The Australasian Corrosion Association

Panelist for Microbially-Induced Corrosion: Global Experiences in the Oil and Gas Industry

December 9, 2020
Dr Torben Lund Skovhus
Agenda
➢ Brief background on myself and VIA University College
➢ Types of MIC models today
➢ MIC R&D vs. Inspection
➢ A path to bridge the gap
➢ Newly developed Risk Based Inspection model
➢ Challenges for MIC models
➢ The end-user perspective
➢ COST Action: Euro-MIC
Torben Lund Skovhus, MSc, PhD

- Full time job as docent, researcher and teacher at VIA UC
- Climate & Supply Engineering Program
- Supervision of BSc, MSc and PhD students
- Project manager of research projects in industrial microbiology, e.g. corrosion, MIC and biofilms
VIA University College

- 8 campuses across Central Region Denmark
- 42 educational programs
- 8 Centers for Applied Research, Development and Innovation
- 18,500 students per year
- 2,100 employees (full-time equivalent)
Research Center for Built Environment, Energy, Water and Climate

- Geothermal energy & sustainable storage
- Climate challenges and adaption
- Geology and groundwater resources
- Drinking water supply
- Wastewater
- Corrosion and materials
- Circular economy
- Indoor climate and comfort
- Digital construction
- Augmented and Virtual Reality
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Henrik er en af landets første klima- og forsyningsingeniører

Danmarks første afgangshold af klima-og forsyningsingeniører får deres eksamensbevis i dag.
Topic of today:

“Bridging the gap between inspection strategies and applied MIC research in the Oil & Gas industry”
www.geno-mic.ca

Microbiologically Influenced Corrosion

geno-MIC: Managing Microbial Influenced Corrosion in Canada's Offshore & Onshore Oil Production Operations

Knowledge
Identify the microbial actors and pathways, chemical species, and MIC mechanisms that lead to facility failures.

Assays & Devices
Develop -omics and chemical-based monitoring tools to detect and measure MIC and associated chemical end-products.

Models
Devise better predictive modeling and risk assessment tools to help improve materials design and maintenance/operating practices.

Translation
Improve corrosion control strategies to reduce potential failures by developing standards and guidelines.

Latest News
We need your input.
Take a short survey.

MIC Forum CORROSION 2019
click here for presentations

MIC Forum NAWC 2019
click here for presentations

Congratulations to Damon Brown on being awarded The Alexander Graham Bell Canada Graduate Scholarship - Doctoral through NSERC
Recent Developments in Prediction and Modelling of Microbiologically Influenced Corrosion in the Oil and Gas Industry

Torben Lund Skovhus, VIA University College
Christopher Taylor, DNV GL
Richard B. Eckert, DNV GL
MIC modelling and prediction is an area that has not been fully developed.

Models can provide numerous benefits:

- guidance on MIC mitigation selection and prioritization
- identification of data gaps
- a scientific basis for risk-based inspections
- technical justification for asset design and life-extension
Publications on MIC

**Figure 1. Temporal distribution of MIC publications.**

Bibliometric Analysis of Microbiologically Influenced Corrosion (MIC) of Oil and Gas Engineering Systems — https://doi.org/10.5006/2620
Development of publications on MIC

Bibliometric Analysis of Microbiologically Influenced Corrosion (MIC) of Oil and Gas Engineering Systems — https://doi.org/10.5006/2620
Highly siloed field...

Bibliometric Analysis of Microbiologically Influenced Corrosion (MIC) of Oil and Gas Engineering Systems — https://doi.org/10.5006/2620
Types of Models

Current:
• MIC mechanistic models
• MIC susceptibility models
• Risk-based models

Future:
• Molecular level models
• Integrated models
• Bayesian models
# MIC Mechanistic Models

<table>
<thead>
<tr>
<th>Authors</th>
<th>Key parameters</th>
<th>Main factors included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxwell and Campbell (2006), Maxwell (2006)</td>
<td>Speed of biofilm development, concentration of sulfide and velocity are considered driving</td>
<td>pH, Temperature, Total dissolved solids, Deposits, Pigging frequency, Oxygen ingress, Fluid velocity</td>
</tr>
<tr>
<td>Allison et al. (2008)</td>
<td>Nutrient availability and quantity of SRB and GHB</td>
<td>Total dissolved solids, Quantified SRB and GHB numbers</td>
</tr>
<tr>
<td>Sørensen et al. (2012), Skovhus et al. (2012)</td>
<td>Quantity of SRP and MET</td>
<td>Quantified numbers of SRB, SRA and MET</td>
</tr>
<tr>
<td>Taxèn et al. (2012)</td>
<td>Quantity of SRB</td>
<td>Oxygen, Quantified SRB numbers</td>
</tr>
</tbody>
</table>
## MIC Susceptibility Models

