  - Sulfate-reducing prokaryotes (SRP)
  - Acid-producing bacteria (APB)
  - Metal oxidizing- and reducing bacteria
  - Methanogens
Why do we need to sample?

What is a representative sample?

How do I take the sample and ensure good sample quality?
Impact of Microbes on the Oil Industry

MIC/Fouling/Souring

- Product spoilage
- Loss of integrity
- Production downtime

Source: Petroleum Microbiology
Why do we need to sample?

- Routine monitoring
- Quality control
- Suspicion about problems
- Troubleshooting
- Fact finding
What is a representative sample?

- Sample type
- Sampling point
- Operational conditions
- Microbial hotspots
- Timely analysis
“Sampling is the process of selecting units from a population of interest so that by studying the sample we may fairly generalize our results back to the population from which they were chosen.”
From sampling to system management

SYSTEM → SAMPLING → LOGISTICS → ANALYSIS → REPORTING

PROBLEM SOLUTION / CORRECTIVE ACTION → ASSESSMENT
What to sample:
Sample type

Sample types

Liquid
- Water
- Fuel
- Crude

Solid
- Pigging solids
- Biofilm
- Scale
- Wax

Gas

Others
- Piping
- Coupons
- Probes
The advantages of different sample types

*Example of offshore injection water system*

**Water samples**
- Easy to collect
- Microbial hotspots ID
- Growth potential
- Trendlines

**Solid samples**
- (biofilm, pigging material)
  - Requires good planning: collected only at shutdown periods/ pigging operation
  - Verify microbial trends
  - Directly linked to MIC risk

**Corrosion coupons**
- Sampling requires specially trained personnel
- Directly linked to MIC risk
- General corrosion/ corrosion rates
When to sample

• Time and timing
• Stable production?
• Before/after mitigation (i.e. biocide) action?
• Several samples?
How do I take the sample and ensure good sample quality?

- The right sample equipment
- Thorough sampling procedures
- Ensure the sample does not change over time
The right equipment for the task

• Chemistry:
  - Bottle and preservatives, analysis dependent
  - Glass often required

• Microbiology:
  - Sterile plastic
  - Standard kits available (+/-preservative)

• If in doubt about purpose/parameters:
  - 1 L blue-cap flasks covers most needs

• Different equipment for different sample types
Ensure the sample does not change

• Preservation needed?
• Redox environment
  – Aerobe/anaerobe?
• Avoid contamination
  – Use sterile equipment
• Temperature
  – Cool to minimize activity – but do not freeze
• Time
  – Minimize transportation (planning and communication)
• Number / ID
• Exact location / sampling point
• Date / time
• Company / field
• Other relevant information:
  - Visual observations
  - Temperature
  - Pressure
  - Sampler..
Microbial Analyses

- Culture based (i.e. MPN)
- Microscopy based (i.e. DAPI, FISH)
- Enzyme based (i.e. ATP)

- DNA based, (MMM)

Molecular microbiological methods:
- qPCR
- RT-PCR
- Microbial community analysis (NGS)

Poulsen M. et al., 2016 SPE-183526-MS
Microbial Molecular Methods

Who is there?
- NGS sequencing

What can they do?
- Metagenomics

How many are there?
- qPCR
- DAPI

Are they active?
- RT-qPCR
- FISH

Biofilm + scale + corrosion product

Pitting
Analysis on water samples:

- Living cells count (DAPI)
- Active cells count (FISH)
- Enzyme based activity

- Total microbial numbers and MIC risk indicator groups (qPCR)
- Microbial community composition (NGS)
- Variety of chemical analyses
Sampling procedure: Water samples

- Always safety first!
- Label sample bottles with time, place, name etc.
- Avoid touching and contaminating bottle and inside of lid.
- **Let water run to flush system thoroughly** – think about, what the water should represent?
- Use stabile flow, sloughing of biofilm should be avoided
- The water is anaerobic and should therefore be aerated as little as possible – and no air gap in the top of the bottle!
  - let **overflow** for a couple of volumes (minimized aeration), close.
- Store cold until shortly before transport, keep cool under transport.
Solid samples

Analysis on pigging samples:
- Total microbial numbers, MIC risk indicator groups (qPCR)
- Microbial community composition (NGS)
- General Corrosion
- Chemical composition (XRD, XRF, mineralogy, etc.)
Sampling procedure: Solid samples

- Label sample jars with time, place, name etc.
- Put on the sterile gloves
- Carefully scrape off/collection sample material directly from the pig or receiver and put it in the sample container.
- **Fill up the container completely** with sample material; otherwise fill up the container with liquid from the pipeline/receiver to avoid headspace.
- Close the jar carefully.
- After sampling, the samples must be stored cold.
Example: Water sampling during pig run

- Require good planning
- Time-consuming sampling
- Use row of 1 L plastic bottles, sample: e.g. every minute
- Label with sampling time
- Sample some time after pig arrival to get water data after pigging
- Pick selection of bottles representing “cloud” for shipping (# can be reduced in lab)
- Store cold (cooling box) until transport and keep cool during transport.
Coupons and Probes

Analysis on coupon samples:
• Total microbial numbers, MIC risk indicator groups (qPCR)
• Microbial community composition (NGS)
• General Corrosion
• Chemical composition
• Pitting and surface scanning
• Weight loss
Sampling procedure: Corrosion coupons

- Label sample jars with time, place, name etc.
- Put on the sterile gloves before handling the coupons.
- Pull the coupon and place it in the sample jar (only one coupon in each sample jar).
- **Fill the sample jar** with sterile saline solution or water representing the system where the coupon was installed *
- Make sure the jar is completely full - avoid air headspace - then close the jar carefully.
- Fill out the delivery note including all process data relevant to the sampling.
- Store cold until and during transport.
Sampling Offshore: Check list

✓ Problem ID - Who to speak to about problems
✓ Speed is important
✓ Accuracy important
✓ Knowledge about oxygen in the samples
✓ Difference between Chemistry (dead) and Microbiology (alive) samples
✓ Right gear / kits /equipment and procedures
✓ Right education in sampling important
✓ Solid data will give an optimal solution
✓ Everybody in the chain is important – communication!
Example: Pigging samples

DNA analysis (MMM)

System data:
- Water cut
- Temperature
- Materials/Corrosion
- Water data
- Inspection data

Chemical analysis

DTI RISK DATABASE
Empirical data from North Sea assets

RISK ASSESSMENT

MITIGATION STRATEGY:
- Mechanical cleaning
- Chemicals
- Follow-up & optimization
- Monitoring

Sample retrieval & trsp.
From sampling to system management

✓ Understand the corrosion threat to the system.

