Managing Microbial Corrosion in Canada's Offshore & Onshore Oil Production Operations

A Brief Introduction to MIC

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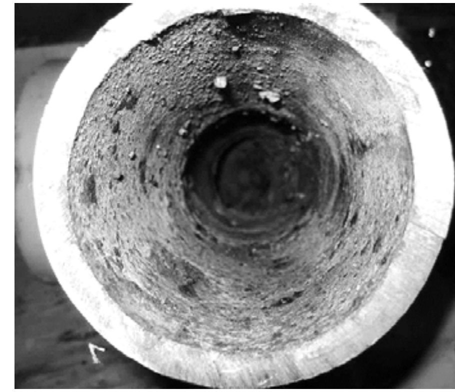
Microbiologically Influenced Corrosion

Corrosion Mechanisms

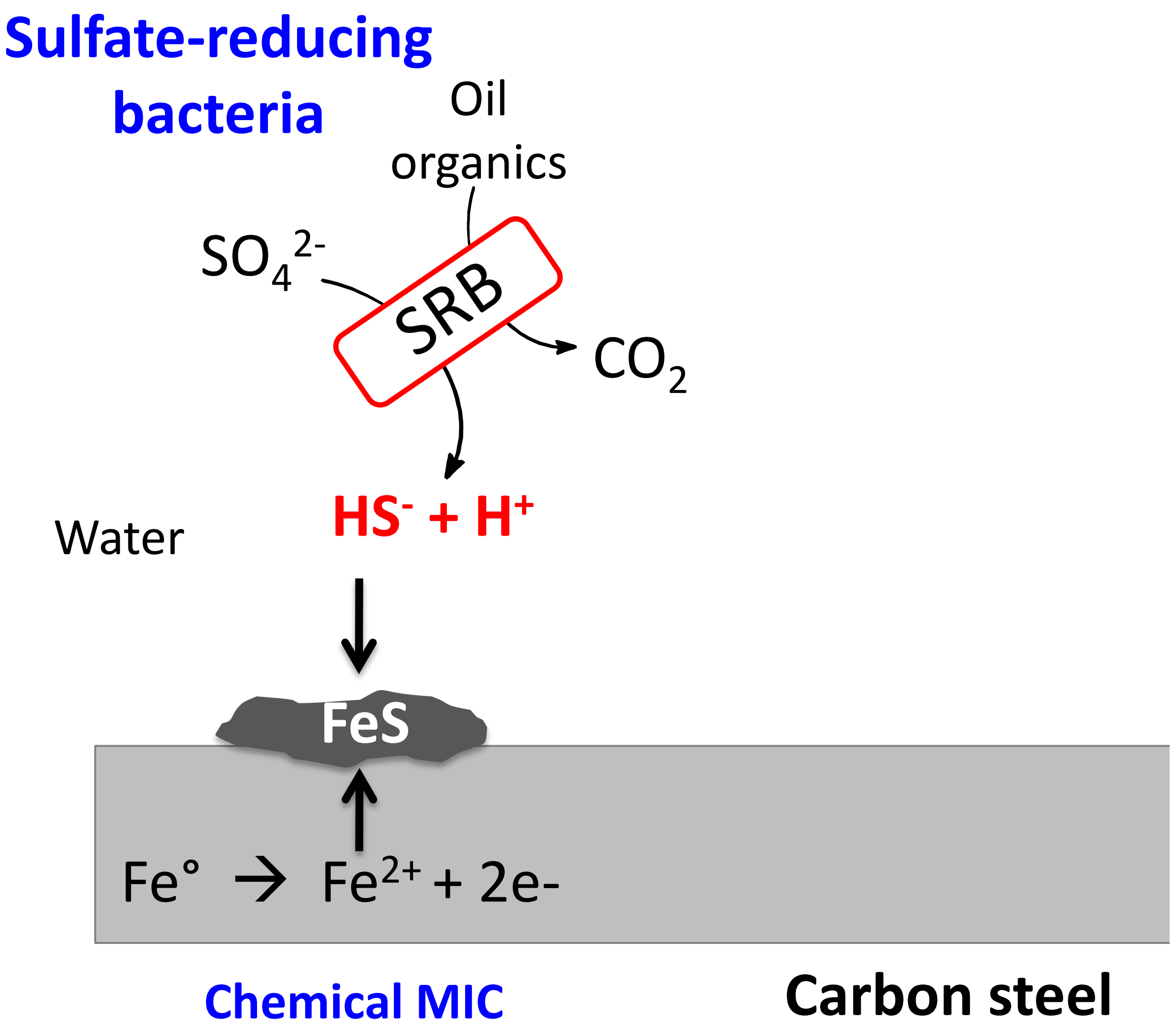
- Abiotic (not microbiological)
  - Oxygen, CO_2, acid, concentration cell, etc.
- Biotic
  - Microbiologically "influenced"
    - Microorganisms had some effect on abiotic conditions
  - Microbiologically "induced"
    - Corrosion caused principally by microorganisms
- Combination
  - Probably common; all corrosion is electrochemical and bacteria are everywhere

