Managing Microbial Corrosion in Canadian Offshore & Onshore Oil Production Operations – Project Overview

Faisal Khan

Engineering and Applied Science

MEMORIAL UNIVERSITY

geno-MIC
microbiologically influenced corrosion

Project Overview

- Improved monitoring, modeling & mitigation of MIC
- Integrate MIC as part of industry standards & corrosion management frameworks

Meeting today:

- Updates on research activities

Project scope

Activity 1: Knowledge

Activity 2: Devices/Assays

Activity 3: Models

Activity 4: Translation

GE^{3}LS

Project Scope & Deliverables

Activity 1

Knowledge
(for action!)

- MIC Genes
- Indicators
- Rates
- SOPs

Activity 2

Devices/ Assays

Activity 3

Models

Activity 4

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MIC into Standards & Corrosion Management Frameworks

Interactions/input/feedback
between Researchers & End-users

Project Activities

Activity 1: Knowledge

- **1.1** – Sampling/genomics
- **1.2** – Database/Ontology
- **1.3** – MIC offshore
- **1.4** – MIC onshore
- **1.5** – Biofilms/resistance

Activity 2: Devices/Assays

- **2.1** – Diagnostic genes
- **2.2** – In line monitoring tools
- **2.3** – Chemical & biosensors

Activity 3: Models

- **3.1** - MIC Mechanistic & Predictive models
- **3.2** - MIC Risk Assessment Models

Activity 4: Translation

- **4.1** – Genomics in O&G – assessing barriers
- **4.2** – Recommended guidelines
- **4.3** – Dissemination

Activity 1

Working Group - Activity 1

Knowledge

Hawboldt, Gieg, Bottaro, Beiko, Strous, Haile, Wolodko, Suflita, Hubert, Turner, Voordouw

1.1 Field Sampling and Genomics

- **Genomics**

  Preliminary Experiment:

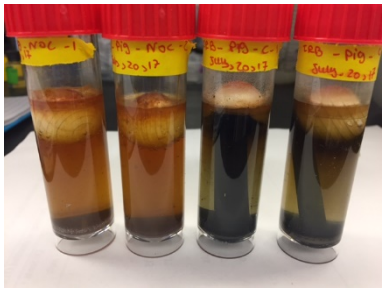
  16S rRNA gene sequencing vs. 'bug bottles' (BART tests and SRB/APB MPNs) for microbial community analysis

Field Samples

Bug Bottles – pre-grow

Extract DNA,
16S rRNA gene sequencing

BART tests
+/- corrosion coupons



SRB, IRB, DN,
HAB, APB, SYLM

SRB/APB MPNs

How do the results compare?

Extract DNA,
16S rRNA gene sequencing

1.2 Database and Ontology

- **Ontology**

MICON (Microbially Influenced Corrosion Ontology)

- Held two MICON meetings
- MetalHCR database schema as initial structure of ontology
- Early ontology build decisions:
  - MICON
  - OWL format
  - Open access
  - Imports of other relevant and established ontologies
- Contacted potential collaborators for the ontology:
  - OBI (Ontology of Biomedical Investigations)
  - OMP (Ontology of Microbial Phenotypes)
  - ECO (Evidence and Conclusion Ontology)

1.3 Offshore Chemistry

- **Objectives**
  - Investigating relationships between chemical species in oil and produced water
  - MIC mechanisms that lead to facility failures in offshore oil production operations and in onshore pipelines
- Progress
  - Review of literature to identify chemical compounds playing role in microbial growth, corrosion, and/or present in offshore process streams (produced water, crude oil)
  - Identified environments we will simulate (sulfur, nitrogen, oxygen and combination0 → inclusion of carbon dioxide?
    - Vary T, pH, P, and salinity → speciation
- Next steps – thermodynamic analysis of proposed “environments”

