NACE International Forum:
An Update of MIC Research and Developments for the Onshore and Offshore Oil and Gas Industry

Microbiologically Influenced Corrosion and Failure Analysis

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DNV·GL

Forensic Analysis of Corrosion

Purpose

- Determine whether corrosion was abiotic, biotic (MIC) or some combination
- Proper, effective choice of mitigation
- Prevent history from repeating itself (reduce risk)

Historically, attaining a convincing diagnosis of MIC has been challenging.

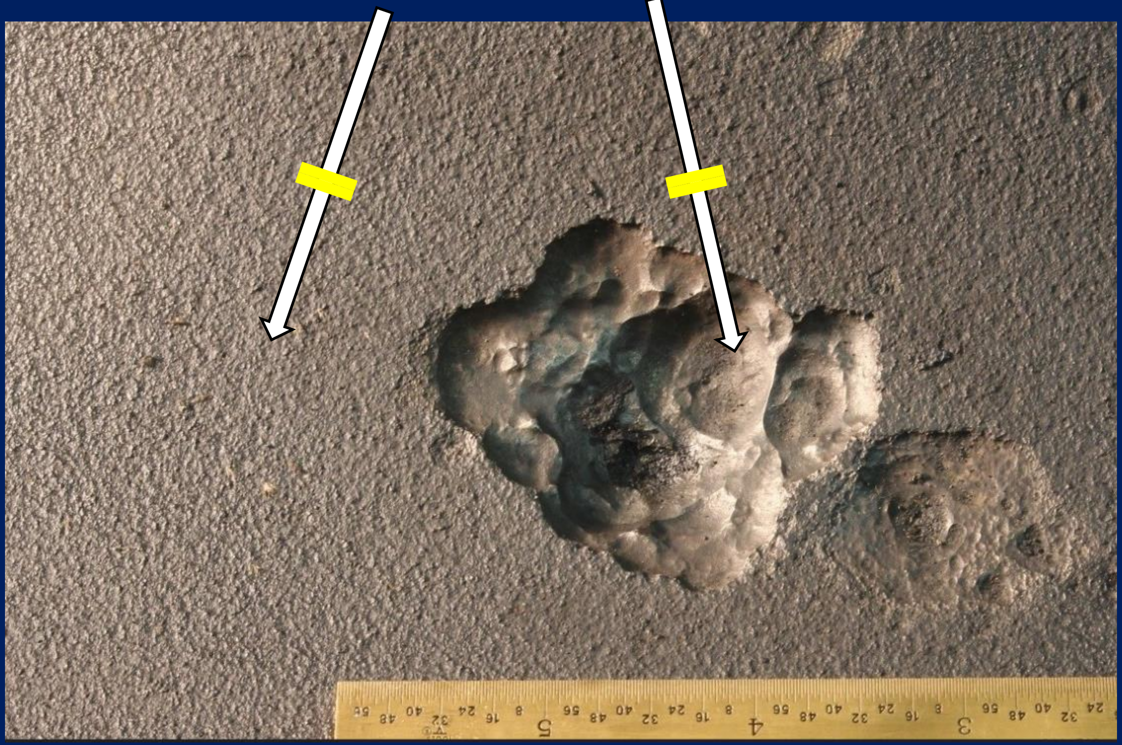
- Sample degradation and contamination
- Limitations of available microbiological methods
- Lack of validated procedures

MIC and Localized Corrosion

Isolated pitting considered at a very fundamental level….

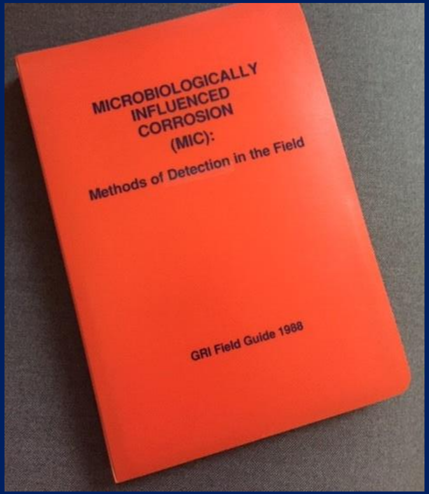
….tells us that <u>something was different</u>…

…… between here and here.