How do microorganisms affect corrosion?



– Fixing anodic sites (on passive alloys in particular)
– Forming crevices and occlusions; concentration cells
– Producing corrosive metabolites (e.g. sulfuric acid, organic acids)
– Changing the nature or kinetics of the rate controlling reaction by;
  - Polarization of the anode or cathode
  - Direct uptake of electrons from the metal surface (EMIC)
  - Altering passivating films and anode/cathode ratios
  - Affecting mass transport (increase and decrease)
  - Facilitating intermediate corrosion cell reactions

SRB CMIC and EMIC



MIC and Under Deposit Corrosion (UDC)

- "Biotic" effects of deposits
  - Increased surface area, retention of water, protection from flow and chemical treatment, energy sources, electron donors/acceptors
- Abiotic effects of deposits
  - Electrochemically inert
    - Sand, wax
  - Electrochemically active
    - Iron sulfides

Biofilms are important

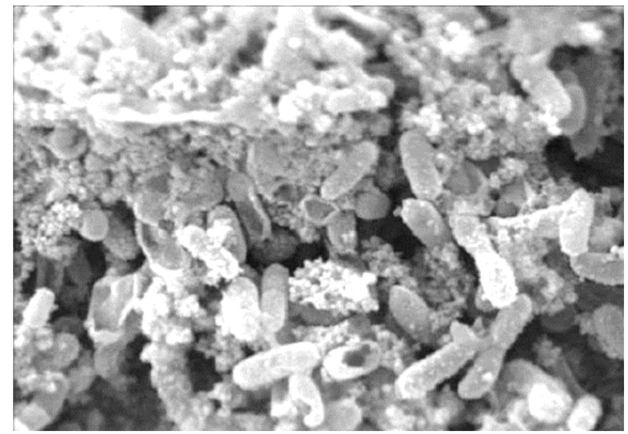
Composed of extracellular polymeric substances (EPS) including polysaccharides, proteins, nucleic acids, etc. in addition to:

… inorganic particles from the fluid phase

… corrosion products

… products of microbial activity

… water



Create a microenvironment on the metal surface that differs significantly from the bulk environment, and also ;

