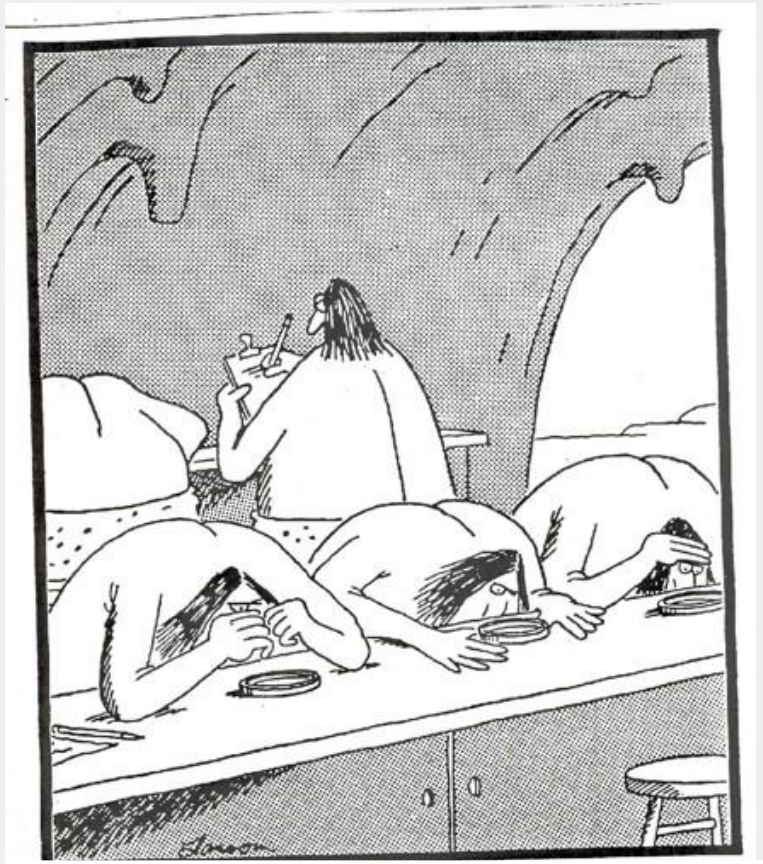
Gør tanke til handling
VIA University College

Mikrobiel korrosion af vandberørte overflader – teori møder praksis

Dr Torben Lund Skovhus
Docent & Project Manager
VIA University College, Denmark



Early microbiologists looking at MIC

@Torben_Skovhus

Torben Lund Skovhus

Researcher and Project Manager at VIA University College

VIA University College • Aarhus Universitet

Horsens, Region Midtjylland, Danmark • 500+

Dr. Torben Lund Skovhus is Researcher and Project Manager at VIA University College in the Centre of Applied Research & Development in Building, Energy & Environment (Horsens, Denmark).

He graduated from Aarhus University, Denmark in 2002 with a Master's degree (cand.scient.) in Biology. In 2005 he finished his PhD from Department of Microbiology, Aarhus University.

In 2005, Torben was employed at Danish Technological Institute (DTI) in the Centre for Chemistry and Water Technology, where he was responsible for the consultancy activities for the oil and gas industry around the North Sea. Torben was heading DTI Microbiology Laboratory while he was developing several consultancy and business activities with the oil and gas industry. He founded DTI Oil & Gas in both Denmark and Norway where he was Team and Business Development Leader for five years. Thereafter Torben worked as Project Manager at DNV GL (Det Norske Veritas) in the field of Corrosion Management in both Bergen and Esbjerg.

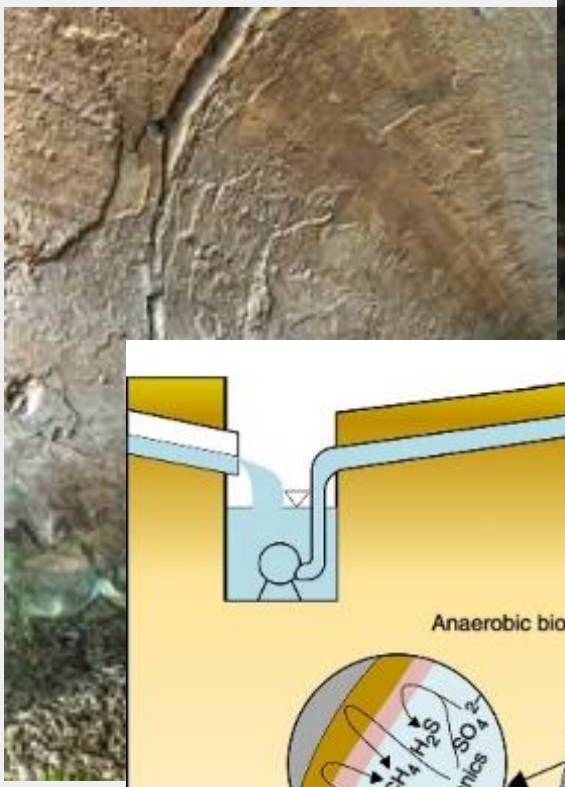
Agenda

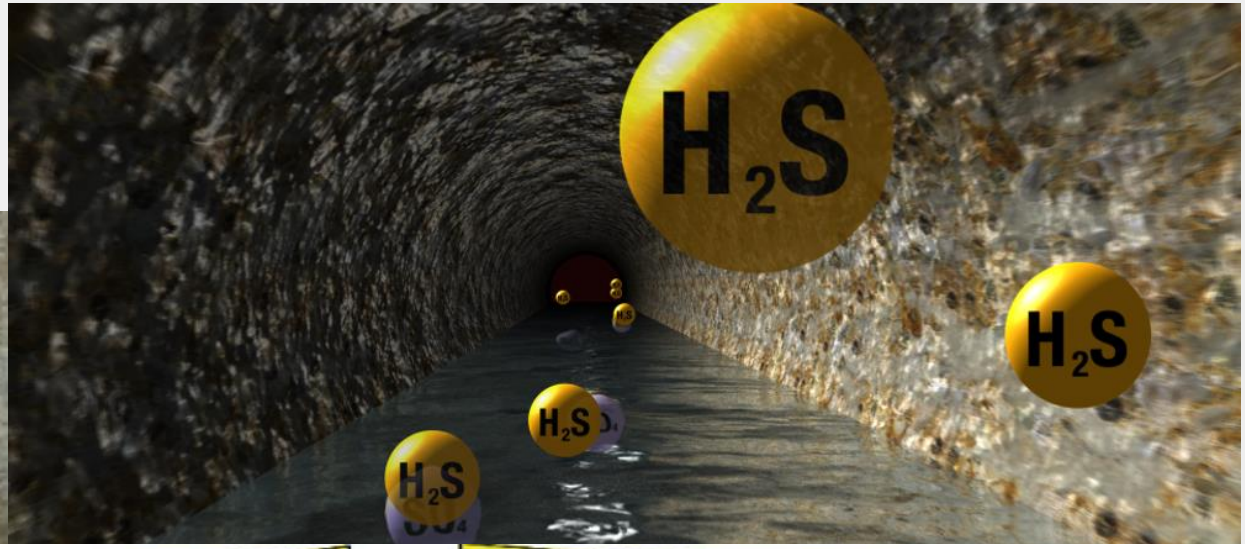
- Teori om biofilmdannelse og mikrobiel korrosion
- Kort om bekæmpelse af mikrobiel korrosion
- Root Cause Analysis med mikrobiel korrosion
- C1 – Otter Oil Multiphase Pipeline, North Sea UK
- C2 – Siri Water Injection Pipeline, North Sea DK
- Spørgsmål