✓ Select and applying appropriate prevention and mitigation measures.

✓ Monitor conditions to determine whether the control measures are effective, or whether adjustments are required.
Setting up a MIC Monitoring Program

- Injection water systems
- Production systems
- Wells
- Storage tanks
- Pipelines
- ...

✓ Integrity management and microbial control
✓ Better choice of materials for future asset design
✓ Improved choice of anti-microbial strategies
✓ Optimized pigging and cleaning programs
✓ **Reduced OPEX** (maintenance, chemical budgets, downtime)
Setting up a MIC Monitoring Program

- **Monitoring over a period of time** allows for looking at **trends**.

  Due to normal **statistical variation** associated with sample collection and microbiological testing, more reliable data typically result from performing tests on samples collected over a period of time, rather than from any single sample.

- **Microbial monitoring data** should be viewed **in combination** with **corrosion data**.

  Such as from corrosion coupons or in-line inspections, to establish system-specific levels of microbial growth that are acceptable to pipeline integrity.
Example of sampling outline: IW system microbial monitoring

<table>
<thead>
<tr>
<th>Sample types</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
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<td>X</td>
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<tr>
<td>Pigging solids</td>
<td></td>
<td></td>
<td>X</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Coupons</td>
<td></td>
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<td>X</td>
<td></td>
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</table>

<table>
<thead>
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<th>Parameters</th>
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<td>Microbiology</td>
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<td>Microbiology</td>
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<tr>
<td>Org/Inorg con.</td>
</tr>
<tr>
<td>Chemical composition</td>
</tr>
<tr>
<td>Microbiology</td>
</tr>
<tr>
<td>Weigh loss</td>
</tr>
<tr>
<td>Surface scan</td>
</tr>
</tbody>
</table>

**Water** – Trends // Hotspot ID // Growth potential in system // Where to focus biocide use

**Solids** – Can be related directly to MIC Risk // Corrosion and System Integrity

**Coupons** – Can be related directly to MIC Risk // Pitting // General Corrosion
Thank you!

www.dti.dk/specialists/oilfield-microbiology/k90453

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Danish Technological Institute
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ICorr Aberdeen Branch Welcomes

Modelling of Pipeline Susceptibility to MIC

Presented By Steven Loftus, Senior Corrosion Engineer
1. Introduction
2. Understanding Pipeline Susceptibility to MIC
3. Modelling MIC in Oil and Gas Industry
4. Proposed MIC Modelling Risk Assessment Procedure
5. Summary
6. Future of MIC Modelling
• Pipeline internal corrosion caused by presence of water at metal surface.

• Sediments (‘sludges’) may accumulate in pipelines, comprised of hydrocarbons, sand clays, corrosion by-products, microorganisms and water.

• Biologically active pipeline sludges known to accumulate and concentrate water from oil, creating a metal-water interface – leads to formation of localized under-deposit corrosion.

• Sludges can support formation and proliferation of microbial colonies in pipeline systems.

Important initial factor to understand – How do microorganisms initially enter pipeline systems?
INTRODUCTION
COMMON SOURCES OF BACTERIA

Water Injection Pipeline
- Introduced during secondary/tertiary recovery

Production Pipeline
- Introduced during shut-in periods

Water Injection Well

Production Well
- Introduced during drilling and well completion

Injection Water

Crude Oil
- Exist naturally in petroleum reservoir
INTRODUCTION

Microbiological activity in pipelines can lead to biofilm formation:

• Reduced efficiency of production and equipment operations.
• Favourable environments for anaerobic sulphate-reducing bacteria (SRB), leading to MIC.

Presence of microorganisms does not necessarily equate to realization and occurrence of MIC:

• Primarily dependent on pipeline environmental conditions being viable for biofilm formation and microbial proliferation.
• System must be systematically and routinely monitored for presence of microorganisms.
UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

MIC relatively difficult to predict and diagnose compared to other corrosion mechanisms:

• Complex due to diversity of contributing factors *i.e.* growth of biofilm governed by a number of **physical, chemical** and **biological** processes (**abiotic** and **biotic processes**).
UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

Breadth of disciplines and understanding required in evaluating and predicting MIC.

Two main subject areas:

- **Materials / corrosion science.**
- **Microbiology / environmental sciences.**
UNDERSTANDING PIPELINE SUSCEPTIBILITY TO MIC

Approaches to MIC threat assessment include:

- Analysis of corroded components.
- Chemical and microbiological surveys in conjunction with corrosion monitoring.
- Use of MIC susceptibility and MIC rate-based models.
MODELLING MIC IN OIL AND GAS INDUSTRY

TYPES OF MODELS

Oil and gas industry use models for many purposes:

- Predicting effects of corrosion on asset design and life extension.
- Materials selection (FEED).
- Establishing appropriate mitigation and monitoring programs.
- Optimisation and prioritization of resources.
- Optimisation of risk-based inspection (RBI).

Many MIC models exist in literature, generally classified into three categories:

- Empirical
- Mechanistic
- Risk-based
MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF EMPIRICAL MODELS

Developed to predict corrosion rates due to MIC based on select measured parameters.