1.3 Offshore Chemistry

- Next Steps
  - Once samples received PDF (Ali) begin analysis to inform PhD (Abdulhaq's) simulations and experiments
  - Information from genomes/microbial group on chemistry they may be "seeing" in samples
  - Biofilm – set up meeting with Ray to discuss role and chemistry in more detail to inform simulations, experiments and analysis

1.4 MIC Onshore

- **Background**

Onshore biologically active sludge corrosivity tests will be conducted using two systems (housed at InnoTech AB, Devon):

  - Bench-top static system
  - Lab/Pilot-scale flow loop system
    - Fabrication and commissioning to be performed once a suitable PhD student is hired

- **Progress**
  - SOP- onshore document in progress
  - Lab scale testing system design:
    - Batch
    - Flow through
    - Flow-loop
  - Recruitment underway for 2 PhD students (Jan 2018)

1.5 Biofilms and biocides

- Damon Brown, the PhD student hired to work on this project completed his transition to the university from a corrosion engineering company and has started his program

- Ongoing discussions regarding experimental biofilm methodology, and are recognizing now the need for very well controlled parameters

    - Defined growth media

    - Model microbial community

Project Overview

<u>Working Group - Activity 2</u>

Devices/Assays

Bottaro, Gieg, Suflita, Pang, Haile, Wolodko

2.1 Diagnostic gene detection

- U of C: Drs. Mohita Sharma and Natalie Rachel newly hired
- Building off RPA (Recombinase Polymerase Amplification) technology devised by TwistX
- Currently surveying literature for key SRB and other groups of microbes, in samples associated with MIC to get consensus sequences for key taxa and genes

2.2 In-line monitoring

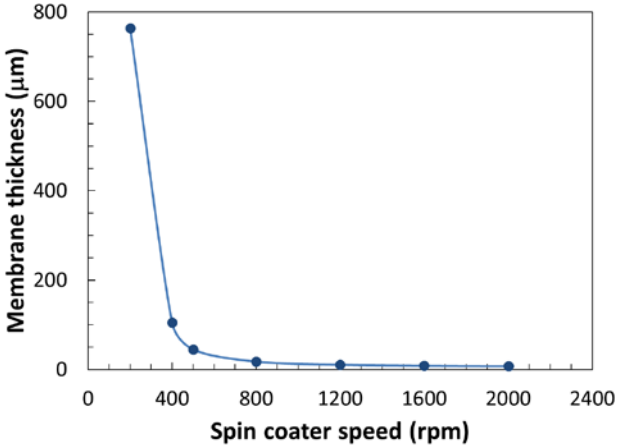
A prototype for monitoring biofilm – Gantt Chart

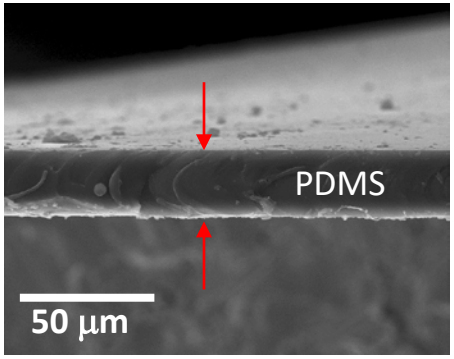
Start Date Oct 1, 2016											
LEGEND CODE											
On = On schedule	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
Ahead = ahead of schedule	2016		2017			2018					
Behind = behind schedule	Oct 1, - Dec 31	Jan 01 - Mar 31	Apr 01 - Jun 30	Jul 01 - Sep 30	Oct 01 - Dec 31	Jan 01 - Mar 31	Apr 01 - Jun 30	Jul 01 - Sep 30	Oct 01 - Dec 31	Jan 01 - Mar 31	A
Complete = milestone finished											
Literature Review											
Biofilm Monitoring Tools/Capacitance Based											
Journal Review Paper											
Patent landscape review and application											
MIC/corrosion Monitoring tools											
Conference Paper											
Prototype development											
Engineering design											
Fabrication											
Prototype Validation											
Bench-top Validation											
Flow-loop Validation											
Journal paper											
Thesis writing											
End											

