Presentation Outline

• Introduction to scale
  – Definition
  – Scale formation
  – Inhibition mechanisms
• Test methods
• Predictive scale modeling
• Conclusions
Definition of Scale

• Deposition of sparingly soluble minerals onto metal or other surfaces in contact with water.

• Common scales
  – Calcium carbonate
  – Calcium sulfate
  – Barium sulfate
Precipitation of Scale

SUSPENDED SOLIDS

SOLUBILISATION

SUPERSATURATION

NUCLEATION

CRYSTAL GROWTH

SCALE

Controlling parameters

- Time
- Temperature
- Pressure
- pH
- Particle size
- Agitation/Velocity
- Flow velocity
- Temperature
- Composition
- Surface
Scale Formation Process

Scale

M⁺ Cation
X⁻ Anion
Scale Inhibition Mechanisms

Threshold Effect

Scale

$M^+$ Cation
$X^-$ Anion

Polymeric Additive
Scale Inhibition Mechanisms

Crystal Growth Inhibition

Scale

$M^+$ Cation
$X^-$ Anion

Polymeric Additive
Scale Inhibition Mechanisms

Crystal Distortion

(i) Crystal Lattice
Hard scale
Good adherence to surfaces

(ii) Distorted Crystal Lattice
Soft scale
Less adherent to surfaces
Scale Inhibition Mechanisms

Crystal Distortion

No additive (magnification x 7500)

10 mg/l polymaleic acid (magnification x 7500)
SCALE INHIBITOR TEST METHODS
Bottle Testing

- Relatively simple and easy test
- Only assesses threshold inhibition mechanism so doesn't give a complete picture of an additive’s performance
Dynamic Testing

[Diagram of a testing setup with labeled components and a graph showing data over time.]
Dynamic Testing

• Requires sophisticated equipment
• More comprehensive test since it assesses all scale inhibition mechanisms - threshold inhibition, crystal growth inhibition, and crystal distortion
Bottle Test - Threshold Inhibition

- Disrupt clusters before reaching critical size for nucleation prior to crystallization
- Low dose levels, typically phosphonates & some low molecular weight polymers
- Fail drastically once crystal formed

Dynamic Test - Crystal Growth Blocking

- Blocks further growth at crystal faces
- Inhibition of growth at crystal face leads to distortion to non-adherent form
- Specialty carboxylic polymers found to be above industry standards
Threshold Inhibition Example*

* Barium Sulfate Inhibition
Crystal Growth Blocking Example*

PCA polymer outperforms phosphonate as a crystal growth blocker.

*Barium sulfate inhibition
PREDICTIVE SCALE MODELING
Modeling Starts with a Water Chemistry

- Very high sulfate concentration in the fresh water
- High barium and strontium concentration in produced water

<table>
<thead>
<tr>
<th></th>
<th>‘Fresh’ water source mg/L</th>
<th>Produced water mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>1171</td>
<td>38,829</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>460</td>
<td>16,893</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>85</td>
<td>1734</td>
</tr>
<tr>
<td>K⁺</td>
<td>0</td>
<td>566</td>
</tr>
<tr>
<td>Ba²⁺</td>
<td>5.0</td>
<td>836</td>
</tr>
<tr>
<td>Sr²⁺</td>
<td>0</td>
<td>2727</td>
</tr>
<tr>
<td>Fe²⁺</td>
<td>0</td>
<td>143</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>2083</td>
<td>5.0</td>
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<tr>
<td>HCO₃⁻</td>
<td>404</td>
<td>0</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>1100</td>
<td>101,269</td>
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<tr>
<td>TDS</td>
<td>5500</td>
<td>162,394</td>
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<tr>
<td>pH</td>
<td>6.40</td>
<td>5.90</td>
</tr>
</tbody>
</table>

Blending these waters is likely to cause severe sulfate scale issues
What Modelling Can Tell Us

- What is the scaling risk with an 80:20 Fresh:Produced water mix?
- How does the scaling risk change with produced water?
- Are there any inhibitors that can reduce or eliminate scale formation?

- Scale modelling performed using ScaleSoftPitzer™
  - Saturation index
  - Amount of precipitate expected

<table>
<thead>
<tr>
<th>Saturation Index</th>
<th>Under-saturated</th>
<th>No scale precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>At equilibrium</td>
<td>No scale precipitation</td>
</tr>
<tr>
<td>Positive</td>
<td>Supersaturated</td>
<td>Potential for scale to precipitate</td>
</tr>
</tbody>
</table>
Modelling Results

- High severity $\text{BaSO}_4$
- Modelling helps you understand where you can operate
- 20% produced water feasible to treat but needs a high performing scale inhibitor.
Scale Inhibitor Performance

Tests run at 60°C

Polymer A = Sulfonated phosphinocarboxylic acid
Summary

• Scale inhibitors work by different mechanisms:
  – Phosphonates – threshold inhibition
  – Polymers - threshold inhibition, crystal growth inhibition, and crystal distortion

• Dynamic scale inhibitor testing is more comprehensive and a better predictor of field performance

• Predictive scale modeling can highlight scaling issues when using recycled water
Thank you

Questions?