The number of empirical models limited – lack of comprehensive datasets from lab or field testing.

• **Fatah et al.** - model that predicts MIC rate for SRB based on abiotic chemistry and linear polarization (LPR) measurements.

• **Grzelak** – statistical analysis of 18 external pipeline defects attributed to MIC:
  • Defects detected by ILI and external pipe environmental conditions collected and evaluated statistically for influence on external MIC.
  • pH and redox potential had highest correlation with MIC rates.
  • SRB concentration – no significant correlation to MIC rate!
MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF MECHANISTIC MODELS

Mechanistic models developed to better relate changes in selected environmental conditions with MIC rates.

- Majority focused on SRB and based on simulating a model biofilm over a corroding metal substrate.

- **Maxwell** - model that predicts MIC occurrence and rate for SRB based on different stages of SRB biofilm formation, as part of risk-based assessment.

- **Gu et al.** – model that predicts MIC considering biochemical reactions at the biofilm-metal interface:
  - Charge resistance one of the most important factors during initial biofilm formation.
  - Model + risk-based framework could predict likelihood of biofilm formation in pipelines.
Area of growing interest – use of data from MMM as input to mechanistic MIC models.

- **Skovhus et al.** – qPCR used to study *in situ* microbial consortia and predict MIC.
- Model is divided into two steps:
  - 1\textsuperscript{st} step – estimates processes that occur prior to onset of MIC.
  - 2\textsuperscript{nd} step – calculates corrosion when MIC has occurred.
- Does not include physical or chemical parameters.
- Model implemented in pipeline operations in Danish sector of North Sea by Maersk Oil.
MODELLING MIC IN OIL AND GAS INDUSTRY

OVERVIEW OF MECHANISTIC MODELS

Some shortcomings with existing mechanistic models:

• Existing models aren’t able to predict where and when MIC will occur.

• Majority do not consider biofilm growth characteristics.

• Most rarely account for effects of metabolic products (e.g. H₂S, FeS, etc.).

• Few models accurately correlate sessile and planktonic bacteria.

• Some models limit assumed cathodic surface area involved which can significantly affect predicted corrosion rates.

• Most of the models only validated based on short-term lab testing, not with actual field test data.
MODELLING MIC IN OIL AND GAS INDUSTRY
OVERVIEW OF RISK-BASED MODELS

Qualitative Approaches

Qualitative assessment of MIC uses collective expertise within a company or from external SMEs hired to take on task.

- SMEs input based on experience and from other analogous / similar situations in the industry.
- Screening assessment to consider all threats and risks – input given in data ranges instead of discrete values and corrosion threats ranked into categories e.g. low, medium or high.
- Advice and guidance limited by existing knowledge.
- Accuracy of results greatly dependent on background and expertise of risk analysts and team members.
Semi-Quantitative Approaches

Any methodology that has aspects derived from both quantitative and qualitative approaches.

- **Sooknah et al.** – MIC susceptibility determined through consideration of pipeline operating conditions that influence microbial growth and biofilm formation. Updated with integration and consideration of MIC-related mitigation measures.

- **Skovhus et al.** – combines elements of Sooknah model in a qualitative assessment, both quantitative + qualitative input combined to assess threat of MIC:
  - Considers both Probability of Failure (PoF) and Consequence of Failure (CoF) in defining ‘risk’.
Semi-Quantitative Approaches

- **Skovhus et al.** – quantitative + qualitative input combined to assess threat of MIC:
  
  1. **1st stage** – PoF screening based on the quantitative and qualitative inputs e.g. mitigation efforts, temperature, pH, past failures, etc.
  
  2. **2nd stage** – if PoF significant, PoF ranked based on quantitative measures alone e.g. settlement potential, nutrient availability, mitigation effectiveness, etc.

- Procedure provides a *MIC susceptibility measure*.

- PoF ranking essential in calculating risk of system when combined with CoF.

- CoF typically independent of failure mechanism *i.e.* consequence of leakage by MIC same as consequence of leakage caused by other mechanisms.
All corrosion models or assessment procedures have some degree of inherent uncertainty:

- No definitive MIC modelling solution to predict MIC in every situation.
- Model predictions should only be used as indicative to plan continuous integrity management monitoring and mitigation measurements.

Suggested ‘best approach’ to model MIC:

- Consider present models.
- Collate best aspects of models ideal and practicable for determining MIC threat, risk and associated PoF for RBI / management.
PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

1. MIC Screening Assessment
2. Is MIC confirmed?
   - Yes
     - Review of MIC Management Strategy Data (Evaluate 3 key parameters)
     - Determine MIC PoF Evaluation
   - No
     - New MIC Susceptibility Assessment
     - Exclusion of MIC?
       - Yes
         - Review System Operating Parameters
       - No
         - Determine MIC Susceptibility RF and Associated PoF
3. Acceptable PoF (< 2)?
   - Yes
     - MIC Risk Low
   - No
     - Revise (or Develop) Appropriate MIC Management Strategy
     - Identify Abiotic / Biotic Causal Factors
     - Implement MIC Management Actions
MIC Screening Assessment

Is MIC confirmed?

1. Bacteria detected by routine detection and monitoring methods.
2. Corrosion rate evaluations and bacteria on internal surfaces.
3. Elimination of other active corrosion mechanisms leaving MIC most probable.

MIC PoF Evaluation – 3 key parameters:

1. Corrosion Control Availability (%) (MIC Mitigation Compliance (MMC)).
2. Localised Corrosion Rate (mm/year) (NACE SP0775).
PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

Example MIC Screening Assessment PoF Interaction Diagram

PoF Ranking

1 Very Unlikely
2 Unlikely
3 Possible
4 Likely
5 Very Likely
PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

MIC Screening Assessment

Is MIC confirmed?

Yes

Review of MIC Management Strategy Data
(Evaluate 3 key parameters)

Determine MIC PoF Evaluation

No

New MIC Susceptibility Assessment

Exclusion of MIC?