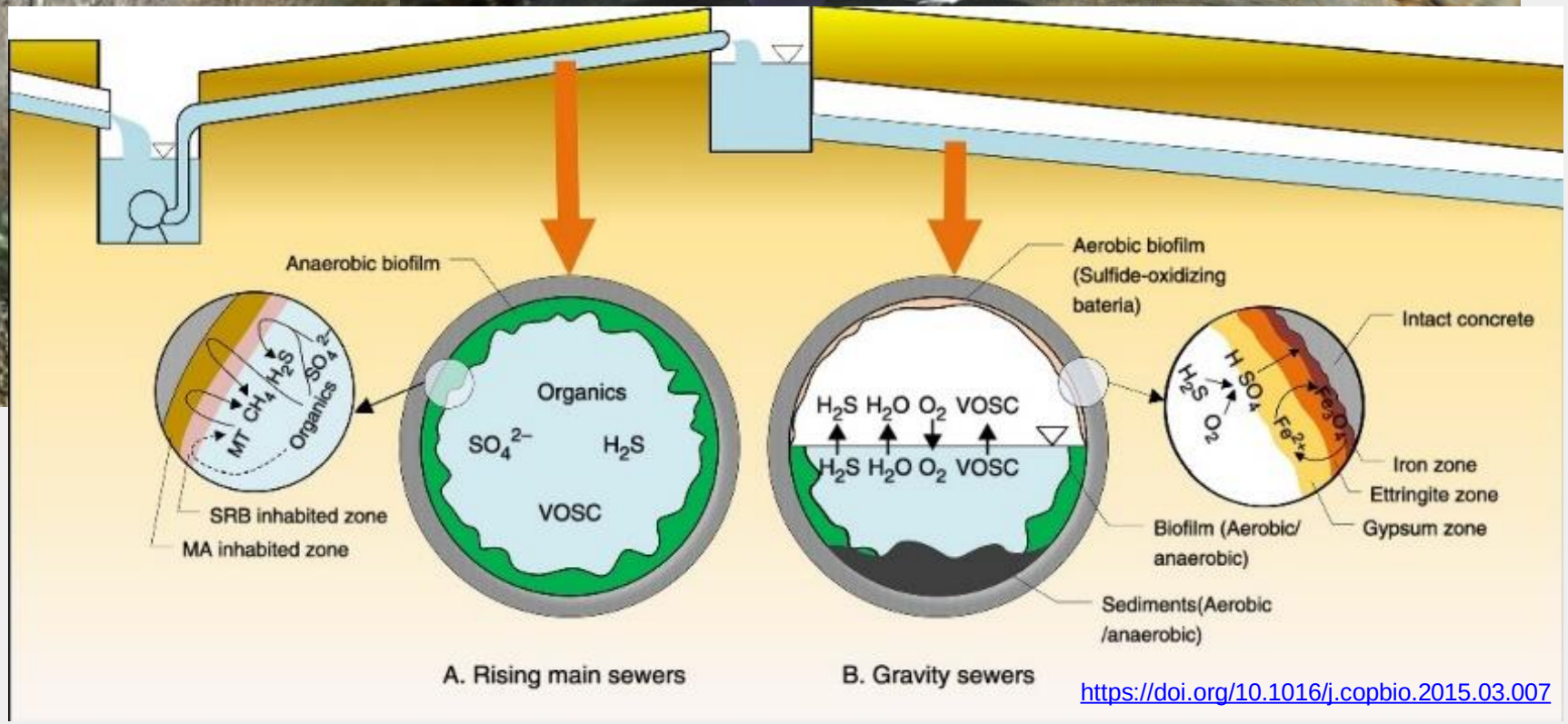
Types of MIC in industry

The Halfdan Field, Denmark (private photo)

Sewers

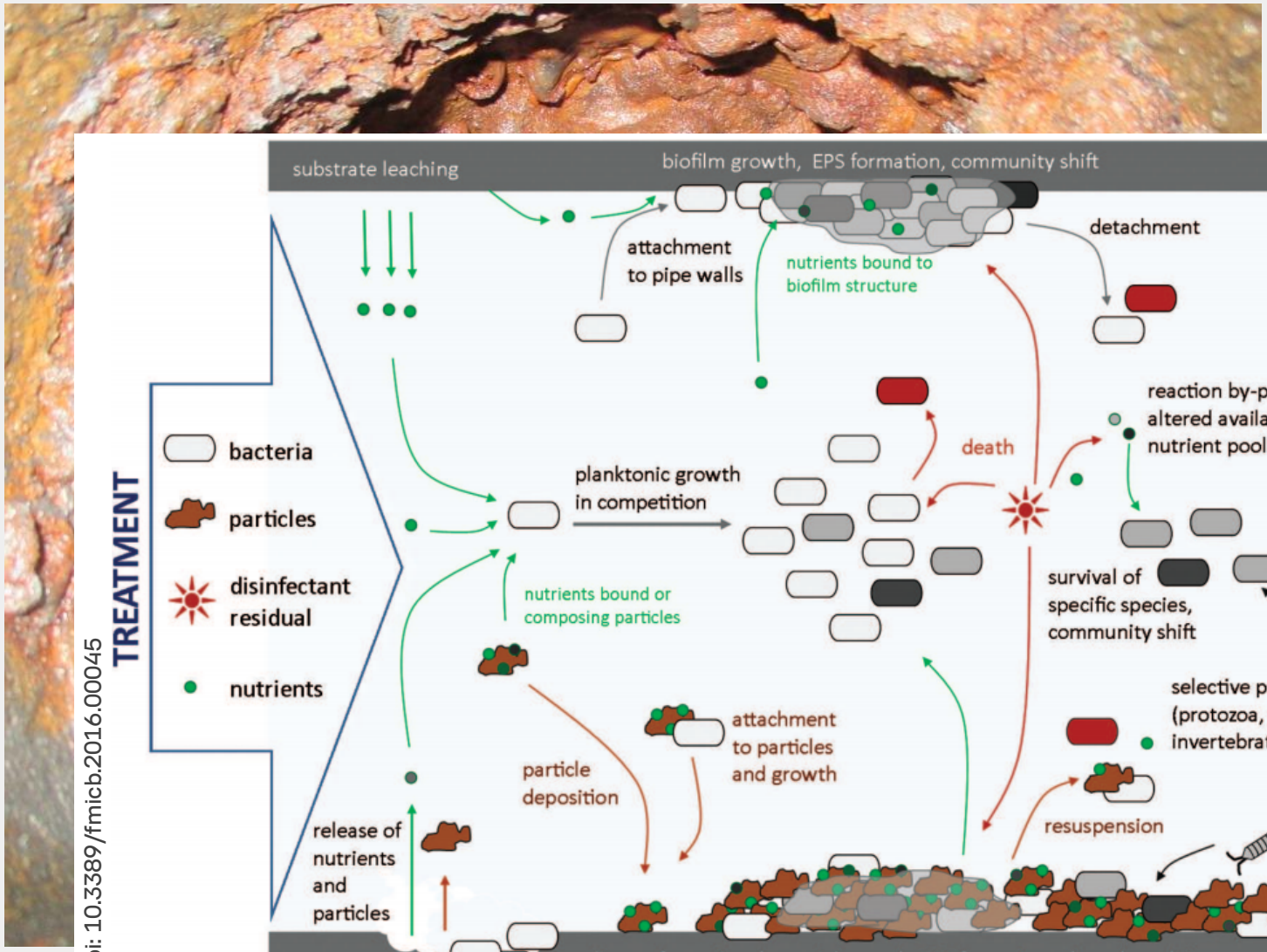






https://doi.org/10.1016/j.copbio.2015.03.007

Drinking water systems

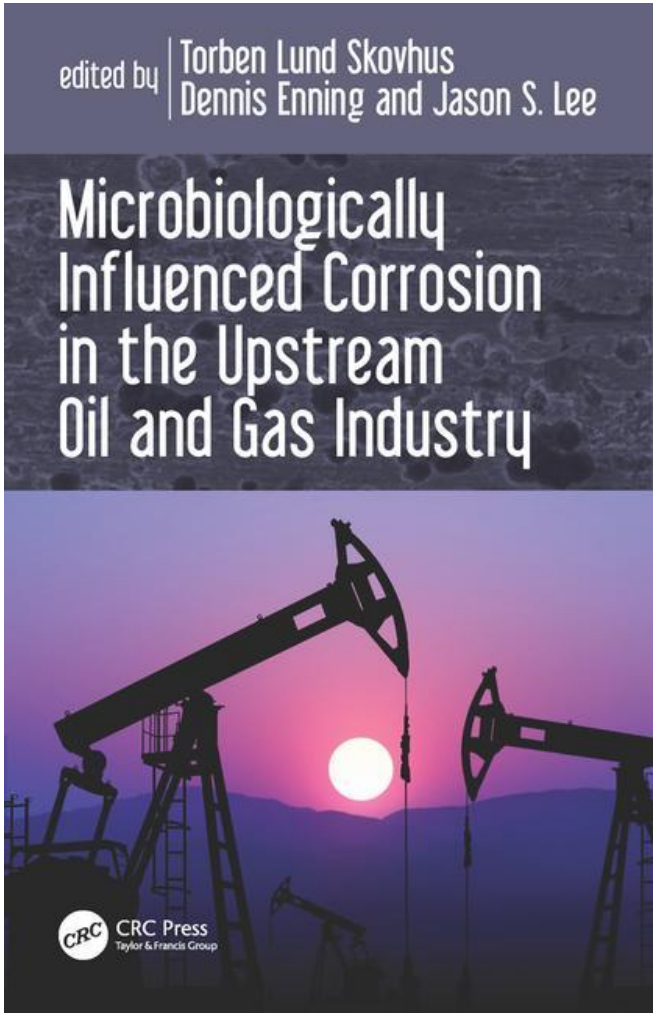


doi: 10.3389/fmicb.2016.00045

Fire sprinkler systems

Hanna Parow , MSc student at NTNU Spring 2018

Oil & Gas



Skovhus et al. (2017)