- ✓ Distribution of deposits and/or biofilms
- ✓ Water wetting phenomenon
- ✓ Concentration cells
- ✓ Anodic/cathodic films
- ✓ Microbiological activities

Guidelines and Procedures



- Gas Research Institute
  - 1988, Field Guide for Investigating MIC
- ASTM
  - ASTM G161-00, "Standard Guide for Corrosion-Related Failure Analysis"
- NACE
  - TM0212-2018, "Detection, Testing and Evaluation of Microbiologically Influenced Corrosion on Internal Surfaces of Pipelines"
  - TM0106-2016, "Detection, Testing and Evaluation of Microbiologically Influenced Corrosion on External Surfaces of Pipelines"

“An accurate diagnosis of MIC requires the following:[1] “

1) A sample of the **corrosion product** or affected surface that has not been altered by collection or storage

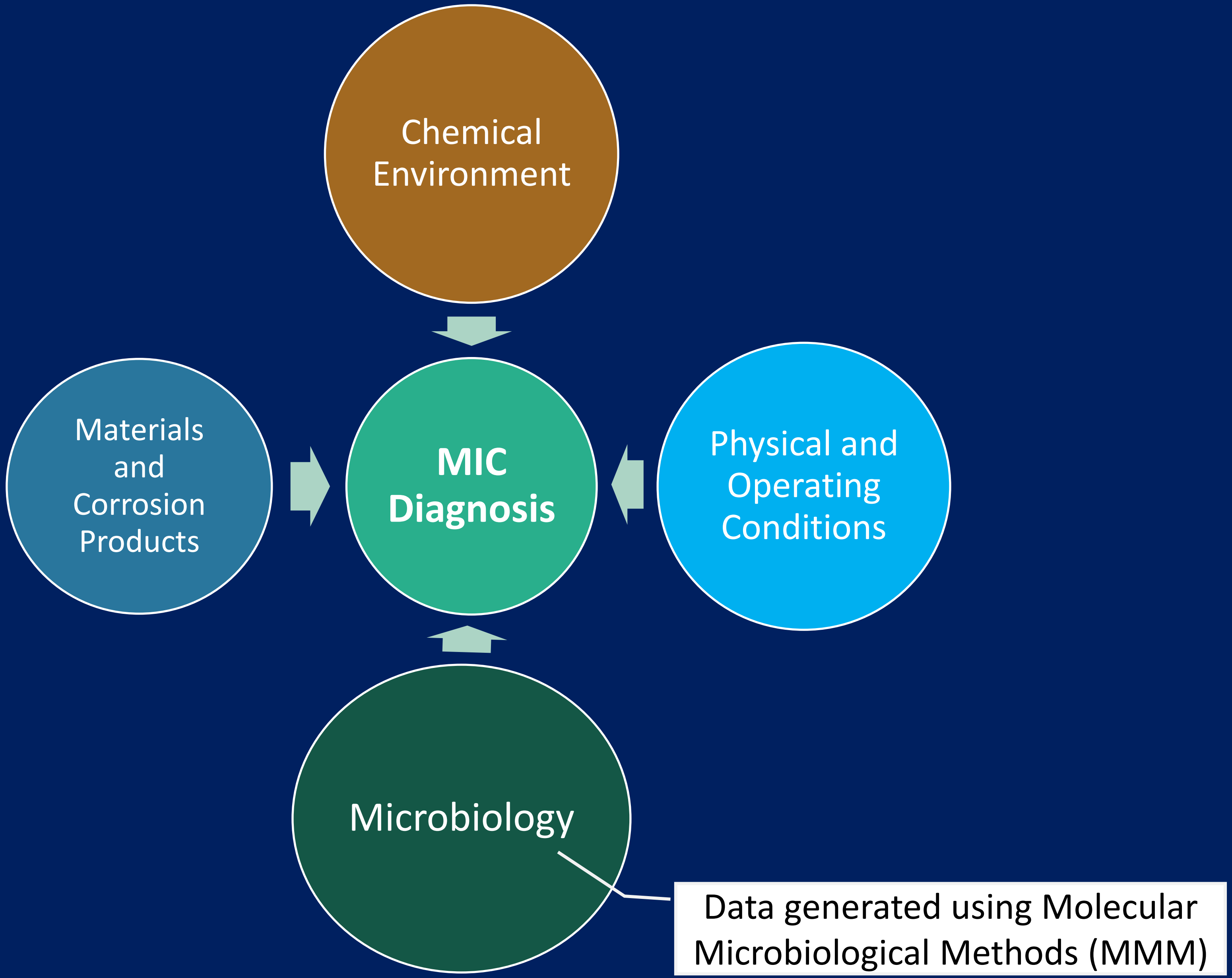
2) Identification of a **corrosion mechanism** that is consistent with the vulnerabilities of the material being examined

3) Identification of **microorganisms** capable of growth and maintenance of the corrosion mechanism in the particular environment

4) Demonstration of an **association** of the microorganisms with the observed corrosion.