2.3 MIPs & sulfide sensor

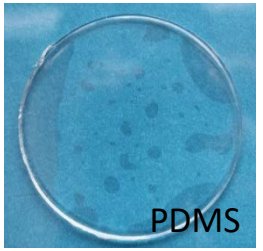
- Sulfide sensor (NRCan)
  - Incorporation of H_2S permeable PDMS polymer membrane for improved sensor selectivity

Fabrication of PDMS by spin coating process optimized





Spin Speed (rpm)	200	400	500	800	1200	2000
Membrane Thickness (µm)	764	105	44.6	17.6	10.6	7.24



- New MSc student Danika Nicoletti just started at U of C
  - Surveying literature for organisms harboring ‘sulfide oxidase’

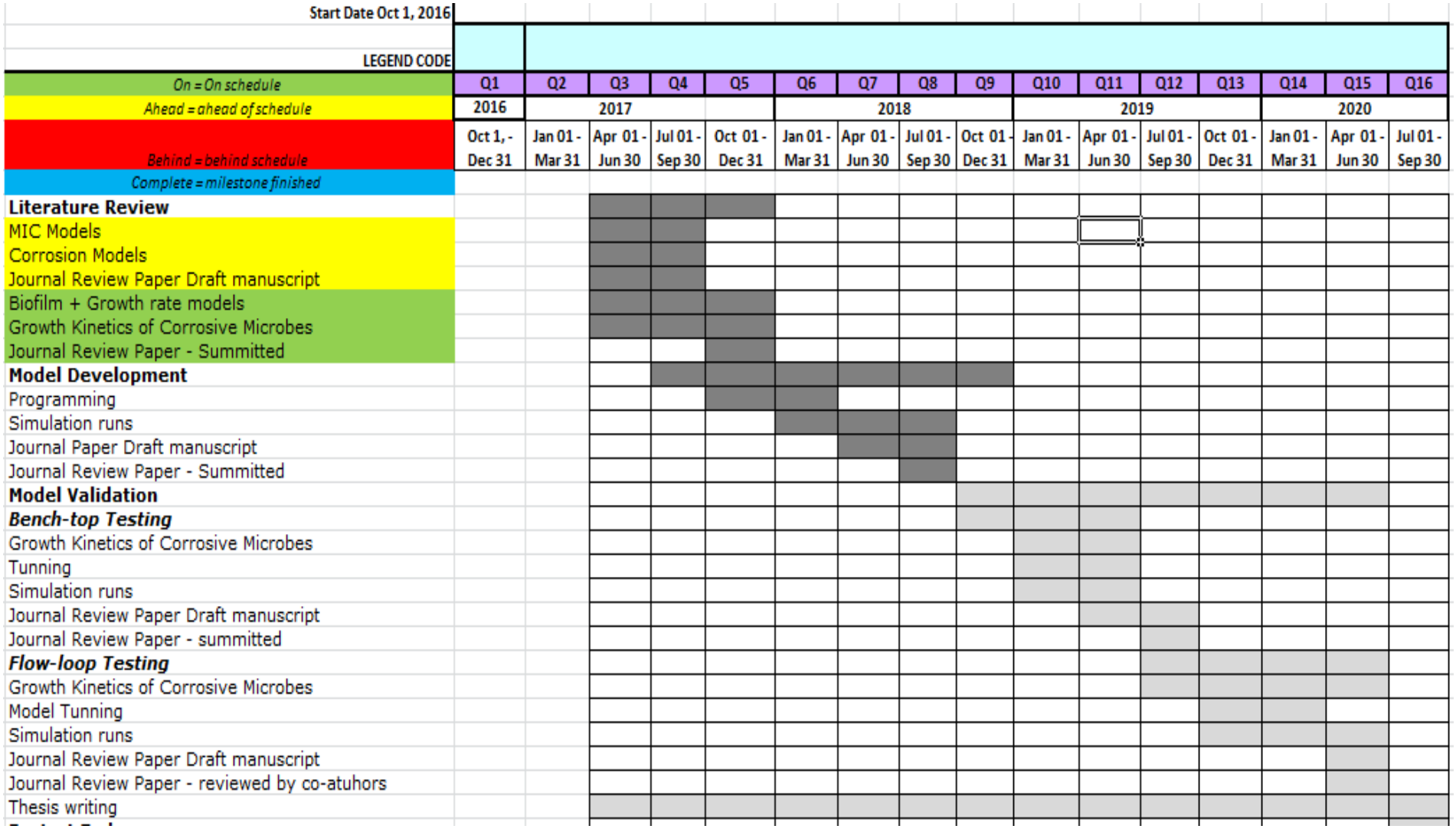
Project Overview

Working Group - Activity 3

Models

Haile, Khan, Wolodko, Skovhus

3.1 Mechanistic and predictive MIC models



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Literature Review																
MIC Models																
Corrosion Models																
Journal Review Paper Draft manuscript																
Biofilm + Growth rate models																
Growth Kinetics of Corrosive Microbes																
Journal Review Paper - Summitted																
Model Development																
Programming																
Simulation runs																
Journal Paper Draft manuscript																
Journal Review Paper - Summitted																
Model Validation																
Bench-top Testing																
Growth Kinetics of Corrosive Microbes																
Tunning																
Simulation runs																
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Model Tunning																
Simulation runs																
Journal Review Paper Draft manuscript																
Journal Review Paper - reviewed by co-atuhors																
Thesis writing																

3.1 Mechanistic and predictive MIC models

- **Model development efforts at InnoTech**

✓ Relationship between planktonic and sessile bacteria: Theoretical/Empirical approach

✓ Effect of flow velocity on detachment rate: boundary condition and Peclet number effect (competition between convection vs diffusion)

✓ Effect of temperature in bacteria kinetics: Monod equation parameters