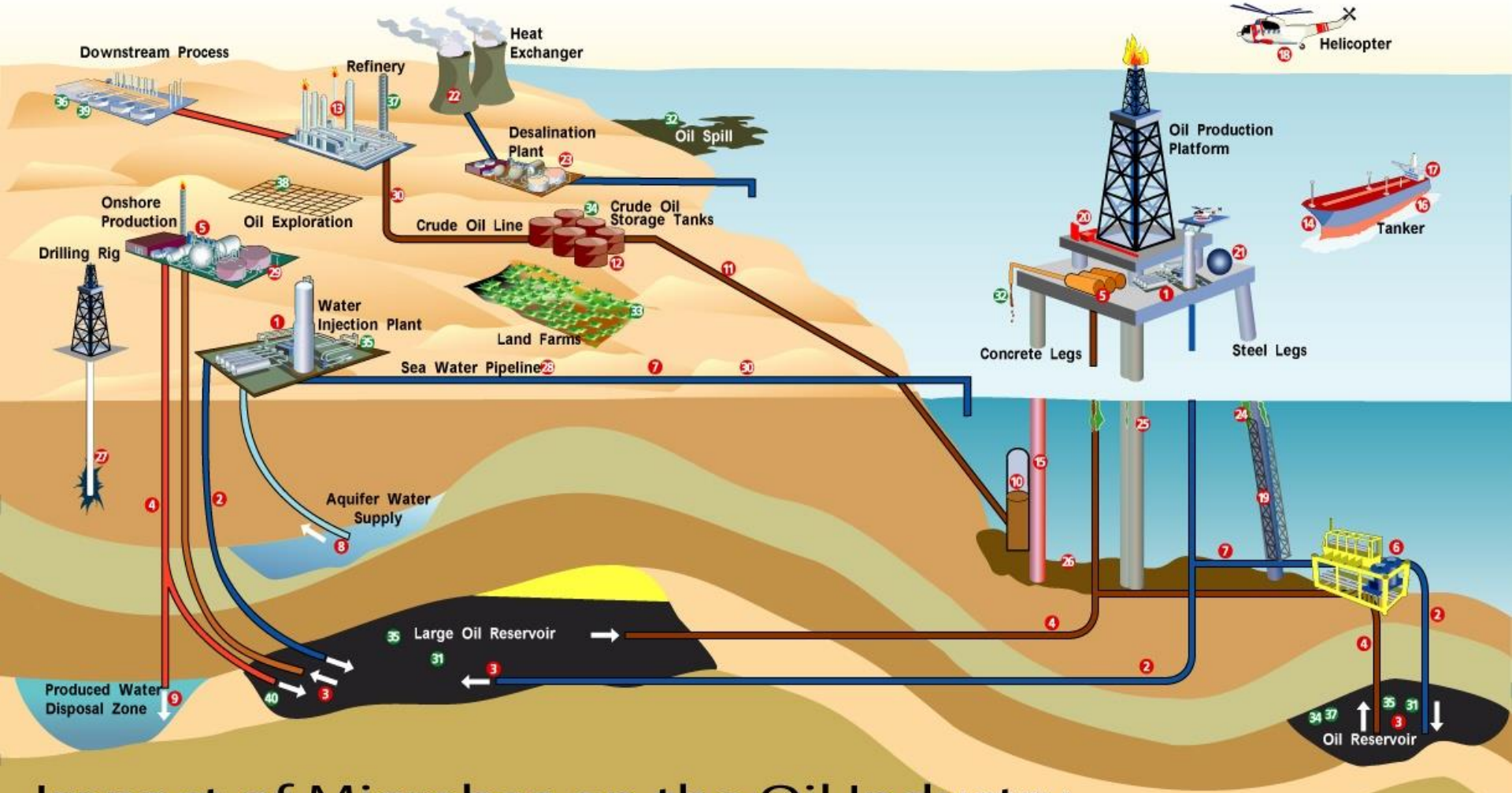
Current research project:
https://bio.ucalgary.ca/microbial-corrosion/

Negative

1- Water Injection System fouling/MIC
2- Down-hole MIC (mesophiles)
3- Reservoir souring & plugging
4- Down-hole MIC (thermophiles)
5- Production system MIC, H_2S, Oil in Water
6- Sub-sea manifold MIC
7- Water flowline internal MIC & fouling
8- Aquifer supply-plugging; ESP MIC
9- Produced water injection well plugging
10- Crude oil storage H_2S, H_2SO_4
11- Oil pipline internal MIC & fouling
12- Onshore crude oil tank MIC
13- Refinery MIC
14- Crude oil cargo tank MIC
15- Diesel tank contamination/spoilage
16- Ship fuel fouling, spoilage & MIC
17- Lubricating & Hydraulic oil contamination
18- Helicopter/aircraft fuel contamination
19- Water filled steel legs & hydrotest MIC
20- Firewater system MIC & fouling
21- Potable water MIC & pathogens
22- Heat exchanger MIC & fouling
23- Desalination/RO plant fouling & MIC
24- Marine growth - steel MIC
25- Marine growth - concrete spalling
26- Discarded drill mud - MIC/environmental
27- Drilling/workover fluids contamination
28- NORM concentration by SRB
29- Production chemicals spoilage
30- Coatings biodeterioration

Positive

31- Microbially Enhanced Oil Recovery
32- Oil spill biodegradation
33- Bioremediation - land farming
34- Biodesulfurization
35- Competitive microbes - control MIC/souring
36- Biosensors
37- Biorefining and upgrading oil
38- Microbial prospecting
39- Bacterial production of novel oilfield chemicals
40- Control by specific pathogens



Impact of Microbes on the Oil Industry

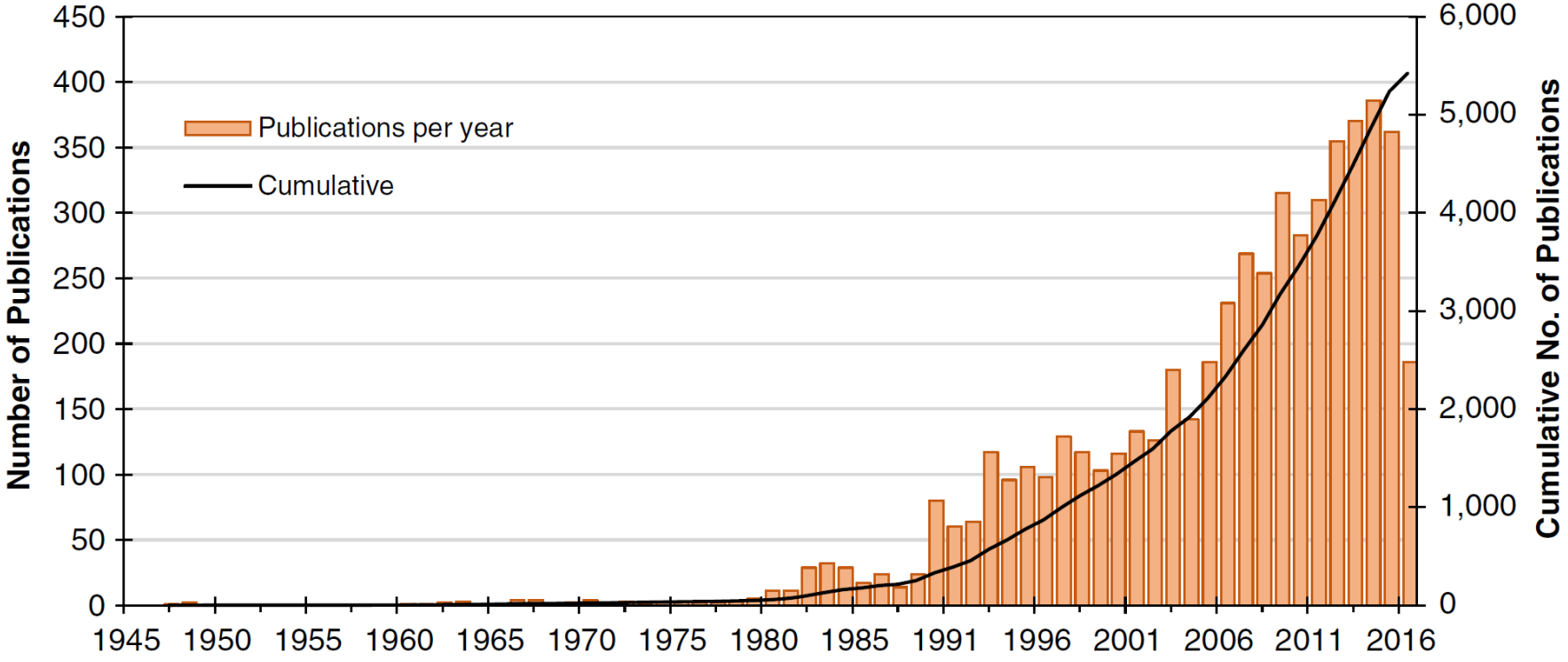
Source: Petroleum Microbiology

Similarities?