... provides protection

... provides access to energy sources

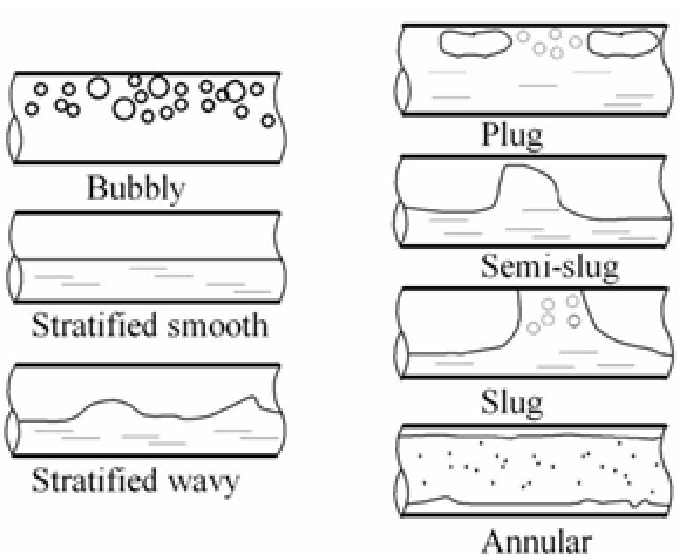
... is not uniformly distributed and can change over time

Where is MIC a problem?



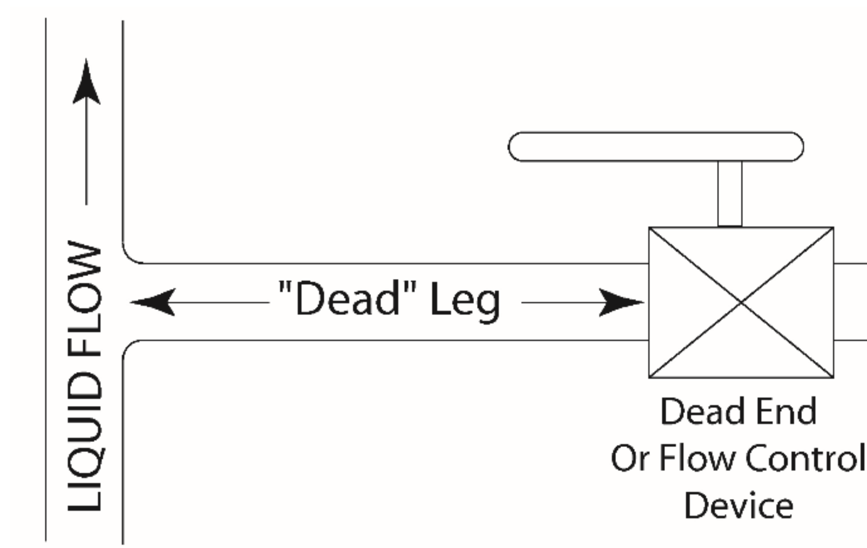

Oil gathering pipeline	Presence of thermophilic archaea
Multiphase gathering station	Presence of methanogens and sulfate-reducing prokaryotes
Seawater injection plant	Role of inadequate mitigation applications for MIC
Produced water handling	Microorganisms and water composition (use of nitrate)
Natural gas pipeline	Dead leg, water accumulation, acid producing bacteria
Gas storage field line	CO_2, water vapor and bacteria present
Crude storage tank	Presence of iron-corroding methanogens
Bitumen extraction water	Presence of methanogenic archaea
Fuel grade ethanol storage	Presence of acid producing and sulfate reducing bacteria

Conditions that promote MIC



Stratified flow or no flow:

- Below critical velocity for water entrainment



Dead legs:

