Advances in the Application of Molecular Microbiological Methods in the Oil and Gas Industry and Links to Microbiologically Influenced Corrosion

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Prologue

- In 1984, the article “Guide for the investigation of MIC”, in Materials Performance pointed out:

  “Through the efforts of NACE Task Group T-3J and others, microbiologically induced corrosion has been identified as a serious problem.”

- In 1984:
  - We didn’t have cell phones – “texting” was not a verb.
  - Apple introduced the Macintosh computer.
  - The US Supreme court ruled that taping shows on VCRs was not a violation of copyright law.
  - Liquid culture media was the prevalent means for assessing pipeline MIC.

Today: Molecular Microbiological Methods (MMM)

- Different MMMs provide far more information about microbial diversity, abundance, activity, identification and function than culture methods.
  - Total DNA, live vs. dead cells
  - DNA per taxonomic and functional groups
  - Overall distribution of major taxa or focus on specific species
  - Activity/condition via ATP and other methods
- Strengths and limitations for each method.
- Molecular methods provide different information from one another and biases can occur in sampling, sample preparation, analysis, and interpretation.
- MMM data are quite different from culture-based results that are used in industry (e.g., medicine, food, agriculture, etc.)

Bad news: In corrosion control, MIC misdiagnosis continues

1984…

MPN

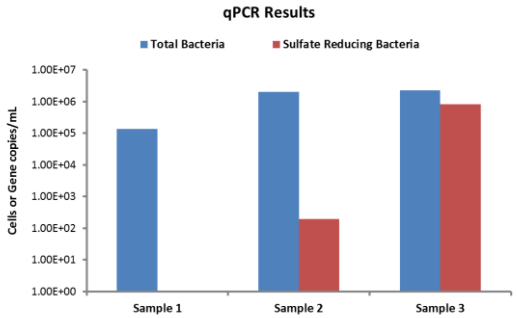
Common assumptions:

High Numbers = MIC

Certain bugs are “bad”

2015…

qPCR (and other MMM)



Common assumptions:

High Numbers = MIC

Certain bugs are “bad”

The Issue:

Despite increased use of molecular microbiological methods (MMM) in the oil and gas industry:

- No common process exists for establishing clear links between microbiological conditions and corrosion mechanisms.
- Many in industry are still misinterpreting and misapplying microbiological data in the process of managing corrosion.

Gaps: Lack of Clarity, Consensus, Consistency

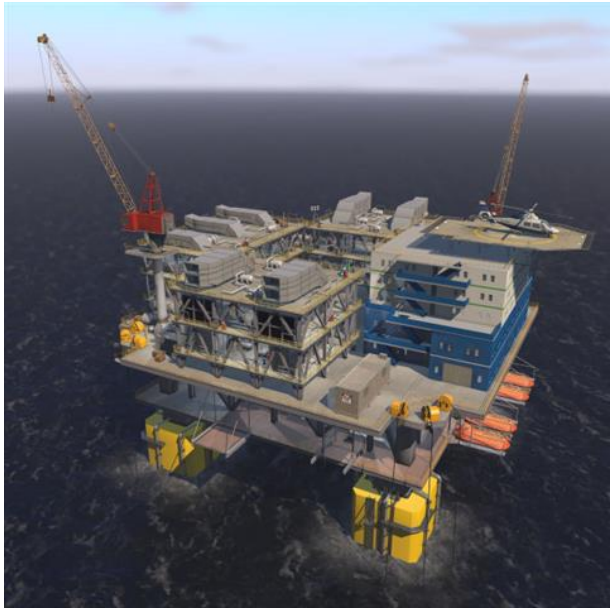
- Without a clear process for using MMM in corrosion management:
  - MMM data are interpreted and applied inconsistently.
  - MMM data are used incorrectly in setting key performance indicators (KPIs)
  - Bacteria testing is assumed to = “MIC Testing”
- We have a number of MIC susceptibility models yet they do not fully incorporate MMM data.

Increasing Value of MMM Data

Two key areas to consider for improved integration and use of MMM data:

1. Use of microbiological data in context of understanding corrosion mechanisms.

2. Use of microbiological data in the process of managing corrosion in assets.



Corrosion Management Process: Core Activities

Practical Application of MMM

Understanding Mechanisms:

Identifying the extent of biotic influence on the damage mechanism and whether it changes over time.

Managing Corrosion:

Applicable in all 3 steps.

- Selecting biocide type/dose
- Monitoring mitigation

Ref: Figure from NACE CORROSION 2014, Paper 3920

Use of MMM Data: Where

In understanding corrosion mechanisms

- Which microorganisms are contributing?
- How do they facilitate or promote corrosion?
- How do environmental conditions promote MIC?
- Is the corrosion biotic, abiotic or both?
- Does the primary mechanism change over time?