- What does these industry systems have in common?
- What will stimulate MIC?

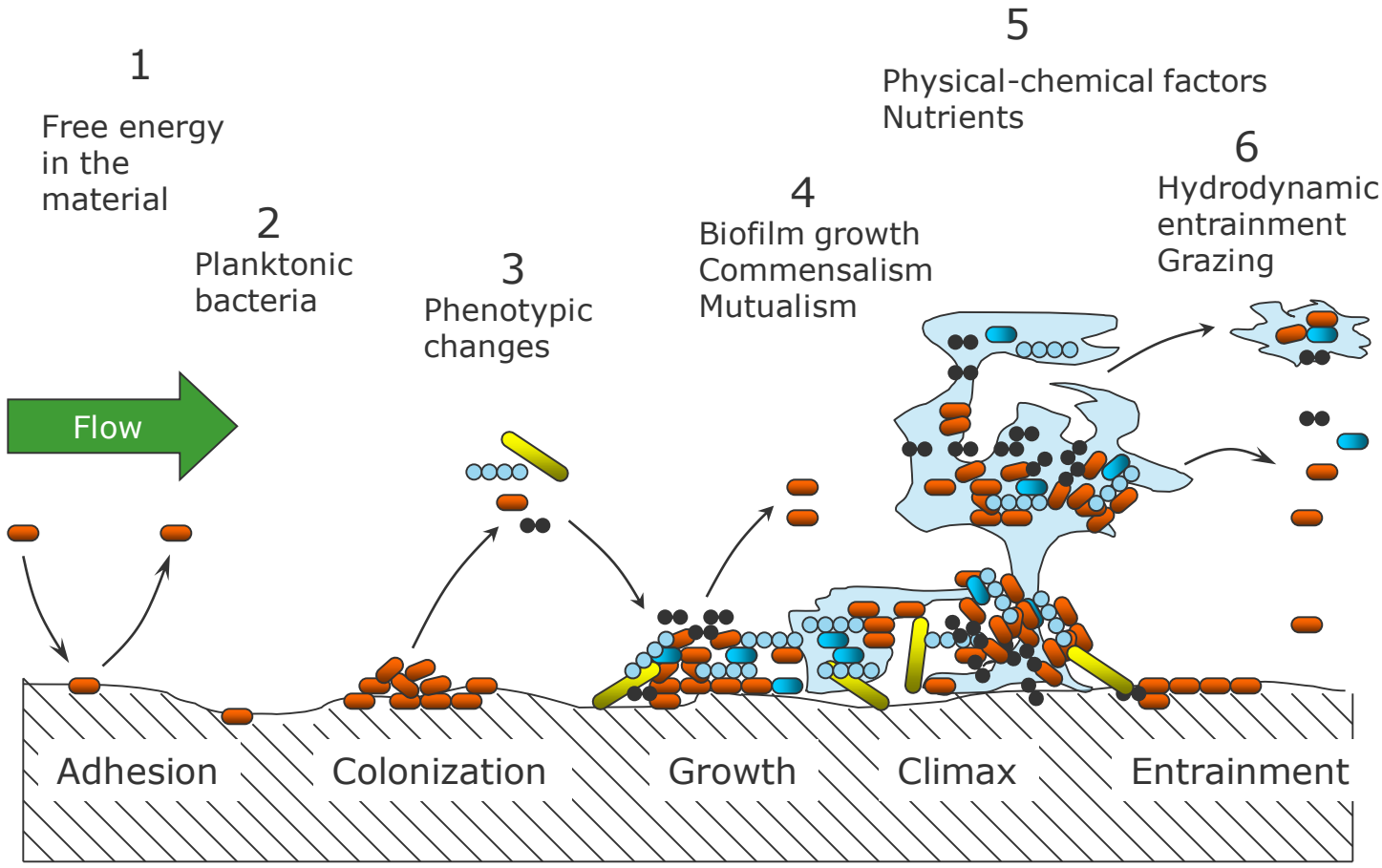
- water
- surfaces
- nutrients
- e-acceptors
- opt. temp.
- opt. flow

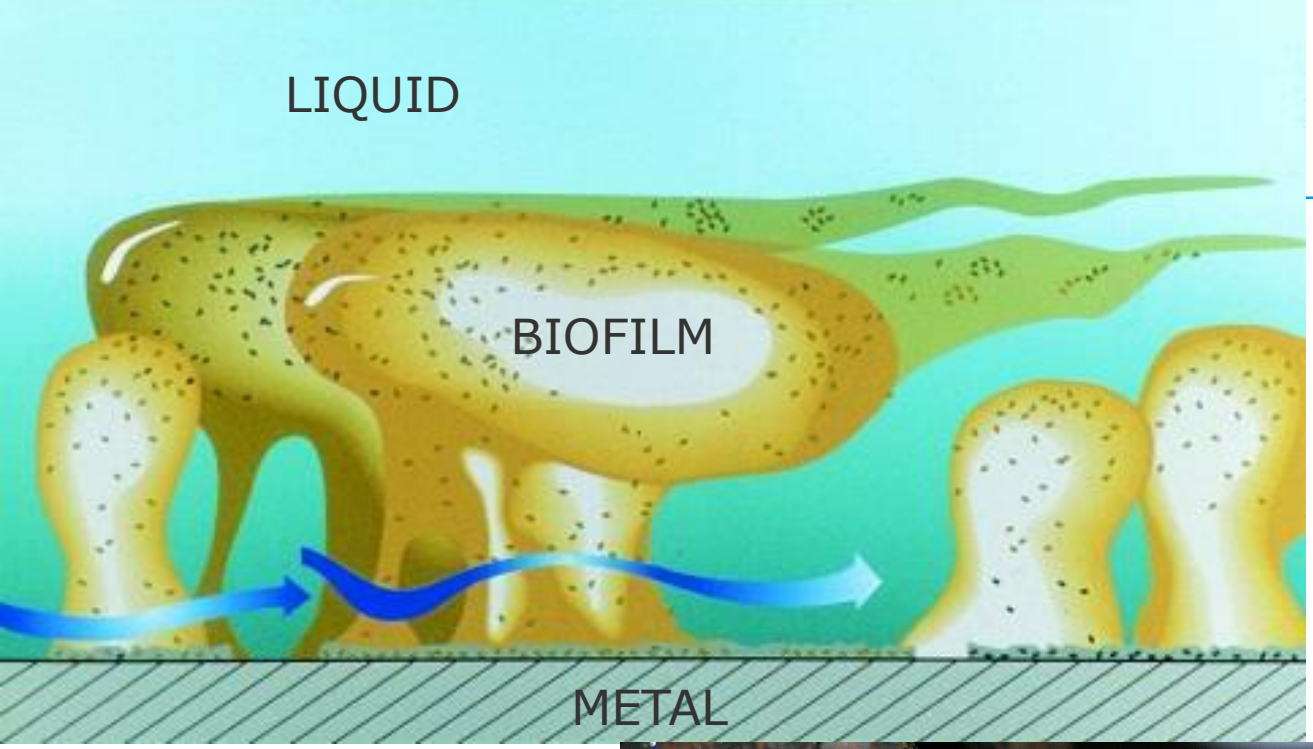
Historical Evolution of MIC Research



Source: Hashemi, Bak, Khan, Hawboldt, Lefsrud, Wolodko (2018) CORROSION, v.74, n.4