- Permanent

- Operational

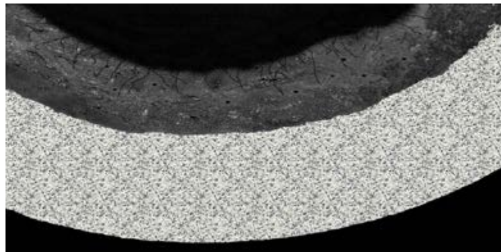
Typical MIC Mitigation

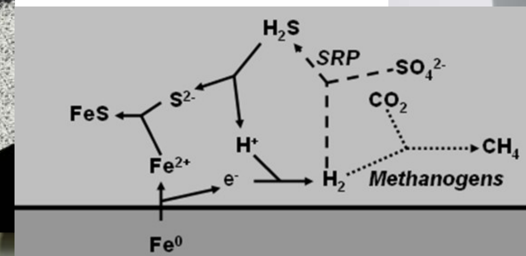
Inhibitor and Biocide Injection

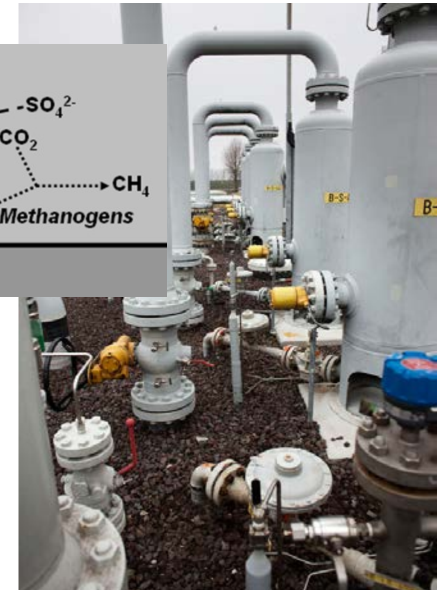
Maintenance Pigging

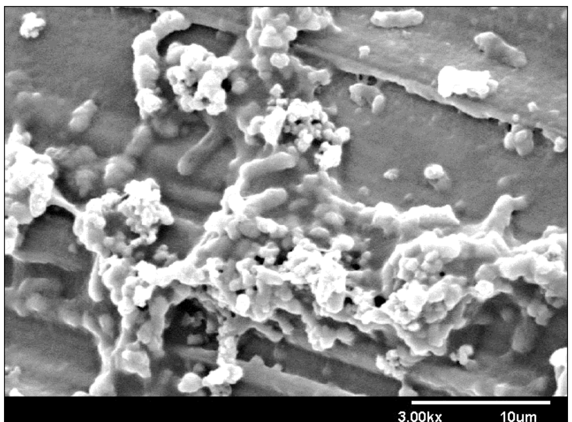
Chemical Batch Pigging

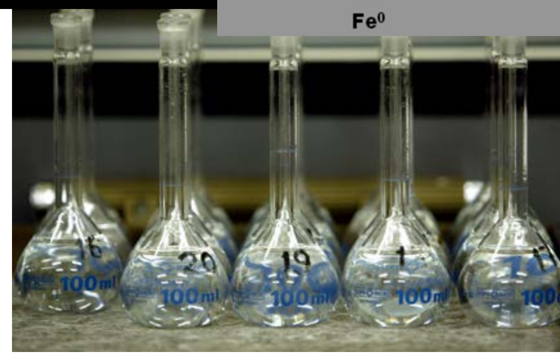
Diagnosing and Predicting MIC

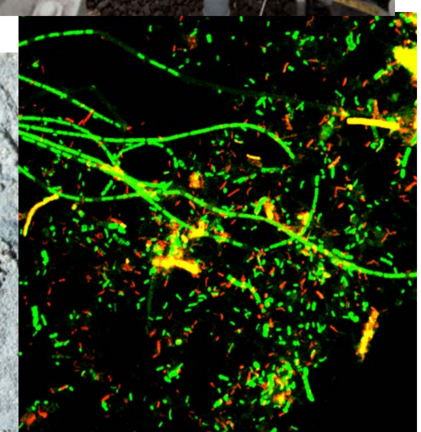












Common Framework for Characterizing MIC

Physical Conditions
Chemical Composition
Corrosion Products
Material Properties
Microbiolog y

1. What physical conditions are present?

- Operations (temp, pres, flow); design (water holdup)

2. What chemical conditions are present?

- Liquids, solids, chemical treatment; energy sources

3. What corrosion products were formed?

- Composition reflect corrosion reactions

4. How does the material behave in this environment?

- Metallurgy; susceptibility

5. What are the microbiological characteristics of the biofilm? - Differences in microbial distribution (numbers, types, functions) relative to corrosion

- Predominant, active species and/or functional groups of microorganisms present; what do they do?