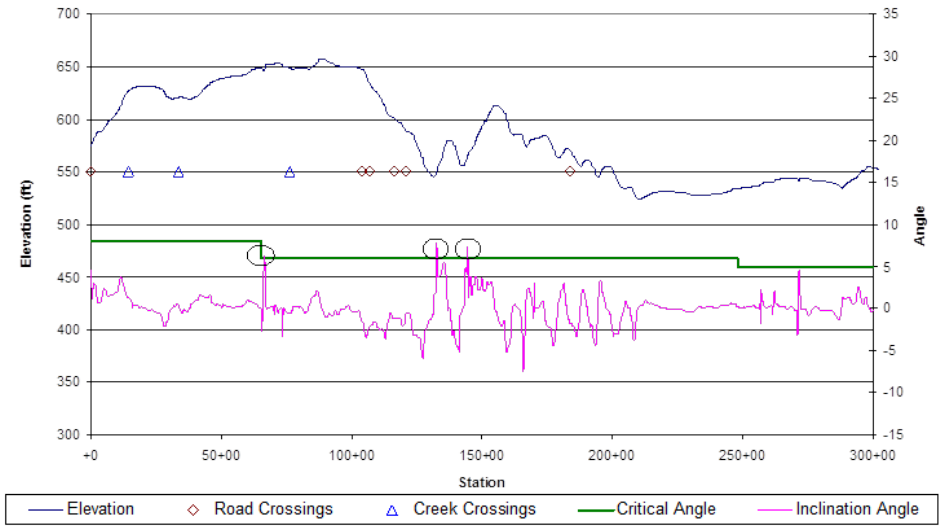
In the process of managing corrosion

- Threat assessment; which corrosion threat do I mitigate?
- Mitigation selection and application parameters; chemical, dose, frequency
- Measuring effectiveness of mitigation;
  - ✓ Top priority – Are we controlling corrosion?
  - ✓ Less priority – Are we controlling microorganisms?

Understanding Corrosion Mechanisms: Abiotic

If we ignored microbiology for a moment, and were seeking to understand corrosion in an engineered system, we would consider:

- Design of the asset
- Metallurgy
- Construction and Fabrication
- Operation
- Chemical Conditions
- Mitigation
- Condition/ Integrity



When using microbiological data to assess corrosion, all of these factors must still be considered.

Some factors influence both abiotic and biotic corrosion mechanisms.

– Ex: Temperature, salinity, flow rate, geometry, elevation profile, etc.

MMM in Understanding Corrosion Mechanisms: Data

Category	Examples of Data and Information
Design and Construction	Elevation profile, diameter changes, connections, piggable, crevices, hydro-test methods, quality, etc.
Operation	Flow regime, velocity, presence of solids, pressure, temperature, periods of no flow, fluid sources, etc.
Chemical	Fluid chemistry, organic carbon, electron donors/acceptor, redox potential, dissolved oxygen, pH, salinity, potential for abiotic corrosion, solids composition, etc.
Microbiological	Microbial abundance, diversity, activity; relationships within consortia; metabolism and relationship to corrosion location and severity and to other parameters (environment, operating practices, mitigation, etc.)
Metallurgy	Carbon steel or corrosion resistant alloy (CRA); pitting resistance equivalence number (PREN), thermo-mechanical history, welding, surface condition, galvanic effects, etc.
Mitigation	Inhibitor, biocide, cleaning, pigging methods/history, etc.
Condition/ Integrity	ILI and inspection results; corrosion distribution and severity; history, step-changes, growth rates, etc.

MMM in Understanding Corrosion Mechanisms: How

Category	Data and Information	Data Reliability, Error, Bias	Interpretation of Data	Integration of Data
Design and Construction	Elevation profile, diameter changes, connections, piggable, crevices, hydro-test methods, quality			Black Box
Operation	Flow regime, velocity, presence of solids, pressure, temperature, periods of no flow, fluid sources			
Chemical	Fluid chemistry, organic carbon, electron donors/acceptor, redox potential, pH, salinity, potential for abiotic corrosion, solids composition			
Microbiological	Microbial abundance, diversity, activity; relationships within consortia; relative to corrosion location and severity, relative to other parameters (design, operation, mitigation, etc.)			
Metallurgy	Carbon steel or CRA; PREN, thermo-mechanical history, welding, surface condition, galvanic effects			
Mitigation	Inhibitor, biocide, pigging methods and history			
Condition / Integrity	ILI and inspection results; corrosion distribution and severity; history, step-changes, rates			

= **Relationship** between **microbes** and **corrosion**

MMM in Understanding Corrosion Mechanisms: Integration

The Black Box of Data Integration – (i.e., why this is not simple!)