Yes

No

Review System Operating Parameters

Determine MIC Susceptibility RF and Associated PoF

Acceptable PoF (< 2)?

Yes

MIC Risk Low

No

Revise (or Develop) Appropriate MIC Management Strategy

Identify Ablotic / Biotic Causal Factors

Implement MIC Management Actions
New MIC Susceptibility Assessment

Stage 1: Exclusion of MIC

Biofilm growth can be reasonably excluded if:

• Operating temperature >120°C.
• Absence of water / moisture.
• Absence or reduced availability of organic / inorganic nutrients.

If any of conditions above satisfied - MIC Risk Low.
New MIC Susceptibility Assessment

Stage 2: Biofilm Formation, Microbial Adhesion and Growth

Review of system operating parameters – microorganism proliferation greatly influenced by:

- Presence of water.
- Nutritional requirements.
- Oxygen levels, redox potential.
- Temperature.
- pH.
- Salinity.
- Pressure.
- Flow rate.
- Water quality.
- Cleaning frequency.
### New MIC Susceptibility Assessment

#### Stage 3: MIC Risk Assessment

MIC RF: Sum of all F values divided by total number of contributing operational parameters

<table>
<thead>
<tr>
<th>Operational Parameter</th>
<th>Parameter Value(s)</th>
<th>Parameter Risk Factor (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Velocity</td>
<td>≥3 m/s</td>
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</tr>
<tr>
<td></td>
<td>&gt;2&lt;3 m/s</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>&gt;0&lt;2 m/s</td>
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<tr>
<td></td>
<td>0 m/s</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>5</td>
</tr>
</tbody>
</table>

#### MIC Susceptibility Index – MIC PoF Ranking Score

<table>
<thead>
<tr>
<th>0 - 1</th>
<th>1.1 - 2</th>
<th>2.1 - 3</th>
<th>3.1 - 4</th>
<th>4.1 - 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Unlikely</td>
<td>Unlikely</td>
<td>Possible</td>
<td>Likely</td>
<td>Very Likely</td>
</tr>
</tbody>
</table>
## PROPOSED MIC SUSCEPTIBILITY RISK ASSESSMENT PROCEDURE

### Corrosion Management Actions

<table>
<thead>
<tr>
<th>PoF Ranking</th>
<th>MIC Management Action</th>
</tr>
</thead>
</table>
| 1 Very Unlikely | - No immediate action required.  
- Continue with present MIC mitigation, monitoring and inspection.  
- Current monitoring and inspection frequencies may be reduced with sufficient knowledge of the data trends.  
- Mitigation activities may also be reduced, but would requires additional monitoring above the present frequency to monitor effectiveness. |
| 2 Unlikely | - As PoF Ranking 1, no additional actions required. |
| 3 Possible | - Identify which abiotic / biotic parameter is leading to a possible MIC threat. If this is not immediate then it may be necessary to conduct a new MIC susceptibility assessment.  
- Regain control of that parameter through the current MIC control strategy, through increasing the current mitigation element along with more frequent monitoring and inspection to determine if control has been regained.  
- If control is not regained over a 6 to 12 month period using current mitigation practices then the PoF ranking shall be elevated to PoF 4 and associated actions undertaken. |
| 4 Likely AND | - Conduct a new MIC detailed assessment to determine which abiotic / biotic parameters of the system are causing an elevated risk of MIC.  
- Review operational history to determine if there has been any change to the system parameters that has led to a high-risk evaluation.  
- Conduct a review of the present MIC strategy to determine why it is not being effective.  
- The present biocide used with respect to both planktonic kill efficacy and biofilm penetration efficacy is potentially limited and selection of a new biocide or increased dose regime may be required.  
- Continuous injection of the same biocide has led to microorganism phenomic adaptation resulting in a strain that now has resistance to the biocide. At best the biocide is resulting in injury rather than kill. Utilisation and frequent variation of at least two blends of specific microbially-targeted biocides is required. Dose and frequency will be established through consultation with the chemical manufacturers based on laboratory and field testing. Note: Ensure suitable biocide testing protocols are followed with specific consideration to; bacterial kill, biofilm penetration, regrowth, contact time and dosage.  
- Pipeline cleaning frequency may be insufficient, if so consider increasing the frequency and conduct additional microbial monitoring to determine if the additional control has been effective.  
- The type of cleaning (cleaning pig) utilised may not be efficient. Try an alternative (more aggressive) cleaning pig type more suitable to the removal and disruption of stubborn biofilms.  
- With any mitigation change it will be necessary to conduct further corrosion and microbial monitoring to determine the effectiveness of the new strategy.  
- If corrosion rates are unknown then the installation of appropriately located corrosion coupons, probes, bio-studs should be considered.  
- Alternatively monitor corrosion rates through direct assessment at appropriate locations which have been determined to be high-risk locations for MIC. |
| 5 Very Likely | - |
SUMMARY OF PROPOSED PROCEDURE

- MIC Risk Assessment Procedure:
  - MIC Screening Assessment and PoF Evaluation for systems with **confirmed MIC**.
  - New MIC Susceptibility Assessment for systems where **MIC is unconfirmed**.
  - Based on recently developed strategies for assessment of MIC – elements of Skovhus approach to determine PoF of MIC.
  - Assess key abiotic and biotic parameters to establish potential for biofilm formation and microbial proliferation.
  - Appropriate MIC management actions can be implemented based on evaluated PoF score.
FUTURE OF MIC MODELLING IN OIL AND GAS

INDUSTRY NEEDS

• Current MIC models are principally susceptibility ranking models or mechanistic rate-based models focused on a specific microbiological activity.