Case Study: Otter Crude Oil Production

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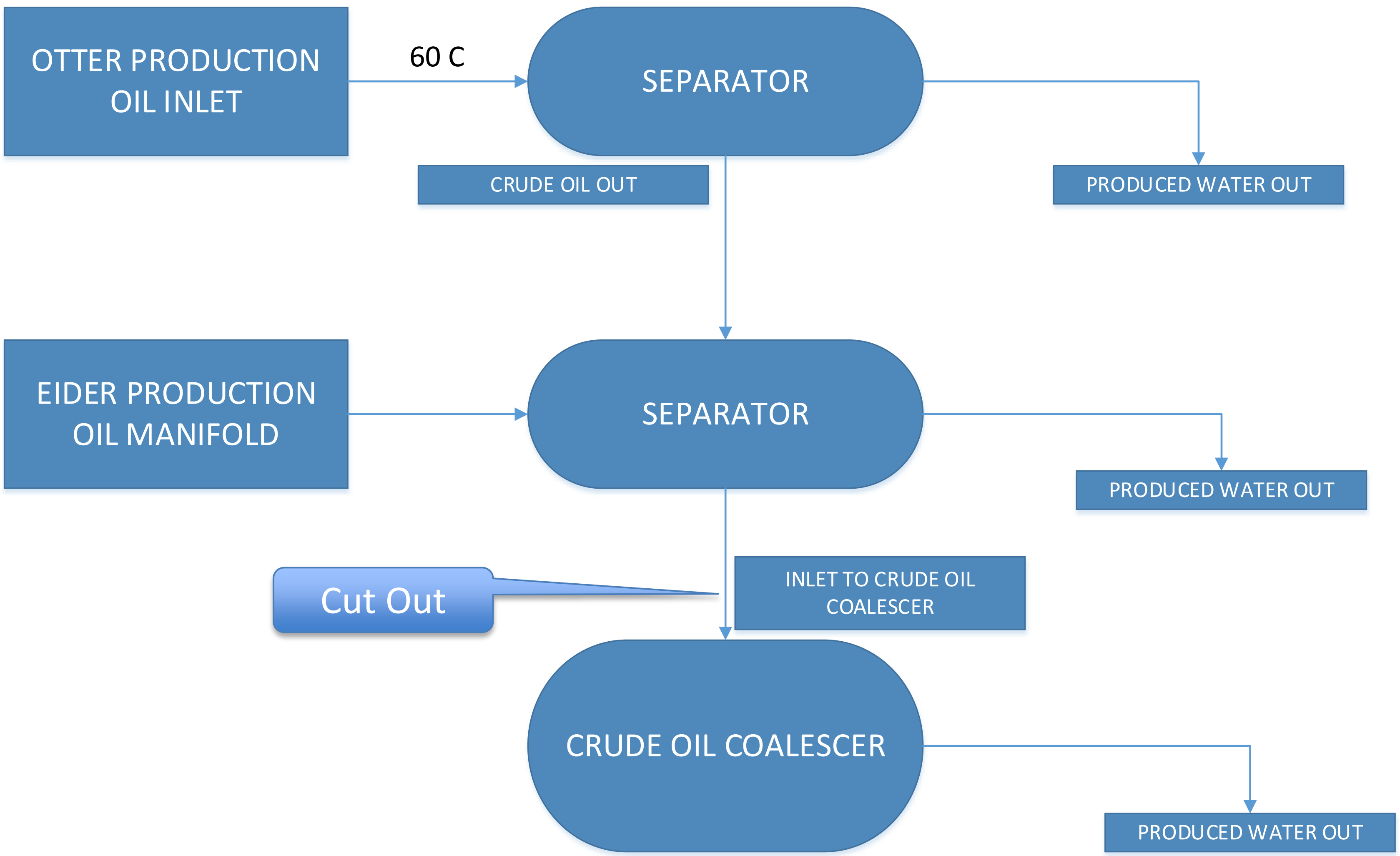