- Data have various significance in establishing MIC and abiotic corrosion
- Data can be interpreted differently
- Various expertise is needed to fully understand the meaning of the data
- Microorganisms can influence corrosion in many different ways
- Conditions may have occurred over a period of time – resulting in the current condition.
  - *Ex: pipe with pits from previous corrosion may not be corroding now*
- Many conditions are dynamic; changing over different time intervals
  - *Ex: Dissolved oxygen increases gradually over weeks as equipment is close to planned maintenance*
- Many conditions change with scale; macro-micro-nano; micro can affect macro and vice versa
  - *Ex: Dissolved oxygen (macro) may have excursions but beneath biofilms (micro) is strictly anaerobic*

Data Integration: Not a new idea…

- *"Diagnosis of MIC is based on chemical, microbiological and metallurgical conditions…" D. Pope, GRI, 1988*
- *"It is becoming apparent that it is extremely difficult to prove MIC conclusively. …In diagnosing MIC, as many techniques and tests as possible should be used"* P.J.B. Scott, Materials Performance, 2004
- *"The following are required for an accurate diagnosis of MIC: a sample of the corrosion product from the affected surface that has not been altered by collection or storage, identification of a corrosion mechanism, identification of microorganisms capable of growth particular environment, and demonstration of an association of the microorganisms with the observed corrosion."* B. Little, Corrosion Journal, 2006
- *"To determine the cause of, or potential for MIC, all chemical, microbiological, metallurgical, and operational data about the pipeline must be examined, integrated, and analyzed."* NACE Standard TM0212, 2012

MMM in Understanding Corrosion Mechanisms: How

Data requirements

Interpretation and integration require a multi-disciplinary approach!

Category	Data and Information	Data Reliability, Error, Bias	Interpretation of Data	Integration of Data
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Operators and Engineers

Production Chemists

Microbiologists

Materials/Corrosion Engineers

Chemical Vendors

Inspection and integrity experts

Without a Process, misdiagnosis will continue…

- In reality, we have missing information, must make assumptions, and have economic limitations on the ability to collect ALL of the data.
- This level of complexity, the lack of a MIC assessment framework, and the fact that it is rare to have a closely collaborative team of multidisciplinary experts available, leads to where some still are today:

What Next?

We can do better.

Industry needs a MIC assessment framework.

- To identify the necessary data and its significance.
- To provide a defined process for data integration and analysis.

Category	Data and Information	Data Reliability, Error, Bias	Interpretation of Data	Integration of Data
Design and Construction	Elevation profile, diameter changes, connections, piggable, crevices, hydro-test methods, quality			DEFINED PROCESS FOR DATA ANALYSIS
Operation	Flow regime, velocity, presence of solids, pressure, temperature, periods of no flow, fluid sources			
Chemical	Fluid chemistry, organic carbon, electron donors/acceptor, redox potential, pH, salinity, potential for abiotic corrosion, solids composition			
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Data Integration and Analysis: “Nobody told us how”

What would a MIC Assessment Framework provide?

1. Identify the data required for differentiating biotic and abiotic corrosion
2. Clarify the significance of data collected via various methods, limitations, etc.
3. Provide an multidisciplinary expert framework for integration and analysis of various categories of data (e.g., microbiological, chemical, metallurgical, operations, etc.)
4. Help in interpreting the results relative to corrosion threat management

Key requirements:

- General consensus of experts from key technical disciplines
- Sufficient clarity and simplicity for industry adaptation

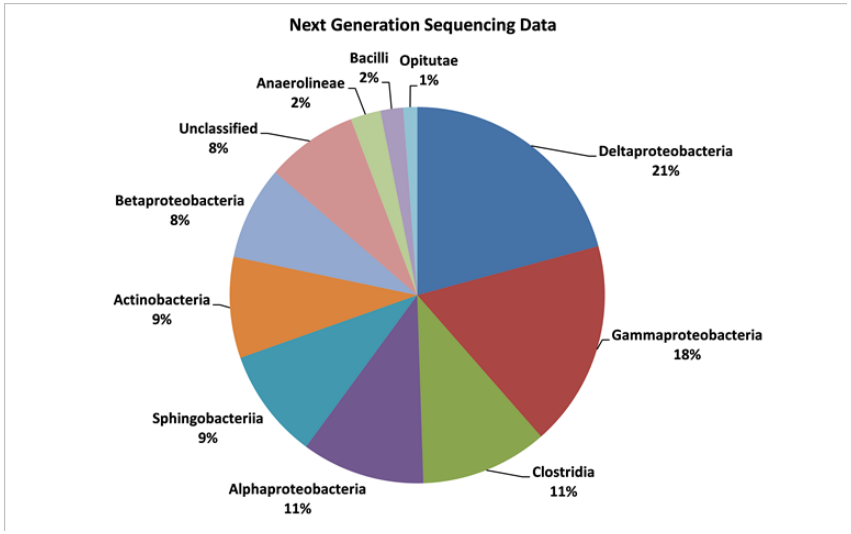
MIC Assessment Framework: How would we build it?