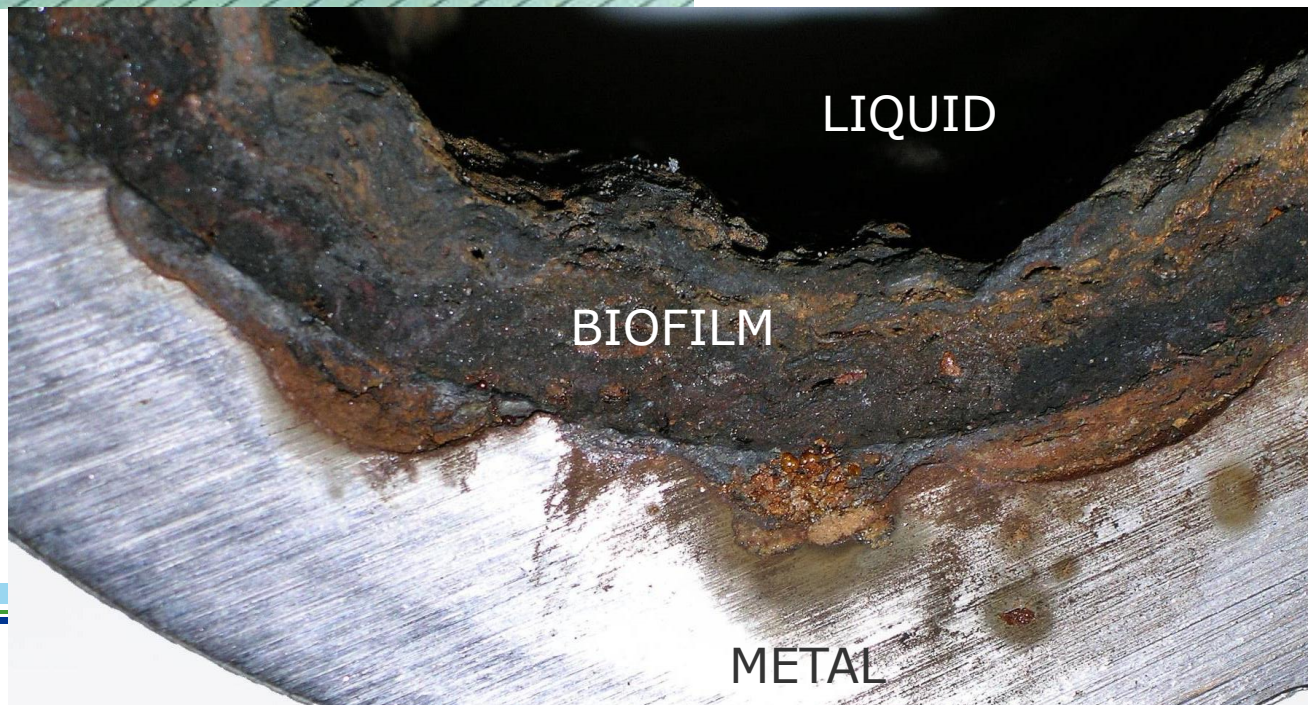
Distribution of microorganisms in industrial systems



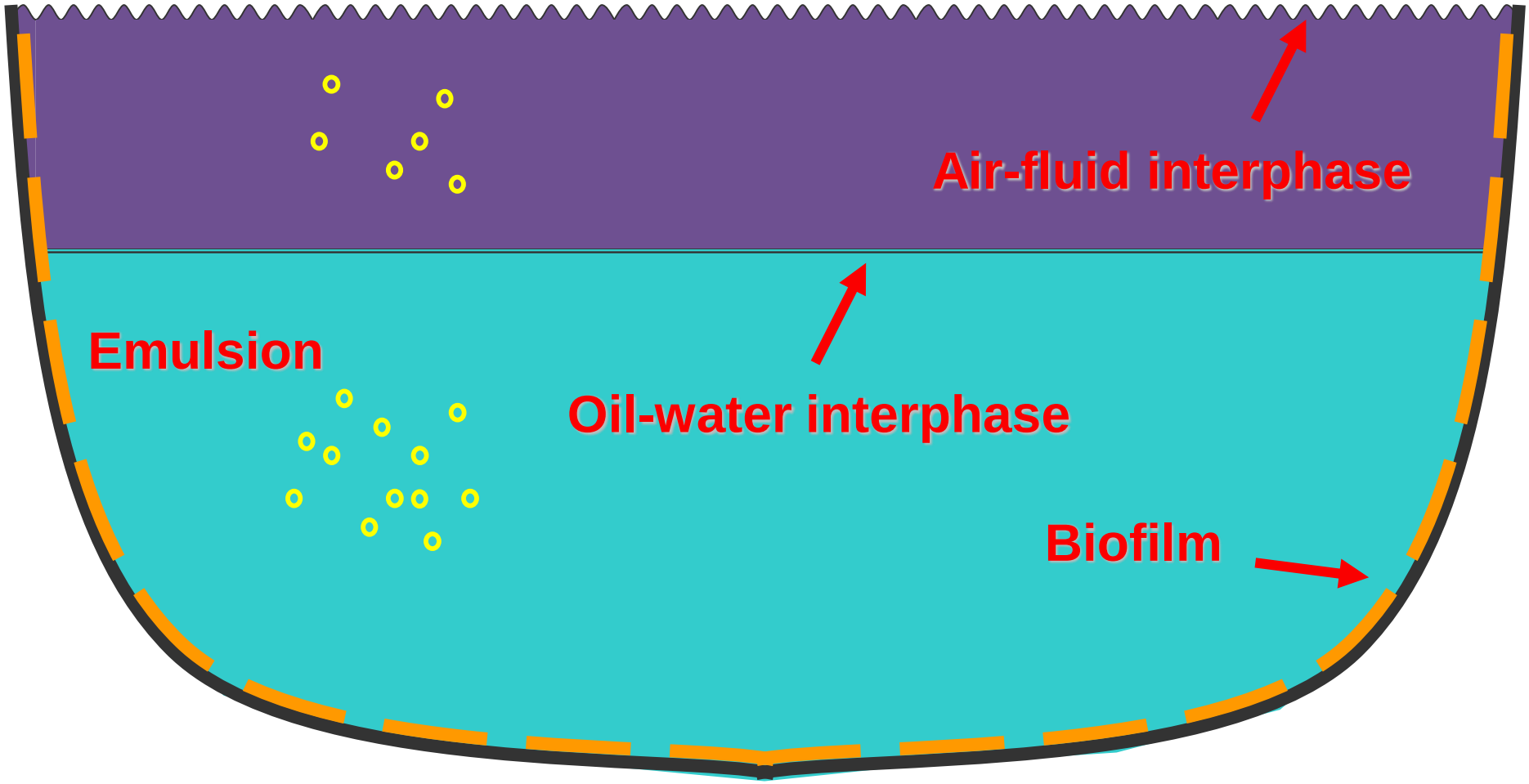


Water vs.

Biofilm
Scale
Slime
Corrosion Products
Debris
Solids
Deposits



Distribution of microorganisms in industrial systems



What actions can be taken to prevent MIC?