<table>
<thead>
<tr>
<th>Authors</th>
<th>Key Outcome</th>
<th>Main factors included</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sooknah et al Corrosion/2008, paper no. 08503 Internal MIC</td>
<td>MIC susceptibility - likelihood</td>
<td>Temperature, partial pressure of gases, flow rate, water quality, oxygen and pipe pigging, ability for biofilm growth</td>
</tr>
<tr>
<td>Pots et al Corrosion/2008, paper no. 08503 Internal MIC</td>
<td>Ranking of oil pipelines for MIC susceptibility</td>
<td>Temperature, pH, dissolved solids, and nutrients; operating parameters, mitigation measures (pigging and biocide)</td>
</tr>
<tr>
<td>Gas Research Institute GRI-92/0005, 2005 Internal or external MIC</td>
<td>Likelihood of corrosion damage on a sample being MIC</td>
<td>Bacteria numbers by MPN Sulfide, Iron Oxide forms, pit shape, chlorides, pH</td>
</tr>
</tbody>
</table>
MIC Research vs. Inspection

• MIC research has been carried out in silos
• Just like corrosion and metallurgical research
• Inspection has focused on more mature methods
• Bringing DNA-based methods (MMM) into the play has been a game changer for many industries
• The Oil and Gas industry has still to see the benefits...
• NACE TM21465-xxxx now established
• NACE TM0212-2018 (internal)
• NACE TM0106-2016 (external)
• More to come...
MIC Research vs. Inspection

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“the cost to generate a high-quality 'draft' whole human genome sequence in mid-2015 was just above $4,000; by late in 2015, that figure had fallen below $1,500. The cost to generate a whole-exome sequence was generally below $1,000”
A path to bridge the gap...

• MSc Student at University of Stavanger 2013-14

• Working with DNV GL Norway and Operators from the Danish Sector in the North Sea


• A new MSc student from University of Alberta onboard from 2018-2021 (ISMOS-7 presentation and several talks)
MIC-RBI Model for O&G Topside Systems

Stepwise procedure for assessment of MIC

SPE-179930-MS 2016, Management of Microbiologically Influenced Corrosion in Risk Based Inspection Analysis, TL Skovhus, ES Andersen, E Hillier
MIC-RBI Model for O&G Topside Systems

Step 1. Screening flow chart:

- Qualitative data
- Historical/inspection data
- Microbiological monitoring and mitigation
- Temperature, pH

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MIC-RBI Model for O&G Topside Systems

Step 1. Screening flow chart:
- Qualitative data
- Historical/inspection data
- Microbiological monitoring and mitigation
- Temperature, pH

Step 2. PoF ranking tool:
- Semi-quantitative parameters
- Settlement potential
- Oxygen ingress
- Mitigation effectiveness
- Availability of nutrients
- Expected rate of metal dissolution

SPE-179930-MS 2016, Management of Microbiologically Influenced Corrosion in Risk Based Inspection Analysis, TL Skovhus, ES Andersen, E Hillier
MIC RBI model: Step 1

**MIC SCREENING ASSESSMENT**

- **Already established**
  - Historical data: what has happened since last assessment?
    - Old screening assessment satisfactory
      - Old screening assessment NOT satisfactory
        - $10^\circ C \leq T \leq 90^\circ C$
          - False
          - $3.5 \leq \text{pH} \leq 12$
            - False
            - MIC mitigation effort
              - True
              - Negligible PoF
              - False
              - Significant PoF
        - False
          - Does not identify type of microbial group present
            - Identifies type of microbial group present
              - SRP and/or methanogens identified
                - YES
                - NO
              - Identifies type of microbial group present
                - YES
                - NO
        - NO
MIC RBI model:
Step 2

Settlement potential

Nutrients / E(rate)

Mitigation effectiveness

Oxygen ingress

Path number

PoF Ranking

<table>
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<tr>
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<tr>
<td>Very high</td>
</tr>
<tr>
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Real Data Testing: Screening Assessment