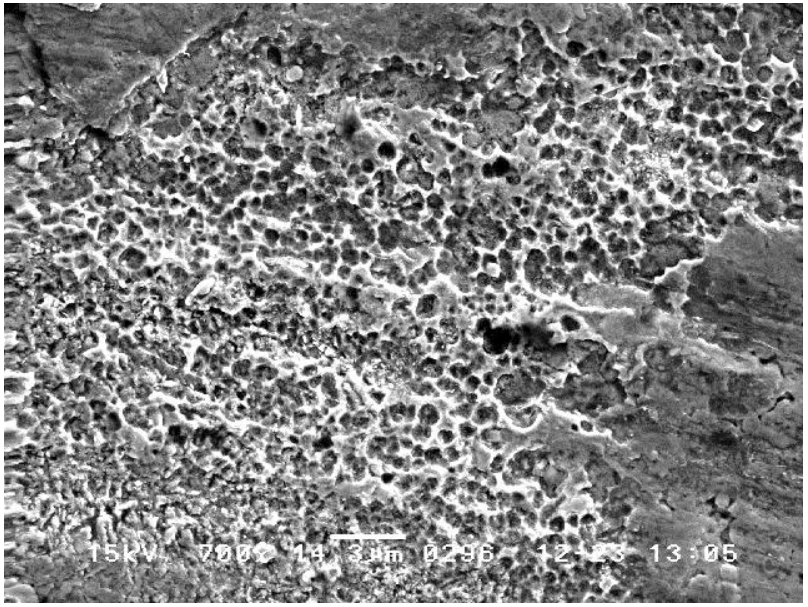
- A defined process for data integration and analysis is the core of the framework; linking microbiology and corrosion.
- Data elements in each of these categories are identified, along with data reliability and interpretation considerations:
  - Design
  - Metallurgy
  - Construction and Fabrication
  - Operation
  - Microbiology
  - Chemical Conditions
  - Mitigation
  - Condition/ Integrity

- Next, the significance of each data element relative to the other data elements is explained to provide guidance to the “end user” in interpreting the data.

MMM in Managing Corrosion

- MMM data have proven extremely useful in diagnosing MIC and managing corrosion when used correctly.
- The following case studies provide some examples of situations where MMM provided important insights that MPN could not.





Example 1 - Oil production spool in the North Sea

Medium	Issue	MIC Assessment
Crude oil	Internal corrosion with significant metal loss in 6 o'clock position	• Initial microbial monitoring using MPN gave low values; no MIC threat assumed • Metal loss due to internal corrosion was detected during ILI • MIC was found to be the cause of the corrosion based on failure analysis and quantitative polymerase chain reaction (qPCR) analysis • With these results the operator began to mitigate and monitor the corrosion threat using better methods

Ref: SPE-169603, SPE International Conference and Exhibition on Oilfield Corrosion, Aberdeen, UK, May 2014

Example 2 – Oil Production – No Microbial Issues

Medium	Issue	MIC Assessment
Wyoming oil and gas production system	None. No indication of MIC, plugging or H_2S production yet MPN results often showed high numbers of SRB and bacteria.	• 16S shotgun sequencing showed no true SRB in pig envelope samples, yet SRB culture media showed up to 10^8 positive • Genetic analysis of the positive media showed sulfidogenic bacteria but no true SRB • Sulfidogenesis was not believed to be a concern in the field, yet produced a result in the culture media not attributable to SRB • Use of MPN data at “face value” would have been misrepresentative and could have led to incorrect mitigation