“The objective is to have independent types of measurements that are consistent with a mechanism for MIC.”

MIC Diagnosis = Multiple Lines of Evidence[2]



Sampling and Preservation

- Getting access to the right samples
  - "Proxy" samples
- Collecting appropriate, meaningful samples
  - Corroded vs. non-corroded
- Preservation
  - Avoid - Oxidation, dehydration, heat, contamination
  - Prevent/minimize microbiological and chemical changes
- Transport and shipping
  - Temperature control
  - Chemical preservatives

Physical and Operating Conditions

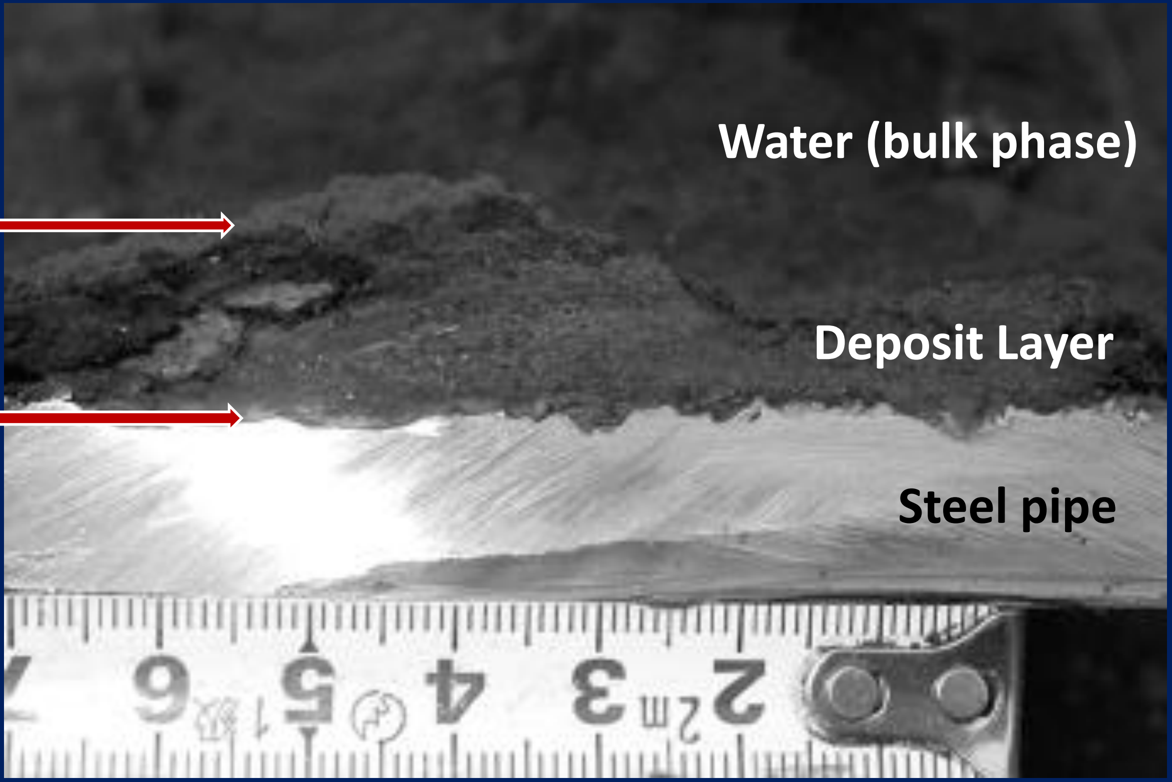
- Pressure, temperature, velocity
- Velocity, periods of no flow
- Operational changes
- Process upsets
- Fluid sources – consistent?
- Maintenance and mitigation
- Historical conditions, service conversion

TIMELINE

- All of the above can affect chemistry and microbiology

Chemical Environment

- Liquid (water) phase
- Surface deposits, material within or under deposits[3]
- Corrosion products removed from isolated pits
- Deposits collected from on top of, within or beneath deposits
- Surface films adhered to the metal surface



Chemical Composition Parameters

- Dissolved gases, CO_2, H_2S, O_2
- Anions and cations
- Organic acids
- pH (bulk and local)
- Solids/sludge composition
  - Elemental and mineralogical
  - Organic
  - Inorganic
  - Particle characterization

Microbiological Conditions

- Who is where? How many? What are they doing?