✓ Effect of microbes interaction in growth kinetics and corrosion rate

- **Next step**

✓ Coding to include the following parameters:

- Few microbes to be included in addition to SRB
- Growth kinetics
- Transport phenomenon (mass transfer vs momentum)
- Environmental conditions (Chemistry + Operating conditions)

3.1 Mechanistic and predictive MIC models

- **Mechanistic Model development efforts at MUN**
  - **Mechanistic Model development:** A modification of the Gu-Zhao-Nesic model is proposed to incorporate the impact on the corrosion rate of this by-product **(Nonso Ezenwa)**
  - **Predictive Model development:** A symptom based approach is being considered in the mechanistic model using microbial footprint **(Abdul Waris)**
  - **Molecular Model development:** Literature review in progress; the use of molecular mechanics and quantum mechanics can be used verify the various hypothesis that have been proposed to explain SRB corrosion **(Nonso Ezenwa)**

3.2 – MIC Risk Assessment Models

Objectives

- Understanding the state-of-the-art and the requirements for practical MIC Quantitative Risk Model
- Integrating the probabilistic failure rate model with MIC failure consequence model to develop a MIC Quantitative Risk Model
- Use of risk-time profiles as a criteria for remining life evaluation and fitness-for-service decisions
- Sharing the model with the industry to test and improve
- Developing recommendations for existing integrity assessment and FFS codes, standards and guidelines

3.2 – MIC Risk Assessment Models

Progress

- A bibliometric MIC review is submitted to NACE Corrosion
- MIC Risk Models Literature review is complete
- Knowledge gap analysis started, review paper manuscript in preparation
- A probabilistic failure rate model based on Object Oriented Bayesian Analysis (OOBA) is under development. Manuscript under preparation

Project Overview

Working Group - Activity 4 Translation (GE^{3}LS)