Ref: NACE CORROSION 2015, Paper 5555, Dallas, TX

A Practical Issue in Industry: Need for Emphasis on Biofilms

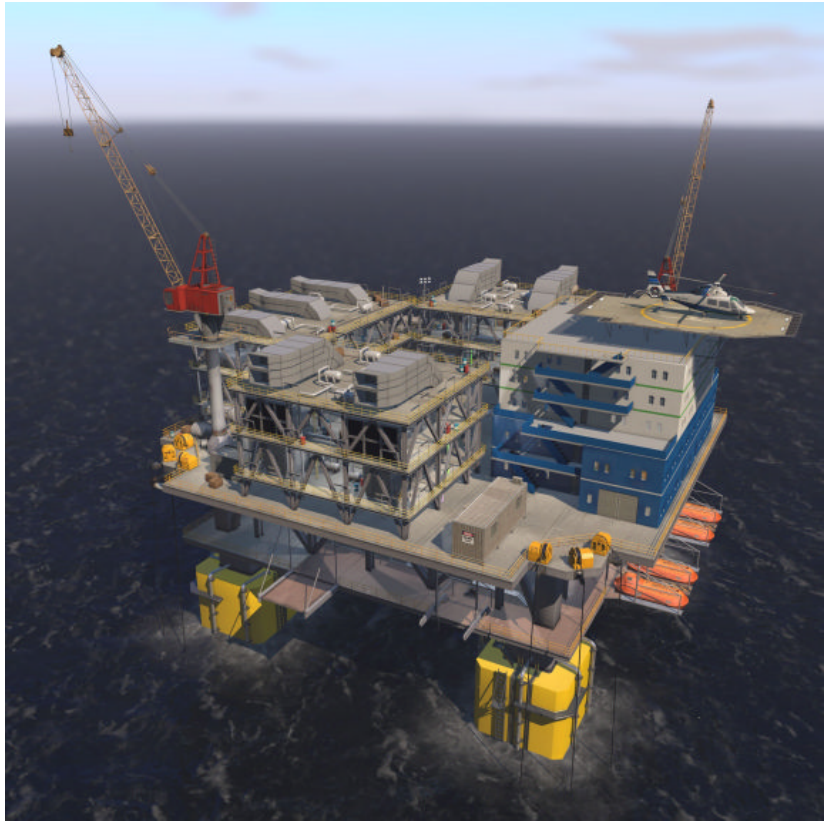
- We can't diagnose MIC from 35,000 ft.
- MIC is occurring on the pipe surface – we need to get down to that level to understand it.
- Assessments should focus on biofilms and surface deposits.
- Bulk fluid conditions do not provide enough information to diagnose MIC.

In reality, it can be difficult to get surface samples from pipeline systems.

MMM in Mitigation Selection: Guidance Needed

What to Apply:

- Treatment chemicals
  - corrosion inhibitor
  - biocide
  - oxygen scavenger
  - emulsion control
- Mechanical cleaning (pigging)
- Velocity control
- Control of fluid quality
- System maintenance
- Changes in design



How to Apply:

- Frequency
- Dose
- Location

MMM in Monitoring Mitigation Effectiveness

The main question is:
Are we controlling corrosion?

Direct Monitoring

- Coupons, probes
- Inspection, ILI
- Visual inspection, maintenance

Indirect Monitoring

- Microbiology – biofilms (MMM)
- Fluid chemistry parameters
- Chemical injection rates
- Maintenance pig returns analysis

Key Performance Indicators for MIC Management

- KPIs need to be based on the right information – MMM can be included
- For MIC this means integrating **corrosion** and **microbiology** information.
- MIC and abiotic corrosion threats must be assessed together (ref. NACE Standard TM0212)
- There are many examples of conflicting results from microbiology (primarily based on MPN) and corrosion measured.
- Establishing universal threshold values to confirm that MIC is occurring or will occur, is not practical – each situation is different

Final Remarks: There is still work to be done.

- We don't just need new microbiological techniques – we need to increase our understanding of the application (and limitations) of current techniques.

- **Many questions still exist in the MIC world;**
  - When are microorganisms present coincidentally and when are they a concern for promoting corrosion?
  - Is microbial activity any indicator of a potential for corrosion?
  - Do certain combinations of environmental conditions "turn the switch" and start aggressive MIC?
  - How do we establish criteria for MIC diagnosis? For knowing when mitigation works?
  - How is the balance between abiotic, biotic, or combined mechanisms determined?

Closing Summary

- The microbiological insights being afforded by MMMs will not be embraced by many operators until their significance relative to corrosion management and asset integrity are made more transparent.
- Achieving this will require continuing close collaboration between the disciplines of microbiology, corrosion and materials, chemical mitigation, and asset operations.
- An initiative is needed to bring these different corrosion and microbiological monitoring technologies and disciplinary experts together to reach a common understanding and to provide a clear path for broader industry engagement.
- Development of a MIC Assessment Framework could be a means to help industry make better use of MMM and improve corrosion management.

Thank you for your attention!

Questions?

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