Functional Group - qPCR Target	**Away (cells/swab)**	**Pit (cells/swab)**
Total Bacteria (EBAC)	**5.94E+05**	**3.13E+06**
Total Archaea (ARC)	ND	**3.03E+06**
Sulfate Reducing Bacteria (SRB)	**8.81E+03**	**2.55E+05**
Sulfate Reducing Archaea (SRA)	ND	ND
Methanogens (MGN)	**1.50E+03 (J)**	**2.29E+05**
Acetogens (AGN)	ND	ND
Fermenters (FER)	**4.10E+04**	**8.38E+05**
Iron Reducing Bacteria –(IRB)	ND	**3.35E+05**
Iron Oxidizing Bacteria (FeOB)	ND	ND
Sulfur Oxidizing Bacteria (SOB)	ND	**<3.05E+03**

ND denotes not detected (<5.00E+03)

Methods

ATP - Activity

qPCR – abundance

NGS - Diversity

Other methods

Chemical and Microbiological Data

- What do they need? What do they produce[4]?

Functional Group	Examples of Chemical Species Essential for Growth	End Products
Acid producers	Organic carbon compounds, hydrocarbons, oxygen	Organic acids
Nitrate reducers	Nitrate, nitrite, nitrogen, oxygen	N_2, NO_2, NO
Iron reducers	Ferric iron, Sulfur, oxygen, nitrate	Soluble Ferrous Iron
Iron/Manganese oxidizers	Ferrous iron in solution, Mn^{2+}	Insoluble Ferric Iron
Sulfate reducers	Alcohols, organic acids, H_2, sulfate, elemental sulfur, thiosulphate	Sulfide
Methanogens	CO_2, carbonate, bicarbonate, H_2	Methane, CO

Corrosion Products

- Elemental (EDS) and mineralogical (XRD) characterization
- Spatial significance
- Relationship to microbiological activities and chemistry of the environment

Mineral (Compound Formula)	Pit	Away
Magnetite (Fe_3O_4)	10-15%	35-40%
Geothite ($\alpha FeO(OH)$)	<1%	20%
Calcite ($CaCO_3$)	<1%	8-10%
Siderite ($FeCO_3$)	15-20%	10-15%
Mackinawite (Fe_9S_8)	35%	8%
Amorphous (EDS identified as sulfur)	~20%	~5%

Analysis: Questions to ask

1. Are there differences in the types and numbers of microorganisms between corroded vs. uncorroded areas?

2. Are there chemical indicators (sulfides, organic acids, corrosion products, etc.) that could have resulted from the activity of specific groups of microorganisms?

3. Are the microorganisms present capable of growth under the conditions of pH, temperature, oxygen levels, and salinity present in the environment?

Analysis: Questions to ask

4. Are there abiotic conditions present that could explain the corrosion mechanism?

5. Is the composition of the corrosion deposits attributable to the abiotic conditions present?

6. Have the past operating conditions provided an environment that supports MIC, e.g. low flow or dead leg, solids accumulation, and presence of water?

Summary

- Reliable MIC diagnosis requires multiple lines of evidence.

- Molecular methods can provide valuable insights, but data from other analytical methods, including information about the presence of corrosion, is still required.

- Improved procedures for MIC diagnosis are needed, including sample preservation, use of MMM and data integration to support clear conclusions.

- The Geno-MIC project funded by Genome Canada is working on developing improved tools, models, and methods to address MIC in the oil and gas industry.

References in this presentation

1. J. Lee and B. Little, "Diagnosing Microbiologically Influenced Corrosion" in "Microbiologically Influenced Corrosion in the Upstream Oil & Gas Industry", (eds. T.L. Skovhus, J. Lee, and D. Enning), Boca Raton, FL: CRC Press 2017.

2. R. Eckert, T. Skovhus, "Pipeline Failure Investigation: Is it MIC?", Materials Performance, Vol 58, No. 2, February 2018

3. J. Larsen, K. Rasmussen, H. Pedersen, K. Sørensen, T. Lundgaard, T.L. Skovhus (2010). Consortia of MIC Bacteria and Archaea causing Pitting Corrosion in Top Side Oil Production Facilities. Corrosion 2010, paper 10252, Houston, TX: NACE

4. A. Ibrahim, K. Hawboldt, C. Bottaro & F. Khan, "Review and analysis of microbiologically influenced corrosion: the chemical environment in oil and gas facilities", Corrosion Engineering, Science and Technology, 53:8, 549-563, 2018

Thank you!