Skovhus, Wolodko, Gieg, Khan, Eckert, Lefsrud, Jack

4.1 – Genomics in O&G – assessing barriers

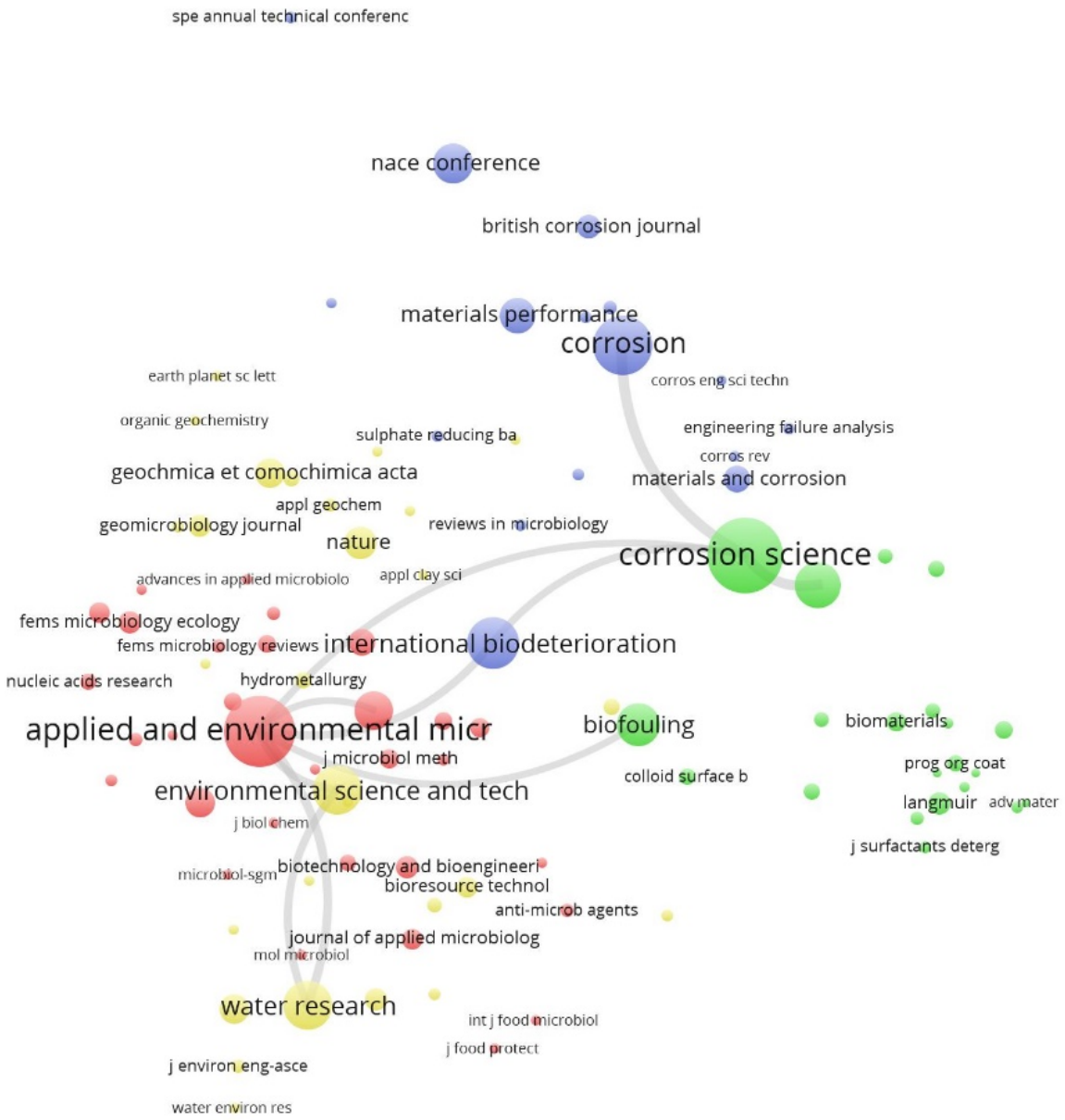
- Completed a high level bibliometric review of MIC in conjunction with Memorial University (lead)

- Review Paper accepted (with revisions) for publication in Corrosion.