Eider Alpha Platform Topside Process Flowchart

Severe Isolated Corrosion

Cut-out from Eider Alpha Oil Coalescer Inlet

A

- Crude oil topsides piping
- Installed in 2002
- Carbon steel
- CO_2 expected to be the main threat
- Corrosion inhibitor used
- No biocide

B

Chemical Analysis and MPN Results

Chemical and corrosion results, from coupons and liquids

Analysis	Location[a]	
	Eider Production Manifold	Otter Production Pipeline
Water Phase Sulphide (mg/L)	0.053	9.536
Temperature (°C)	65	42
pH	Not taken	Not taken
General Corrosion rates (mm/y)	0.003	0.377
Pitting rate (mm/y)	0.04	0.484
Position in line	Side of the line	Bottom of the line
Exposure time (days)	368	558

MPN Results (Planktonic Samples) for the Otter Oil Inlet separator water phase.

Sample Taken (date)	Sample Received (date)	SRB Interim value[a] (cells/ml)	SRB Final value[b] (cells/ml)
20/10/2008	23/10/2008	9.5×10^{0}	2.5×10^{1}
19/11/2008	26/11/2008	0.4×10^{0}	3.0×10^{0}
15/12/2008	30/12/2008	2.5×10^{0}	4.5×10^{0}
10/01/2009	22/01/2009	0.3×10^{0}	2.5×10^{0}
25/04/2009	30/04/2009	4.0×10^{-1}	4×10^{-1}
10/07/2009	15/07/2009	7×10^{-1}	9.5×10^{0}
11/03/2010	15/03/2010	0.4×10^{-1}	9.0×10^{-1}

"Because bacterial numbers determined using the MPN method were low, it was originally believed that no biocide treatment was necessary."

qPCR Results, Sessile Samples

Solids collected from inner and outer layers of internal surface deposits on removable pipe spools and coupons subjected to qPCR for SRB, SRA, methanogens and total bacteria.

Sample label	Total Bacteria (cell per g)	Total Archaea (cell per g)
Inner layer	1.3×10^7	1.1×10^8
Outer layer	1.8×10^7	1.6×10^8
Sample label	*Methanothermococcus* (cell per g)	*Methanocaldococcus* (cell per g)
Inner layer	1.2×10^7	9.1×10^6
Outer layer	4.1×10^7	1.6×10^7

Sample label	Sulphate reducing bacteria (cell per g)	Sulphate reducing archaea (cell per g)
Inner layer	2.3×10^6	2.0×10^7
Outer layer	2.3×10^6	3.5×10^7
Sample label	*Methanosarcinales* (cell per g)	Total methanogens
Inner layer	6.3×10^7	8.3×10^7
Outer layer	8.9×10^7	1.5×10^8

Results into MIC Framework

Physical Conditions	Low fluid flow rate (1 m/s), water, deposits on surface, 60 C
Chemical Composition	pH between 6–7, CO_2 - NORSOK M-506 (2005) and De Waard and Milliams corrosion models predicted 2.2 mm/yr, abundant carbon sources and electron acceptors in produced water, inhibitor used
Corrosion Products	Siderite $FeCO_3$, mackinawite FeS, quartz SiO_2, akageneite, lepidocrocide (Fe-oxyhydroxides)
Material Properties	Carbon steel, not coated
Microbiology	Low numbers of planktonic SRB, $1x10^4$ in pig solids by MPN High numbers of sessile SRB, SRA and methanogens in solid deposits

Conclusions

- CO_2 relevant where bare pipe surface exposed
- Low velocity in process piping, solid deposition
- Under deposits, biofilms with high SRB, SRA and methanogens were associated with corrosion
- MPN missed identifying the threat; qPCR helped
- Inhibitors had no effect on biofilms or corrosion under the deposits
- Biocide alone would likely not be a sufficient mitigation method

Discussion/Questions

Up next, Dr. Lisa Gieg, Associate Professor
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