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Microbially Induced Corrosion (MIC) in Water & Wastewater Conveyance and Treatment Systems

1st NACE-Jubail Industrial Forum
Water Treatment & Cathodic Protection
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Jubail Industrial college (JIC), Al-Jubail Industrial City
Agenda

- What is MIC
- Causes/Mechanism
- Impacted areas in water and wastewater treatment facilitates
- Detection
- Control & Prevention Best Practices
What is MIC?

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<th>Microbially Induced Corrosion</th>
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<td>Microbially Influenced Corrosion</td>
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corrosion that is influenced by the presence and activities of *microorganisms* and/or their *metabolites*
Factors Required for MIC

- Bacteria/Biofilm formation
- Water
- Metal Surface
- Nutrients
- Energy Source (food)
- Environment
  - Aerobic/
  - Anaerobic
  - Microaerophilic
- Optimal Temperature
- Optimal pH

Optimal pH and Temperature
Bacteria Types

- Dissolved Oxygen (O2) (Aerobic)
- Bound Oxygen (SO₄, NO₃) (Anoxic)
- Absence of O2 (Anaerobic)
Aerobic versus Anoxic

**Aerobic Respiration**

\[ \text{SO}_4^- = \text{Sulfate to } \text{H}_2\text{S} \]

\[ \text{NO}_3^- = \text{Nitrate to } \text{N}_2 \]

**Anoxic Respiration**
Environmental Conditions

\[ \text{O}_2, \text{N}, \text{P} \]

**Temperature**
- **Mesophyllic**: 20-35 °C
- **Thermophillic**: 55-65 °C
- **Psychrophillic**: <0 °C

**pH**
- *Ideal pH*: 6.5-8.5
- Filamentous organisms can withstand acidic conditions
Bacteria Involved in MIC

- **Acid Producing Bacteria**
  - Chemical corrosion is a major player in the MIC corrosion process.

- **Sulfate Reducing Bacteria**
  - SRB are probably the most destructive group of the MIC bacteria as they are a primary cause of pitting & pin-hole leaks.

  They mine iron from the pipe, take sulfur from the water & produce iron sulfide (black solids) & hydrogen sulfide gas (rotten egg smell).

- **Iron Related Bacteria**
  - IRB are iron utilizing. They build tubercles & are responsible for the destructive corrosive process in iron & steel. They cause pitting & pin-hole leaks.

  IRBs are known to have a symbiotic relationship with other groups of MIC bacteria.

- **Slime Forming Bacteria**
  - Slime forming bacteria live in conjunction with APB, SRB & IRB.

  They are an important part of the MIC process, often acting as the transient from aerobic to anaerobic conditions & as a support system for the corrosion process.
**Bacteria Involved in MIC**

### Aerobic Bacteria

**Thiobacillus Thioxidans:**
- Produce Sulfuric Acid.

**Thiobacillus Ferrooxidans:**
- Oxidize Ferrous to Ferric.

**Gallionella & Sphaerotilus:**
- Oxidize Ferrous to Ferric. Form Tubercles.

**Pseudomonas:**
- Can Reduce Ferric to Ferrous.

**Fungi:**
- Some Can Produce Organic Acids.

### Anoxic Bacteria

**Desulfovibrio:**

**Desulfotomaculum:**

**Desulfomonas:**
Bacterial Action Leading to MIC

\[ \text{H}_2\text{S} \text{(gas)} + 2\text{O}_2 \xrightarrow{\text{Aerobic bacteria}} \text{H}_2\text{SO}_4 \]

Chemical Attack of Concrete and manhole covers by \( \text{H}_2\text{SO}_4 \)

\[ \text{SO}_4^{2-} \xrightarrow{\text{Anoxic bacteria}} \text{H}_2\text{S} \text{(gas)} \]
Mechanism for MIC

- **Anoxic Conditions**
  - Biofilm
  - Aerobic $O_2$
  - Anoxic
  - Attack on metal surface
  - SRB generate H2S

- **Metal Surface**
  - Bacteria
  - Deposition and attachment
  - Aerobic $O_2$
  - Low DO and/or High F:M
  - High DO
Metals Affected

- Carbon Steels
- Stainless Steels
- Aluminum Alloys
- Copper Alloys
- Nickel Alloys
Ideal Environments for MIC

- **Welds**
  - Provide attachment points for bacteria

- **Threads**
  - Provide attachment points for bacteria

- **Low Velocity**
  - Bacteria have time to attach

- **Temperature**
  - Bacteria thrive at higher temperatures

- **Nutrients**
  - Bacteria grow at a faster rate with adequate nutrients

- **High Oxygen Level**
  - Oxygen cell corrosion can jump start the MIC colonization process and aerobic bacteria thrive

- **Low Oxygen Level**
  - Anaerobic bacteria thrive here

- **Low spots in the system**
  - Sediments from the water settle here and provide nutrients and attachment points for bacteria

- **High spots in the system**
  - Air pockets can be trapped here and provide oxygen for oxygen cell corrosion and aerobic bacteria colonization
Areas Impacted
# Detection Strategies of MIC

<table>
<thead>
<tr>
<th>Inspection</th>
<th>Identify environmental conditions leading to MIC</th>
<th>Identify bacteria responsible for MIC:</th>
<th>Investigate design and installation issues:</th>
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<tr>
<td>• Visual inspection</td>
<td>• Oxygen concentrations</td>
<td>• Direct bacterial testing</td>
<td>• Minimum velocity in pipes</td>
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<tr>
<td>• Removal of specimens for closer inspection</td>
<td>• Temperature/pH</td>
<td>• Detection of specific metabolites</td>
<td>• Bends and low spots</td>
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<tr>
<td>• Cameras</td>
<td>• Stagnant conditions</td>
<td>• DNA testing (useful in postmortem investigations)</td>
<td>• Coating material</td>
</tr>
<tr>
<td>• Divers</td>
<td>• Excessive nutrients</td>
<td></td>
<td>• Coating applications</td>
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Prevention and Control Best Practices

- Cleanliness & general corrosion prevention techniques
- Remove solids and debris that can promote bacterial growth
- Avoid stagnant water where feasible
- Limit bacterial nutrients
- Remove water where appropriate (gas, air and fuel lines)
- Material substitution is of limited value since, MIC affects almost all industrial metals (not titanium)
- Use non-metallic material where appropriate
- Use biocides (continuous or pulse dosing)
Control/Prevention Examples
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Thank You