MATERIALS & COATINGS

CHEMICALS

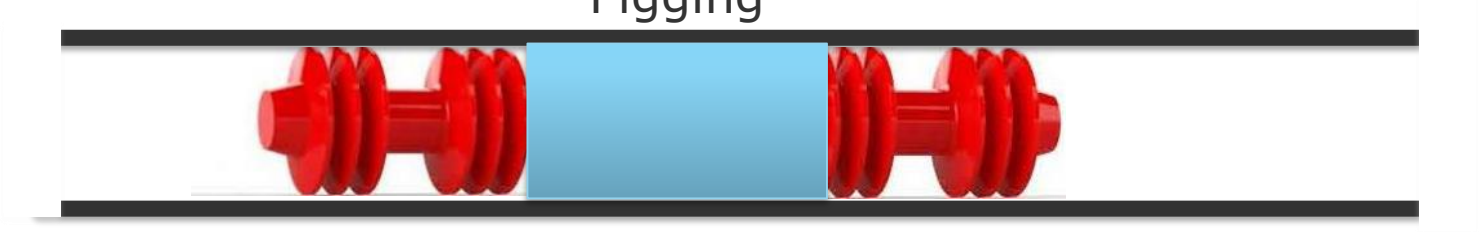
CLEANING

Typical MIC Mitigation

Inhibitor and Biocide Injection

Maintenance Pigging

Chemical Batch Pigging

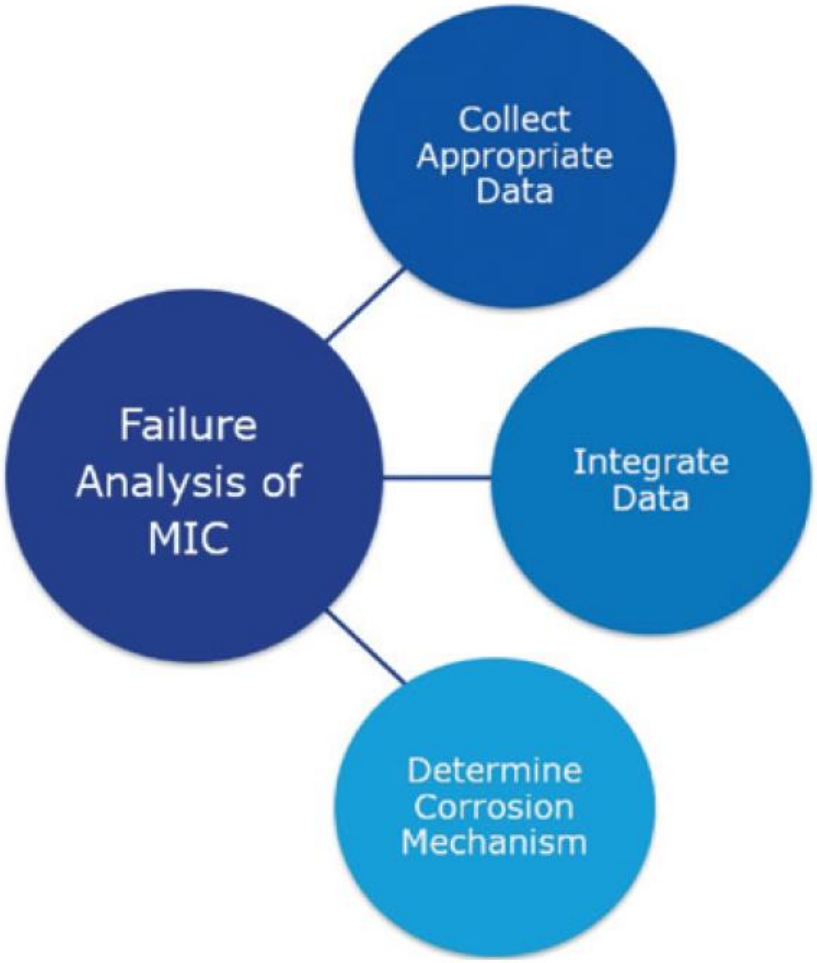


Root Cause Analysis and two cases

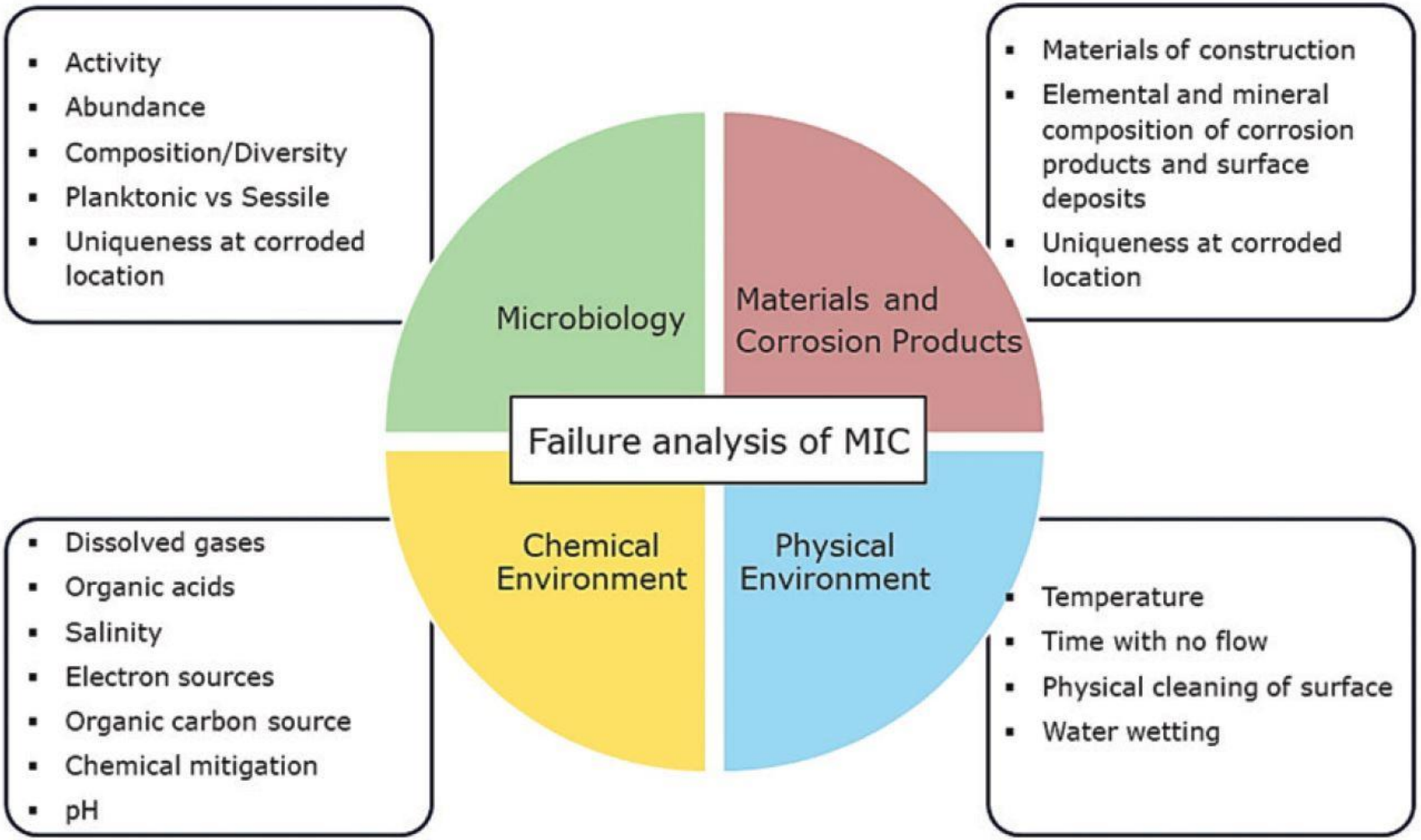
Background information – the failure analysis process

Inspectioneering Journal JULY | AUGUST 2019

Overview of the failure analysis process



Data to be collected for conducting MIC failure analysis



Common Framework for Characterizing MIC

Physical Conditions
Chemical Composition
Corrosion Products
Material Properties
Microbiology

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?