• Industry need – move from reactive to proactive MIC management:
  • Improved prediction models considering both biotic and abiotic corrosion mechanisms.
  • Corrosion rate models.
  • Risk models that can integrate large datasets accumulated for assets over operating life - intelligent input to risk and RBI models.
  • Data from MMM should be incorporated and used in meaningful way – provides greater resolution of microbiome present.
    • MMM data + inspection data (e.g. ILI) to improve prediction methodologies.
  • Models that can ‘learn’ from past occurrences / failures of MIC.
THANK YOU FOR JOINING THIS PRESENTATION.

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Chemical management of Pipeline MIC: strategies for improved mitigation

Lone Tang, Senior specialist DTI
Aberdeen iCorr Day 27 August 2019
Mitigation of MIC

MIC mitigation is about the control of biofilms!

Protective coating  Mechanical cleaning  Chemical cleaning
Mitigation of MIC

- The biofilm challenge - high biocide dosages are required!

- Biofilm defense mechanisms
  - The biofilm matrix act as a diffusion barrier (Mah and O’Tool 2001)
  - Low growth rate slow down biocide uptake
  - Changes in gene expression (e.g. production of enzymes that degrade biocides or production of effluent pumps)
  - Synergistic interactions between microbial groups
Biocide selection – the ideal biocide

- Compatible with system
- Non-corrosive
- Non-toxic/non-hazardous
- Degradable
- Easy transport
- Long shelf life
- Cheap

- Targeting the right organisms
- Fast biofilm penetration
- Rapid effect
- No microbial resistance
- Active in low concentrations
Biocides in the oil & gas industry

- Formaldehyde
- Glutaraldehyde
- Quaternary ammonium compounds
- Quaternary phosphonium compounds
- Chloride
- "Green" solvents e.g. ionic liquids
- Enhancers e.g. EDDA, d-amino acids, norspermidine
- Bacterio-phages?
- Quorum sensing inhibitors?
Biocide overview - aldehydes

Glutaraldehyde

- Good system compatibility (except e.g. primary amines, ammonia)

Acrolein (2-propenal)

- Dissolves FeS
- Soluble in oil
- Biofilm effect only documented by field studies (Penkala et al. 2004)

Common features

- Effective antimicrobial agents; cross-link proteins → inactivate cell membrane, and cross-link DNA
- Can be applied in liquids with high organic content
- Scavenge H₂S and react with R-SH (i.e. bad compatibility with oxygen scavengers)
- Risk of microbial resistance
- Biodegradable
Biocide overview – phosphonium compounds

THPS (Tetrakis hydroxymethyl phosphonium sulfate)
- Quaternary phosphonium compound
- Releases formaldehyde with increased pH
- Proven antimicrobial properties
- Limited effect on biofilms (Sharma et al. 2018)
- Compatibility issues with anionic friction reducers, chlorine and oxygen scavengers

TTPC (Tributyl tetradecyl phosphonium chloride)
- Surfactant!
- Potential foaming and formation compatibility issues
- Effective towards planktonic SRB (Kramer et al. 2006, 2008, Wenthworth et al. 2018)
- Biofilm inhibition and dispersion properties (Kim & Park, 2015)
- No reactions with chlorine (Wenthworth et al. 2018)
- Unknown* compatibility with anionic scale and corrosion inhibitors

* Some vendors list it as TTPC as having compatibility issues, while other list it as being compatible
Biocide overview - surfactants

Benzalkonium chloride (BAC) / alkyl dimethyl benzyl ammonium chloride (ADBAC)
- Risk of bacterial resistance (e.g. Grobe 2002)
- May influence permeability of reservoirs

Didecyl dimethyl ammonium chloride (DDAC)
- Lower foaming, higher tolerance to protein loads and hard water, better kill effect (source chemical vendor)

Some amines e.g. Cocodiamine (1-alkyl (C6-C18)-1,3 propane diamine acetate)

Common features
- Effective at low dosages
- Disrupts cell membrane, destroy proteins, inactivate enzymes
- May improve uptake of other biocides
- Decreased effect with high salinity and mineral content (formations)
- Significant foaming potential and risk of oil emulsions
- Compatibility issues with anionic additives and oxidizing agents

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Biocide overview – Isothiazolones

Isothiazolones e.g. MIT (Methylisothiazolinone)
- React with amino acids and inhibit metabolism (4-6h for kill, minutes for inhibition of metabolism) (Williams 2004)
- Incompatible some corrosion inhibitors, oxygen scavengers
- Inactivated by e.g. amines and sulfides, pH >7
Biocide overview – Organobromides

Bronopol (2-bromo-2-nitro-1,3-propanediol)
- Slow kill efficiency, but longer lasting
- Effective towards biofilm at 250 mg/l (Messi et al. 2017)

DBNPA (2,2-dibromo-3-nitrilopropionamide)
- Very fast killer, but degrades quickly
- Can prevent biofilm formation when dosed continuously, but cannot remove biofilm, and resistant subpopulation in biofilms observed (Siddiqui et al. 2017)

Common:
- Not recommended for sour systems
- Not recommended for high pH
- Not recommended for >50 °C
Biocide overview – oxidizing biocides

e.g. Chlorination, Chlorine dioxide, Hydrogen peroxide, and ozone

Common features
- Attack and oxidize the microbial cell wall, membranes, cell material and DNA
- Relatively efficient towards biofilm
- The disinfection effect depends on concentration and contact time
- Effective for clean water systems such as injection water

- No effect after initial kill
- Poorly effect in liquids with high organic content.
- Not suitable in areas with explosive atmosphere (ATEX)
- Compounds are corrosive
- The oxidizers will react with other chemicals applied
Biocide overview – future chemicals

Polyamines e.g. Norspermidine
- Interact directly with sugar-based molecules that hold biofilm together (Kolodkin-Gal et al. 2012)
- Can disassemble biofilm, but the dispersive and inhibitory activity on biofilms dependent on biofilm species (Ramón-Peréz et al. 2015, Si et al. 2014, Cardile et al. 2017)
- Limited knowledge of compatibility, but contains amine (i.e. not compatible with e.g. glutaraldehyde and chlorine)

D-amino acids
- Disperse some biofilms but not all
- Improved effect of ADBAC and THPS against oil field biofilm (Jia et al. 2017)

Chelators e.g. EDDS
- Proven antimicrobial effect
- Non-toxic biodegradeable
- Compatibility issues as it react with ions and thereby loose effect

Ionic liquid
- Many ionic liquids has antimicrobial properties (e.g. DDAC)
Biocide validation process

- How to indentify the best chemicals for MIC mitigation for your system?