4.1 – Genomics in O&G – assessing barriers

In Progress

- Conducting further bibliometric analyses to investigate the following:
  - Interdisciplinary of MIC research, and whether or not information is being passed between disciplines
  - Relationship between academia and industry, specifically the publishing and citation tendencies between conference papers and journal articles (i.e. Does academic research in MIC get translated to industry?)
- Preliminary research into patents related to MIC tools and technologies, and assessing possible focus areas and analysis outcomes.
- Review of MIC failure statistics and assessment methods in Alberta pipelines (i.e. to determine quantified statistics related to prevalence of MIC). Currently, finalizing agreement with AER to access their failure report databases.
- Revision of industry surveys to reduce length (multiple surveys and methods being considered).
- Developing plan for MIC technology mapping exercise.



Co-citation Map of MIC Related Journals
(Cited 100 or more times)

Source: Hashemi, Khan, Hawboldt, Bak, Lefsrud, Wolodko (2017), NACE Corrosion Journal, Accepted with minor revisions

TABLE 3. Most frequent co-citation linkages between MIC related publications

Node 1	Subject Category	Node 2	Subject Category	VOSViewer Link Strength
Corrosion Science	Metallurgy/Metallurgical Engineering, Materials Science Multidisciplinary	Corrosion	Metallurgy/Metallurgical Engineering, Materials Science Multidisciplinary	14,269
Corrosion Science	Metallurgy/Metallurgical Engineering, Materials Science Multidisciplinary	Electrochimica Acta	Electrochemistry	13,632
Applied Environmental Microbiology	Microbiology and Applied Microbiology	Water Resources	Water Resources, Environmental Sciences, Engineering Environmental	9,701
Applied Environmental Microbiology	Microbiology and Applied Microbiology	International Biodeterioration Biodegradation	Environmental Sciences, Biotechnology Applied Microbiology	7,997
Water Research	Water Resources, Environmental Sciences, Engineering Environmental	Environmental Science Technology	Environmental Sciences, Engineering Environmental	7,954
Applied Environmental Microbiology	Microbiology and Applied Microbiology	Environmental Science Technology	Environmental Sciences, Engineering Environmental	7,677
Corrosion Science	Metallurgy Metallurgical Engineering, Materials Science Multidisciplinary	International Biodeterioration Biodegradation	Environmental Sciences, Biotechnology Applied Microbiology	6,915
Corrosion Science	Metallurgy Metallurgical Engineering, Materials Science Multidisciplinary	Applied Environmental Microbiology	Microbiology and Applied Microbiology	6,387
Applied Environmental Microbiology	Microbiology and Applied Microbiology	Biofouling	Marine Freshwater Biology, Biotechnology Applied Microbiology	6,250
Applied Microbiology Biotechnology	Applied Microbiology and Biotechnology	Applied Environmental Microbiology	Microbiology and Applied Microbiology	6,119

Source: Hashemi, Khan, Hawboldt, Bak, Lefsrud, Wolodko (2017), Corrosion Science, Accepted

4.2 – Recommended guidelines

- A formal request has been sent to NACE to establish a new TG (answer is pending)
- A meeting in Phoenix has been scheduled at CORROSION 2018
- The name of the standard TG would be “Molecular Microbiological Methods – Sample Handling and Laboratory Processing”
- Renato De Paula – Chair
- Torben Lund Skovhus – Vice Chair

4.2 – Recommended guidelines

- Sept. 8 a meeting with DNV GL on the review cycle of DNV-RP-G101 was held
- MIC will be included in a new appendix in the next version of the document
- Torben & Rick agreed to draft a TOC on what the appendix could contain
- DNV GL in Norway will review input and give feedback and a deadline
- Torben & Rick will start to collect input to MIC Failure investigation protocol shortly (operator and end-user input is important)
- A best practice developed by academia for industry application…