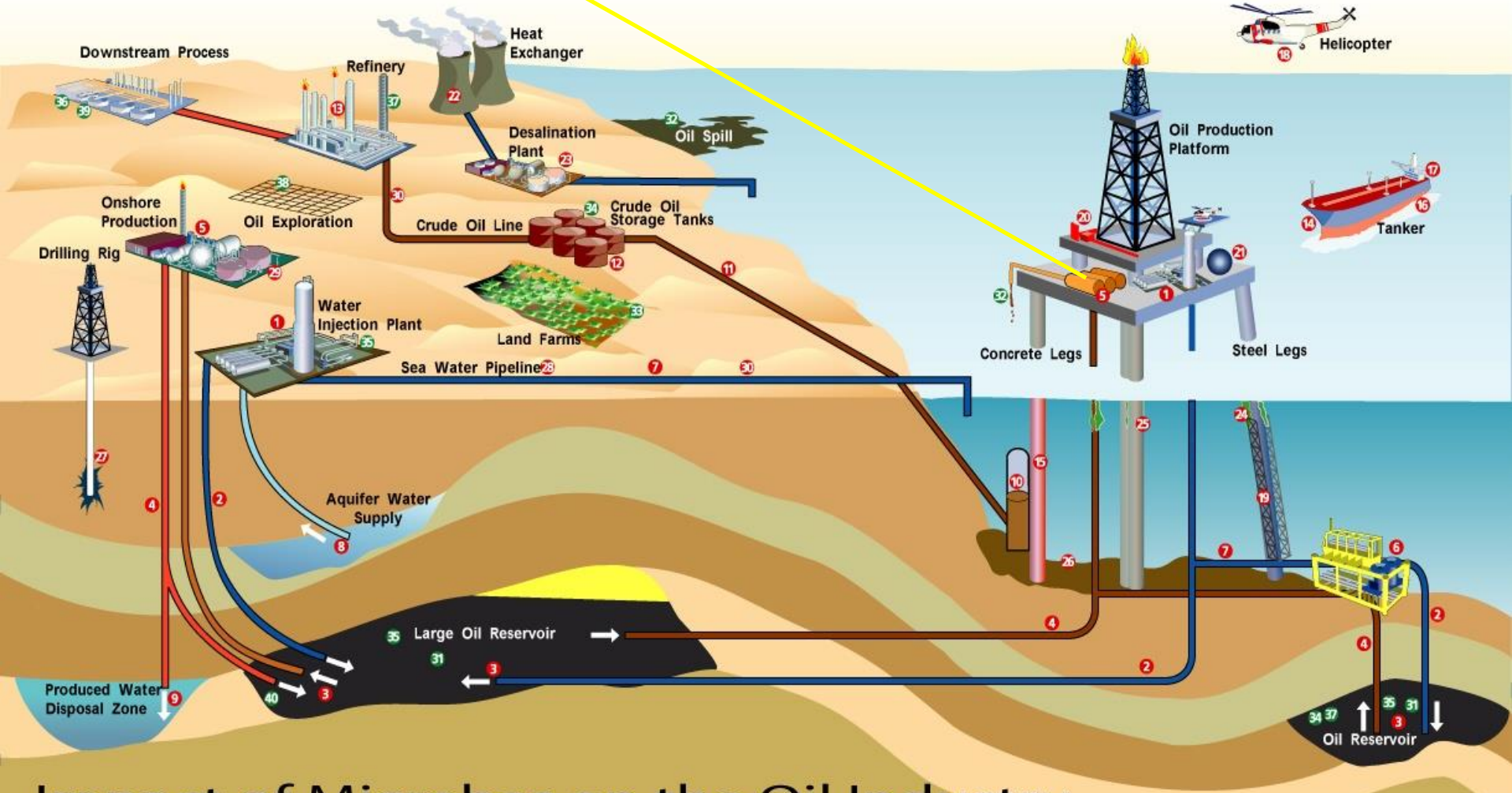
Field Case 1
Otter Crude Oil Production

Negative

1- Water Injection System fouling/MIC
2- Down-hole MIC (mesophiles)
3- Reservoir souring & plugging
4- Down-hole MIC (thermophiles)
5- Production system MIC, H_2S, Oil in Water
6- Sub-sea manifold MIC
7- Water flowline internal MIC & fouling
8- Aquifer supply-plugging; ESP MIC
9- Produced water injection well plugging
10- Crude oil storage H_2S, H_2SO_4
11- Oil pipline internal MIC & fouling
12- Onshore crude oil tank MIC
13- Refinery MIC
14- Crude oil cargo tank MIC
15- Diesel tank contamination/spoilage
16- Ship fuel fouling, spoilage & MIC
17- Lubricating & Hydraulic oil contamination
18- Helicopter/aircraft fuel contamination
19- Water filled steel legs & hydrotest MIC
20- Firewater system MIC & fouling
21- Potable water MIC & pathogens
22- Heat exchanger MIC & fouling
23- Desalination/RO plant fouling & MIC
24- Marine growth - steel MIC
25- Marine growth - concrete spalling
26- Discarded drill mud - MIC/environmental
27- Drilling/workover fluids contamination
28- NORM concentration by SRB
29- Production chemicals spoilage
30- Coatings biodeterioration

Positive

31- Microbially Enhanced Oil Recovery
32- Oil spill biodegradation
33- Bioremediation - land farming
34- Biodesulfurization
35- Competitive microbes - control MIC/souring
36- Biosensors
37- Biorefining and upgrading oil
38- Microbial prospecting
39- Bacterial production of novel oilfield chemicals
40- Control by specific pathogens



Impact of Microbes on the Oil Industry

Source: Petroleum Microbiology

Case Study: Otter Crude Oil Production
Journal of Biotechnology 256 (2017) 31–45

Journal of Biotechnology 256 (2017) 31–45

Contents lists available at ScienceDirect

Journal of Biotechnology

journal homepage: www.elsevier.com/locate/jbiotec

Management and control of microbiologically influenced corrosion (MIC) in the oil and gas industry—Overview and a North Sea case study

Torben Lund Skovhus[a,*], Richard B. Eckert[b], Edgar Rodrigues[c]

[a] VIA University College, Centre for Applied Research and Development in Building, Energy & Environment, Chr. M. Østergaards Vej 4, DK-8700 Horsens, Denmark
[b] DNV GL, 5777 Frantz Road, Dublin, OH, USA
[c] TAQA Bratani Limited, Prospect Road, Westhill, Aberdeenshire, AB32 6FE, United Kingdom

ARTICLE INFO

Keywords:
Biocorrosion
Oil and gas industry
Corrosion management
Field case
MIC Modeling
North Sea

ABSTRACT

Microbiologically influenced corrosion (MIC) is the terminology applied where the actions of microorganisms influence the corrosion process. In literature, terms such as microbial corrosion, biocorrosion, microbially influenced/induced corrosion, and biodegradation are often applied.

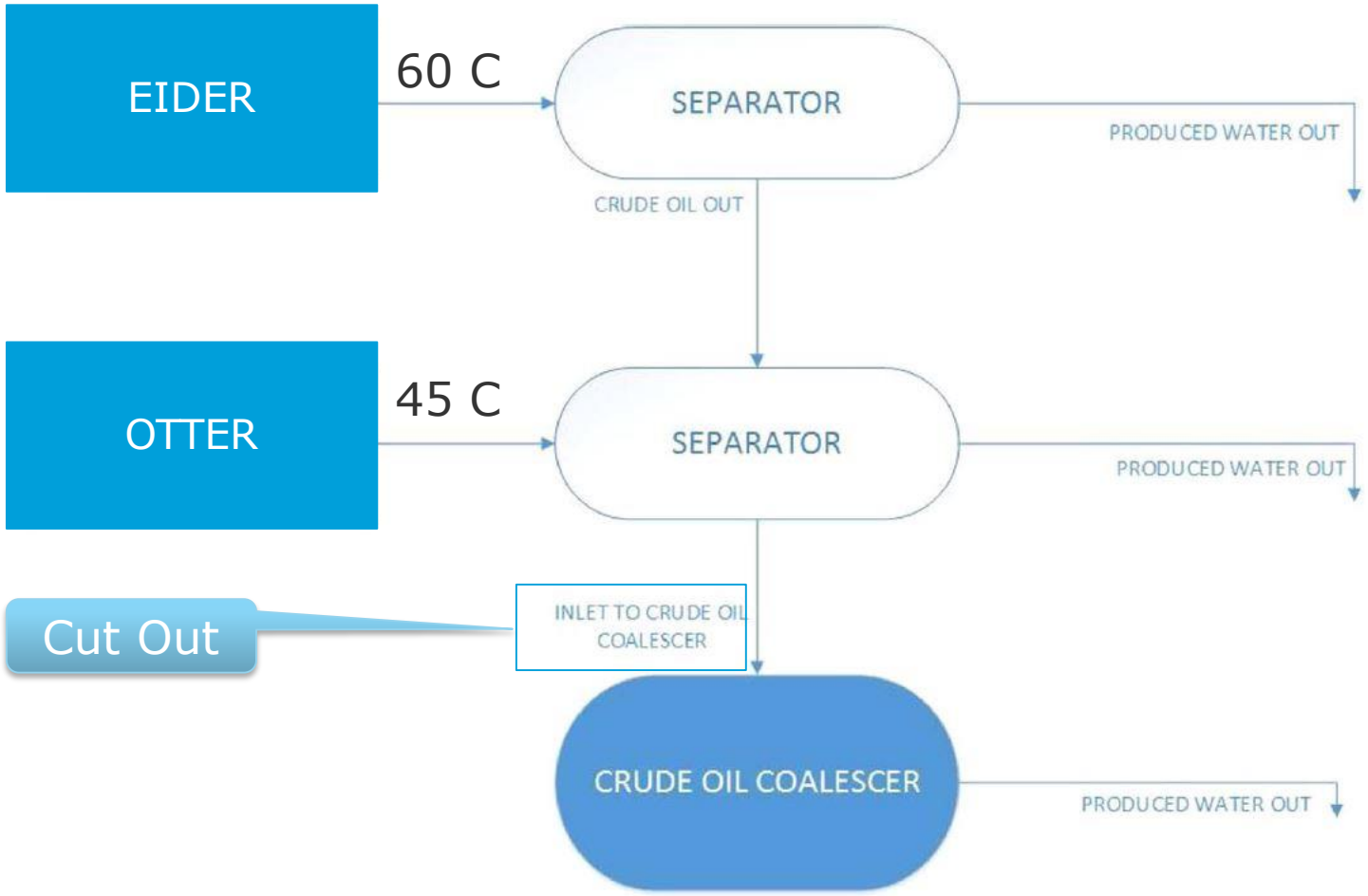
MIC research in the oil and gas industry has seen a revolution over the past decade, with the introduction of molecular microbiological methods: (MMM) as well as new industry standards and procedures of sampling biofilm and corrosion products from the process system.