  Challenges:
  - Compatibility: system water composition, other chemicals, materials
  - Efficacy and required dosages depend on liquid composition and microbial species present
  - Biofilms will regrow due to the continuous flow of water
  - Repeated treatments with a biocide may promote growth of microorganisms more resistant to this biocide
Biocide validation process

1. Lab Biocide Optimization
2. System Sampling
3. Field Implementation
4. Risk Evaluation
Testing biocide efficiency

- Targeting the right organisms

**Standard lab organism**
*Laboratory organism*

**System relevant organisms**
*Very diverse population, incl. both Bacteria and Archaea*
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency

How many are there?  How active are they?  Who is there?
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

*Free planktonic cells*  
*Microbes grow in biofilm*

*Control*

*Biocide A*

*Biocide B incl. surfactant*

*Alive cells ; Dead cells*
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

NACE 2004 vs new nace
NACE TM0194-2014

Planktonic tests are common practice, but results are not valid for biofilms!

Tests with biofilm are recommended!

Further recommendations:
- Use water from offshore system
- Investigate for signs of water/system incompatibility
- Verify by coupon or system monitoring
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

Biofilm screening test:
- Ranking of large number of biocides
- Influence from production chemicals

Output

Relative biofilm activity or density compared to a control
Testing biocide efficiency

- Targeting the right organisms
- Analysis for measuring efficiency
- Evaluation on suspended cells vs. biofilm

Optimization of biocide dosage regimes

Output

[Diagram of biocide test setup]

**Clean carbon steel**

**System–related methanogen**

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## Biocide selection and considerations

### 1. Biocides compatibility
- Sample from system
- Selection of potential biocides
- Evaluation of injection points
- Which biocides are stable in the specific system and for how long

### 2. Choice of biocides
- Sample from system
- Identification of microorganisms
- Screening of potential biocides
- Selection of best-in-class biocide(s)

### 3. Dosage concentration
- Lab-scale biofilm
- Selection of minimum dosage concentration giving best performance

### 4. Dosage frequency
- Lab-scale biofilm
- Selection of optimal dosage frequency for sustained biofilm control

### 5. Maximum effect at minimum cost

**ICorr** ABZ - CAD 2019
Case 1 – choice of chemicals

- Example of biocide optimization strategy in produced water where MIC and fouling is experienced.
- Article will be published at NACE 2020.
Case 2 - optimization of biocide application

- Microbially influenced corrosion in oilfield: microbial quantification and optimization of biocide application (Senthilmurugan et al. 2019)

**Diagram:**
- Field Implementation
- Lab Biocide Optimization
- System Sampling
- Risk Evaluation

**Images:**
- Laboratory setup
- Graph showing microbial quantification
- Data analysis chart
Case 2 - optimization of biocide application

- Mapping of system microorganisms in system waters
  - SRB (e.g. desulfovibrio and desulfobacter) are abundant in seawater and brackish water systems
  - Acid-producing halo-tolerant (e.g. Halanaerobium spp.) was abundant in effluent waters

- Laboratory enrichments targeting identified troublesome microorganisms
Case 2 - optimization of biocide application

- Biocide screening with system-derived biofilms for each of the three water types
Case 2 - optimization of biocide application

Before biocide challenges

- pH reduced in all reactors
- Natural fluctuations (ATP signal)
- Acid-producing Haloanaerobium dominate
- SRB Desulfovibrio are present but H$_2$S not detected

pH levels before biocides

Community composition before biocides
Case 2 - optimization of biocide application

- Biocidal effect on microbial activity (levels of ATP) in effluent waters
  - Temporary effect of THPS + GLU blend
  - Long-term effect of ADBAC
Case 2 - optimization of biocide application

Seawater enrichment in biofilm reactors treated with two biocides

**Microbial numbers and activity**
- 500 ppm → growth “under control”
- 1500 ppm → numbers decreased
- SRB activity increased within a day after biocide treatments

![Graph showing relative change in microbial numbers and activity](image)

**Sulfide concentration** *before* biocides
![Graph showing sulfide concentration before biocides](image)

**Sulfide production** *after* biocides
![Graph showing sulfide production after biocides](image)
Case 2 - optimization of biocide application

- Next step – field implementation
Case 3 – effect of operational decisions - field monitoring

Since December 2010: Free chlorine not present in the injection water

2009: Installed new O₂ analyser

July 2008: Reduced flow rate from > 4 m/s to < 2 m/s

April 2005: Nitrate + phosphate

January 2005: Minox in operation

September 2003: Ended use of biocide. Started injection of nitrate. Increased turbidity

February 2013: Ended phosphate injection. Started biocide injection (glutaraldehyde)

June 2014: Changed oxygen scavenger (reduced nitrogen addition)

March 2015: Ended nitrate injection

May 2015: Increased flow rate from < 2 m/s to >4 m/s

Liengen et al. 2017 Eurocorr
Chemical management of Pipeline MIC: strategies for improved mitigation

Needed considerations for improved MIC mitigation

- MIC Mitigation concerns control of biofilms
- Biocides should reach pipelines – combination with pigging is beneficial
- Ensure that biocides are compatible with system waters, applied production chemicals (e.g. oxygen and H₂S scavengers), materials

Recommended strategies for improved MIC mitigation

- Biocides should be effective towards troublesome biofilm from the system
- Monitor effect when new mitigation strategies are implemented
- Alternate between two or more biocide products to avoid promoting development of microbial resistance
Thank you for your attention

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ICorr Aberdeen Branch Welcomes

Inspecting for MIC

Presented By Daniel Sandana, Principal Corrosion Engineer
• could we physically inspect for MIC reliably to prevent failure?