- Danish sector of the North Sea
- CC1: Downstream of the 1\textsuperscript{st} stage separator on the outlet pipework to the 2\textsuperscript{nd} stage separator
- Key operating parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Corrosion circuit 1</th>
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<tbody>
<tr>
<td>Temperature</td>
<td>74 °C</td>
</tr>
<tr>
<td>pH</td>
<td>6.4 (production wells)</td>
</tr>
<tr>
<td>MIC mitigation effort</td>
<td>Sulfate removal, biocide</td>
</tr>
<tr>
<td>Microbe monitoring</td>
<td>Sessile and planktonic</td>
</tr>
<tr>
<td>Flow velocity</td>
<td>2.8 m/s</td>
</tr>
<tr>
<td>Sulfate content</td>
<td>&gt; 10 mg/l (production wells)</td>
</tr>
<tr>
<td>Carbon from fatty acids</td>
<td>-</td>
</tr>
<tr>
<td>Nitrogen content</td>
<td>-</td>
</tr>
<tr>
<td>Mitigation effectiveness</td>
<td>Not established</td>
</tr>
<tr>
<td>Oxygen ingress</td>
<td>No</td>
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MIC RBI model: Step 2

Settlement potential
Nutrients / E(rate)
Mitigation effectiveness
Oxygen ingress
Path number

PoF Ranking

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Challenges for MIC Models

- Reliability of microbiological data from field samples (MPN vs. MMM)
- Inclusion of biotic and abiotic effects of the environment on corrosion
- Microbiological/material interactions in complex biofilms/corrosion products
- Diverse microbiological/chemical/physical environments in engineered systems
- Lack of insight about MIC growth rates
  - Microorganisms can initiate and promote corrosion different ways
MIC Models: End-User Needs

- Design and Life Extension
  - Materials selection
  - Mitigation design
  - Monitoring design
  - Basis for life extension
MIC Models: End-User Needs

• Design and Life Extension
  • Materials selection
  • Mitigation design
  • Monitoring design
  • Basis for life extension

• Operations
  • MIC control
  • Sourcing control
  • RBI
  • Resource prioritization
  • Optimization of mitigation
Our real challenge is *true* collaboration among disciplines... for the benefit of the end-users.
Current Efforts – Canada & USA

- Models must provide a *practical result* for operators to drive decision making
- Data inputs must be accurate and reliable, e.g. MPN vs. MMM
- Models need to use each other’s outputs to get a more refined answers to benefit the end user corrosion management system
- Integrating different models, molecular, mechanistic, probabilistic, risk – can it be done?
- A current research project (LSARP MIC) deals with this challenge (2016-2021)
- Project website: [www.geno-mic.ca](http://www.geno-mic.ca)
Integration of State-of-the-Art Methods for Assessing Possible Failures due to Microbiologically Influenced Corrosion

Andre Abilio, EIT
Rick B. Eckert, DNV GL | Torben Lund Skovhus, VIA University College | John Wolodko, University of Alberta
Future Efforts - Europe

- European MIC Network Webinars and Workshops (2 workshops and 4 webinars in the spring and 5 webinars in the fall of 2020)

- European MIC Network Webinars and Workshops – more to come in 2021

- COST Action: “Euro-MIC” was submitted November 13 by 90 applicants world wide

- Looking into an application of a PhD Training network – Australia welcome!
COST Action: European MIC Network – New paths for science, sustainability and standards

Acronym: Euro-MIC

Interdisciplinary topic:
Biological sciences, Microbiology, Chemical sciences, Corrosion, Materials engineering, Biophysics for materials engineering applications, Environmental engineering, Risk assessment, prevention and mitigation, Environmental biotechnology, Environmental biotechnology, e.g. bioremediation, biodegradation
Goals of Euro-MIC

The main challenges include:
1. Lack of an effective communication network between stakeholders in the MIC field
2. Incoherent terminology
3. Fragmented expertise, including gender, age and geographic aspects
4. Reluctance of industry involvement
5. Limited number of trained personnel due to insufficient educational programs and resources
6. Ineffective monitoring and mitigation strategies
Working Groups

WG 1: Intersectoral bridging
WG 2: Diagnostic technology development
WG 3: Development of innovative monitoring technologies
WG 4: Strategize ‘green’ mitigation methods
WG 5: Achieving standardization
References for this presentation

- Microbiologically Influenced Corrosion in the Upstream Oil and Gas Industry (2017)
- Management and control of microbiologically influenced corrosion (MIC) in the oil and gas industry—Overview and a North Sea case study (2017)
- Management of Microbiologically Influenced Corrosion in Risk-Based Inspection Analysis (2018)
- Modeling of Microbiologically Influenced Corrosion (MIC) in the Oil and Gas Industry - Past, Present and Future ID#11398 (2018)
- Educational video on MIC (free to use): LINK
Contact details

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[Link: Corrosion & Materials]
[Link: References and activities]

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