This review aims to capture the most important trends the oil and gas industry has seen regarding MIC research over the past decade.

The paper starts out with an overview of where in the process stream MIC occurs – from the oil reservoir to the consumer. Both biotic and abiotic corrosion mechanisms are explained in the context of managing MIC using a structured corrosion management (CM) approach.

The corrosion management approach employs the elements of a management system to ensure that essential

Case Study: Otter Crude Oil Production
Journal of Biotechnology 256 (2017) 31–45



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

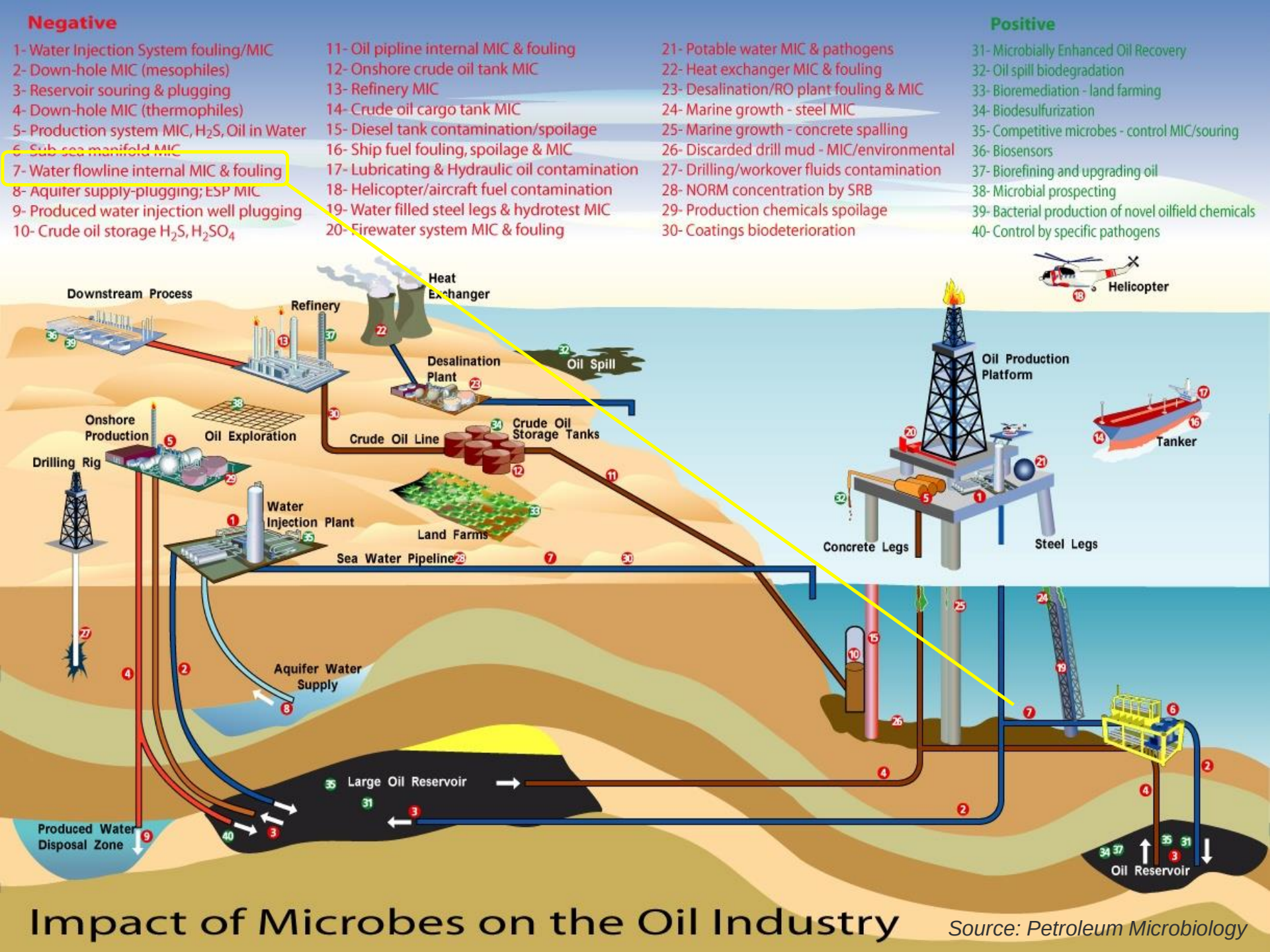
Results into MIC Framework

Physical Conditions	Low fluid flow rate (1 m/s), brine, deposits on surface
Chemical Composition	pH between 6–7, CO_2 corrosion models predicted 2.2 mm/yr, abundant carbon sources and electron acceptors in produced water, inhibitor used for CO_2 corrosion
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 worked
- Inhibitors had no effect on biofilms or corrosion under the deposits
- Biocide alone would likely not be a sufficient mitigation method

Field Case 2
Subsea seawater injection pipeline



Impact of Microbes on the Oil Industry

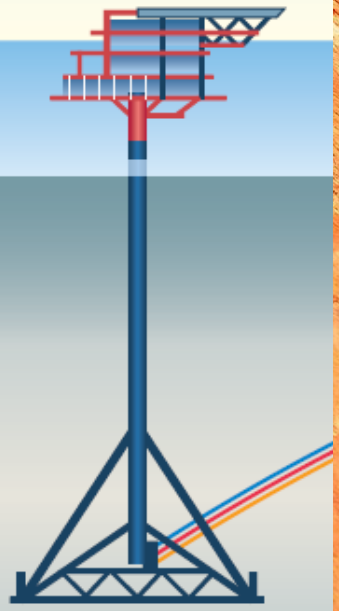
Source: Petroleum Microbiology

Subsea injection water pipeline from Siri to Nini

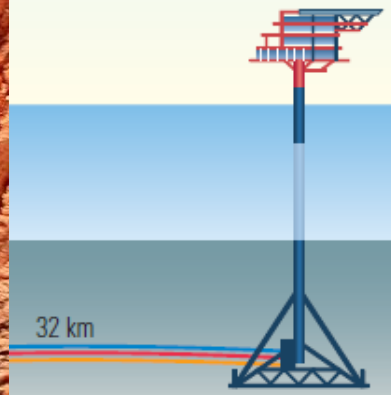
- Oil produced to storage tank below production platform
- Offload of oil to tanker
- Siri main oil production platform
- Cecilie & Nini satellite platforms
- A 10” subsea water injection pipeline 32 km in length transports seawater from the offshore Siri oil production platform to the Nini platform
- Mixing of seawater and produced water
- In Q4 2007 a rupture of the pipeline occurred 2 km from the Siri platform at the 6 o’clock position
- Pipeline had been in service for 4 years

Siri production platform

Cecilie



Nini



Water injection
Gas lift
Multiphase
Oil
Umbilical

Oilfield Review
24, no. 2: 4–17

Post Rupture Initiatives – Corrosion Management Perspective

- After rupture in 2007 major focus was on:
  - Corrosion management in the organization
  - Corrosion monitoring programs
  - Data interpretation
  - Biocorrosion monitoring (DNA approach)
  - Chemistry performance (lab and field tests)
  - Educational aspect for offshore personnel
  - Evaluation of all mitigation programs

European Workshop on Microbiologically Influenced Corrosion

- BAM i Berlin
- Den 19.-20. maj 2020
- To EU ansøgninger er målet for workshoppen
- COST Action og Industridrevet Træningsnetværk (INT)
- Begrænset antal pladser (<20 tilbage, tilmelding senest 4. maj)

Contact details

Torben Lund Skovhus, MSc, PhD
Docent and Project Manager

VIA Built Environment, Energy, Water and Climate - Centre for Applied Research & Development

VIA University College
Chr. M. Østergaards Vej 4
DK-8700 Horsens

T: +45 87 55 42 96
E: tols@via.dk
https://en.via.dk/

@Torben_Skovhus