• Are there any MIC defects we could not inspect and manage in suitable time to prevent leaks with traditional tools?

• Are Inspection tools and schemes sufficient to manage identify the threat of MIC and manage MIC?

1. Review of MIC morphologies…
2. Traditional ILI Vs ID/Sizing of MIC… any limitations?
3. New advances for MIC ID/Sizing?
4. Is ILI sufficient to manage MIC?
5. Conclusions
MIC MORPHOLOGIES…
ONE UNIQUE?

Most commonly associated with MIC?

✓ Pit of semi-hemispherical (scoop) shape…

… but not the only one…
A slight variation

✔ Typical Cup-type scooped out hemispherical pits with crater in pit

(Gas Technology Institute, Illinois)
A completely different one

✓ Large craters surrounded by uncorroded metal
MIC MORPHOLOGIES…
OTHERS SEEN…

Another completely different one

✓ Striations or contour lines in the pits or craters also running parallel to the longitudinal axis of pipe
MIC MORPHOLOGIES…
OTHERS SEEN…

- No diagnostic possible just based on morphologies…..

- Abiotic vs biotic corrosion morphologies…
PIPELINE INTEGRITY MANAGEMENT & CORROSION...

- Where? ... Locations.... Axial/circumference distribution
- What?... Shape... morphology… Pit? General? Crack?
- How much?... Severity
- Active or non-active? ... Corrosion growth

Mitigation... Repairs ... Rehabilitation plans...
TRADITIONAL PIPELINE ILI TECHNOLOGIES
…FOR METAL LOSSES

RoCorr MFL-A

RoCorr MFL-C

RoCorr UT

RoCorr SIC
Each metal loss technology is best suited for certain types of morphologies.

If NWT < 10 mm, then A = 10 mm
Else A = NWT

Metal Loss Feature Type Definition by POF
TRADITIONAL ILI … LIMITATIONS?

**MFL-A**

*Better able to detect and size features with a greater circumf. profile*

**MFL-C**

*Better able to detect and size features with a greater axial profile*

**Compression wave UT**

*Able to detect and size larger areas of metal loss (e.g. general corrosion, channelling)*

*(Eddy current technology… shallow internal corrosion of minor sizes)*
TRADITIONAL ILI … LIMITATIONS?

...all but the smallest metal loss features are detectable…
• Can MIC defects be detected/sized by traditional ILI?
CAN MIC DEFECTS BE DETECTED/SIZED BY TRADITIONAL ILI?

Many occurrences … MIC can be detected and sized by traditional ILI …
Many occurrences … MIC can be detected and sized by traditional ILI …
**HOWEVER…**

**MIC & PINHOLES…**

Pinhole leaks
In North Sea WI due to MIC

3-4 mm diam

---

**…Can not be ID/sized by traditional ILIs…**
HOWEVER…
MIC & PINHOLES AT COMPLEX CORROSION CLUSTERS…

…Can not be reliably ID / sized by traditional ILIs…
ANY ILI SOLUTIONS FOR MIC PINHOLES & COMPLEX CORR. CLUSTERS? ... MFL ULTRA...

Circumferential Resolutions of common inspection technologies

<table>
<thead>
<tr>
<th>MFL-A</th>
<th>Ultrasonic</th>
<th>MFL-A Ultra</th>
<th>3D Laser Scan</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-6 mm</td>
<td>4 mm</td>
<td>1.6 mm</td>
<td>1-2 mm</td>
</tr>
</tbody>
</table>

24"
ANY ILI SOLUTIONS FOR MIC PINHOLES?

… MFL ULTRA…

- Enhanced Ultra-density sensors…
- Fully triaxial MFL sensor elements consisting of 3D integrated circuit modules…
- Sensor circumf. spacing of 1.6 mm & axial sampling of 1 mm …
- Factor 10 increase in the number of sensor elements per ILI tool compared to traditional MFL-A ILI

- Sensor suspension optimized for smooth girth weld passage

Pipeline Imaging resolution close to that of Laserscan reports
Dual sensor ring of MFL-A Ultra ILI tool as prerequisite to exploit full potential of new sensors

Traditional MFL high-resolution tools
- Sensor carriers placed on one sensor ring
- Carriers located min. 2 mm (0.08 inch) apart because of mechanical constraints

MFL-A Ultra tool
- Two sensor rings within magnetic yokes
- Improved axial track precision
Two magnet units for sizes from 8” to 18”:

Two staggered sensor rings in one magnet unit for sizes ≥ 20”:
Example: 1-dimensional lineplot – complex corrosion feature
ROCORM MFL-A VS. ROCORM MFL-A ULTRA

- Example: about palm-sized complex corrosion
• Carriers mounted in slightly offset fashion to achieve desired circumferential resolution
MFL A ULTRA…
COMPLEX CORROSION FEATURE VS FFS
TECHNOLOGY ADVANCES…

Constraints prevailed in medical imaging…

X-Ray

3D CT

…until these were resolved by a step change in technology.
MFL RESULTS LIKE A LASERSCAN

So why not doing the same in ILI?
MIC MORPHOLOGIES VS ILI CAPABILITY…

• Is there 1 and unique typical MIC defect morphology?
• Can MIC defects be detected/sized by traditional ILI?

• Can the sole use of ILI define whether MIC is present in my pipeline?
ILI PATTERNS – MIC CASE STUDIES (1)…

Typical pattern for MIC???

….Randomly distributed pits??….
ILI PATTERNS – MIC CASE STUDIES (2)…

- Crude oil line, 7% water cut; Constructed in 2004
- Inspected in 2007 by ILI
- 70% wt depth in 3 years!
- Pipeline failed...

ILI Pattern… Could we think MIC is a threat?

- Corrosion pitting in the BOL … characteristic pattern expected in a crude oil pipeline with a separate water phase… CO₂ corrosion?
ILI PATTERNS – MIC CASE STUDIES (3)…

- Crude oil line, 50% water cut; Constructed in 2005
- Inspected in 2007 by ILI MFL
- 85% wt depth!
- Aggressive cleaned & written off in 2 years….

ILI Pattern… Could we think MIC is a threat?

…..Deep pits in uniform metal loss areas
……
$\text{CO}_2/\text{H}_2\text{S}$ corrosion? Erosion at bottom? MIC?
MIC RECOGNITION FROM ILI?

Sampling?
• Pigging… sand, sessile bacteria, iron sulphide …

Susceptibility modelling?
• Historical ops review…
• elevation profile, etc. ..

• Holistic Threat review? What is the main driver?
• CO₂? H₂S? Bacteria? Water separation? Solid deposition? Flow characteristics?
• Can the sole use of ILI define whether MIC is present in my pipeline?

NO!

… No Sole Gold-Standard Technology yet exists through which MIC can be reliably verified…
CONCLUSIONS

• NO typical or unique MIC morphologies & metal loss patterns
• Traditional ILIs can detect most of MIC type defects…
• However… black swans…
  • Isolated pinholes <4mm
  • Pinholes in complex corrosion clusters, near GWs

• MFL-A Ultra has been developed to address pinholes and detailed resolution of complex corrosion geometry areas and near GWs
  • 3D imaging close to laser scan
  • Improved FFP assessments
  • Optimised intervention/management strategies
CONCLUSIONS

• **Sole Use** of ILI …
  - not enough to ID whether MIC is present & active
  - Not enough to manage MIC

• Requirement of a **framework** of different activities… **sampling, susceptibility modelling, inspection** to manage **reliably** MIC
THANK YOU FOR JOINING THIS PRESENTATION.

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MANAGEMENT OF MIC
MITIGATION OF MIC IN PIPELINES

- Scrub it Clean
- Microbial Contamination
- Disinfect
TIMELINE OF MIC

1920s-40s
Study of microorganisms in oil production

1934
Desulfovibrio (SRB) genus implicated in corrosion of metals

1940-50s
Depolarisation theory

1980s
Increase in MIC research – focused on SRB

1970s-80s
Biofilm – its importance and role in MIC

1990s
Advances in research techniques
Movement away from SRB

1920s
MIC awareness as a known problem

1920s-40s
Study of microorganisms in oil production

1934
Desulfovibrio (SRB) genus implicated in corrosion of metals

1940-50s
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MITIGATION OF MIC IN PIPELINES

Scrub it
Clean

Microbial
Contamination

Disinfect
MANAGING MIC IN PIPELINES
IT’S JUST ANOTHER CORROSION THREAT

Corrosion Management

- Organic Acids
- MIC
- Under Deposit
- CO₂
- Erosion
- H₂S
- Oxygen
- Oxygen
ELEMENTS OF THE CORROSION MANAGEMENT STRATEGY

Corrosion Management

Design

Control

Monitor (Report)

Assess

Feedback

Leading Indicators

Lagging Indicators
Corrosion Management System

Balanced: Non-biased to stakeholders, based on industrial standards & best practices (3rd party)

Effective: Process must be able to put in place the timely right course of action, must be both proactive & reactive.

Economic: Time/resource consuming process will be frowned upon

Transparent: Auditable clear decision making processes, engineering judgment should be peer reviewed

Living Process: Active to allow for incorporation of new research, legislation etc.

On Feedback Control: Part of the ‘active document’ requirements, timing is key to an effective system.

Data Management Control: By nature will be data hungry, easily managed with data from various functions, increased accuracy and reduced conservative assessment.
STEPS TO EFFECTIVE MIC MANAGEMENT

Step 1: Designing for MIC
- Make pipeline piggable
- Assess MIC threat – susceptibility modelling
- Abiotic & biotic parameters – modelled process data
- Preventive corrosion control engineering – materials selection/process control
- Early return on biofilm & inner surface condition – bioprobes/flush coupons/side streams
- Pre-Commissioning plan – start clean
- Baseline ILI – know your starting point
- Devise protocols for MIC controls, sampling, extraction, analysis and assessment.

Step 2: Control and Implementation
- MIC control systems in place – pigging, biocide & monitoring facilities
- Type of cleaning pig and initial frequency determined from flow modelling
- Biocide type & mode of deployment determined – injection/batch
- Simulation testing of controls for initial optimization – max biocide contact time
- Everything to set protocols for reproducibility
- Implementation according to strategy

Step 3: Monitoring and Assessment
- Collect microbial, corrosion & operational information according to monitoring protocols
- Determine mitigation effectiveness – KPI management – need return of system corrosion rates via ILI or on-line mode.
- Determine relationship between sessile & planktonic numbers
- Re-evaluate susceptibility assessment
- Data trending for confidence – feedback to change management
- Change frequencies for optimization of early warning based on MIC risk level
- Re-set cleaning frequency
MIC KPI?
CLEANING FOR MIC

1. Water, deposits, biomas
2. Sealing & scraping
3. Progressive pigging strategy
4. Increasing aggressiveness of pig type
5. Maintenance pig type & frequency on feedback
TYPES OF CLEANING TOOLS

- Sphere
- Foam
- Solid Cast
- Steel Mandrel
- Wires
- Cups
- Discs
- Smart
CHALLENGES WITH MIC

A unified predictive model for MIC susceptibility, risk, corrosion rate and location within pipelines

Protocols for sampling and analysis of a pipeline system to enable the use of global data

An EU program of collaboration on the problem of MIC
THANK YOU